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Article

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Cogent Economics & Finance

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Suggested Citation: Acheampong, Patricia Pinamang; Addison, Monica; Wongnaa, Camillus Abawiera (2022) : Assessment of impact of adoption of improved cassava varieties on yields in Ghana: An endogenous switching approach, Cogent Economics & Finance, ISSN 2332-2039, Taylor & Francis, Abingdon, Vol. 10, Iss. 1, pp. 1-18, <https://doi.org/10.1080/23322039.2021.2008587>

This Version is available at:

<https://hdl.handle.net/10419/303539>

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To cite this article: Patricia Pinamang Acheampong, Monica Addison & Camillus Abawiera Wongnaa (2022) Assessment of impact of adoption of improved cassava varieties on yields in Ghana: An endogenous switching approach, Cogent Economics & Finance, 10:1, 2008587, DOI: 10.1080/23322039.2021.2008587

To link to this article: <https://doi.org/10.1080/23322039.2021.2008587>



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Received 29 September 2020
 Accepted 15 November 2021

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GENERAL & APPLIED ECONOMICS | RESEARCH ARTICLE

Assessment of impact of adoption of improved cassava varieties on yields in Ghana: An endogenous switching approach

Patricia Pinamang Acheampong^{1*}, Monica Addison² and Camillus Abawiera Wongnaa³

Abstract: The paper assesses the potential impact of the adoption of improved cassava varieties on yields of smallholder farmers. Agricultural intensification is associated with increasing yields per hectare through the use of improved varieties. Studies have established the relationship between adoption and yield, yet this relationship is understudied in the cross-national literature. Using cross-sectional data collected from a randomly selected sample of 1,176 farmers dispersed across Ghana and employing an endogenous switching regression model, the causal impact of improved variety adoption was estimated. Our results revealed that adoption decisions were conditioned by age, extension access, extension visits, awareness and farm size. Also, adoption had a significant positive impact on cassava yields. Adopters had 18 t/ha increases in yields and non-adopters should they have adopted had increases of 10 t/ha. Strategies to resource research extension linkage system to promote and create awareness about the existing improved cassava varieties for increased adoption are recommended.

Subjects: Agricultural economics; Applied economics; Research and development; Agricultural and Food policy

Keywords: Adoption; awareness; dissemination; smallholder farmer; switching regression

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PUBLIC INTEREST STATEMENT

Cassava is a food crop that provides multiple opportunities for poverty reduction and nourishment for many Ghanaians. Production of the crop in Ghana is mostly reliant on landraces developed by generations of farmers using traditional breeding techniques. Cassava yields relative to potential yields remain low in Ghana reflecting the influence of subsistence production systems. The rapid increase in cassava production will certainly have significant implications on food security, employment creation, living conditions and economic growth. The research has revealed the contribution of improved varieties to yield improvement. Interventions to increase adoption of improved cassava varieties by smallholder farmers should be the focus.

Subjects: Q12; Q16; Q18

1. Introduction

One of the primary goals of Ghana's agricultural development programs and policies is increasing agricultural productivity for accelerated economic growth (Ministry of Food and Agriculture, 2018). Predominantly, the majority of Ghanaians depend on agriculture for their livelihoods thus, the agricultural sector has been recognized as important for driving economic growth, overcoming poverty, and enhancing food security (Ministry of Food and Agriculture, 2010). The crop is of major importance due to its consumption and income generation benefits for smallholder farmers and other key stakeholders along the cassava value chain. The economic importance of cassava is due in part to its good adaptation in marginal soils, but even more to a long and strongly held tradition among Ghanaians for eating it. Per capita consumption of cassava is 153 kg (Ministry of Food and Agriculture, 2019b), the highest among all staple foods. Because cassava has the potential to provide multiple opportunities for poverty reduction and nourishment for poor people in Ghana, lots of research efforts have gone into the development and dissemination of it for increased production in order to meet increasing demand. As a result, 25 varieties of the crop had been released over the years (Ministry of Food and Agriculture, 2019a). Cassava yields relative to potential yields remain low in Ghana reflecting the influence of subsistence production systems. Cassava yield in Ghana is 21 t/ha whilst potential yield is about 49 t/ha (Ministry of Food and Agriculture, 2019b). The huge gap in yields is attributed mainly to the poor uptake of improved cassava technologies (FAO, 2015). With variability in climatic conditions and associated effects on agricultural production, increasing yield per unit area of smallholder farmers and creating rural off-farm employment opportunities are necessary.

In order to increase food production and achieve the policy objectives of cassava crops, the research emphasis has been on increased efficiency in production and adaptability to variable production systems and environments (Nweke et al., 2002). The rapid increase in cassava production will certainly have significant implications on food security, employment creation, living conditions and economic growth. The first step to achieving food security is through the production and supply of food staples to meet the demands of the population. Strategies found to increase food security are on-farm food production and income diversification (Gladwin et al., 2001). Food production strategies focus on how farmers can increase their production and this includes the use of new varieties, new crops, agricultural intensification and agricultural extensification (Stout, 1990). Agricultural intensification is associated with increasing yields per hectare through the use of external inputs such as fertilizers, improved varieties, whereas agricultural extensification involves crops yield increase through land expansion (Stout, 1990) which is thought to be unsustainable with increasing population. Several research findings (Asfaw et al., 2012; Donkor et al., 2016; Mendola, 2007) have pointed to the fact that the use of new agricultural technology, such as high-yielding varieties and improved agronomic practices could lead to a significant increase in agricultural productivity. According to World Bank (2007), the transition from low productivity subsistence agriculture to a high productivity agro-industrial economy depends on new agricultural technologies. The agricultural productivity growth over the years would not be possible without the development and dissemination of yield-increasing technologies (Irz et al., 2001).

