Adoption and impact of an award winning post-harvest technology: The ASI rice thresher in the Senegal River Valley

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1. Introduction

High rice import-dependent countries in sub-Saharan Africa are attempting to overcome the world rice crisis by boosting local rice production. In Senegal, to achieve this target, double cropping is considered as an important component of the national program for the Great Offensive for Food and Abundance (GOANA) and impels the respect of cropping calendar. The ASI rice thresher-cleaner, an improved post-harvest technology developed and released in 1997, aims at reducing post-harvest labor bottlenecks and increasing rice quality of irrigated rice farmers in the Senegal River Valley (SRV). It is a result of collaborative and adaptive research involving two CGIAR centers (Consultative Group of International Agricultural Research), i.e. WARDA (Africa Rice Center) and IRRI (International Rice Research Institute) and national partners such as ISRA (Senegalese Institute for Agricultural Research), SAED (Senegal River Valley National Development Agency), artisans, an agricultural machinery factory, farmers and farmers' organizations. In 1995 IRRI introduced two stripper/gatherer systems, which were subsequently adapted to the conditions in the SRV by WARDA and its partners. In 2003, the ASI thresher-cleaner won the special President of Senegal Prize for Science Research. It is thus useful to identify the determinants of ASI adoption and to derive its impact mainly on post-harvest labor use. The competition between rice and vegetable crop in the SRV leads to frequent shortage of labor during rice harvest and post-harvest period.

The purpose of this study is to estimate the adoption rate of the ASI thresher and assess its impact on threshing labor using the *causal* or *treatment effect* framework from the perspective of modern evaluation theory (Abadie *et al.*, 2002; Angrist *et al.*, 1996a; Angrist, 2004; Blundell and Costa Dias, 2000; Heckman, 1990; Heckman, 1979;

Heckman and Vytacil, 2000; Imbens and Angrist, 1994). First, the consistent adoption rate of the ASI thresher and its determinants are depicted so as to mainly derive strategic and steering programmes for future investment in small- farm equipment in the SRV. The technology adoption method used is straightforwardly based on the treatment effect methodology of ATE (Average Treatment effect in the population) which avoids the "nonexposure" and population selection bias occurring in the traditional approaches of technology adoption. The adoption of a technology is conditional to farmers' awareness of its existence (or exposure). Second, the impact of the ASI thresher on threshing labor is underpinned by the other treatment effect approach of LATE (Local Average Treatment Effect). The LATE methodology allows evaluating, without endogeneity bias, the mean effect of exposure or awareness of the ASI thresher in the threshing labor demand by its adoption or not. The adoption of the ASI thresher is a priori expected to decrease the number of labor needed and to save time for the threshing activity of irrigated rice farmers in the SRV. It increases the potential for double cropping, which has been identified as a priority in Senegal's Great Offensive for Food and Abundance (GOANA) launched by the authorities in 2008.

In section 2 presents the empirical specifications. Section 3 describes the data. In section 4, the empirical results are presented and discussed. Conclusions are drawn in section 5.

2. Empirical models

2.1 Adoption model

The ATE methodology provides both consistent estimates of technology adoption rates and the parameters that reflect the effect of covariates on technology adoption. The ATE estimation is performed here by using the *ignorability or conditional independence* of treatment assumption (Wooldridge, 2001)[1]. Formally for an irrigated rice farmer randomly selected in the population the effect or impact of a treatment is measured by the difference $y_{i1} - y_{i0}$, where y_{i1} is the potential technology outcome of individual i when the treatment is received and y_{i0} the potential technology outcome of individual i when the treatment is not received. The potential outcome in adoption context is represented by a dichotomous variable (1 for adoption and 0 otherwise). The treatment is here the exposure to the technology. In the level of population the average treatment effect, *ATE*, is given by the expected value

