Institutional constraints and adoption of improved rice varieties: Econometric evidence from Ivory Coast

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Summary *– The main objective of this article is to analyze the impact of institutional constraints on the adoption and use intensity of improved rice varieties at the farm level. Among institutional barriers to the adoption of improved technologies by farming households, this paper focuses on credit constraints and deficiencies of transportation infrastructures. In our methodological process, a formal theoretical framework is examined before specifying the econometric model. The theoretical findings show a positive relationship between the amount of credit available and the adoption level of improved rice varieties. They also indicate a negative impact of transportation costs on the intensity of use of these new varieties. Econometric evidence was implemented from 311 Ivorian rice farmers using a fractional logit model. The econometric estimates confirm the findings that improving access to credit and reducing transportation costs encourage the adoption of modern rice varieties.*

Keywords: *adoption, agricultural innovations, food security, fractional logit*

Contraintes institutionnelles et adoption des variétés améliorées de riz : évidence économétrique en Côte d'Ivoire

Résumé – L'objectif principal de cet article est d'analyser l'impact des contraintes institutionnelles sur l'adoption et l'intensité d'utilisation des variétés améliorées de riz. Parmi les barrières institutionnelles à l'adoption des technologies modernes par les ménages ruraux, l'article se focalise sur les contraintes de liquidité et les déficiences des infrastructures rurales. Notre démarche méthodologique est d'examiner en premier lieu un modèle théorique formel, avant de spécifier le modèle économétrique. Les résultats de l'analyse théorique indiquent une relation positive entre le montant de crédit disponible et le niveau d'adoption des variétés améliorées de riz. En revanche, ils indiquent une relation inverse entre les coûts de transport et l'intensité d'adoption de ces innovations. Une application économétrique est présentée à partir d'un échantillon de 311 riziculteurs de la Côte d'Ivoire en utilisant un modèle de données de proportions. Les estimations économétriques confirment le résultat selon lequel accroître l'accès au crédit et réduire les coûts de transport améliorent le taux d'adoption des variétés modernes de riz.

Mots-clés : adoption, innovations agricoles, sécurité alimentaire, logit fractionnaire

JEL Classification: Q12, Q16, C24

1. Introduction

The agriculture sector is the dominant sector in most countries of Africa, especially in Sub-Saharan Africa. It provides employment to most of the people in rural areas and makes significant contributions to the gross domestic product (GDP) and foreign exchange earnings.

Because of its dominant role in the economy and society of African countries, agriculture has been called the engine of economic growth. In spite of its dominant role, agricultural productivity is low and the people depending on agriculture are generally poor. Increased productivity in the agriculture sector mandates that African farmers move from the traditional mode of agricultural production to one based on science and technology. Science-based agriculture is embodied in the use of modern inputs such as improved seed, fertilizers, crop protection products (CPPs), and other improved agronomic practices.

Although other crops and inputs are necessary, this paper's main focus is on High Yielding Rice Varieties (HYVs). Indeed, rice is one of the most important sources of nutrition and revenue for many African smallholders (Sall *and al.*, 2000). However, current rice producing growth in Sub-Saharan Africa lags far behind that in other regions of the world and is well below the growth required to meet food security and poverty reduction goals (UN Millenium Project, 2005).

Particularly, Ivory Coast imports 735,711 tones of rice per year at a cost of more than 150 millions US$ to achieve food security and meet rice consumption needs (FAOSTAT, 2005). National production could not cover rice demand, which has grown over time since 1973 driven by the population growth and rapid urbanization (WARDA, 2000).

Table 1 provides an overview of trend in rice yield and rice self-reliance in Ivory Coast and two main sub-regions in Sub-Saharan Africa. The value of self-reliance ratio in Ivory Coast in 2004 was only of 40.36% that is low when compared with 84.98% in East Africa and 49.15% in West Africa.

The dynamics of the rice economy of Ivory Coast demonstrates the need to increase the level of farm productivity in order to ensure self-sufficiency in rice. Indeed, yields are generally low because of the prevalence of traditional cropping systems, the preponderance of rainfed cropping and the low levels of use of improved seeds (Kama, 2010).

Table 1. **Rice yield and self-reliance ratio: Ivory Coast, West Africa and East Africa**

	Yield (t/ha) yearly average			Self reliance ratio (%) yearly average		
	81-90	91-00	Value 04	81-90	91-00	Value 04
Sub-Saharan Africa	1.51	1.63	1.50	55.54	64.95	49.02
East Africa	1.81	1.93	2.32	80.62	85.90	84.98
West Africa	1.46	1.64	1.33	54.55	60.11	49.15
Ivory Coast	1.16	1.47	1.30	44.58	59.88	40.36

Source: West Africa Rice Statistics Data Bank (WARSDB), 2005

To reverse the decline in rice production per capita, an emergency programme was developed by the Government and focus on the multiplication and distribution of improved varieties bred by research institutes [1]. Three agencies have a lead role in managing this programme: the National Rice Programme (PNR), the National Laboratory for Agricultural Services Support (LANADA) and the National Agency for Support to Rural Development (ANADER).

The PNR produces first generation seed from parental material bred by the National Agricultural Research Center (CNRA) and the Africa Rice Center (WARDA). Seeds are certified by the LANADA. ANADER and farm cooperatives ensure the dissemination of certified seeds. The marketing of complementary agricultural inputs such as fertilizers and weed killer is ensured by a wide range of actors, including small business and various interest groups.

Despite this initiative to promote the adoption of HYVs, the use intensity of these new technologies at the farm level remains low. Indeed, the national survey conducted in 2001 by WARDA on improved rice varieties officially diffused in Ivory Coast estimated 1% adoption rate in the savanna and 6% adoption rate in the forest zone for an overall 4% (Diagne, 2006).

Given the potential role of these new varieties in the revitalization of the Ivorian rice production and the fight against food insecurity, it is crucial to investigate the factors that explain these low levels of adoption.