New technology adoption is a significant source of productivity gains in various production systems. Beyond the production system, the widespread adoption of new agricultural technology will also have economic implications (Chandio et al., 2021; Tibamanya et al., 2021). Adoption of improved agricultural production technologies has been reported to have positive impacts on agricultural productivity growth in the developing world (Minten & Barrett, 2008; Nin et al.,

2003). Minten and Barrett (2008), for instance, found that in Madagascar communities with higher rates of adoption of improved agricultural technologies have higher yields and lower levels of food insecurity. According to Evenson and Gollin (2003), wide spread adoption of improved varieties of wheat and rice led to major increases in yields and increases in food security in Asia. Estimating the impact of cassava research for development approach on productivity, uptake and food security in Malawi, Rusike et al. (2010) found a positive effect of area planted to improved cassava varieties on cassava yields and household caloric intake. Studying adoption of improved cassava varieties on household welfare in Nigeria, Omonona et al. (2006) found that non-adopters of improved cassava varieties had lower yields and thus lower levels of food security.

Despite the evidence that adoption of improved cassava varieties has an association with yield, the magnitude of the impact of adoption on yield, by controlling for the role of selection problem on production and adoption decisions has received low attention. This paper addresses two questions, viz. 1) what factors influence farmers' decision to adopt improved cassava varieties? and 2) what is the impact of adoption of improved cassava varieties on cassava yields. This study

Figure 1. Map of Ghana showing the study area.
 Source: Abbam et al. (2018).

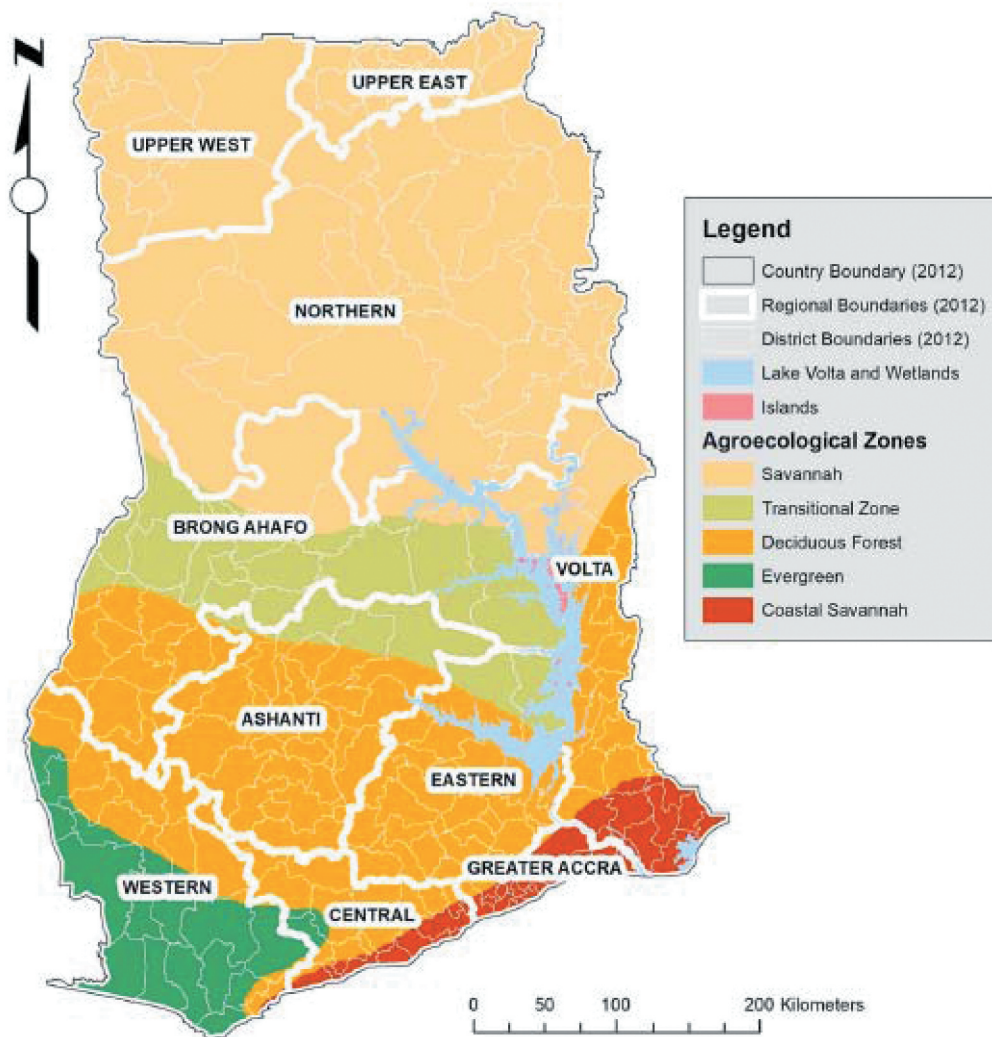


Table 1. Sampling frame for data collection

Regions	Number of Cassava districts	Selected number of districts	Selected number of villages	Selected sample units
Ashanti	24	9	36	216
Brong Ahafo	21	6	24	144
Central	13	6	24	144
Eastern	26	8	32	192
Volta region	18	6	24	144
Western	22	4	16	96
Greater Accra	5	3	12	72
Northern	14	7	28	168
Upper West	11	5	20	120