$$ATE = E(y_1 - y_0)\,, \tag{1}$$

where y_1 is the potential outcome (1 or 0) when exposed to the technology and y_0 the potential outcome (1 or 0) when not exposed to the technology. However, as an individual cannot be at the same time exposed and not exposed to the technology, it is not possible to have both y_1 and y_0 for any individual, hence the missing data problem and the impossibility to obtain the difference $y_1 - y_0$ if there is no additional information. Here we know that y_0 is always equal to 0 whether exposed or not to the technology. Then the *ATE* is trivially expressed as

$$ATE = E(y_1)\,. \tag{2}$$

Consequently, the *ATE* on the adoption outcomes of population members is the (potential) *population adoption rate* or diffusion rate of the technology. When the sample of exposed subpopulation is drawn from the population, another quantity is computed named ATE on the *treated* (exposed subpopulation) or $ATE1$. The $ATE1$ measures the effect of a 'treatment' on the treated subpopulation. To allow for 'exposure', a variable w is defined which equals 1 if the individual is exposed and 0 otherwise. In the context of technology adoption, the $ATE1$ is equivalent to the adoption rate of the technology among the exposed subpopulation and is formulated as:

$$ATE1 = E(y_1 - y_0 | w = 1) = E(y_1 | w = 1). \quad (3)$$

Taking the potential outcome framework in Rubin (1974), the observed adoption outcome can be obtained as $y = wy_1 + (1-w)y_0 = wy_1$. Following the conditional independence assumption (Imbens, 2004; Wooldridge, 2001), the parameters of interest (ATE, $ATE1$ and $ATE(\mathbf{x})$) are formulated as:

$$ATE = E(y_1) = E(\frac{y}{p(\mathbf{z})}) \quad (8)$$

$$ATE1 = \frac{E(y)}{P(w=1)} = \frac{E(wy_1)}{P(w=1)} = \frac{P(w=1)E\langle y_1 \mid w=1 \rangle}{P(w=1)} \quad (9)$$

$$ATE(\mathbf{x}) = \frac{E\langle y \mid \mathbf{x}, \mathbf{z} \rangle}{p(\mathbf{z})} = E\left\langle \frac{y}{p(\mathbf{z})} \middle| \mathbf{x}, \mathbf{z} \right\rangle, \quad (10)$$

where $p(\mathbf{z})$, named *propensity score*, is the conditional probability of exposure and can be estimated separately by parametric or semi-parametric methods, $\mathbf{x}$ is a vector of covariates that determines the value of y_1 and $\mathbf{z}$ is a vector of covariates that determines exposure ($w = 1$).

Empirically and from our observational data set of irrigated rice farmers, the observed binary dependent variable ($USEASI_i$) is the adoption or not of ASI. Let a latent variable

$USEASI_i*$ be the number of times the ASI thresher is used by farmer *i* during the period 2002/03-2006/07. Then we consider that there is adoption ($USEASI = 1$) for whichever farmer if he uses the ASI at least one time ($USEASI^* \succ 0$) during the period 2002/03-2006/07.

2.2 Impact model

The instrumental variables approach is used to consistently identify and estimate the mean treatment effect on *compliers* denoted by LATE (Angrist *et al.*, 1996b; Imbens and Angrist, 1994). The assessment of the impact of ASI adoption on labor demand during the threshing of rice in the SRV faces the problem of *endogeneity* or *non-compliance* because of the *nonignorability* of the treatment not randomly assigned. Following the framework established by Imbens and Angrist(1994) and Angrist *et al*. (1996c), the counterfactual outcome in the impact model of ASI is the quantity of labor employed per hectare during the threshing when the ASI thresher is adopted or not. Consequently the treatment is the adoption or not of the ASI thresher. The instrumental variable correlated with the treatment variable is the exposure to (or awareness of) the ASI thresher. It meets the main conditions for an IV (Wooldridge, 2001) as a farmer cannot adopt the ASI thresher without being exposed and the exposure affects the quantity of labor used only through the adoption of the ASI.[2] The LATE is the mean effect on threshing labor for irrigated rice farmers who used ASI as they were aware of its existence. The estimation of LATE is first obtained non-parametrically and without covariates (Imbens and Angrist, 1994; Imbens and Rubin, 1997) and further improved by Abadie (2003b) with covariates.