The literature on issues relating to the adoption of improved technologies in Sub-Saharan Africa is voluminous possibly because improved technologies are critically important in increasing the productivity and welfare of small or limited resource farmers (Sall *et al.*, 2000). However, in such studies, too much emphasis is placed on individual attributes and farm characteristics such as age, literacy, family size, social status, farm size, risk aversion, etc., implying a "person blame" rather than a "system blame" situation. This approach not only viewed non adoption as the result of insufficient innovativeness or entrepreneurship but seemed to suggest that the entire responsibility for agricultural modernization ultimately rests with the individual.

In this study, not only farm and farmers' characteristics affecting adoption decisions are analyzed, but also institutional constraints that limit adoption of modern inputs are examined. Indeed, constraints to the adoption of improved technologies involve undeniably critical factors such as the lack of credit and the deficiency of transportation infrastructures (Alene *et al.*, 2007).

Smallholder generally is dispersed over wide areas, and infrastructure connecting farms with markets often is poor (Binswanger and Sillers, 1993). Yet the potential effects of transport costs on the cropping choices of smallscale farmers have been investigated by a surprisingly small number of agricultural economists (Goetz, 1992; Jayne and Jones, 1997). Additionally, agricultural producers face significant liquidity constraints that limit effective demand for improved technologies. To investigate these

[1] Table A3 in Annex gives description and performance of improved rice varieties officially diffused in Ivory Coast by the National Rice Programme.

links, we develop an agricultural household model in which transport costs and credit constraints are made explicit.

The objective of this paper is thus to assess the extent to which credit constraints and transportation costs affect producers' adoption decisions. It includes an analysis of policy, especially with regard to the institutional constraints associated with transportation costs and credit accessibility.

Economic issues in the adoption of agricultural innovations have received considerable attention by the mid 1980s. Indeed, econometric tools have allowed economists to provide a better understanding of the relationship among adoption decision and factors influencing it (Marra *et al.*, 2003).

However, much of the empirical work has lacked a theoretical basis on which to specify structural relationships between the level of adoption and factors influencing it. Thus, the econometric functional forms, which have been estimated may not correspond to any reasonable underlying decision behavior (Feder *et al.*, 1985).

In this paper, a formal microeconomic model is used for investigating the relationship among credit constraints, transportation costs and adoption of new rice technologies.

More importantly, most of the previous empirical studies viewed the adoption decision in dichotomous terms. Adoption variables are thus categorized simply as "adoption" or "nonadoption". Knowing that a farmer is using HYVs may not provide much information, because he may be using 1% or 100% of his hectarage. Indeed, for divisible innovations such as High Yielding rice Varieties, the most interesting question is related to the intensity of use at the individual farm level (the share of farm area utilizing the HYVs) rather than to the initial decision to adopt these new varieties (Feder *et al.*, 1985).

Given the need for quantitative analysis, many studies require explicit treatment of the limited nature of dependent variables that reflect adoption intensity. In this study, we avoid biased estimation of parameters by using a fractional logit model.

The rest of the paper is divided in six sections. The next section discusses the theoretical adoption model. Econometric specification of the adoption model is presented in section 3. Sections 4 and 5 present the survey methodology and the descriptive analysis of data collected, respectively. Section 6 discusses the econometric results and section 7 concludes the paper.

2. The theoretical model

2.1. Theoretical framework

Individual adoption decisions can be modeled using an economic framework based on standard profit maximization assumptions. Economic aspects of adoption decisions are thus analyzed using a simple model involving credit constraints and transportation costs.

Following Feder (1982), we assume that a crop yielding R monetary units (francs) per hectare has been grown for years by all farmers using traditional technologies irrespective of their holding size, H.

One innovation is now introduced. This innovation is an improved rice variety which has a higher yield per hectare if appropriate amounts of fertilizers are applied. Adoption of High Yielding rice Variety (HYV) enables a farmer to obtain on average $y(x)$ tons per hectare, where x is fertilizers (a variable input related to the new technology) and y (.) is a concave production function ($y(x) > 0; y''(x) < 0$). The cost of fertilizer is c and the unit price of output is p.

Two central hypotheses are now presented. The first is that farmers do not all face similar credit constraints. We assume that cash availability increases with the farm size H. Thus, a function $K(H)$ is added to denote total cash availability for a farm of size H. The opportunity rate of interest is denoted by r. For simplicity the following proportional relationship is specified: $K(H) = kH$, where k is a parameter denoting per hectare cash supply.

The second is that the net income per hectare decreases with the amount of transportation costs, while the costs of acquiring inputs increase with it. The amount of transportation costs is denoted by t, so as we can write, $R(t) < 0$ and $c(t) > 0$.

Farmers are assumed to maximize their profit subject to the credit constraint by properly choosing the levels of the variables that they control. The decision regarding HYV involves an optimal level of adoption since the innovation is divisible. The farmer can thus cultivate a proportion h of his holding using the HYV, where $0 \le h \le 1$. The second decision variable is the volume of x to be applied per hectare cultivated with HYV. Since the actual expenditure on inputs cannot exceed the amount of available liquidity of the household (disposal income + available credit), the liquidity constraint can thus be written as follows: $Hhc(t)x \le kH + I$ where I denotes the disposal income of the household.

We denote the profit function by Π and formulate the following decision problem:

$$\max_{x,h} \Pi = H[h(py(x) - c(t)x) + (1-h)R(t) - rk]$$

$$S/C \begin{cases} Hhc(t)x \le kH + I \\ h \le 1 \\ x \ge 0,\ h \ge 0 \end{cases} \qquad (1)$$

Set up the Kuhn-Tucker Lagrangian associated with the optimization problem described above:

$$\tilde{L} = H[h(py(x) - c(t)x) + (1-h)R(t) - rk] - \mu(Hhc(t)x - kH - I) - \lambda(h-1) \qquad (2)$$

The Kuhn-Tucker conditions

$$\frac{\partial \tilde{L}}{\partial x} = h[py'(x) - (1+\mu)c(t)] \le 0 \qquad (3)$$

$$\frac{\partial \tilde{L}}{\partial h} = H[py(x) - (1+\mu)c(t)x - R(t)] - \lambda \le 0 \qquad (4)$$

$$x\frac{\partial \tilde{L}}{\partial x} = xh[py'(x) - (1+\mu)c(t)] = 0 \tag{5}$$

$$h\frac{\partial \tilde{L}}{\partial h} = h[H(py(x) - (1+\mu)c(t)x - R(t)) - \lambda] = 0 \tag{6}$$

$$\mu[Hhc(t)x - kH - I] = 0 \tag{7}$$

$$\lambda(1-h) = 0 \tag{8}$$

$$\lambda \geq 0;\ \mu \geq 0 \tag{9}$$

$$Hhc(t)x \leq kH + I \tag{10}$$

$$0 \leq h \leq 1;\ x \geq 0 \tag{11}$$

We focus first on interior solutions.

