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Market participation and technology adoption: An application of a triple-hurdle model approach to improved sorghum varieties in Mali

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ABSTRACT

This study examines the relationship between market participation and agricultural technology adoption. Using data collected in 2017 from 542 sorghum household farms in Mali, a triple hurdle model that integrates the three following separate stochastic decisions: improved sorghum varieties adoption, market participation and marketed quantity is proposed to investigate the underlying process of market participation. Results indicate that the adoption decision plays a key role in market participation and marketed quantities. Adoption decision precedes that of market participation, and this latter precedes marketed quantity. These findings extend the market participation and agricultural technologies adoption literature and have methodological and political implications. First, the triple-hurdle model consistently controls for selection bias and endogeneity between market participation and adoption. Second, the process of sorghum breeding needs to take into account market opportunity and market demand. Third, upscaling projects might facilitate initiatives that enhance market access to smallholder farmers. The study concludes that interventions that facilitate households' participation in the sorghum market and the accounting for market demand in breeding programs could enhance the uptake of improved varieties.

1. Introduction

Smallholder market participation is a critical issue to improving household welfare in rural areas and poverty reduction in developing countries [25]. Indeed, increased participation of smallholders in markets allows farmers to focus on producing goods for which they are skilled and trade their surplus for other goods they desire but for which they do not have

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a comparative production advantage [30]. Market participation also allows benefiting from opportunities that emerge from large-scale production and use of improved technologies, leading to more rapid total factor productivity growth [7]. Several efforts have been made in the wave of market-oriented liberalization for promoting smallholder market participation in developing countries. However, farm households from Sub-Saharan Africa face many barriers that make it difficult to gain access to markets and productive assets [29]. One of the key elements is the lack of access to enhanced production technologies which could contribute to increasing productivity and household income in rural areas. In most West African countries, adoption rates of improved agricultural technology remain low despite such technologies being encouraged as a means of improving productivity and increasing production [28]. In the specific case of Mali, area shares devoted to improved sorghum varieties range from 13% to 30% according to the regions [28].

The relationship between market participation and technology adoption is complex and can be analyzed in two directions [7,8]. Market participation influences technology adoption patterns by affecting the gross margins due to increased output. Technologies also directly affect market participation because the productivity of assets used by households considerably influences its net marketable surplus. Farm households using productive modern technologies are more likely to produce more and generate a marketable surplus than those who use traditional technologies in their production system. For example, Smale et al. [28] find a positive relationship between growing improved sorghum varieties and the share of sorghum marketed by households from the harvest. Thus, improved production technologies provide a more reliable driver of increased supply than do exogenous price-increasing shocks due to policy change [7]. In a small open economy in which producers face infinitely elastic demand, the gains related to any adoption of improved technologies accrue totally to producers in terms of higher gross margin. By contrast, if demand is perfectly inelastic, the gains accrue to consumers in terms of lower prices. Thus, the distribution of the gains related to the adoption of improved sorghum varieties depends on the price elasticity of demand for the sorghum, which in turn depends heavily on how the local market is integrated with national and regional markets. Better integration of local markets into national and regional markets could contribute to improving income for smallholder sorghum producers.

The literature on market participation mainly focuses on modeling in two steps, the double- hurdle approach. The first stage is the household's decision whether to participate in the market as a buyer, a seller or remains autarkic and if it decides to participate, the second stage is to determine the intensity of participation in terms of quantity to be bought or to be sold. Several empirical studies were conducted in this area (see e.g. [18]; and [8]). Goetz [18] investigated the participation of farm households in grain markets in Senegal using the double-hurdle approach. The author applies a probit regression for the first stage and a switching regression for quantities bought and sold in the second stage and assumes that choices are sequential. He found that fixed transaction costs have significantly limited smallholder market participation. Bellemare and Barrett [8] developed a two-stage econometric method to test the two hypotheses of simultaneous and sequential choices regarding household-level marketing behavior in Kenya and Ethiopia livestock markets. They applied an ordered probit model in the first stage to separate producers into net buyers, autarkic, and net sellers. In the second stage, the authors applied two truncated normal models for net quantities bought and sold. Recently, Burke et al. [9] identified factors associated with smallholder farmers choosing to participate in the dairy production and the role that these producers play in the marketplace in Kenya. They applied a triple-hurdle model with an initial stage that includes non-producers of dairy and found that net sales are significantly higher when farmers have access to informal private markets.

Regarding technology adoption, many empirical studies assess the determinants of agricultural technologies adoption in developing countries (see e.g. [4,5]). For instance, Adesina and Baidu-Forson [4] analyzed farmers' perceptions of technology characteristics on their adoption decisions of modern sorghum and rice varietal technologies in Burkina Faso and Guinea using Tobit models. They found that farmers' subjective preferences for characteristics of new agricultural technologies are the main determinants of adoption behavior. Amponsah et al. [5] examined factors influencing adoption decisions of modern technologies among rural farmers in Mali using Ordinary Least Squares regression and Cost-Benefit analysis. The technologies tested include crop technologies, animal husbandry technology, human nutrition enhancement technologies, and agroforestry technologies. They concluded that household size and proximity of the technologies to farms positively determine the adoption decisions.