Let w be a binary exposure outcome variable, which equals 1 when a farmer is exposed to ASI and 0 otherwise. Let $A_1 = 1$ be the potential adoption treatment outcome when exposed to ASI, $A_0 = 0$ the potential adoption treatment outcome when not exposed to ASI and $A = A_0 + w(A_1 + A_0) = wA_1$ the observed adoption outcome given that $A_0 = 0$ for all farmers. Considering this setting, the LATE estimator from Imbens and Angrist (1994) and Imbens and Rubin (1997) is derived as follows:

$$E(y_1 - y_0 \middle| A_1 - A_0 = 1) = \frac{E(y|w=1) - E(y|w=0)}{E(A|w=1) - E(A|w=0)}, \tag{16}$$

where y_1 is the potential labor outcome used when farmer is exposed to ASI; y_0 the potential labor outcome otherwise and; y is the observed labor outcome during the threshing. The sample analogue of the right hand side of equation (16) is called the Wald estimator and is expressed as:

$$\left[\frac{\sum_{i=1}^{n} y_i w_i}{\sum_{i=1}^{n} w_i} - \frac{\sum_{i=1}^{n} y_i (1-w_i)}{\sum_{i=1}^{n} (1-w_i)}\right] \times \left[\frac{\sum_{i=1}^{n} A_i w_i}{\sum_{i=1}^{n} w_i} - \frac{\sum_{i=1}^{n} A_i (1-w_i)}{\sum_{i=1}^{n} (1-w_i)}\right]. \tag{17}$$

Accounting for covariates, Abadie (2003b) ruled out the plausibility of the random assignment of the instrument (exposure to ASI) and used the weaker conditional independence assumption: the instrument w is independent of the potential outcomes (A_1, y_1, y_0) conditional on a vector of characteristics ($\mathbf{x}$) of compliers determining the observed outcome y. Abadie (2003b) defined a function of (A, $\mathbf{x}$) referred as the Local Average Response Function (LARF) that describes the effect of treatment (adoption) for the treated (compliers) given $\mathbf{x}$ and expressed as:

$$LARF = f(\mathbf{x}, A) = E(y|\mathbf{x}, A; A_1 = 1) = h(\boldsymbol{\theta}, \mathbf{x}, A), \quad (18)$$

where $\boldsymbol{\theta}$ is the set of parameters to be estimated. To estimate equation (18), Abadie (2003b) relied on the following equation:

$$E(g(y, A, \mathbf{x})|A_1 = 1) = \frac{1}{P(A_1 = 1)} E(k.g(y, A, \mathbf{x})), \quad (19)$$

where $k = 1 - \frac{w}{P(w=1|\mathbf{x})}(1-A)$ is a weight function that takes the value 1 for a potential adopter and a negative value otherwise. The conditional probability $P(w=1|\mathbf{x})$ is estimated by a probit model in a first stage.

In the case of the more commonly used linear specification and assuming that the treatment (adoption of ASI) interact with some covariates such that $h(\theta, X, A) = \alpha_0 + \alpha A + \beta X + \delta AX$, where $\theta = (\alpha_0, \alpha, \beta, \delta)$, the LATE is $E(y_1 - y_0|X, A_1 = 1) = \alpha + \delta X$ and implies a heterogeneous effect of treatment across the subpopulation of *compliers*. We use a probit mean conditional functional form of the labor during threshing to get the LATE and the others estimated parameters with Stata.