Interior solutions

$$Case\,1: \lambda = 0;\ 0 < h < 1;\ x > 0;\ \mu > 0$$

From (5) and (6), we have respectively:

$$\frac{\partial \tilde{L}}{\partial x} = py'(x) - (1+\mu)c(t) = 0 \Rightarrow y'(x^*) = (1+\mu)\frac{c(t)}{p} \tag{12}$$

$$\frac{\partial \tilde{L}}{\partial h} = py(x) - (1+\mu)c(t)x - R(t) = 0 \tag{13}$$

Using equations (12) and (13) and rearranging gets:

$$y(x^*) - x^* y'(x^*) = \frac{R(t)}{p} \tag{14}$$

From the liquidity constraints (equation (7)), we obtain:

$$h^* = \frac{kH + I}{Hc(t)x^*} \tag{15}$$

Optimal level of fertilizers used and optimal adoption level of HYV (say x^* and h^*) are characterized by equations (14) and (15) above.

Corner solutions

We examine the following cases:

$$Case\,2: \lambda = 0;\ \mu = 0;\ \frac{\partial \tilde{L}}{\partial h} < 0;\ \frac{\partial \tilde{L}}{\partial x} < 0$$

If $\frac{\partial \tilde{L}}{\partial h} < 0$, from (6), we obtain:

$$h^* = 0$$

We can observe that no adoption ($h^* = 0$) is an optimal solution for the farmer if $py(x) - (1+\mu)c(t)x < R(t)$ that is the net return obtained from the improved variety is strictly less than the net return from the traditional one.

If $\frac{\partial \tilde{L}}{\partial x} < 0$, from (5), we obtain:

$$x^* = 0$$

No use of fertilizer ($x^* = 0$) is an optimal choice for the farmer if $py'(x) < (1+\mu)c(t)$ that is the marginal product of the fertilizer (x) is strictly less than its marginal cost. Since by assumption, fertilizers and improved seeds are used in complementary way, the corner solution ($h^* = 0$, $x^* = 0$) is an optimal outcome for the farmer if $\frac{\partial \tilde{L}}{\partial h} < 0$ or $\frac{\partial \tilde{L}}{\partial x} < 0$.

$$Case\,3: \lambda > 0;\ \mu > 0$$

If $\lambda > 0$, from (8), we have $h^* = 1$. Thus, using (6), we obtain:

$$H[py(x) - (1+\mu)c(t)x - R(t)] = \lambda > 0$$

We can observe that full adoption ($h^* = 1$) is an optimal solution for the farmer if $py(x) - (1 + \mu)\, c(t)\, x > R(t)$ that is the net return from the improved variety is strictly greater than that from the traditional one.

From (7), we obtain: $x^* = \frac{kH + I}{Hc(t)}$. The solution $\left(h^* = 1,\ x^* = \frac{kH + I}{Hc(t)} \right)$ is an optimal outcome for the farmer if $\mu > 0$ and $\lambda > 0$.

2.2. Comparative static and theoretical results

Comparative static is used to analyze the effects of various policies on the adoption of HYVs and the demand for fertilizers. We limit attention to interior solutions since we use partial derivatives to investigate the properties of the optimal solutions.

2.2.1. Optimal level of fertilizers

The first order conditions for optimal level of corresponding to the problem (say x^*) are characterized by equation (14) above.

As evidenced in (12), without a binding credit constraint ($\mu = 0$, we have $py'(x) = c(t)$. This condition indicates that the optimal level of fertilizer is obtained where the marginal product of fertilizer equals its marginal cost that is consistent with the theory of the firm However, with a binding credit constraint ($\mu > 0$), the marginal product of fertilizer equals the sum of the marginal factor cost of fertilizer and a marginal cost of acquiring credit.

2.2.2. Effect of transportation costs and price subsidy on demand for fertilizers

We seek the sign of partial derivatives of x^* with respect to (t) and (p). We can write:

$$(14) \Rightarrow \psi(x^*) = \frac{R(t)}{p} \text{ with } \psi(x^*) = y(x^*) - x^* y'(x^*)$$

Since, $\psi'(x^*) > 0$ and the equality (14) holds at the optimum, a decrease of the ratios $R(t)/p$ implies a decrease in the optimal level of fertilizer x^*. Since the ratio $R(t)/p$

is negatively related to the output price (p) and the amount of transportation costs (t), an increase in p or t will reduce the ratio $R(t)/p$ and therefore will reduce the optimal per hectare fertilizer use. We can conclude that the demand for fertilizers is negatively related to the transportation costs. On the other hand, subsidies increasing the price of output (p) will reduce the demand for fertilizers, but will increase the adoption rate of HYVs with a binding credit constraint. This is somewhat counterintuitive since fertilizers and improved seeds are complementary. This holds in the present case because with a binding credit constraint, an element of substitutability enters in the decisions regarding optimal use of both inputs (fertilizers and improved seeds) to comply with the cash constraint.

2.2.3. Optimal adoption rate of HYVs

The first order conditions for optimal level of corresponding to the problem (say h^*) are characterized by equation (15) above.

2.2.4. Impact of subsidy on ($\boldsymbol{p}$) on adoption of HYVs

By equation (15), h is negatively related to x, therefore, subsidies increasing the price of output (p) will decrease the demand for fertilizers but will increase the adoption rate of HYVs as we said before. With a binding credit constraint, a higher price of output certainly makes HYVs more attractive and discourages per hectare fertilizer use to comply with the cash constraint.

