Modeling interrelated technology adoption decisions in rainfed agriculture in rural Senegal

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Introduction

- Advanced technology adoption is key to increase crop yield and agricultural profitability.
- However, the level of adoption of agricultural technologies is still low in African countries.
- On average over 2002-2003, 9 kg/ha of fertilizer applied in Sub-Saharan Africa, 100 kg/ha in South Asia, 135 kg/ha in Southeast Asia and 73 kg/ha in Latin America (Gebeyehu, 2016).
- According to Gebeyehu (2016), in 2012, the fertilizer use intensity was 23.7 kg/ha in Ethiopia; 44.3 in Kenya; 39.9 in Malawi, 181.7 in Brazil, and 163.67 in India.
- In some context such as Senegal, there is few literature on agricultural technology adoption.
- There is a need to conduct new empirical studies in Senegal.
- In addition, some technologies are interrelated (*Feder, 1982, Feder et al., 1985*).

Introduction

- Thus, univariate technology adoption studies may bring misleading results (*Teklewold et al., 2013, Abay et al., 2018*).
- Therefore, this study adopts a bivariate probit model to jointly analyze the adoption of certified seeds and inorganic fertilizers in rainfed agriculture in Senegal.
- Thus, we test whether the adoption of certified seeds and chemical fertilizer are dependent or not, on average.
- A key contribution of this study is that we allow the correlation between both technologies to be heterogenous among farmers.
- Does the decision to adopt of certified seeds independent to that to use inorganic fertilizers in rural Senegal?
- What are the key determinants of technology adoption?
- What are the main determinants of multiple technology adoptions in Senegal?
- Does the correlation between technologies constant across farmers?

Quick review of technology adoption in Senegal

Two papers found on improved inputs technology adoption in Senegal:

- Thuo, M., Bravo-Ureta, B. E., Hathie, I., & Obeng-Asiedu, P. (2011). Adoption of chemical fertilizer by smallholder farmers in the peanut basin of Senegal. *African Journal of Agricultural and Resource Economics*, *6*(1), 1-17.
- Thuo, M. W., Bravo-Ureta, B. E., Obeng-Asiedu, K., & Hathie, I. (2014). The adoption of agricultural inputs by smallholder farmers: The case of an improved groundnut seed and chemical fertilizer in the Senegalese Groundnut Basin. *The Journal of Developing Areas*, *48*(1), 61-82.

- Both studies used data collected between 1998-2006 in the peanut basin of Senegal.
- Thuo et al. (2011) analyzed the adoption of chemical fertilizer among groundnut and millet farmers.
- They found that education, family size and farm size encourage the use of chemical fertilizer.
- Their study also revealed a decrease of fertilizer application intensity over the period under consideration.

Quick review of technology adoption in Senegal

- Thuo et al. (2014) were interested by the joint adoption of groundnut variety (La Fleur 11) and chemical fertilizer.
- Thuo et al. (2014) found that the two decisions were independent.
- The adoption of the groundnut variety was positively associated with ownership of draft power, but negatively related to farmer's experience.
- Farm size, and the number of plots increased the probability of fertilizer use,
- While this probability was negatively affected by access to off-farm income and ownership of draft power.

A Flexible framework for multiple agricultural technology adoption

- Observed technology adoption of farmers can be modelled following a random utility formulation.
- A household adopts a specific agricultural technology if the net benefit of using the new technology is greater than zero.
- Hence, we can link the observed sequence of a binary adoption decision outcome and farmers expected net benefit from a new technology

$$y_{ick} = \begin{cases} 1 \;\; if \;\; y_{ick}^{*} > 0 \\ 0 \;\; if \;\; y_{ick}^{*} \leq 0 \end{cases} \qquad (1)$$

Where i for farmer, *c* for crop *and k* for technology, y_{ick}^{*} is the latent net benefit, and y_{ick} is the observed binary choice.

- The joint adoption of two individual technologies such as certified seed (CS) and chemical fertilizer (CF) can be model using copular approach:

$$p_{11i} = \mathbb{P}(y_{1i} = 1, y_{2i} = 1 | z_{1i}, z_{2i}) = \mathcal{C}(\mathbb{P}(y_{1i} = 1 | z_{1i}), \mathbb{P}(y_{2i} = 1 | z_{2i}); \theta_i) \qquad (2)$$

A Flexible framework for multiple agricultural technology adoption

The probability of the joint adoption is:

$$p_{11i} = \mathbb{P}(y_{1i} = 1, y_{2i} = 1|z_{1i}, z_{2i}) = \mathcal{C}(\mathbb{P}(y_{1i} = 1|z_{1i}), \mathbb{P}(y_{2i} = 1|z_{2i}); \theta_i) \quad (2)$$

$$\mathbb{P}(y_{ki} = 1|z_{ki}) = \Phi(\eta_{ki}) \quad (3)$$

Where $\Phi(.)$ is cdf of the standard univariate Gaussian distribution,

η_{ki} is the linear predictor based on covariates z_{ki},

$\mathcal{C}$ stands for the two dimensional Gaussian copula,

and θ_i is the correlation parameter between the adoption of certified seeds and that of inorganic fertilizers.