reports on rich cross-sectional data collected on randomly selected individual farm owners. We accounted for the differences in yields between adopters and non-adopters of improved cassava variety due to unobserved heterogeneity by employing the endogenous switching regression technique. Endogeneity in adoption decision (that is, heterogeneity in the decision to either adopt or not adopt improved cassava variety as well as unobservable characteristics of farmers and their farms) was accounted for by estimating simultaneous equations with endogenous switching by the method of full information maximum likelihood (Lokshin & Sajaia, 2004). A counterfactual analysis was then built to compare the expected yield under the actual and counterfactual cases that farmers adopted or not. Treatment effect and heterogeneity effect was calculated to understand the differences in yields between farmers that adopted and those that did not adopt and to explore the potential impact of changes on agricultural policy. To the best of our knowledge, this research is one of the few that has used switching regression to estimate the impact of adoption on cassava yields. Therefore the study contributes to the literature on the important role of improved crop technologies in Africa's economy. In particular, the study contributes to a better understanding of farmers' decisions on technology adoption, which in turn will help design policy options to increase cassava productivity and enhance food security across the country. The rest of the paper is organized as follows. The next section presents the methodology. This is followed by the results and discussion. The last section presents the conclusions and policy recommendations.

2. Methodology

2.1. Description of the study area

The data for this study were from nationwide survey on root and tuber crops collected in 2017. The study area map¹ is presented in Figure 1. Except for the Upper East region, where cassava was not produced, all other regions where cassava was produced were selected for the study. The Southern regions (Greater Accra, Central, Western, Eastern, Ashanti, Brong Ahafo and Volta regions) experienced bimodal rainfall with a mean minimum amount of 800 mm to a mean maximum amount of 2200 mm. The mean annual temperature ranges from 24°C to 30°C. The Northern regions (Upper East, Upper West and Northern regions) have unimodal rainfall with a mean annual rainfall of 1,100 mm and a mean annual temperature of 25°C. Ghana's climate is very conducive for the production of various food crops including root and tubers, cereals, legumes and oil seeds.

Table 2. Variable names, definitions, and descriptive statistics for the sample

Variable	Description	Mean	Std. Dev.
Cassava yield	Total output of cassava (t/ha)	19.44	7.61
Adoption	1 if farmer cultivated improved cassava variety (ICV), 0 otherwise	0.39	0.49
Gender	1 if farmer is a male, 0 otherwise	0.72	0.43
Age	Age of a farmer (years)	46.87	11.86
Education	Number of years of schooling of farmer	6.77	5.23
Experience	Number of years a farmer has spent farming	22.52	12.27
Household size	Number of person in a farmer's household	7.57	4.12
Plot owner	1 if a farmer owned land, 0 otherwise	0.69	0.45
Farm size	Total cassava area (ha)	4.00	0.12
Awareness	1 if farmer was aware of ICV, 0 otherwise	0.81	0.40
Extension access	1 if farmer got information from extension agent, 0 otherwise	0.61	0.48
Extension visits	Number of times extension agent visited a farmer	2.30	2.018
Distance to market	Distance from farm to output and input market (km)	5.61	5.00
Membership	1 if farmer is a member of an association, 0 otherwise	0.59	0.49
Fertilizer application	1 if farmer used fertilizer, 0 otherwise	0.15	0.01
Monocrop	1 if farmer practice cassava monocrop, 0 otherwise	0.41	0.49
Fertility status	1 if farmer perceived land as fertile, 0 otherwise	0.62	0.48
Recommended Spacing	1 if farmer used recommended spacing of 1 m by 1 m, 0 otherwise	0.43	0.49

2.2. Sampling and data collection

A multi-stage sampling technique was employed to select districts and villages. Firstly, districts within regions were clustered into cassava districts. Using volumes of production, a number of districts were purposively selected from the cassava districts (see Table 1). A list of communities within the districts was collected from the district directorate of agriculture and using random numbers, four communities per district were selected. Finally, the sampling units were randomly selected using random numbers. At

this stage, a proportional sampling technique was employed to select six farmers from each of the selected communities. A total of 216 communities across the country were visited and 1,296 farmers were interviewed. However, due to incomplete responses 120 data sets were discarded and data from 1,176 cassava farmers were used.

Data were collected through structured questionnaires administered to sampled farmers by trained enumerators. Before the actual survey, the questionnaires were pretested in non-sampled villages. The questionnaire pretesting was not only used to test the appropriateness of the tool in collecting the required data but also to evaluate the trained enumerators on the capability of administering the questionnaire. Information sought included farmer demographics, farm characteristics, membership of association and other social networks, household livestock ownership and control, saving and credit access, access to extension services and other information, income activities, cassava technologies etc.