2.2.5. Impact of subsidy on ($\boldsymbol{c}$) on adoption of HYVs

The partial derivative of h^* with respect to c gives the following relation:

$$\frac{\partial h^*}{\partial c} = -\frac{k}{x^* c^2} < 0 \qquad (16)$$

It follows from the equation (16) above, that a lower cost of fertilizers encourages adoption of HYVs.

2.2.6. Impact of an increase in credit availability ($\boldsymbol{k}$) on adoption of HYVs

$$\frac{\partial h^*}{\partial k} = \frac{1}{cx^*} > 0 \qquad (17)$$

It results from (17) that an increase in overall availability of credit (*i.e.*, an increase in k) encourages adoption of HYVs.

2.2.7. Impact of transportation costs ($\boldsymbol{t}$) on adoption of HYVs

The partial derivative of h^* with respect to t give:

$$\frac{\partial h^*}{\partial t} = \frac{\partial h^*}{\partial c}\frac{\partial c}{\partial t} < 0 \qquad (18)$$

By assumption $c'(t) > 0$. This assumption implies that the sign of relations (18) depends only on the sign of the derivative of h^* with respect to c which is negative. Hence, high transportation costs (t) have negative impact on the adoption of HYVs at the farm level.

3. Econometric specification of the adoption model

3.1. Functional specification and estimation techniques

In this study, we seek to explain the level of adoption on the basis of exogenous explanatory variables. The dependent variable is the proportion of total rice area planted with improved varieties, thus it is fractional.

Given the form of adoption variable, we focus on fractional response dependent variables. The technique used to estimate the model with fractional dependent variables follows the work of Papke and Wooldrige (1996). The functional form proposed by the authors is stated directly in terms of $E(y_i / X_i) = G(X_i\beta)$ where X_i is observable and $G(.)$ is a known function satisfying $0 < G(Z) < 1$. Typically $G(.)$ is chosen to be a Cumulative Distribution Function (CDF).

As proposed by the authors, we choose a logistic functional form that ensures that the predicted values of the dependent variable are between zero and one, and a Bernoulli Quasi-likelihood function that leads to an efficient Quasi-Maximum Likelihood Estimation (QMLE).

As indicated in the introduction, factors conditioning adoption decisions include farm and farmer specific characteristics, but also institutional and economic factors. Institutional and economic factors included are extension contact, transportation costs and credit constraints.

In our analysis, we have a presumption that the credit constraint status of a household is endogenous in the adoption model since access to credit depends largely on farm and household characteristics as shown by many studies (Simtowe *et al.*, 2009; Diagne and Zeller, 2001). While access to credit has been hypothesized as influencing the adoption of agricultural innovations (Smale and Phiri, 1998), past research rarely considered the potential simultaneity bias that arises from using the endogenous credit constraint status as a regressor in the adoption equation (Zeller *et al.*, 1998).

Following Diagne and Zeller (2001), Jappelli (1990) and Sawada *et al.* (2006), a two-stage procedure can be used to produce unbiased and consistent estimate of the adoption model given that the credit constraint status is an endogenous variable.

We construct a qualitative response model of endogenous credit constraint by defining an indicator variable of credit constraint w. The demand for credit and the maximum available credit to the household can both be expressed as a linear function of observable variables such as household and farm characteristics.

A reduced form equation of the gap between the supply of credit (S) and the demand for credit (D) can thus be written as follows:

$$S - D = w^* = Z\gamma + \mu$$

$$w = \begin{cases} 1 \, if \; w^* < 0 \\ 0 \, if \; w^* \geq 0 \end{cases} \tag{19}$$

where: Z represents household and farm characteristics that determine credit demand as well as the supply of credit to the household; μ is a random error term with zero

mean. A household is said to have a binding credit constraint if $w^* < 0$ and thus $w = 1$. The credit constraint is not binding if $w^* \geq 0$ and thus $w = 0$.

The econometric model of the adoption of High Yielding rice Varieties can be composed of two interrelated dependent variable models. The first model is a credit constraint equation (equation 19). The second model relates to the adoption of improved varieties in which the endogenous credit constraints status of a household is included as an explanatory variable as in the following equation:

$$E(y/X, w) = G(\delta w + X\beta) \tag{20}$$

where is the proportion of land cultivated with high yielding seed varieties, G is the logistic CDF, X is a matrix of household specific socioeconomic and demographic characteristics that affect adoption decisions. The variable w is an indicator of credit constraints which takes the value of one if the credit constraint is binding and zero otherwise.

For consistent estimation, a two-step approach is applied. In the first stage, an estimate of w, $\hat{w}$, is obtained by probit maximum likelihood method for equation (19). The predicted probability is then used in the second stage as an instrumental variable for credit constraint status to obtain estimates of the adoption model by quasi-likelihood method as proposed by Papke and Wooldridge (1996).

3.2. Justification and expected signs of variables used

The explanatory variables used in this study are suggested by the literature on adoption of agricultural innovations (Feder *et al.*, 1985; Adesina and Zinnah, 1993; Adesina and Seidi, 1995; Marra *et al.*, 2003). These variables could be classified into 4 broad categories: (a) Farm characteristics (use of fertilizer, farm size, animal traction, irrigation); (b) Producer characteristics (household size, age, gender, education, ethnic group); (c) Institutional and economic factors (extension contact, transportation costs, credit constraints); (c) Psychological factors (farmer's perceptions). Table A.2 in Appendix provides definition and descriptive statistics of these variables.

3.2.1. Fertilizers

An important factor in explaining adoption patterns is the availability of complementary inputs. Since the high-yield potential of the seed can be realized only if at least some fertilizers are applied, we hypothesize that farmers will be more likely to adopt the HYV seeds if some fertilizers are available.

3.2.2. Farm size

Most adoption studies include a variable reflecting farm size because large farms can better spread the fixed cost of a given practice over a large output than can small farms, thereby lowering average fixed costs. In our context, the modern rice varieties involve little fixed capital investment. However, landed properties can be used as collateral to gain access to the formal credit market. Thus, all things being equal, large farms are more able to purchase HYV fertilizers package than do small farms. We therefore expect the sign of the coefficient of the variable "farm size" to be positive.