- The main contribution of our framework is that θ_i is constant across farmers.
- The correlation between both decisions may vary from one group of farmers to another du geographic criteria, farmer's knowledge regarding complementarity across technologies.

A Flexible framework for multiple agricultural technology adoption

- Recently, Giampiero Marra and his coauthors (Marra and Radice, 2011, 2013a, 2013b, Filippou et al., 2017) developed more flexible bi/trivariate probit models.
- One feature of their works useful for our study is the non-constant correlation between binary choices.

$$\theta_i = m_i(X_i) \qquad (4)$$

Where m_i is a parametric/semiparametric specification of covariates X_i.

- Equation (4) is usually specified as generalized additive models (see Wood, 2017 for details).
- The model was estimated using the Maximum Penalized Likelihood Estimator (*Marra and Radice, 2013*).
- In our application, (4) is specified as a linear model of covariates such as: access to extension services, farmers' organization membership, household head education, and regional fixed effects.

Data description

- We used dry cereals (rainfed agriculture) survey collected in 2017 under the PAPA project.
- The PAPA project (*Projet d'Appui aux Politiques Agricoles*) is an ambitious countrywide project to shed light on the farming system in Senegal.
- A total of 4,480 farm households are considered for this analysis.
- At the plot level (main crop per plot), there are 10,442 observations in the sample.
- We conducted the study at plot level (pooled) and at crop levels for the most popular crops in Senegal.

Data description

Table 1: Overview on dry cereals in Senegal

	General information		Certified seeds			Chemical fertilizers		
	% of producers	Average Land area (ha)	Adoption rate	% land	Average quantity (kg/ha)	Adoption rate	% land	Average quantity (kg/ha)
Millet	60.69	2.3	3.49	5.51	0.41	23.13	29.76	21.97
Sorghum	16.56	1.32	3.1	3.25	0.16	4.45	5.7	3.56
Maize	34.62	1.39	9.99	12.32	2.1	38.43	46.04	60.13
Rice	19	0.89	21.15	26.33	16.31	37.84	48.61	85.13
Beans	22.23	1.36	11.14	17.16	1.53	2.51	3.04	2.14
Groundnut	69.8	2.44	22.96	27	12.19	24.4	35.82	23.93
Other	9.4	1.03	30.04	32.82	-	28.51	27.66	28.25
All crops	100	1.88	13.59	16.76	-	23.92	31.54	27.24

- Groundnut is the most popular crop in Senegal,
- The average farm size is 1.88 ha,
- Certified seed is used on 16.76% of cultivated area,
- Chemical fertilizers are used on 31.54% of cultivated area,
- The average use of chemical fertilizers is 27.24 kg/ha.

Results and discussion

- The model proposed here to study multiple technology adoption of improved seed and inorganic fertilizer was estimated using the software *R* (*R Core Team, 2018*).
- The parameters of the model can be estimated simultaneously within a penalized likelihood framework through the use of the ***gjrm*** function in the R package GJRM (*Marra and Radice, 2017*).
- Two model specifications were considered and compared.

(1) Standard Bivariate Probit with a constant correlation parameter,

(2) Bivariate Probit with a variable correlation parameter.

Results and discussion (*pooled model*)

Table 3: Bivariate Probit results (coefficients and standard errors) of multiple technology adoptions

	(1)		(2)		
	CS	CF	CS	CF	Correlation (CS, CF)
Intercept	-0.267	-0.051	-0.3*	-0.04	0.232***
1= Extension services	0.237***	0.238***	0.238***	0.242***	0.14*
1= Farmers organization membership	0.397***	0.308***	0.399***	0.313***	0.141*
1=Credit access		0.266***		0.263***	
1= household head can read and count in local language	-0.093*	0.176***	-0.093*	0.176***	
1= Received seed subsidies	0.58***		0.583***		
1= Received fertilizer subsidies		1.026***		1.027***	
Farmsize (ha)	0.016***	0.033***	0.016***	0.033***	
distance to market, KM	-0.007***	-0.008***	-0.007***	-0.008***	
Number of risk events over the past 5 years		-0.149***		-0.15***	
Number of risk events over the past 5 years, square		0.016***		0.016***	
Theta (estimate)	0.266		0.251		
Theta (Lower bound, 95%)	0.223		0.181		
Theta (Upper bound, 95%)	0.315		0.306		
Log Likelihood	-7,427.04		-7,423.01		
AIC	14,982.08		14,978.01		
BIC	15,446.11		15,456.54		
Observation	10,408		10,408		