Few studies investigated the relationships between market participation and improved agricultural technology adoption in developing countries. Mekonnen [23] accounting for the potential selection bias (observed and unobserved factors) between adoption and market participation decision, analyzed the impact of improved agricultural technologies on smallholders' output market participation. He concluded that access to high-yielding varieties (wheat, maize, sorghum, barley, and tef) and chemical fertilizer determine marketable surplus crop production and market participation of farmers in Ethiopia. Awotide et al. [6] identified the physical and socioeconomic factors affecting the intensity of adoption of improved rice varieties, the determinants of market participation and its effect on rural farming households' welfare in Nigeria. They concluded that the area under improved rice varieties and access to improved seeds are positively and statistically significant in determining market participation.

This paper examines the relationship between market participation and the adoption of improved agricultural technologies. Its main contribution to the literature is the integration of the issue of the adoption of improved varieties into that of market participation. We extend the double hurdle approach generally applied in market participation modeling [2,8,27] to integrate the issue of market participation conditional on the adoption of improved varieties. Indeed, the paper proposes a triple hurdle model that integrates three separate stochastic decision choices about technology adoption (first stage), market participation (second stage) and marketed quantity decisions (third stage). Following Burke [10], the paper assumes that the three decisions (the three stages of the triple hurdle model) are sequential. The outcome on participation in sorghum market decision (second stage) precedes that on the amount of sorghum to buy/sell decision (third stage) and the decision of adoption of improved sorghum varieties precedes the outcome of participation in sorghum market decision (first stage). However, while the proposed model is an adaptation of Chi [11] and Burke et al. [9], to the best of our knowledge, no study so far has integrated adoption decision in the first step of a triple hurdle model.

The rest of this paper is organized into six sections as follows. The second section briefly describes the sorghum market and adoption pattern of improved sorghum varieties in Mali. The third section presents the conceptual framework with special attention giving to the triple-hurdle approach. The fourth section describes the empirical modeling with a comparison between a one-step market participation modeling, a double-hurdle market participation modeling and a triple-hurdle market participation modeling. The fifth section presents survey data, variables, and statistic tests between the three market participation categories. The sixth section provides the results and discussions in two parts - the specification testing of the three types of market participation models and cross-analysis of determinants of adoption of improved sorghum varieties and their effects on the outcome of market participation of smallholder farms in Mali. The concluding section presents policy implications of the main findings.

2. Sorghum market and adoption of improved sorghum varieties in Mali

Sorghum grain is a major staple crop in Mali. The main production areas include western Sahel (Kayes and Koulikoro regions), recession zone (Kayes, Mopti, and Timbuktu regions), and Sudanese zone (Koulikoro, Sikasso, and Segou regions). However, sorghum is produced in six out of the eight regions of the country. The marketable surplus is sold outside the production areas in both urban and rural markets. The rural market ensures farm gate collection, and it is a pole of attraction of farmers for product marketing and procurement of their goods and services. In all regions, rural markets are generally weekly markets where the global volume of transactions is estimated between two and six tons at the harvest time, and between 0.5 and 1 ton during other periods depending on the markets and the level of production by cropping season. The urban market is rather permanent and is a central pole of farm gate collection and supply for the urban wholesale and retail markets [16].

Sorghum marketing in Mali involves several categories of traders. Depending on the amounts traded and the level of financial capital, traders include collectors, wholesalers, semi-wholesalers, and retailers. Collectors are specialized in farm gate collection and are working mostly for themselves. Sorghum grains collected weekly in rural markets are sold to wholesalers and semi-wholesalers who are in urban markets. Semi-wholesalers have purchasing and storage capacities estimated on average at 400 tons and 800 tons per year respectively, while wholesalers can manage 5,000 tons to 10,000 tons per year [16]. Semi-wholesalers and wholesalers play a major role in sorghum imports and exports in neighboring countries including Senegal, Mauritania, Niger, and Cote d'Ivoire. Retailers buy sorghum from collectors and wholesalers; however, the largest share of their sorghum grains is supplied by wholesalers [16]. Retailers are based in cities and ensure distribution among consumers. There are also industrial and small-scale processors who buy sorghum grains from farmers, rural cooperatives, and collectors. Access to credit is strongly limited to major traders. However, collectors benefit from credit from major traders (65%), relatives and friends (35%). In 2009, the retail price of sorghum was estimated to 125[1] FCFA/kg. This price is distributed among value chain actors as follows: farmer earns 45%, the collector receives 10%, semi-wholesaler and wholesaler 14% and 18%, respectively and retailer 13% [16].

Sorghum grains market appears to be well organized, but this does not seem to be the case for the seed companies especially for the sorghum improved varieties. There is almost no structured market for the production and marketing of certified seeds. Farmers often use recycled seeds which are most of the time of poor quality. However, during recent years, producers supervised by Non-Government Organizations and development projects use improved seeds which have a yield potential of two to three tons per ha against less than one ton per ha on average for local varieties. This situation inevitably leads to relatively low performance that considerably limits the ability of the sorghum sector to meet domestic demand although national and international research centers have intensified their interventions on improved seed development. Hybrids seed is newly introduced in Mali and is at an initial stage of the diffusion process [28].