3.2.3. Animal traction

In the Ivorian context, use of animal traction is related to wealth as well as to the potential interest in new agricultural practices. Moreover, cattle reflect social status and the latter may be related to access to the informal credit market. Use of animal traction is, therefore, expected to be positively related to the adoption intensity of high yielding rice varieties.

3.2.4. Irrigation

In the Ivorian context, due to the shortening of rainy seasons, the HYV fertilizer package is more profitable and less risky if means of developing an assured and regulated water supply are also provided. Thus, the hypothesis is that, all things being equal, irrigation may provide incentives for producers to use the improved rice varieties. We therefore expect the sign of the coefficient of the variable "Irrigation" to be positive.

3.2.5. Household size

Households with a large quantity of family labor available for farm work are hypothesized to be more likely to adopt labor-intensive technologies. In the Ivorian context, rice cultivation is labor intensive, thus High Yielding rice Varieties are more likely to be adopted by a household with significant quantities of family labor.

3.2.6. Age

Age is an indicator of years of farming experience. Since experience is correlated with adoption of rice innovations, we expect age to be positively related to the intensity of adoption of improved rice varieties. However, the square of age is included as a variable to capture the fact that there might be a certain point after which age leads to lower levels of adoption.

3.2.7. Gender of the farmer

Because females often tend to be poorer and more subsistence oriented in the Ivorian context, we expect a female farmer to be more likely to adopt intensively the High Yielding Varieties.

3.2.8. Human capital

Several studies have found a correlation between human capital and technological adoption. Higher human capital accumulation is hypothesized to increase the adoption of new agricultural practices or modern agricultural inputs. In our study, the formal education level reached by the farmer is used to reflect the human capital.

3.2.9. Ethnic groups

In the Ivorian context, land is owned by native farmers and cannot be sold to foreigners or non-natives. Therefore, in the tenure arrangements, tenant farmers are generally

foreigners or non-natives. Since owners are less affected by credit constraints than are tenants, we hypothesize that tenants (foreigners and non-natives) have a lower tendency to adopt HYV technology than owners (native farmers).

3.2.10. Contact with extension services

Farmers who have more information about technological practices are hypothesized to be more likely to adopt those practices. In our study variables used to reflect the sources of agricultural information are the village past contact with the old rice development agencies (SATMACI and SODERIZ) and the frequency of contact with current agencies which are in charge of rice extension (WARDA, CBSS and ANADER).

3.2.11. Transportation costs

For rice producers far from the local market, transportation costs may be prohibitive leaving no incentive to produce more than a subsistence level of output. Thus, farmers facing high transportation costs are hypothesized to be less likely to adopt improved rice varieties.

3.2.12. Access to credit

Utilizing new technologies in agricultural production often requires cash to purchase the inputs such as HYV seeds and chemical fertilizer. Rice farmers that have more sources of cash are hypothesized to be more likely to adopt modern practices. All things being equal, farms having access to credit would have the means to purchase the inputs associated with improved technologies and thus are hypothesized to be more likely to adopt these modern technologies.

3.2.13. Farmer's perception

We hypothesize that producers' general perceptions of a new technology significantly influence the level of adoption. In our case, we expect that a good perception on the eating quality, the cycle of production and the drought resistance of improved rice varieties will be positively related to the level of adoption.

4. Data type and source

The empirical study relied on cross-section data collected from a total of 311 rice farmers in 16 villages in upper west of Ivory Coast (the region of Touba) between February and August 2008. The department of Touba is geographically a transition zone between the savanna and forest regions. It contains the main agroecological zones (forest, savanna and lowland). This department was chosen so as to cover all the different rice ecologies of Ivory Coast. Moreover, Touba is one of the main rice producing regions of Ivory Coast but the use intensity of HYVs is one of the lowest (WARDA and REI, 2003).

The rice farmers were randomly selected and were interviewed using structured questionnaires. The survey questionnaire consisted of several modules including (*i*)

socio-demographic variables such as farmer's age, farmer's gender, his household size, his education attainment, (*ii*) farm structure such as farm size, rice farming system, (*iii*) variables that describe institutional and economic factors such as extension contact, credit availability, trade costs and (*iv*) farmer's perceptions variables.

In the credit module, respondents were asked whether or not they were in need of credit in the past crop season. Those who asked for credit were asked whether or not they had access to loan facilities and whether they received the full amount demanded. Respondents who did not access loan facilities or did not receive as much credit as requested were classified as credit constrained.

In the transportation costs module, the questions were as follows:
– How do you market your product?
– What is the approximate/average transportation cost of accessing agricultural input and output markets during the cropping season?
– How much do you spend to get your products to the local market?

5. Descriptive analysis of data

5.1. Demographic characteristics of surveyed farmers

Table 2 presents some demographic characteristics of the surveyed farmers by rice farming system. Rain-fed rice farming was the most common type of rice cultivation among the surveyed farmers (55%). Of the 311 farmers interviewed, only about 5.4% were female. The observed male dominance in rice cultivation could be due to the fact

Table 2. **Demographic characteristics of the sample by rice farming system**

Variable	Rain-fed system	Irrigated system	Total
Number of farmers	170 (55%)	141 (45%)	311
Sexe (%)			
Men	95.88	92.91	94.53
Women	4.12	7.09	5.47
Age (%)			
Age (less than 16 years)	4.71	4.96	4.82
Age (from 16-59 years)	82.35	84.40	83.28
Age (+ 60 years)	12.94	10.64	11.90
Marital status (%)			
Married	92.94	89.36	91.32
Unmarried	5.29	4.96	5.14
Widower, widow	1.76	5.67	3.54
Ethnic (%)			
Mahou	75.29	73.76	74.60
Yakouba	9.41	4.26	7.07
Non-natives	7.06	7.80	7.40
Foreigners	8.24	14.18	10.93

Source: Own computation from survey data

that male farmers have greater access to rice lands than their female counterparts. The average age in the sample at the time of the survey was 47. Indeed, the majority of farmers is composed of adults (from 16 to 59 years) (83%). Then farmers aged 60 years or more (11%) and youth under 16 years with a ratio of 4%. Two-thirds of the surveyed farmers were born in the villages chosen for the study.