3. Data

The data used here are from the WARDA/Sahel survey on Rice Integrated Crop Management (RICM). The survey is conducted in two ecological zones, i.e. the Delta-Valley and the Middle-Valley, representing 89% of total acreage for rice in the SRV (SAED/DDAR/CSE, 2007). The RICM database is an unbalanced panel data set containing, among other things, technical information on fertilizer, weed and water management, harvest/post-harvest farmers' activities and production costs. The dataset is based on a continuous survey of farmers since 2002. The unbalanced panel data set is based on a sample of 153 farmers, surveyed during one to five agricultural seasons, yielding a total of 506 observations (farmer seasons) recorded between 2002/03 and 2006/07. To account for the overriding factors of farmers' perception in technology adoption in West Africa (Adesina and Baiduforson, 1995), we completed the WARDA/Sahel survey with an additional survey on farmers' perceptions of the ASI thresher and exposure. Additional data was collected on (i) farmers' awareness and use of the ASI thresher since its release in 1997; (ii) farmers' perception of socioeconomic characteristics and performance of the ASI thresher; (iii) the importance of gender issue during harvest and post-harvest work; (iv) the channel through which irrigated rice farmers first acquired information about the ASI thresher; (v) how they usually access to the ASI thresher and (vi) their other on-farm and off-farm activities. During this additional survey, only 119 unique farmers were reached and selected from the original unbalanced panel. For this study the pooled dataset is used because of lack of information prevent us from applying for example the Difference-In-Difference approach (Abadie, 2003a).

4. Empirical results and discussion

4.1 Adoption of ASI and its determinants

In the model of ASI adoption we use the following irrigated rice farmers' socioeconomic characteristics variables in table 1: *AGE*, AGE^2, *WOLOF*, *EXP*, EXP^2, *OFFFACT*, *LNSIZE*, *PERCWOM*, *Y97AKN*, *and PARTPROV*. All the variables are exogenous except the variables *Y97AKN* and *PARTPROV* that unlikely suffer from endogeneity. But the covariates are allowed to be either exogenous or endogenous and should not change for any farmer if the exposure status changes. The latter condition is as well satisfied because the variables *Y97AKN* (awareness gap) and *PARTPROV* are known simultaneously or prior to exposure.

Table 2 shows that the ATE estimate of the true population adoption rate of the ASI thresher in the period 2002-2006 is 86 % if all the population was exposed in the wet season 2006/07. The adoption is, as mentioned above, the use of at least one time the ASI by irrigated rice farmers in the SRV during the period of investigation. The estimated ASI adoption rate within the subpopulation currently exposed to the ASI thresher ($ATE1$) is 91 % and estimates upward the true population adoption rate. This is the result of the low population selection bias (3 %) when the $ATE1$ is used to estimate the true population adoption rate of the ASI thresher

With regard to probability of exposure or knowledge of ASI, irrigated rice farmer who received a formal education are more likely to be exposed to the ASI thresher (Table 3). The probability of exposure is therefore negatively affected when the time allocated to off-farm activities by the head of farming is more important than his time for on-farm activities. As the ASI thresher is a time saving technology, there may have then a negative impact of off-farm activities on irrigated rice technical efficiency (Fernandez-Cornejo *et al.*, 2007). The other farm characteristic that weakens the probability of exposure is the percentage of women used during the threshing. The highest is the percentage of women used during the threshing lesser is the probability to be exposed to ASI.

The results of the two adoption models show right away that all statistically significant variables in the classic probit model are as well significant in the ATE model, apart from the variable ethnic group. The Wolof ethnic group is more likely to adopt the ASI thresher. Four variables (age, level of education, percentage of farmers in the threshing and off-farm activities) are not significantly related to the adoption of ASI as a post-harvest technology. The variables that increase the probability to adopt the ASI thresher in the SRV are experience, farmer's size, awareness gap and participation to field experiment of ASI and/or the contact with service providers.

4.2 Impact of ASI adoption on threshing labor.

The real causal interpretation is given by the LATE estimates whose approach is discussed above. The LATE is the mean effect on threshing labor for irrigated rice farmers who used ASI for the awareness of its existence. The WALD estimator of LATE, which does not control for irrigated rice farmers' socioeconomic characteristics, is not statistically significant (table 4). The LARF based-method of LATE estimates controlling for covariates, with or without interaction with adoption outcome, are all negative and statistically significant. Then the adoption of ASI thresher has an impact on the labor demand during rice threshing confirming the labor saving technology attributed to ASI. The gain ranges between 22 to 24 workers per hectare for ASI adopters which is not negligible (Table 4) when it is known that one threshing day can last 8 hours.