3. Conceptual framework

The framework applied in this paper is an extension of the standard double-hurdle market participation in the past studies (see for example [2,27]) which consider market participation as a two-stage phenomenon involving two decision processes. For a given commodity, households decide first to participate in the market as net buyers, net sellers or remain autarkic. Second, net buyers and net sellers determine the quantity to buy or to sell. Recently, Burke et al. [9] introduced the triple-hurdle approach for market participation analysis. They modeled the production decision in the first stage. In the second stage, they focused on the decision to participate in the market (net buyers, net sellers and autarkic) and in the third stage they analyzed the intensity of participation for net buyers and net sellers. In this study, we follow a triple-hurdle approach but taking a different perspective. Specifically, in the first stage, we use a probit model to analyze factors

[1] 1000 FCFA = USD 1.7 in August 2018.

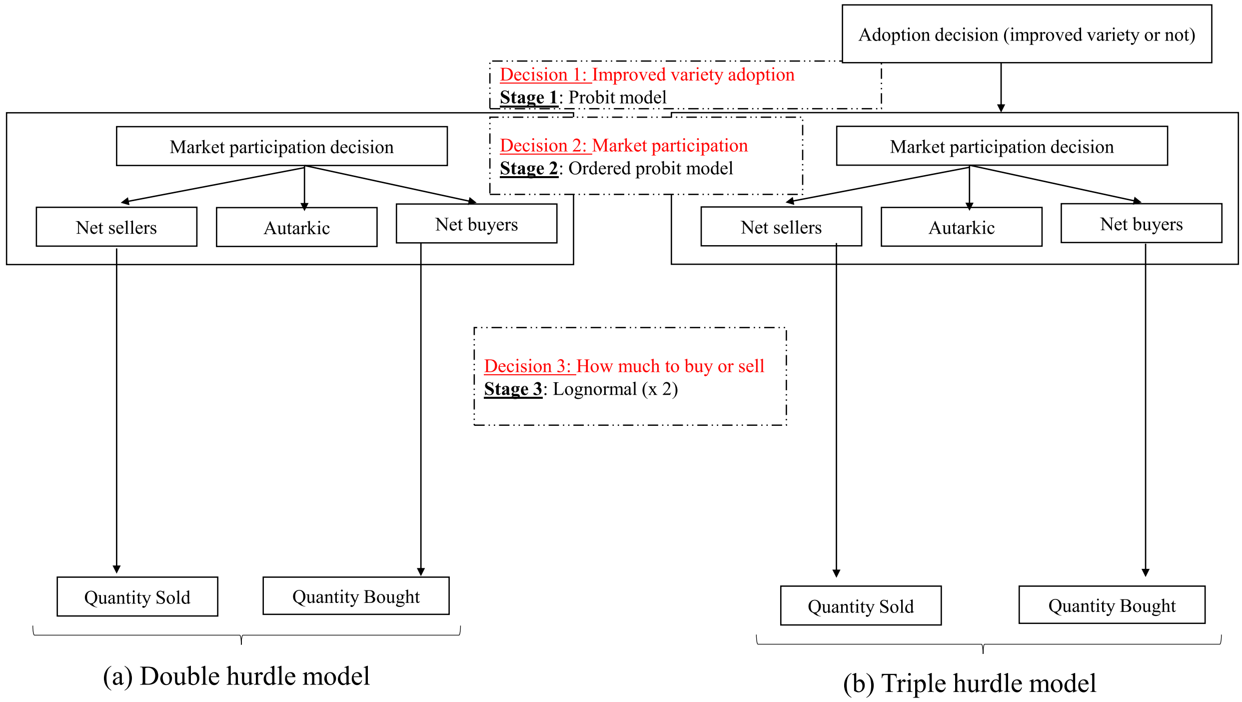

Fig. 1. Illustration of double-hurdle model (a) and triple-hurdle model (b).

affecting the adoption of sorghum improved varieties. In the second stage, we apply an ordered probit regression approach to analyze factors that affect market participation (net buyer, net sellers, autarkic). Finally, in the last stage, we use two lognormal models (one for net sellers and another for net buyers) to investigate the intensity of market participation. Since all farmers in the selected regions of Mali cultivate sorghum, it is not convenient to model the decision to produce sorghum like in Burke et al. [9]. More recently, Chi [11] provides guidance in the choice between the one-step decision method, double hurdle model and triple hurdle approach in an empirical expenditure analysis. Besides, this paper is different from Burke et al. [9] in the first stage where we investigate the decision to adopt improved varieties. In particular, both adopters and non-adopters participate in sorghum market but probably differently. We consequently assume that technology adoption and market participation decisions are sequential. Our triple hurdle model integrates three separate stochastic decision choices for the first stage of adoption, the second stage of market participation, and a final stage of the quantity to sell or to buy. The framework of the analysis is presented as follows:

$$y_1 = y_1(X) \tag{1}$$

$$y_2 = y_2(W, y_1^*) \tag{2}$$

$$y_3 = (q_1 - q_2) = y_3(Z, y_2^*) \text{ for net sellers} \tag{3}$$

$$y_4 = (q_2 - q_1) = y_4(Z, y_2^*) \text{ for net buyers} \tag{4}$$

where y_1 is an indicator which characterizes the decision of farmer to adopt improved sorghum varieties, X is a vector of covariates that influences adoption decision of farmers. Then y_2 is an indicator that takes one of three values depending on whether a farmer is a sorghum net buyer, autarkic, or a net seller, q_1 is the quantity produced by the farmer, q_2 is the quantity consumed by the farmer, and the difference between the two is the net quantity sold or bought., W is a set of covariates explaining market participation status of farmer, and y_1^* is the unobserved latent variable underlying the observed adoption status. In Eqs. (3) and (4), y_3 and y_4 are respectively the observed net sales and net purchases, and they are nonnegative variables. y_2^* is the unobserved latent variable underlying the observed market participation status, y_2, Z is a vector of covariates that influences the outcome of market participation for net sellers and net buyers. Fig. 1 is a diagram of the data generating process for market participation associated with sorghum improved varieties adoption that summarizes our triple-hurdle modeling. Fig. 1.a is the standard double-hurdle econometric method developed by Bellemare and Barrett [8] to test whether the decisions related to market participation and volume marketed (sold or bought) are simultaneous or sequential. Fig. 1.b is somehow borrowed from the standard triple hurdle market participation decision [9] with an initial stage that includes the decision for the adoption of improved varieties. As such, this paper estimates the relationship between market participation and the adoption of improved varieties.

The adoption of improved varieties that is addressed in the first stage of our triple-hurdle modeling in this paper has been much discussed in the literature. However, empirical studies do not generally separate the effect of the adoption decision on market participation status and marketed volumes to test whether market participation and adoption decisions are sequential or simultaneous. In general, empirical studies apply bivariate or multivariate regression models to a pooled sample of observed adoption outcome data and the outcome of market participation status. Diagne and Demont [13] applied the average treatment effect (ATE) estimation framework to derive population adoption rate of rice varieties NERICA (New Rice of Africa) in Côte d'Ivoire by controlling for adoption rates after and before intervention for the groups who were exposed to improved varieties and for the non-exposed groups. Adegbola and Gardebroek [3] made use of a generalized method of moments (GMM) framework to control for selection bias to investigate the effect of alternative information sources on adoption decision of improved maize storage technologies in the southern region of Benin. In the same vein, Smale et al. [28] applied an ordered logit model to analyze factors explaining adoption of sorghum improved seed and hybrids by sorghum farmers in Mali. These studies consider market participation status as an explanatory variable for adoption of improved technology. Muamba (2011) analyzed market participation using a farm-level sequential market participation model that takes into account the conditional nature of farmer's decision to participate in the market. He concluded that a farmer's decision to participate in the market of a given crop depends on whether the crop is produced or not by the farmer. Recently, Burke [10] revisits the consistency of the double hurdle model in market participation or adoption studies where part of the population of interest does not participate or adopt. He then concludes that the simultaneousness or sequence of decisions may reasonably be made by introspection or cannot be considered either consistent or inconsistent with the results of a statistical comparison of the one-step specification. The author suggests that whether or not a statistical test leads to rejecting the restriction assumptions cannot imply whether decisions are sequential or simultaneously. However, the validity of the hurdle modeling is related to the data generating mechanisms (DGMs) and most importantly the number of observations.[2] To circumvent the problem, Chi [11] and Burke [10] show that the likelihood ratio (LR) test is convenient to select the appropriate model in terms of the underlying processes.

4. Estimation procedure

In applied econometrical applications, various mechanisms are put forward to explain the appearance of zero volume sale or buy observations [8,9]. This paper focuses on three modeling components including a two-stage market participation model (Fig. 1.a) and a three-stage market participation model (Fig. 1.b). For the two-stage model, the double hurdle model originally proposed by Cragg [12] is established to allow two separate stochastic processes for market participation status and volumes sold or bought. In this modeling, an ordered Probit is applied in the first stage and a lognormal model in the second step. For the three-stage model, the triple hurdle model is developed to integrate the three separate stochastic decision choices for the first stage of adoption of improved sorghum varieties, the second stage of market participation, and a final stage of quantity sales or purchases. In the first stage of the triple-hurdle model approach as indicated above, a probit model is applied to estimate the adoption decision. In the second stage, the sample is partitioned into net buyer, autarkic and net seller households and an ordered probit model of household discrete choice concerning market participation is estimated following Burke et al. [9]. Market participation status is determined by quantity sold minus quantity bought. Starting at negative infinity and moving right on market participation status line, net buyers are the first group we find before reaching zero, autarkic farmers are next at zero, and then net sellers to the right of zero [9]. In the third stage, the determinants of the quantity of sorghum that each net buyer or net seller household transacts in the market are investigated. Then, the two Lognormal models to estimate the net sales and net purchase volumes are applied. The likelihood function integrating the three steps, a probit model, an ordered probit model, and two lognormal models is then estimated by limited information maximum likelihood.