Table 2 presents the description of variables used and sample descriptive statistics. It can be observed that 39% adopted improved cassava varieties and that the average yield per hectare was 19 tonnes. Cassava yield was measured using the farmer recall method (Casley & Kumar, 1988). Adult males were more than adult females. 72% of the respondents was adult males. The average age of a farmer was about 47 years. Average years a farmer had spent in formal education were about 7. Education is expected to have a positive impact on technology adoption (Huffman, 2001). On average, a farmer had 22 years' experience in farming. The average number of persons in a farmer's household was 7. Household size affecting adoption is indeterminate as it could serve as an alternative to labour availability and influence the adoption or could serve as a labour force to off-farm activities thus affecting adoption negatively (Faturoti et al., 2006). 61% of farmers had access to extension, however, a farmer had on an average two visits from an extension agent. Extension access and visits are hypothesized to influence adoption positively (Zhang et al., 2016). Awareness on improved cassava varieties was high. Awareness is expected to influence adoption significantly (Dontsop et al., 2013). The average farm size was 4 ha and 69% of farmers owned farm land. Only 15% of respondents applied fertilizer on cassava farms. 41% practiced cassava monocropping and 43% planted cassava at the recommended spacing. Good agronomic practices are expected to positively affect cassava yield.

2.3. Theoretical framework and empirical model

In order to estimate the impact of the adoption of improved cassava varieties (ICV) on cassava yields, the following general model is used:

$$y = \beta Z + \sigma ICV + \varepsilon \quad (1)$$

where y represents yields, Z denotes a vector of independent variables; adoption of ICV is a dummy variable, σ is a measure of the impact of the adoption of ICV on yields, while ε is the error term.

Adoption of ICV is a dummy and potentially endogenous because farmers decide whether to adopt or not (self-selection bias), thus estimating the coefficients with ordinary least square (OLS) will yield biased results. Heckman selection, instrumental variable (IV) and propensity score matching (PSM) are some of the other models used to handle such biases in literature (Heckman & Vytlačil, 2001; J. J. Heckman et al., 1998). These methods also have several limitations; for example, both Heckman selection and IV methods tend to impose a functional form assumption by assuming that adoption of ICV has only an intercept shift and not a slope shift in the outcome variables (Alene & Manyong, 2007). PSM produces bias results when there are unobservable factors that influence both treatment and the outcome indicator (yield) (Abdulai & Huffman, 2014). In order to address these issues, an endogenous switching regression (ESR) technique which has been employed in many impact assessment studies (Abdulai & Huffman, 2014; Bidzakin et al., 2019) was used. In the switching regression

approach, farmers are segregated according to whether they are adopters or non-adopters in order to capture the differential responses of the two groups (Abdulai & Huffman, 2014).

The model uses a probit model in the first stage to determine the relationship between adoption decision and possible determinants of adoption. The second stage regression estimates involve the determinants of cassava yields of adopters and non-adopters. Let's consider a situation where a farmer may decide whether or not to adopt improved cassava variety. Let $A_i^* > 0$ be a latent variable indicating a composite index of the satisfaction from adoption of ICV. A probit model of the decision to adopt is specified as:

$$A_i^* = Z_i\alpha + \eta_i \quad \text{with} \quad A_i = \begin{cases} 1 & \text{if } A_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

where Z_i is a vector of factors influencing the adoption decision α is a vector of unknown parameters; and η is an error term with a mean of zero and a variance σ_η^2 . Probit maximum likelihood estimation is used to estimate the parameters of Equation (1). The decision of whether to adopt or not to adopt improved varieties affects yields. Let the yield function be $y = f(X)$, where y is yield and X is a vector of possible factors that determines yield. To estimate a separate regression function for each of the two situations, we specify the following Yield functions:

$$\text{Regime 1 (Adopters)} : y_{1i} = X_{1i}\beta_1 + \varepsilon_{1i} \quad \text{if } A_i = 1 \quad (3a)$$

$$\text{Regime 2 (Non – Adopters)} : y_{2i} = X_{2i}\beta_1 + \varepsilon_{2i} \quad \text{if } A_i = 0 \quad (3b)$$

where y_{1i} and y_{2i} are the yield of adopters and non-adopters, respectively, and β is the vector of parameters to be estimated. The error terms in Equations (2), (3a), and (3b) are assumed to have a trivariate normal distribution with zero mean and covariant matrix $\Sigma(i, e.(\eta, \varepsilon_1, \varepsilon_2) : N(0, \Sigma))$, with:

$$\Sigma = \begin{bmatrix} \sigma_\eta^2 & \sigma_{\eta 1} & \sigma_{\eta 2} \\ \sigma_{1\eta} & \sigma_1^2 & \cdot \\ \sigma_{2\eta} & \cdot & \sigma_2^2 \end{bmatrix}$$

where σ_η^2 is the variance of the error term in the selection Equation (2), which can be assumed to be equal to 1, since the coefficients can be estimated only up to a scale factor (Lee, 1978; Maddala, 1983). σ_1^2 and σ_2^2 are the variances of the error terms in the yield functions (3a) and (3b); $\sigma_{1\eta}$ represents the covariance of η_i and ε_{1i} and $\sigma_{2\eta}$ is the covariance of η_i and ε_{2i} . Note that y_{1i} and y_{2i} are not observed simultaneously, which implies that the covariance between ε_{1i} and ε_{2i} is not defined, and they are therefore indicated as dots in the covariance matrix. Since the error term of the selection Equation (2) is correlated with the error terms of the yield functions (3a) and (3b), the expected values of ε_{1i} and ε_{2i} conditional on the sample selection are non-zero and are defined as:

$$E[\varepsilon_{1i}|A_i = 1] = \sigma_{1\eta} \frac{\phi(Z_i\alpha)}{\Phi(Z_i\alpha)} = \sigma_{1\eta}\lambda_{1i} \quad (4)$$

$$E[\varepsilon_{2i}|A_2 = 0] = \sigma_{2\eta} \frac{\phi(Z_i\alpha)}{1 - \Phi(Z_i\alpha)} = \sigma_{2\eta}\lambda_{2i} \quad (5)$$

where $\phi(\cdot)$ and $\Phi(\cdot)$ are the standard normal probability density function and normal cumulative density function, respectively; $\lambda_{1i} = \phi(Z_i\alpha)/\Phi(Z_i\alpha)$ and $\lambda_{2i} = \phi(Z_i\alpha)/(1 - \Phi(Z_i\alpha))$. It is important to note that if the estimated $\hat{\sigma}_{1\eta}$ and $\hat{\sigma}_{2\eta}$ covariances are statistically significant, then the decision to adopt and the yield are correlated. This implies evidence of endogenous switching, and the null hypothesis of the absence of sample selectivity bias is rejected.

A more efficient method of estimating endogenous switching regression models is the full information maximum-likelihood method (Greene, 2000; Lokshin & Sajaia, 2004). Given the previous assumptions regarding the distribution of the error terms, the logarithmic likelihood function is:

$$\ln L_i = \sum_{i=1}^N \left\{ A_i \left[\ln \phi\left(\frac{\varepsilon_{1i}}{\sigma_1}\right) - \ln \sigma_1 + \ln \Phi(\theta_{1i}) \right] + (1 - A_i) \left[\ln \phi\left(\frac{\varepsilon_{2i}}{\sigma_2}\right) - \ln \sigma_2 + \ln(1 - \Phi(\theta_{2i})) \right] \right\} \quad (6)$$

where $\theta_{ji} = Z_i\alpha + \rho_j\varepsilon_{ji}/\sqrt{1-\rho_j^2}X_{\frac{1}{2}}^1$, with $j = 1, 2$; and ρ_j denotes the correlation coefficient between the error term η_i of the selection Equation (1) and the error term ε_{ji} of the yield functions (3a) and (3b), respectively.

2.4. Conditional expectations, treatment, and heterogeneity effects

The endogenous switching regression model can be used to compare expected crop yields of farmers that participated in improved cassava cultivation as shown in equation (7a) and those who did not participate as shown in equation (8b). To investigate the expected yield in the counterfactual hypothetical cases, comparison can be made with the expected yield in the counterfactual hypothetical cases in equation (9c) that the farmers did not participate in improved cassava cultivation, and equation (10d) that the non-adopters participated in improved cassava cultivation. The conditional expectations of the Yield in the four cases are presented in Table 2 and defined as follows:

$$E(y_{1i}|A_i = 1) = X_{1i}\beta_1 + \sigma_{1\eta}\lambda_{1i} \quad (7a)$$

$$E(y_{2i}|A_i = 0) = X_{2i}\beta_2 + \sigma_{2\eta}\lambda_{2i} \quad (8b)$$

Table 3. Conditional expectations, treatment, and heterogeneity

Subsamples	Decision stage		Treatment effect
	Adopters	Non-adopters	
Farmers that participated in improved cassava varieties	(a) $E(y_{1i} A_i = 1)$	(c) $E(y_{2i} A_i = 1)$	TT
Farmers that did not participate in improved cassava varieties	(d) $E(y_{1i} A_i = 0)$	(b) $E(y_{2i} A_i = 0)$	TU
Heterogeneity effects	BH_1	BH_2	TH

Note. (a) and (b) represent observed expected yield; (c) and (d) represent counterfactual yield.

$$E(y_{2i}|A_i = 1) = X_{1i}\beta_2 + \sigma_{2\eta}\lambda_{1i} \quad (9c)$$

$$E(y_{1i}|A_i = 0) = X_{2i}\beta_1 + \sigma_{1\eta}\lambda_{2i} \quad (10d)$$

Cases (7a) and (8b) in Table 3 represent the actual expectations observed in the sample, and cases (9 c) and (10d) represent the counterfactual expected cassava yield.

$A_i = 1$ if farmer adopts improved cassava variety; $A_i = 0$ if the farmer does not adopt improved cassava variety. y_{1i} = yield of the farmer if the farmer participates in improved cassava varieties; y_{2i} = yield of the farmer if he does not participate in improved cassava varieties; TT represents the effect of the treatment (adoption) on the treated group (adopters); TU represents the effect of the treatment (adoption) on the untreated group (non-adopters); BH_1 and BH_2 are the effect of base heterogeneity for adopters ($i = 1$) and non-adopters ($i = 2$), respectively; $TH = (TT - TU)$, which represents transitional heterogeneity.