Table 5 shows the OLS-LARF estimates with and without interaction between treatment, i.e. adoption of ASI, and socioeconomics variables related to total (external and family) labor threshing. The first remark is that the model without interaction is less efficient than the model with interaction. All the chosen variables in the latter model are statistically significant at 1% level contrary to the former model. The heterogeneous impact of adoption on threshing labor among potential adopting farmers is then confirmed. Following the two models, the adoption of ASI clearly decreases the number of workers needed.

Except the variable *EDUC*, the signs of coefficients are the same in the two models but in absolute value, the coefficients in the interaction model are by far higher. The non interacted variables that can be associated with a lower labor demand are experience (*EXP*), ethnic Wolof (*WOLOF*), age of farmer (*AGE*), existence of bird damage (*BIRD*). Then bird pressure prevent from the availability of labor when it is known that rice maturity is not homogeneous among farmers in the SRV. The use of ASI vanish the negative correlation between these variables and the demand of labor. For the non interacted variables associates with a high labor use during the threshing we found the level of education (*EDUC*), the existence of other on-farm activities (*OTHONFAC*), and early start of sowing (*RECDSOW*). Even irrigated rice farmers start the sowing at the recommended date and finish the season at time, they will use a high quantity of labor if they do not adopt the ASI thresher (see the coefficient of interacted variable *USEASI-RECDSOW*). The contribution of variable *PERCWOM* when the ASI is adopted is very low in increasing the labor used. Within the potential ASI adopters, the role of women is not important. A big farmer's size is once more associated with a low use of labor when the ASI is adopted. In the results of adoption model we showed that off-farm activities reduce the probability of ASI adoption. But in the subpopulation of potential adopters, the time-allocation dominance of off-farm activities drops the labor needed when the ASI is adopted.

5. Conclusion

The ASI thresher, developed by a partnership-based research approach between WARDA and its partners, is the most important post-harvest improved technology existing in the SRV. The study initiated in this paper, first, highlights the adoption rate while depicting the factors determining its adoption. The ATE methodology for technology adoption is applied to have consistent estimate of the true population adoption rate. Second the impact of ASI adoption on labour demand during the threshing is estimated by the LATE approach. The results show that the ASI thresher can help irrigated rice farmers to cope with labour scarcity by decreasing significantly the number of workers needed. The labour-gain is between 22 man-day per hectare in the subpopulation of potential adopters. The true ASI adoption rate is 86 % if all the population of irrigated rice farmers is exposed to it. The socioeconomic characteristics that increase the probability to adopt the ASI thresher are experience of farmer, farmer size, the participation to field experiment and/or contact with service providers, and a high awareness gap. Indeed, irrigated rice farmers who recently know the ASI thresher are high potential of adoption.

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Table 1: Classification and description of the variables used in the models

Description of variable	Variable
Outcome of adoption model	
Use (adoption) of ASI (1 if adoption, 0 otherwise)	*USEASI*
Outcome of impact model	
Labor use during the threshing (man day/ha)	*LABTHR*
Instrument	
Exposure (knowledge of ASI) (1 if exposure, 0 otherwise)	KNASI
Covariates	
Age of farmer	*AGE*
Farm size (ha)	*SIZE*
Logarithm of mean farm size (ha)	*LNSIZE*
Experience in rice growing (years)	*EXP*
Education level (1 if not illiterate, 0 otherwise)	*EDUC*
Rice yield (tons per hectare)	*YIELD*
Knowledge of ASI thresher (1 if yes, 0 otherwise)	*KNASI*
Use of ASI at least one time between 2002-2006 (1 if yes, 0 otherwise)	*USEASI*
Number of years between 1997 and the first year of ASI awareness (years)	*Y97AKN*
Share of women labor in threshing (%)	*PERCWOM*
More time spent on other on-farm activities than in rice (1 if yes, 0 otherwise)	*OTHONFACT*
Off-farm activities (1 if yes, 0 otherwise)	*OFFFACT*
Wolof ethnic group (1 if yes, 0 otherwise)	*WOLOF*
Awareness of ASI through field experiment or service provider (1 if yes, 0 otherwise)	*PARTPROV*
Bird damage (1 if yes, 0 otherwise)	*BIRD*
Sowing at recommended date (1 if yes, 0 otherwise)	*RECDSOW*