For the specification of the likelihood function of the triple hurdle model, we define values for variable y_1 that takes the value 0 for non-adopter and 1 for adopter. Along, we define values for variable y_2 that takes the value 0 when $[q_1 - q_2 < 0]$, the value 1 when $[q_1 - q_2 = 0]$, and the value 2 when $[q_1 - q_2 > 0]$. Let x_1 be the variables explaining the adoption decision; x_2 be the variables explaining the decision to participate as a net buyer or net seller or remain autarkic, x_3 be the variables explaining net purchase volumes, and x_4 be the variables explaining net sale volumes. This leads to a conditional probability of market participation intensity given by Equation (5):

$$\left(y|\alpha', \beta', \sigma'\right) = [1 - \Phi(x_1\beta_1)]^{\mathrm{I}[y_1=0]} \cdot [\Phi(x_1\beta_1)]^{\mathrm{I}[y_1=1]} \left\{ \begin{array}{c} \left[\frac{\Phi(\alpha_1 - x_2\beta_2)\phi\left(\frac{[\ln(y_3) - x_3\beta_3]}{\sigma_3}\right)}{y_3\sigma_3}\right]^{\mathrm{I}[y_2=0]} \\ [\Phi(\alpha_2 - x_2\beta_2) - \Phi(\alpha_1 - x_2\beta_2)]^{\mathrm{I}[y_2=1]} \\ \left[\frac{\Phi(x_2\beta_2 - \alpha_2)\phi\left(\frac{[\ln(y_4) - x_4\beta_4]}{\sigma_4}\right)}{y_4\sigma_4}\right]^{\mathrm{I}[y_2=2]} \end{array} \right\} \quad (5)$$

where α_1 and α_2 are the unknown threshold parameters from an ordered probit (Stage 2); $\beta_1, \ \beta_2, \ \beta_3$ and β_4 are parameters on the variables x_1, x_2, x_3 and x_4, respectively; σ_2, σ_3 and σ_4 are variance parameters, one for each linear component,

[2] If the number of non-adopters in our case tends to zero, the hurdle model tends to OLS estimates [10].

that is, net purchases and net sales; $\phi(\cdot)$ is the standard normal distribution function and $\Phi(\cdot)$ is the standard normal cumulative distribution function. Following Chi [11] and Burke [10], selection between the one-step, the double hurdle and the triple hurdle models can be tested by the likelihood ratio test statistic (LR), which is based on the principle of maximum likelihood estimation. It is used to test the hypotheses that the one-step model performs over the double hurdle model or this latter over the triple model by comparing the values of the maximized likelihood functions under the restricted (H_r) and unrestricted (H_{unr}) models. Systematically, the LR is twice the difference of the log-likelihood of the unrestricted model and the restricted, or $LR = -2[L(H_{unr}) - L(H_r)]$. As indicated by the two authors, LR is asymptotically χ^2_K distributed, where K is the difference in the number of parameters estimated in the unrestricted and restricted models. The null hypothesis is that the restricted model (H_r) is rejected when $LR > \chi^2_K$ [19].

Analytical models widely used to investigate the adoption of improved technologies include probit, logit, and Tobit models. To analyze the adoption behavior, a limited dependent variable provides a good framework where there is a cluster of farmers with zero adoption of the improved technology. This study uses a probit model, which is applied to Equation (1) to test the hypothesis that, adoption of improved varieties of sorghum increases the market participation of farmers in the production systems in Mali. In the specification of the Lognormal model (Stage 3), there is a latent unobservable y^*_{3i} for net buyer and y^*_{4i} for net seller. This variable depends linearly on x_{3i} or x_{4i} via a parameter vector β_3 or β_4. There is an error term ε_{3i} or ε_{4i} normally distributed that captures random influence on this relationship. The observed variable y_{3i} or y_{4i} is defined as being equal to the latent variable whenever the latent variable is above zero and to be equal to zero otherwise.

5. Data description

Data were collected in the four main regions producing sorghum in Mali including Kayes, Koulikoro, Segou and Sikasso. A two-stage sampling technique was used. Firstly, 16 villages where sorghum is the major crop produced were randomly selected. Secondly, 30 to 35 households were randomly selected from the census of households in each village. A total of 542 households were interviewed in 2017 using a structured questionnaire covering qualitative and quantitative information about sorghum improved varieties adoption, market participation, farming systems and other socioeconomic characteristics of households.

Table 1 presents descriptive statistics of outcomes and explanatory variables. Results show that net buyers, autarkic and net sellers represent respectively 22%, 38% and 40% of the sample. About 30% of net buyers have grown improved varieties. Adopters represent 20% and 28% of autarkic and net sellers, respectively. This distribution is consistent with the findings of Kelly et al. [20] in sorghum production system in Mali. On average, there are 8 adult-equivalents per household in the study areas. Household heads are on average 49 years old with relatively low education levels. Most household heads belong to farmer groups (83%) and are in contact with extension services (61%) but few received training in sorghum production (35%). About 42% of households surveyed have off-farm income. On average 10 ha of land and at least one motorbike are available in each household. Households have to travel for about 17 km on average to reach the nearest market. Except for the variables contact with extension services and selling price, there are significance difference between market participation status for the other variables.