5.2. Socioeconomic characteristics of surveyed farmers

Socioeconomic characteristics of farmers by rice farming system are presented in table 3. An estimated 23% of the farmers interviewed had formal education. A total of 27% of surveyed farmers have never had any contact with extension and research organizations. Although agriculture is the main source of income, some 10% of the farm households have sources of income besides farming. A total of 53% of surveyed farmers had received credit to finance their farm operations and 67% of them have low access of market because of high transportation costs.

5.3. Credit constraints and adoption of improved rice varieties

Table 4 presents the rate of adoption of improved rice varieties by credit constraint status. The statistic of the mean comparison test indicates that credit unconstrained farmers have on average a higher rate of adoption compared to those facing difficulties in accessing credit.

5.4. Transportation costs and adoption of improved rice varieties

We create a dummy variable for transportation costs which takes value 1 if the transportation costs of accessing agricultural input and output markets is greater than the average group and 0 if not. According to the statistic of the mean comparison test, we cannot reject the hypothesis that increase in transportation costs is associated with lower adoption rate of new rice varieties (see table 5).

6. Results of econometric estimates and discussion

The results from the fractional logit model, which corrects for the endogenous credit constraints are presented in table A1 (see Annex). Columns 1 and 2 present estimates of the credit constraint equation while Columns 3, 4 and 5 present estimates of the adoption equation. The results of the first stage probit estimation of the credit constraint status will be discussed first before discussing the results of the determinants of the adoption of HYVs (second stage).

6.1. Determinants of credit constraint status

The probit model used for the credit constraint status fits the data reasonably well about 84.79% of the outcomes are correctly predicted and the LR test of the hypothesis that all regression coefficients are jointly equal to zero is strongly rejected.

Having a secondary occupation has a reducing effect on the likelihood of facing credit constraints. Indeed, secondary activities reduce the risk to be credit constrained by providing liquidity from nonfarm sources.

Table 3. **Socioeconomic characteristics of the sample by rice farming system**

Variable	Rain-fed system	Irrigated system	Total
Education (%)			
Illiteracy	80.59	46.81	65.27
Primary	12.94	36.88	23.79
Secondary	6.47	16.31	10.93
Contacts with Ivorian extension structures (%)			
SATMACI, SODERIZ.	12.35	4.26	8.68
WARDA, FAO, ANADER.	52.94	77.30	63.99
No organization	34.71	18.44	27.33
Secondary occupation (%)			
Housework	1.76	5.67	3.54
Trading	1.18	14.89	7.40
Other	1.18	0	0.64
Credit constraint status (%)			
Credit unconstrained farmers	33.53	77.30	53.38
Credit constrained farmers	66.47	22.70	46.62
Transportation costs (%)			
Greater than the average group	66.47	29.08	49.52
Lower than the average group	33.53	70.92	50.48

Source: Own computation from survey data

Table 4. **Credit constraints and adoption of improved rice varieties**

	Credit constraint status		Mean comparison test
	Unconstrained	Constrained	t
Number of farmers (%)	53.38	46.62	
Average rate of adoption (%)	75.20	8.42	– 26.2077***

Source: Own computation from survey data. ***, **, * : significance at 1%, 5% and 10% level

Table 5. **Transportation costs and adoption of improved rice varieties**

	Transportation costs		Mean comparison test
	High	Low	t
Number of farmers (%)	49.52	50.48	
Average rate of adoption (%)	12.77	74.76	19.66***

Source : Own computation from survey data. ***, **, * : significance at 1%, 5% and 10% level.

Farmers who have frequent contacts with extension structures are less likely to face credit constraints. Contacts with extension organizations allow farmers to participate in formal credit programs and meet their financial needs.

The education level of the farmer has a negative effect on the probability of facing credit constraints. The ability to read and write would imply greater access to formal sources of credit. The findings are also consistent with an observation made by Musebe *et al.* (1993) in which they report that as the household gets more formal education, the probability of obtaining credit increases.

As expected, foreigners are significantly more likely to face credit constraints. A more plausible explanation that relates to the system of land tenure in Ivory Coast is that, unlike native farmers, foreigners cannot use land as collateral to gain access to the formal credit market.

Finally, with respect to the district dummies, the results show that they are significant. Further, the coefficients have positive signs implying that the less credit accessed farmers are living far away from the regional center (Touba). This result is explained by the lack of formal credit institutions in rural districts compared to the regional center (Touba). This suggests that distance is a limiting factor to access credit from the formal sources.

6.2. Determinants of adoption and use intensity of HYVs

Columns 3, 4 and 5 present the determinants of adoption and use intensity of HYVs with correction for endogeneity of credit constraint status.

The results indicate that variables reflecting farmer/farm characteristics, institutional factors and farmers' perceptions are important in influencing the level of adoption of improved rice varieties.

In terms of the farmer characteristics, the statistically significant variables are age and ethnic group. Since age is a proxy for farming experience, the positive coefficient indicates that more experienced farmers adopt more intensively the improved rice varieties. Indeed, by augmenting technical skill in growing rice, experience helps to profit from the full potential of improved rice varieties thereby influencing positively their adoption. The significant negative effect of the square of age included as variable implies that there is a certain point after which high age leads to lower levels of adoption. This suggests that after a certain age, older farmers may incur higher efforts in implementing new agricultural practices.

Dummy variables included for ethnic groups indicate that non-natives of Touba region are less inclined to adopt the HYVs. As discussed in the previous sub-section (6.1), non-native farmers are more affected by credit constraints thus are less likely to access and use modern agricultural inputs relatively to the native farmers.

In terms of the farm specific characteristics, the statistically significant variables are the amount of fertilizer used and the use of irrigated system. As we should expect, these variables reflecting complementary physical resources have a positive and significant effect on the adoption of improved rice varieties. This result is explained by the fact that fertilization and a regulated water supply are important for realizing the full potential of HYVs.

In terms of the economic and institutional variables, contacts with extension organizations, transport costs (district dummies) and credit constraints are all significant determinants of the use intensity of improved rice varieties.

Contacts with current extension organizations (ANADER, FAO, WARDA) have a positive and significant effect implying that rice farmers exposed to the High Yielding Varieties allocate a higher proportion of land to improved rice cultivation.