Table 2: Estimates of ASI adoption rates

	ATE Probit adoption model
Joint exposure and adoption rate (probability of awareness and adoption of ASI at least once)	
In the full population	0.81
Within the ASI exposed subpopulation	0.91
ASI adoption rate (probability of adoption of ASI at least once)	
In the full population (ATE)	0.86
Within the ASI-exposed subpopulation (ATE1)	0.89
Within the subpopulation not exposed to the ASI (ATE0)	0.55
Estimated population adoption gap	
Expected non-exposure bias (NEB)	-0.05
Expected population selection bias (PSB)	0.03

Table 3: Estimates of ASI thresher adoption determinants in 2002-2007

Description of variable	Exposure	Classic joint exposure and adoption model	ATE probit adoption model
Age of farmer	-0.129	-0.206	-0.134
Age square	0.002	0.002	0.001
Logarithm of mean farm size (ha)	0.152	**0.856	**1.050
Experience in rice growing (years)	-0.130	*0.126	**0.180
Experience in rice growing square (years²)	0.002	*-0.002	**-0.003
Education level (1 if literate, 0 otherwise)	*0.965	0.002	-0.853
Share of women labor in threshing (%)	*-0.038	-0.018	-0.015
Off-farm activity (1 if yes, 0 otherwise)	*-1.08	-0.747	-0.458
Wolof ethnic group (1 if yes, 0 otherwise)	-0.673	0.476	*0.931
Awareness of ASI through field experiment or service provider (1 if yes, 0 otherwise)		***2.170	*1.435
Lag between ASI invention (1997) and first awareness		***0.420	*0.293
Intercept	7.552	3.815	3.22
N	118	118	107
Pseudo R^2	0.29	0.62	0.54
Log likelihood	-25.88	-22.05	-17.40
Chi-square	21.39	57.34	41.76
Df	9	11	11

***Significant at 0.1% level , **Significant at 1% level, * significant at 5% level,

Table 4: LATE estimates of the impact of ASI on threshing labor

	Total labor in threshing (man day/ha) (a+b)
Mean impact in the subpopulation of potential ASI adopters	
Number of observations	458
Number of ASI adopters	212
Number of farmers exposed to ASI	422
WALD LATE estimate	-32
LATE in LARF without interaction	***-24
LATE in LARF with interaction	***-22

*** Significant at 1% level

Table 5: Estimation of the OLS LARF for total threshing labor with and without interaction

		LARF with adoption variable interacted with some covariates	
	Estimates for LARF without interaction	Estimates of the non interacted variable	Estimates of the interacted variable
CONST	***45.64	***189.97	
USEASI	***-24.11	***-182.16	
EDUC	-0.80	***2.15	
EXP	-0.05	***-0.04	
OTHONFAC	***5.73	***3.80	
WOLOF	***-4.21	***-8.94	***9.068
AGE	**-0.17	***-3.54	***3.61
BIRD	-1.88	***-16.54	***16.04
RECDSOW	***4.01	***46.09	***-43.38
SIZE			***-2.34
OFFFACT			***-4.16
PERCWOM			***0.12
Number of observations	227	227	
R^2	0.48	0.98	
R^2 adjusted	0.46	0.98	
Prob>F	***0.000	***0.000	

*** Significant at 1 % level, ** significant at 5 % level.

[1] More generally, in the counterfactual framework of ATE the estimation of parameter is based on the ignorability of treatment assumption or the Instrumental Variables methods (Wooldridge, 2001). But for the adoption of ASI model the main constraint was to find the appropriate instrument(s) for exposure, hence the adoption of the former method for the estimation of adoption rates of ASI.

[2] The conditions for a variable to be considered as an Instrumental Variable are largely explained in Angrist et *al*. (Angrist *et al.*, 1996b),