6. Results and Discussions

6.1. Specification testing

Three different specifications of the the underlying process of market participation are estimated for validity testing. The one-step market participation model is typically a seemingly unrelated Lognormal model - that is one Lognormal for net buyer households and another for net seller households – under the standard hypothesis that discrete participation and continuous volume decisions are made simultaneously [8,9]. The coefficients of the two Lognormal models are reported in Table 2. This specification implies that the probability of market participation and the quantity to sell or buy are determined by the same set of variables and parameters. If this assumption is violated, coefficients estimated from the one-stage model are biased and the model is irrelevant to understand the market participation process [8,11]. To check for this assumption, we estimate the double hurdle model of market participation and marketed volumes as suggested by Bellemare and Barrett [8] to control for selection bias. In the first stage, an ordered probit on market participation is estimated. Market participation here is a multinomial variable including 0 for net buyers, 1 for autarkic and 2 for net sellers. In the second-stage, net purchases and net sales volume choices conditional on expected market participation, repeating the intuitive results from the Lognormal model (Table 3). The Inverse Mills Ratio (IMR) is then calculated from the first stage and included in the second stage as an explanatory variable to control for endogeneity and selection bias [8]. The likelihood ratio test is then calculated to test the consistency of the double hurdle model [10]. In the paper, this two-stage market participation model is then extended to the triple hurdle model that includes the adoption of improved sorghum varieties in the first stage (Table 4). The benefit of this later specification as indicated above is that it allows integrating the three separate stochastic decision choices about adoption, market participation and net quantity sold and bought. The first stage of this model is a probit model on adoption (dummy)[3]. The second stage is an ordered probit on market participation status (net buyer,

[3] Since all households in our sample data do not adopt improved sorghum varieties, a probit model is preferred over a tobit model.

Table 1
Descriptive statistics by market participation status.

Variables	Pooled data (n=542)	Net Buyers [a] (n_B=120)	Autarkic [b] (n_A=205)	Net Sellers [c] (n_S=217)	Test of difference		
					[a-b]	[a-c]	[b-c]
Household characteristics							
Age of household head (years)	49.06 (12.02)	51.46 (11.40)	50.67 (12.35)	46.22 (11.50)	0.79	5.24***	4.45***
Education level (Number of years of formal education)	1.30 (2.95)	1.52 (3.20)	0.98 (2.83)	1.47 (2.89)	0.53	0.04	0.49*
Household size (Equivalent adult)	7.50 (5.62)	8.27 (7.93)	6.80 (4.21)	7.75 (5.19)	1.47**	0.52	0.95**
Institutional support							
Belonging to farmers' groups (dummy, yes=1)	0.83 (0.37)	0.73 (0.44)	0.85 (0.35)	0.87 (0.33)	0.12***	0.14***	0.02
Training on sorghum production (dummy, yes=1)	0.35 (0.48)	0.17 (0.38)	0.38 (0.49)	0.42 (0.50)	0.21***	0.25***	0.04
Contact with extension services (dummy, yes=1)	0.61 (0.49)	0.55 (0.50)	0.61 (0.49)	0.64 (0.48)	0.05	0.08	0.03
Household assets							
Off-farm income (dummy, yes=1)	0.42 (0.49)	0.35 (0.48)	0.48 (0.50)	0.39 (0.49)	0.13**	0.04	0.10**
Means of transportation (number of motorbike)	1.25 (0.93)	0.22 (0.43)	2.17 (1.22)	0.94 (0.76)	1.95***	0.72***	1.23***
Total land available (ha)	9.70 (6.36)	5.30 (4.25)	8.65 (4.89)	13.13 (6.73)	3.34***	7.82***	4.47***
Access to market							
Distance to market	17.11 (4.75)	13.39 (4.23)	20 (7.12)	16.44 (5.54)	6.61***	3.05***	3.56***
Sorghum selling price (USD/kg)	132.85 (15.42)	132.07 (10.87)	132.88 (2.65)	133.26 (22.88)	0.82	1.96	0.38
Outcome variables							
Net quantity of sorghum sold/bought (kg)	-	613.31 (520.16)	-	638.25 (442.93)	-	-	-
Percentage of adopters	29.70	20	27.80	36.86	-0.08	0.17***	0.09**

Robust standard error in parenthesis
The superscript ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels.

Table 2
One-step method estimates for market participation intensity (bivariate lognormal).

Variables	Quantity sold		Quantity bought	
	Coef.	Std. Err	Coef.	Std. Err
Age of household head	-0.042	0.027	0.027	0.023
Age squared of household head	0.000	0.000	-0.000	0.000
Education level of household head	0.007	0.016	-0.027**	0.012
Household size	-0.021**	0.009	-0.003	0.005
Belonging to farmers group	0.198	0.147	-0.178*	0.092
Training on sorghum production	0.204*	0.105	0.100	0.098
Contact with extension services	-0.267***	0.103	0.203**	0.079
Off-farm income	0.152	0.094	0.210***	0.075
Means of transportation	-0.105	0.079	-0.665***	0.164
Distance to market	-0.086***	0.013	-0.087***	0.017
Total land available	0.067***	0.009	-0.014	0.010
Constant	7.569***	0.674	6.964***	0.596
Ancillary Parameters				
Lnsigma	-0.417***	0.048	-0.976***	0.065
Goodness of fit				
Log likelihood	-270.602***			
R-squared	0.63	0.76		
Observations	217	120		

Standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 3
Double-hurdle model estimates of market participation status and intensity.