The positive impact of contact with extension service is explained by the fact that farmers who have contacts with extension organizations are likely to hear about improved varieties and thus have more incentive to adopt these new agricultural technologies. Another factor with important contribution to the adoption intensity of HYVs is the village past contact with the old rice development agencies, SATMACI and SODERIZ. This might be an indication of their lasting impact in terms of established channels of formal and informal diffusion of rice technologies in Ivory Coast, which happen to be still active long after the agencies have been dissolved.

Because agricultural input and output markets are located in the regional center (Touba), producers residing far from the regional center face larger costs in accessing agricultural markets. District dummies were included to represent such costs. Indeed, district dummies included to capture geographic differences in the costs of transport are all statistically significant and have negative signs implying that farmers in villages far from the regional center are less likely to adopt the HYVs. This result is consistent with expectations and suggests that with higher transport costs of accessing agricultural markets, the level of adoption of HYVs declines. The negative association between transport costs and adoption intensity of HYVs is explained by the fact that high transportation costs to agricultural markets outlet reduce the financial incentives to adopt new agricultural technologies.

The other statistically significant variable reflects household's access to credit. The coefficient for predicted probability of being credit constrained has a negative and significant effect on the adoption and use intensity of improved rice varieties. This suggests that credit constraints tend to reduce the adoption of HYVs, which is consistent with *a priori* expectations that due to liquidity constraints farmers are unable to purchase improved seed.

With reference the farmer perception variables, eating quality and crop cycle length are all statistically significant and have signs consistent with expectations. This implies that improved varieties that compared favorably with local varieties in terms of these criteria would likely be adopted by farmers. As indicated by the results, a favorable impression of the improved varieties in terms of taste is significant in the adoption process. This attribute is specially important for these farmers because rice is grown partly for home consumption.

The other perceptual variable that is statistically significant is the growing cycle of the variety (a shorter growing cycle is viewed as desirable). The results show that farmers who perceive a shorter crop cycle for the improved varieties *vis-à-vis* the local should be more inclined to adopt them. The importance of the criterion relating to length of growing cycle in the adoption decision can be explained by the increasing shortness of rainy season in Ivory Coast.

7. Summary and conclusion

Development and adoption of improved technologies play a critically important role in improving the productivity, and hopefully the welfare, of limited resource farmers in developing countries. Adoption studies have consistently emphasized the importance of

various farmer and farm characteristics in determining whether such technologies will be adopted.

Using a theoretical model and data collected from 311 farming households in Ivory Coast, this paper demonstrates that not only farm and famers' characteristics, but also institutional factors, significantly influence the adoption and use intensity of improved rice varieties.

In terms of variables reflecting both farmer/farm characteristics and farmer's perceptions about the improved varieties, the findings establish that age (a proxy for farming experience), the use of improved agronomic practices such as fertilization or irrigation and favorable farmer's perception in terms of eating quality and crop cycle length are the determinants with significant positive impact on the intensity of use of improved rice varieties.

For the institutional factors namely, extension contact, credit accessibility and costs of accessing agricultural markets, this paper shows that the variables reflecting such factors are critically important in influencing the adoption and the use intensity of HYVs. The results reveal a positive relationship between extension contacts and the level of adoption of HYVs. On the other hand, they indicate that credit constraints and transport costs in accessing agricultural markets have significant negative effects on the adoption intensity of improved rice varieties.

The overall conclusion deduced from this analysis is that Ivorian farmers are able to adopt intensively improved agricultural technologies, such as high yielding rice varieties, if policies improve their access to credit, extension, input and output markets.

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ANNEX

Table A1. **Determinants of adoption of HYVs with correction for endogeneity of credit constraint status**

	Step 1 Credit Constraint Status Probit Model [a]		Step 2 Adoption of HYVs Fractional Logit Model [b]		
	(1)	(2)	(3)	(4)	(5)
Farmer characteristics	**Coef.**	**P-value**	**Coef.**	**P-value**	**Mg. Ef**
Household size	– 0.0036	0.875	0.02105	0.254	0.004
Age	– 0.0657	0.240	0.0804**	0.043	0.174
Age^2	0.0005	0.371	– 0.0007*	0.070	– 0.0001
Secondary occupation	– 1.999**	0.042			
Gender					
Men	–	–	–	–	–
Women	-0.1863	0.773	0.5701	0.191	0.1329
Education					
Illeteracy	–	–	–	–	–
Primary	– 0.8903***	0.003	0.3249	0.259	0.0724
Secondary	– 0.7473**	0.015	– 0.2838	0.324	– 0.0589
Ethnic group					
Mahou (native)	–	–	–	–	–
Non-native	0.2722	0.499	– 0.3879*	0.098	– 0.0791
Foreigner	1.0503**	0.017	– 0.2308	0.605	– 0.0517
Marital status					
Married	–	–			
Unmarried	0.2380	0.794			
Windower, window	– 1.3947	0.107			
Farm characteristics					
Amount of fertilizers used per hectare			1.2681***	0.000	0.2751
Farm size	– 0.0449	0.670	0.0489	0.512	0.0106
Animal traction			– 0.1697	0.326	– 0.0365
Irrigation			1.9919*	0.089	0.4322
Institutional and economic factors					
Contact with extension organization					
No organization	—	–	–	–	–
With SODERIZ, SATMACI	– 1.0697***	0.007	1.7197***	0.000	0.40504
With ANADER, FAO, WARDA	– 1.5330***	0.000	2.0573***	0.000	0.3822
Distance consideration					
District dummy Touba (regional center)	–	–	–	–	–
District dummy Foungbesso	1.1030***	0.001	– 1.0545***	0.000	– 0.1975
District dummy Guinteguela	1.8267***	0.000	– 2.0731***	0.000	– 0.3157
District dummy Ouaninou	2.6116***	0.000	– 2.7643***	0.001	– 0.4775
Probability of being credit constrained			– 1.1616***	0.000	– 0.2441

Table A1. **Determinants of adoption of HYVs with correction for endogeneity of credit constraint status *(continued)***