Following J. Heckman et al. (2001) and Di Falco et al. (2011), the heterogeneity effects can be defined as:

$$TT = E(y_{1i}|A_i = 1) - E(y_{2i}|A_i = 1) = X_{1i}(\beta_1 - \beta_2) + (\sigma_{1\eta} - \sigma_{2\eta})\lambda_{1i} \quad (11)$$

$$TU = E(y_{1i}|A_i = 0) - E(y_{2i}|A_i = 0) = X_{1i}(\beta_1 - \beta_2) + (\sigma_{1\eta} - \sigma_{2\eta})\lambda_{2i} \quad (12)$$

$$BH_1 = E(y_{1i}|A_i = 1) - E(y_{1i}|A_i = 0) = (X_{1i} - X_{2i})\beta_{1i} + \sigma_{1\eta}(\lambda_{1i} - \lambda_{2i}) \quad (13)$$

$$BH_2 = E(y_{2i}|A_i = 1) - E(y_{2i}|A_i = 0) = (X_{1i} - X_{2i})\beta_{2i} + \sigma_{2\eta}(\lambda_{1i} - \lambda_{2i}) \quad (14)$$

Conditions in Equations (11)–(14) can be described as follows:

(1) The treatment on adopters (TT) is the difference between (7a) and (9 c), which is given by Equation (11).

(2) The effect of the treatment on non-adopters (TU) is the difference between (10d) and (8b), which is given by Equation (12).

(3) The effect of heterogeneity of adopters is the difference between (7a) and (10d).

(4) The effect of base heterogeneity (BH) of non-adopters is the difference between (7a) and (10d).

Finally, transitional heterogeneity (TH) is estimated, as if the effect of participating in improved varieties is larger or smaller for the farmers that actually participated or for the farmers that actually did not participate in the counterfactual case that they did participate, that is the difference between Equations (11) and (12) (TT and TU). The estimations were implemented in STATA using the *movestay* command developed by Lokshin and Sajaia (2004).

Table 4. Differences between adopters and non-adopters of improved cassava varieties

Variable	Adopters (39.97%)		Non-adopters (60.03%)		Diff.
	Mean	Std.	Mean	Std.	
Cassava yield (t/ha)	22.50	7.99	17.34	6.74	5.08***
Gender: Male =1	0.71	0.45	0.74	0.44	0.03
Age (years)	46.26	11.84	47.27	11.87	-1.21*
Education (years)	6.81	5.22	6.76	5.23	0.24
Experience in farming(years)	20.54	14.42	22.34	15.53	-1.79**
Household size (continuous)	7.64	4.21	7.48	4.14	0.16
Plot owner (1/0)	0.64	0.48	0.73	0.44	-3.47***
Farm size (ha)	4.16	4.08	3.00	2.95	1.17***
Awareness (1/0)	0.98	0.13	0.68	0.46	0.29***
Extension access (1/0)	0.74	0.43	0.52	0.49	0.21***
Extension visits (continuous)	2.88	2.09	1.92	2.16	0.95***
Distance to market (km)	5.79	4.77	5.48	5.15	-0.30
Membership of association(1/0)	0.71	0.45	0.51	0.50	0.20***
Fertilizer application(1/0)	0.14	0.36	0.15	0.35	-0.01
Monocrop(1/0)	0.42	0.49	0.41	0.49	0.01
Fertility status (1/0)	0.62	0.48	0.62	0.48	0.00
Recommended Spacing(1/0)	0.45	0.49	0.41	0.49	0.04

Note. ***, **, * denote significance at 1%, 5% and 10%, respectively.

3. Results and discussion

3.1. Farm and farmer characteristics

Table 4 presents differences in the characteristics of adopters and non-adopters, with their t-values. Comparing yield of adopters and non-adopters, the results showed that adopters had more yields than non-adopters and the difference was statistically significant. The mean yield of adopters was 22.5 t/ha, that of non-adopters was 17.3 t/ha. Abdulai and Huffman (2014) found similar results in their soil and water conservation adoption studies. Adopters were found to be younger than non-adopters and the difference was significant. There was a significant difference between adopters and non-adopters as regards farming experience. Both adopters and non-adopters had on average about eight persons as family members. The majority of the farmers were plot owners, with non-adopters constituting more of the plot owners. Adopters had larger farm sizes than non-adopters and the difference was statistically significant. Chandio and Yuansheng (2018a) find farm sizes of adopters to be higher than that of non-adopters. There was a significant difference between adopters and non-adopters on access to extension and visits by extension to farmers. Adopters had more access and more visits than non-adopters. Likewise, Tibamanya et al. (2021) obtained results that showed

Table 5. Endogenous switching regression results for adoption and impact of adoption on Cassava yields
Cassava Yield

	Selection		Regime1 =Adopters		Regime2 =Non-adopters	
	Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error
Constant	1.624***	0.267	-12.129***	3.875	16.269***	1.537
Gender	-0.134	0.854	-1.676	1.086	-0.630	0.574
Age	-0.005*	0.003	-0.033	0.041	-0.004	0.020
Education	-0.005	0.007	-0.023	0.092	-0.030	0.020
Experience	-0.004*	0.002	-0.025	0.033	0.004	0.015
Household size	-0.021*	0.012	-0.069	0.162	-0.001	0.070
Plot owner	0.218***	0.081	1.991 **	1.030	-1.873***	0.592
Farm size	0.052***	0.012	0.463 ***	0.132	-0.107	0.088
Awareness	1.597***	0.161	21.315***	2.544	0.294	0.934
Extension access	0.210*	0.119	2.633*	1.526	0.423	0.820
Extension visits	0.048**	0.025	0.312	0.320	-0.189	0.191
Membership	0.327***	0.085	4.139***	1.100	1.791***	0.546
Fertilizer application	-0.173*	0.107	-1.300	1.389	1.104	0.698
Monocrop	0.026	0.086	-1.124	1.114	0.120	0.544
Fertility status	0.082	0.101	0.583	1.305	-0.206	0.632
Recommended Spacing	0.112	0.087	2.592**	1.118	-0.040	0.040
/lns1	2.566 ***	0.0497				
/lns2	1.868 ***	0.0271				
/r1	2.3946***	0.279				
/r2	0.054	0.200				
sigma_1	13.019	0.648				
sigma_2	6.478	0.175				