Variables	Stage 1		Stage 2			
	Market participation		Quantity sold		Quantity bought	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Age of household head	-0.081**	0.032)	0.009	0.026	0.003	0.024
Age squared of household head	0.001**	0.000)	0.000	0.000	-0.000	0.000
Education level of household head	0.007	0.018)	-0.006	0.015	-0.029**	0.012
Household size	-0.029***	0.010)	0.003	0.010	-0.009	0.007
Belonging to farmers group	0.208	0.154)	–		–	
Training on sorghum production	0.524***	0.119)	–		–	
Contact with extension services	-0.122	0.121)	-0.211**	0.091	0.195***	0.076
Off-farm income	-0.021	0.106)	0.184**	0.090	0.186**	0.076
Means of transportation	-0.273***	0.088)	0.136	0.086	-0.735***	0.168
Distance to market	0.105***	0.018)	-0.167***	0.018	-0.064***	0.021
Total land available	0.129***	0.010)	-0.022	0.018	0.003	0.021
Constant		9.119***	0.713	6.822***	0.633	
Ancillary Parameters						
$\widehat{IMR}$		-1.861***	0.357	0.271	0.227	
$\widehat{\alpha_1}$	-0.556	(0.827)				
$\widehat{\alpha_2}$	0.822	(0.827)				
lnsigma		-0.461***	0.048	-0.963***	0.065	
Goodness of fit						
Log likelihood	-459.552***	-262.523***				
R-squared		0.66	0.75			
Observations	542	217	120			

Standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

autarkic, net seller). The third stage consists of two truncated normal regressions, one for net sales and the second for net purchases. To control for endogeneity and selection bias, the estimated IMR of the first stage is included in the second stage and the estimated IMR of the second stage is included in the third stage [9]. The likelihood ratio (LR) test is performed test between our model of interest – the triple hurdle model – and the double hurdle model and the result suggests that a more flexible triple hurdle model is preferred to the double hurdle model ($LR = 22.48$ with $p = 0.000$). This finding suggests that the triple-hurdle model is more accurate in analyzing the relationship between market participation and improved variety adoption. We, therefore, focus discussions on results from the triple hurdle model estimation (Table 4).

From stage 1 to stage 2, the exclusion restriction is imposed on two variables that are assumed to have a direct effect on the adoption decision but not on the market participation status. Typically, two institutional support variables are excluded,

Table 4
Triple-hurdle model estimates for sorghum improved variety adoption and market participation in Mali.

Variables	Stage 1		Stage 2		Stage 3			
	Adoption		Market participation		Quantity sold		Quantity bought	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Age of household head	0.031	0.039	-0.102***	0.033	-		-	
Age squared of household head	-0.000	0.000	0.001***	0.000	-		-	
Education level of household head	-0.040*	0.022	0.033*	0.018	0.004	0.016	-0.027**	0.012
Household size	0.002	0.012	-0.030***	0.010	-0.011	0.011	-0.007	0.007
Belonging to farmers group	0.411**	0.209	-					
Training on sorghum production	0.761***	0.132	-					
Contact with extension services	0.393***	0.144	-0.358**	0.152	-0.193**	0.095	0.190***	0.074
Off-farm income	0.106	0.125	-0.086	0.107	0.158*	0.094	0.195***	0.075
Means of transportation	0.019	0.102	-0.282***	0.088	0.001	0.083	-0.727***	0.168
Distance to market	-0.015	0.020	0.115***	0.019	-0.127***	0.019	-0.070***	0.021
Total land available	-0.028***	0.011	0.145***	0.011	0.020	0.020	-0.002	0.021
Constant	-1.365	0.977		8.556***	0.699	6.915***	0.656	
Ancillary Parameters								
$\widehat{IMR}$		-0.828***	0.189	-0.503**	0.208	0.136	0.172	
$\widehat{\alpha_1}$		-2.070**	0.907					
$\widehat{\alpha_2}$		-0.699	0.902					
lnsigma			-0.412***	0.048	-0.958***	0.065		
Goodness of fit								
Log likelihood	-285.137	-461.39245	-273.76396					
Percent correct	73.25%							
LR chi2	89.17***	234.98***	379.75***					
R-squared			0.63	0.75				
Observations	542	542	542	217	120			

Standard errors in parentheses
*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

i.e., membership of farmers' groups and training on sorghum production.[4] These two variables are statistically significant in the adoption decision (stage 1). To test the conditionally uncorrelated hypothesis between Stage 2 and Stage 3, the exclusion restriction is imposed on the age of the household head and its squared. These variables are significant in the ordered probit model and conceptually irrelevant in explaining the net quantity sold/bought. The age of the head of household, as such, cannot influence the net quantity sold/bought. Its effect on the net quantity sold/bought - if it exists - would be taken into account by other variables such as the size of the household. This is particularly true in the context of Mali, where an elderly head of household is associated with a large household. The likelihood function in the models is nonlinear, implying that the coefficients estimated are not partial effects, but the statistical significance and the direction are highly informative. The coefficient of $\widehat{IMR}_{Adoption}$ in the second hurdle is -0.83 and significant at 1%, suggesting that the two decisions are correlated. This also confirms the hypothesis that the adoption decision precedes the one of market participation. The coefficients of the $\widehat{IMR}_{\text{Market participation}}$ is significant in the net quantity sold model and not significant in the net quantity bought model. This result implies that the decision to adopt improved sorghum varieties influences that of market participation. However, once the decision to participate in the market as net buyers is made, the adoption decision does not influence the net quantity bought. On the other hand, there is a significant relationship between the market participation decision and the net quantity sold.

6.2. Cross-analysis of determinants of market participation and adoption decisions

The triple-hurdle model (Table 4) offers room for cross interpretation of factors influencing sorghum improved varieties adoption, market participation and net quantity sales or purchases. We take advantage of this modeling that integrates the three separate stochastic decision choices and analyze the effect of each explanatory variable on market participation, conditional on the adoption of improved varieties.