	Step 1 Credit Constraint Status Probit Model [a]		Step 2 Adoption of HYVs Fractional Logit Model [b]		
Farmer's perceptions of HYVs compared with local varieties					
Taste					
Poorer			–	–	–
Superior			1.5807***	0.000	0.2836
Growing cycle					
Longer			–	–	–
Shorter			0.4096*	0.055	0.0867
Drought resistance					
Low			–	–	–
High			0.2749	0.351	0.0606
Constante	1.5944	0.205	– 7.2471***	0.000	
Log Likelihood	– 95.269		– 77.9482		
LR Chi2	236.11***	0.000			
Pseudo R2	0.5534				
% correct prediction overall	84.79				
Specification test			0.010347	0.833	
AIC			0.657		
BIC			– 1588.27		

(a) Dependent variable: binary variable indicating the credit constraint status.
(b) Dependent variable: proportion of rice area cultivated with improved rice varieties.
Source: Own computation from survey data. ***, **, * : significance at 1%, 5% and 10% level

Table A2. **Definition and descriptive statistics of explanatory variables used**

Variables	Definition	Mean	Std.dev	Min	Max
Farmer characteristics					
Household size	Number of persons in farmer's household	8.720	5.134	1	30
Age	Farmer's age	42.62	13.84	14	72
Age^2	Square of farmer's age (scale down by 100)	20.09	12.05	19.6	51.84
Gender					
Women	=1 if farmer is a woman	.0546	.2276	0	1
Men	=1if farmer is a man	.9453	.2276	0	1
Education					
Illiteracy	=1 if the farmer has no level of formal education; 0 otherwise	.6527	.4768	0	1
Primary	=1 if the farmer has some primary school level; 0 otherwise	.2379	.4265	0	1
Secondary	=1 if the farmer has some secondary school level; 0 otherwise	.1093	.3125	0	1
Ethnic group					
Mahou (native)	=1 if farmer is Mahou ; 0 otherwise	.7459	.4360	0	1
Foreigner	=1if farmer is a foreigner ; 0 otherwise	.1093	.3125	0	1
Other ethnic group (non-native)	=1 if farmer is non-native ; 0 otherwise	.0739	.2621	0	1
Secondary occupation	=1 if farmer has a secondary occupation; 0 otherwise	.1157	.3204	0	1
Marital status					
Married	=1 if farmer is married; 0 otherwise	.9131	.2820	0	1
Unmarried	=1 if farmer is unmarried; 0 otherwise	.0514	.2212	0	1
Widower, widow	=1 if farmer is widower or widow; 0 otherwise	.0353	.1850	0	1
Farm characteristics					
Fertilizers	Amount of fertilizers used per hectare (100kg/ha)	1.055	.7467	0	2.437
Farm size	Total rice area cultivated (ha)	1.897	1.274	.25	6
Animal traction	=1 if animal traction is used by the farmer ; 0 otherwise	.3665	.4826	0	1
Irrigation	=1 if the farming rice system is the irrigated system; 0 if it is the rainfall system	.4533	.4986	0	1
Institutional and Economic factors					
Contact with extension organization					
No organization	= 1 if the farmer has no contact with extension	.2733	.4463	0	1
SODERIZ, SATMACI	=1 if the village had contact with any of these organizations; 0 otherwise	.0868	.2820	0	1
ANADER, FAO, WARDA	=1 if the farmer has contact with any of these organizations; 0 otherwise	.6398	.4808	0	1

Table A2. **Definition and descriptive statistics of explanatory variables used *(continued)***

Variables	Definition	Mean	Std.dev	Min	Max
Distance consideration					
Distric dummy Touba (regional center)	=1 if the farmer resides in the regional center (Touba); 0 otherwise	.3086	.4626	0	1
District dummy Foungbesso	=1 if the farmer resides in the district of Foungbesso; 0 otherwise	.1897	.3927	0	1
District dummy Guinteguela	=1 if the farmer resides in the district of Guinteguela; 0 otherwise	.1511	.3587	0	1
District dummy Ouaninou	=1 if the farmer resides in the district of Ouaninou; 0 otherwise	.3504	.4778	0	1
Credit constraints status					
Credit unconstrained	=1 if farmer received as much credit as requested for farm operations; 0 otherwise	.5337	.4996	0	1
Credit constrained	=1 if farmer did not access loan facilities or did not receive as much credit as requested; 0 otherwise	.4662	.4996	0	1
Farmer's perceptions of HYVs compared with local varieties					
Taste					
Superior		.7524	.4323	0	1
Poorer		0.2476	.4323	0	1
Growing cycle					
Shorter		.6430	.4798	0	1
Longer		.3570	.4798	0	1
Drought Resistance					
High		.3247	.4690	0	1
Low		.6753	.4690	0	1

ANADER=National Agency for Rural Development; SATMACI=Technical Support Agency for the Modernization of Agriculture in Ivory Coast; SODERIZ=Rice Development Agency
Source: Own computation from survey data

Table A3. **Description and performance of improved rice varieties diffused in Ivory Coast from 1990 to 2007**

Improved Varieties	Bred by	Potentiel Yield (t/ha)	Average Yield (t/ha)
Rain-fed farming			
IDSA 76	CNRA	4	2
IDSA 91	CNRA	3,7	1,7
IDSA 85	CNRA	3,1	1,8
IDSA 92	CNRA	3	1,3
Nerica 1	WARDA	4	2,5
Nerica 2	WARDA	4.9	2.5
IDSA 77	CNRA	4	2
Nerica 9	WARDA	5	2.5
Nerica 10	WARDA	5	2.5
Nerica 11	WARDA	5	2.5
Irrigated farming			
Bouaké 189	CNRA	8	4,5
Wita 3	WARDA	9	4,5
Mixed farming			
Wita 1	WARDA	9	5
Wita 7	WARDA	10	6
Wita 8	WARDA	8,5	5,8
Wita 9	WARDA	8,5	5,8
Wita 12	WARDA	10	6

Source: Catalogue of improved rice varieties officially diffused in Ivory Coast, MINAGRA/PNR. MINAGRA = Ministry of Agriculture; PNR = Rice National Program; WARDA = Africa Rice Center; CNRA = National Agricultural Research Center