Notes: CS for certified seeds, CF for Chemical fertilizer

(1) For standard bivariate probit, (2) for Non-constant correlation bivariate probit

Results and discussion (*pooled model*)

- Based on the AIC, model (2) is preferred.
- The correlation parameter in the two models was found significant, adoption decisions about certified seed and inorganic fertilizers are not independent.
- In rainfed agriculture in Senegal, certified seed use and inorganic fertilizer are complementary.
- Similar results were found by *Teklewold et al. (2013), Ogada et al. (2014), Abay et al. (2018).*
- Increased access to agricultural extension services is critical in promoting adoption of certified seeds, inorganic fertilizer and their joint adoption.
- Farmer's organization increased adoption of certified seeds, inorganic fertilizer and their joint adoption.
- Subsidies through input prices had a large impact on their use.
- Surprisingly, the access to credit only increased the adoption of chemical fertilizer.

Results and discussion

- The land holding showed a very marginal but strongly significant influence on technology adoption.
- Distance to the nearest market has a negative and significant effect on the adoption of certified seed and joint adoption.

Results and discussion (*crop specific model*)

Table 4: Crop level technology adoption (marginal effects, bivariate probit)

	Millet			Maize			Rice			Groundnut		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Extension services	0.033***		0.014***				0.057***		0.038**		0.043**	0.014**
Organization membership	0.033***	0.065**	0.016***		0.136***	0.015***	0.041***		0.027*	0.048***		0.017**
Access to credit							0.085***		0.056*			
Head gender (1=Male)				-0.051**		-0.039**						
Education: local language	0.016**		0.007*		0.083***	0.009***		0.048	0.012*	-0.041**	0.027	-0.005
Education: primary school	0.024***	0.076***	0.013***	0.027*	0.065**	0.023*					0.066***	0.021***
Education: secondary school		0.069***	0.003***								0.101***	0.033***
Education: high school or more		0.092**	0.004**		0.121*	0.014*				0.073**	0.096***	0.045***
Off-farm income dummy		0.028*	0.001*					-0.035*	-0.009**			
Remittances dummy		0.053**	0.002**								0.034**	0.011*
Has received seed subsidy				0.055***		0.042***	0.101***		0.067***	0.191***		0.066***
Has received fertilizer subsidy		0.24***	0.011***		0.311***	0.035***		0.264***	0.066***		0.2***	0.065***
Household size					0.006***	0.001***						
Household's human capital	0.005***	0.014***	0.003***									
Head's age (years)	0**		0*					0.001*	0**			
Land holding (ha)	0.002***	0.011***	0.001***	0.004***	0.006**	0.003***		0.01**	0.002***	0.006***	0.013***	0.005***
distance to market, KM				-0.002***		-0.002***	0.002***		0.001**	-0.003***		-0.001***

Notes:

(1) Marginal effect on the probability to adopt Certified Seed (CS),

(2) Marginal effect on the probability to adopt Chemical Fertilizer (CF),

(3) Marginal effect on the probability of joint adoption.

Results and discussion (*crop specific model*)

- For all crops considered, we cannot reject the dependency between the decisions to adoption CS and CF
- The level of dependency varies from one crop to another;
- Non-constant correlation is rejected for some crops;
- Determinants of technology adoption are specific to crop under consideration.
- Main determinants identified include extension services, farmers organization membership, credit access, input subsidies, and agroecological zones in Senegal.

Conclusion

- Agricultural technology adoption is very low in rural rainfed context in Senegal.
- About 14% of cultivated plots are under certified seeds.
- About 32% for inorganic fertilizers, with about 27 kg/ha fertilizer use on average.
- Decision to adopt certified seeds in rural Senegal is not independent to that to adopt inorganic fertilizer.
- Farmer's organization and extension services play a key role in the adoption of technologies under consideration.
- Subsidies on agricultural inputs are central in the use of these inputs.
- Considerable differences were found across regions.
- These results can help to design technology adoption in rainfed agriculture in Senegal.

Merci beaucoup

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