The coefficient of the age of the household head is negative and significant while its squared is positive and significant in the market participation status model. This implies that the age of household head tends to decrease the probability to participate in the sorghum market as net buyer or net seller compared to autarkic. The relationship between the age of household head and adoption of agricultural improved technologies is mixed in the literature. While Abdulai [1] reported a positive effect, Mazvimavi and Twomlow [22] found that the age of household head is negatively linked to the adoption of improved technologies. Regarding the relationship between market participation and age in the empirical literature, it is generally negative as shown by Abu et al. [2], Burke et al. [9] and Siziba et al. [27], among others. These authors found that

[4] It is standard to impose at least one justifiable exclusion restriction when estimating the second stage [32].

the likelihood to participate in the market decreases as farmers' age increases. In the context of Mali as shown in this result, elderly household heads usually have a large household size to manage and meeting the household's food needs is their priority. This could probably explain their propensity to adopt improved varieties, which would increase their productivity. Similarly, it would justify their aversion to adopting improved varieties because of their confidence in their old variety.

The educational level of farmers is hypothesized to be positively related to the market participation decision. Enete and Igbokwe [15] argued that education will endow households with better production and managerial skills which could lead to increased market participation. Results in this paper suggest that though education is statistically significant and positively related to market participation. Surprisingly, there is a significant and negative relationship between educational level and improved varieties adoption. A plausible explanation of this finding can be found in the characteristics of farmers. Data show that educational level is negatively associated with main activity, namely agriculture (correlation coefficient = -0.20) and area under crops (correlation coefficient = -0.21) suggesting a trend of reduction in agricultural activities as the educational level is increasing. The same result was found by Reimers and Klasen [26] in their study of revisiting the role of education for agricultural productivity.

Results also show that the size of households is not significant in the adoption decision but once the adoption decision is made, the household size is significantly and negatively associated with market participation decision. This finding is consistent with Woldeyohanes et al. [31], Abu et al. [2], Siziba et al. [27] who also found a strong and negative relationship between household size and market participation. For instance, Abu et al. [2], using a sample selectivity probit model for maize-producing households' market participation in Ghana found that the probability of selling maize decreases by 4.2% for an additional member of a household. In Mali, households produce sorghum mainly for home consumption, and it has been shown by Siziba et al. [27] that families with large household size fail to produce a marketable surplus beyond their consumption needs. Besidesthe decision to sell is made after consumption needs are met and more family members are associated with more consumption and, therefore, a decrease in selling probability and quantity.

Institutional support is one of the drivers of technology adoption and market participation in sub-Saharan Africa [3,14]. Three institutional support proxies are included in the models, these are: belonging to farmers' groups and receiving training on sorghum production and benefiting from extension services. Results indicate that these factors positively influence the adoption decision. In contrast, being in contact with extension services decreases the probability of market participation. This result implies that institutional support (farmers' training, belonging to farmers' groups and extension support) mainly focuses on the production side. Farmers also need extension services on a diverse range of rural development options including information on markets [17]. Specific market participation interventions could be designed and implemented to help households to enhance their market participation. However, in Mali, as indicated above sorghum plays a crucial role in household food security in rural areas that limits the marketing of the produce. Coefficients of distance from households to the nearest market and the availability of transportation means in the households suggest that these factors are highly important in both market participation probability and net quantity sales and purchases. Conditional to the adoption of improved sorghum varieties, the distance to the market tends to reduce the net quantity sold/bought. On contrary, the availability of transportation means decreases the net quantity purchases. These results corroborate the finding in market participation literature which indicates that distance to market is a limiting factor for market participation [21,24].

Conclusion

Smallholder farmers' market participation is a critical issue to improving household welfare in rural areas and poverty reduction in developing countries. However, farm households from Sub-Saharan Africa face several constraints that make it difficult for them to get access and to participate in the agricultural markets. Like most Sub-Saharan Africa countries, the level of agricultural technologies adoption amongst farmers in Mali remains low, despite the promotion of such technologies as a means of increasing productivity. This paper examines the relationship between smallholder market participation and improved agricultural technology adoption in Mali. To this end, the paper examines the extent to which the adoption of improved sorghum varieties affects market participation by applying a triple-hurdle model approach that integrates the three separate stochastic decision choices about improved variety adoption, market participation and marketed quantity. A total of 542 sorghum household farmers were randomly interviewed in 2017 including 22 % net buyers, 38% of autarkic households and 40% net sellers.

Key findings suggest that by separating households into net selling and net buying and modeling net quantity sold and net quantity bought, the triple-hurdle model estimates reveal that net sellers and net buyers behave somehow differently toward improved sorghum varieties adoption. Among net sellers, improved sorghum adoption decision, market participation decision as well as marketed quantity decision are shown to be sequential, indicating that the adoption decision precedes the outcome of market participation which precedes the decision on the quantity to sale. On the other hand, in the case of net buyers, the decisions to participate in the market and the quantity to buy are simultaneous. These results are critical, both from a scientific and a political point of view. In terms of policy implication, the findings suggest that interventions that encourage and/or facilitate market participation would enhance improved sorghum varieties adoption.

Declaration of Competing Interest

The authors declare no conflict of interest.

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