(Continued)

Table 5. (Continued)		Cassava Yield					
		Selection		Regime1 =Adopters		Regime2 =Non-adopters	
		Coeff.	Std. error	Coeff.	Std. error	Coeff.	Std. error
rho_1		0.983	0.009				
rho_2		0.054	0.199				
Log likelihood		-4594.764					
Wald test χ^2 (15)		136.110					
Likelihood ratio test of independent equations $\chi^2(1)$		9.000***					

* Significant at the 10% level; ** significant at the 5% level, *** significant at the 1% level.

Table 6. Impact of adoption on cassava yields: Conditional expectations, treatment and heterogeneity effects

Subsamples	Decision stage		Treatment effect
	To adopt	Not to adopt	
Adoption of improved cassava varieties	(a)22.034	(c)3.752	18.281*** (35.873)
Non-adoption of improved cassava varieties	(d)17.416	(b)6.442	10.974*** (66.13)
Heterogeneity effects	BH ₁ =4.618	BH ₂ =-2.690	TH =7.307

Note. *** denotes significant at 1%. Values in parentheses are t-values.

adopters had more access to the extension. The difference between adopters and non-adopters on awareness was significant. 98% of adopters were aware of the improved cassava varieties.

3.2. Empirical results and discussion

The estimates of the determinants of adoption and the impact of adoption on cassava yields are presented in Table 5. The full information maximum likelihood approach estimates both the adoption and the outcome equations jointly. Therefore, the selection equation represents the determinants of adoption of improved cassava varieties and these coefficients can be interpreted as normal probit coefficients. Results showed that age was negative and significant at a 10% level. This suggests that younger farmers are more likely to try new cassava varieties than older farmers. Danso-Abbeam et al. (2017) as well as Wongnaa et al. (2018) discovered that younger farmers were more likely to adopt improved maize varieties supporting the findings from this study. The experience was found to influence the probability to adopt improved cassava varieties significantly but negatively. As argued early on, less experience and probably younger farmers are more likely to adopt improved cassava varieties.

Extension access and extension visits were both found to positively and significantly influence the likelihood of adoption of improved cassava varieties. Agricultural extension is an efficient source of information on improved technologies for farmers (Abdulai & Huffman, 2014). Onyemauwa (2012) on determinants of improved cassava adoption found extension access as very influential in farmers' decision to adopt improved cassava varieties. Ghimire et al. (2015) reiterate the importance of extension access in the adoption of improved technology. The variable for awareness was positive and significantly different from zero, suggesting that farmers adopt improved technologies when they are knowledgeable of them. According to Abdulai and Huffman (2005), farmers that acquire knowledge about new technology through extension services or other channels are more likely to adopt the technology. Consistent with this result is a finding from Shiferaw et al. (2008), who reports awareness affecting the adoption of improved pigeonpea varieties.

The probability of adoption is affected significantly and positively by total landholding. The implication is that those with larger farm sizes are more likely to adopt improved varieties as they can afford to try out new things on parts of their farm. Consistent with the study's results are studies (Bidzakin et al., 2019; Langyintuo & Mekuria, 2008; Udensi et al., 2011) that found landholding to affect the adoption of improved technology. Belonging to an association significantly and positively influenced adoption of improved cassava technology, a finding that agrees with the opinion that social networks facilitate the flow of information and enhance the adoption of new agricultural technologies (Abdulai & Huffman, 2014).

Results of the impact of adoption on yield are presented in columns 3 and 4 of Table 4. The result of the likelihood ratio test of independence was significant at one percentage level, rejecting the hypothesis that the three equations are jointly independent. Furthermore, the coefficient of correlation between adoption and cassava yield “rho” in one equation is positive and statistically significant at 1%, indicating a failure to reject the hypothesis of sample selection bias. The parameter has a positive sign in the equation for adopters of improved cassava varieties, suggesting that farmers who adopt improved cassava varieties have significantly higher yields than a randomly selected farmer from the study area. In contrast, the parameter was insignificant in the equation for non-adopters, signifying that farmers who do not adopt improved cassava varieties have significantly lower yields than a randomly selected farmer from the study area. Generally, the results suggest that both observed and unobserved factors influence the decision to adopt improved cassava varieties and yield given the adoption decision.

The results showed that farm size was important in explaining higher yields in adopters. The positive and significant coefficients for adopters indicate that for this group of farmers, larger farms obtained significantly higher yields. This suggests that farmers with large farms adopt improved technology and obtain higher yields (Gabre-Madhin & Hagblade, 2001; Ghimire et al., 2015). For non-adopters farm size did not have any significant influence on yield. The ownership variable was found to explain yield of adopters positively and that of non-adopters negatively. The result reiterates the importance of ownership in crop variety adoption and consequent improvement in yields (Chandio & Yuansheng, 2018b).

Memberships of associations, extension access and awareness have positive and significant impacts on yields of adopters. These variables are proxies for information for farmers. Abele et al. (2007) reported of positive impact of access to an extension on the adoption of improved cassava varieties in Uganda. Agricultural extension enhances the efficiency of making adoption decisions. The introduction of new technologies creates a demand for information useful in deciding on adopting new technologies (Amengor et al., 2018; Zhang et al., 2016).

Recommended spacing had a positive and significant effect on yields of adopters. The spacing at which a crop is planted determines plant population per unit area, seed rate, plant competition for limited environmental resources, interception of solar radiation, weed suppression and the yield per unit area (Karaye & Yakubu, 2006). The inherent yield potential of varieties can be fully expressed when management practices are properly adopted and carried out accordingly.

3.3. Estimates of impact of adoption of improved cassava on yields

The estimates for the average treatments effects (ATT), which show the impact of adoption on cassava yields, are presented in Table 6. The expected yields under actual and counterfactual conditions are also reported. The expected yield of farmers that adopted improved cassava variety is higher than the group of farmers that did not adopt. It is clearly shown that the treatment effect for adopters is 18.28 t/ha. This represents a 487% increase in yields per hectare of cassava production. Also, results showed that farmers who did not adopt had they adopted, would have had 10 t/ha more in cassava yields representing a 170% increase in yields. The transitional heterogeneity effect is positive, implying that the impact of adoption on yields is significantly higher for farmers who actually adopted compared to those who did not adopt. These results are consistent with the position that the adoption of improved agricultural technologies improves yields (Abdulai & Huffman, 2014; Asfaw et al., 2012; Tufa et al., 2018).

3.4. Conclusions and Policy Implications

This paper has assessed the potential impact of the adoption of improved Cassava varieties on cassava yields in Ghana. By using endogenous switching techniques and accounting for selection bias, the true impact of the adoption of improved cassava variety has been estimated. The results revealed that

sample selection bias would result if the outcome equations (yields) were to be estimated without considering the adoption decision. Therefore, the adoption of improved variety may not have the same effect on the non-adopters should they adopt. The treatment effect that accounts for selection bias showed that adopters and non-adopters may be systematically different. Our study found that ownership and farm size significantly affected adoption decisions and cassava yields. The results highlight the importance of land ownership and landholdings in improved agricultural technology adoption.

The findings also indicate a positive and significant influence of extension access on adoption, as well as the impact on yields, sanctioning the importance of extension services in crop production areas. Awareness variable also positively and significantly affected both adoption decision and impact on yields. Our findings also confirm the significance of membership of the association in determining adoption and impact of cassava variety. Group membership engenders information flow, therefore encouraging farmers to join associations can reduce information barriers to adoption.

The results revealed a positive and significant impact of the adoption of improved cassava varieties on cassava yields in Ghana. Adoption significantly increased the yields of adopters by 487%. This increase in cassava yields shows the potential direct role of agricultural technology adoption on food increases and on food security.

Overall our findings have policy implications on the adoption of agricultural technologies. In order to improve adoption and consequent increases in yields, government policy on agriculture should include land tenure, extension, improved variety awareness and group membership. Land tenure systems in Ghana still have challenges that make it difficult for landless people to enter farming. The government will need to take the lead role in land reforms concerning agriculture to enable entrants, especially by the youth. The need for policy to resource research-extension linkage system to promote and create awareness about the existing improved cassava varieties and complementary technologies would go a long way to increase adoption. The results disclosed that the younger and less experienced farmers had a greater propensity to adopt improved cassava varieties. Normally, the youth lack initial capital and land resource to venture into agriculture. The youth could be incentivized to enter agriculture by the provision of needed resources.

3.5. Limitations and recommendation for future study

The study only focused on the impact of improved cassava variety adoption on cassava yields. We recommend future research on impact on income and food security.

Acknowledgements

The authors are grateful to the West Africa Agricultural Productivity Program for providing funds for this study. The staff of CSIR-Crops Research Institute who helped in the data collection are duly acknowledged.

Public interest statement

Cassava is a food crop that provides multiple opportunities for poverty reduction and nourishment for many people. Ghanaian government and the World Bank have assisted in the development of 25 new varieties to increase production and improve food security for more than three decades. Though studies have been carried out to find adoption rates of cassava varieties among farmers across Ghana, there are limited studies on cassava varieties adoption impact on farmers yield.

This study was carried out to examine and understand how research has led to outputs, uptake and outcomes, and the distributional consequences of these. It was also to identify and understand barriers to agricultural technology enhancement as a strategy for achieving larger goals such as increased incomes and food security. This study has shown the contribution of improved cassava varieties to yield improvement and Interventions to increase dissemination and uptake by smallholder farmers should be the focus.

Funding

This work was supported by the World Bank Group.

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Citation information

Cite this article as: Assessment of impact of adoption of improved cassava varieties on yields in Ghana: An endogenous switching approach, Patricia Pinamang Acheampong, Monica Addison & Camillus Abawiera Wongnaa, *Cogent Economics & Finance* (2022), 10: 2008587.

Note

1. Note that the study was conducted when Ghana had 10 regions.

Data availability statement

Data for the study are available upon reasonable request from the corresponding author.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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