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Modelling adoption of natural resources management technologies: the case of fallow systems

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ABSTRACT. This paper presents an adoption model of a resource management technology derived from a three-step decision process (information, adoption, and intensity of adoption).

From the theoretical results it is found that while the levels of technical parameters such as duration and regeneration rate of soil fertility by improved fallow are relevant for adoption, it is misleading to ignore economic and social factors as they are reflected in the discount rate, risk, information, and prices of inputs and outputs.

It is also shown that models that do not take account of the problems of self-selection due to the ability of the potential adopters to acquire and process the relevant information about a technology, lead to biased estimators.

Empirical estimations generally confirm the theoretical results. It is found that the acquisition of information about resources management technology is influenced by age of farmers and actions of official extension services; the adoption decision is influenced by prior utilization, the bundle of land property rights owned, and the level of financial liquidity; and the intensity of adoption is influenced by the percentage of the farm that is degraded.

1. Introduction

An international evaluation of land degradation conducted in 1990 by the United Nations Environment Program (UNEP) showed that 1.2 billion hectares of land (11 per cent of world land cover) was degraded by human activity between 1945 and 1990. Estimates of the impact of the gross loss of soil report economic growth losses ranging from 0.5 per cent to 1.5 per cent

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in countries like Costa Rica, Malawi, Mali, and Mexico. Such negative effects may lead to growth stagnation (Banque Mondiale, 1992). This confirms the narrow and reciprocal link between biophysical problems and socio-economic conditions of farmers (WCED, 1987).

Land degradation is one of the factors contributing to the agricultural crisis in Africa (Kebe and Defoer, 1997). Seventy per cent of sub-Saharan African soils are classified as low-fertility (Sanchez, 1994; Seckler, 1993). It is therefore important to find and encourage adoption of technologies that restore soil fertility. However, to date, modelling of adoption of natural resources management technologies is not always adequate.

In optimal control models, an adoption decision is often assumed to be taken once and for all in an economic environment of complete markets and uniform technology. Such assumptions usually justify derivation of steady state (long-run) equilibrium results that bring a better understanding of farmers' behaviour (Barrett, 1997; Barbier, 1998; Babu *et al.*, 1995). However, those assumptions may be unnecessarily strong.

This paper presents an adoption model derived from a three-step decision process (information, adoption, and intensity of adoption). Comparative static theoretical results are derived, and field data are used to test them.

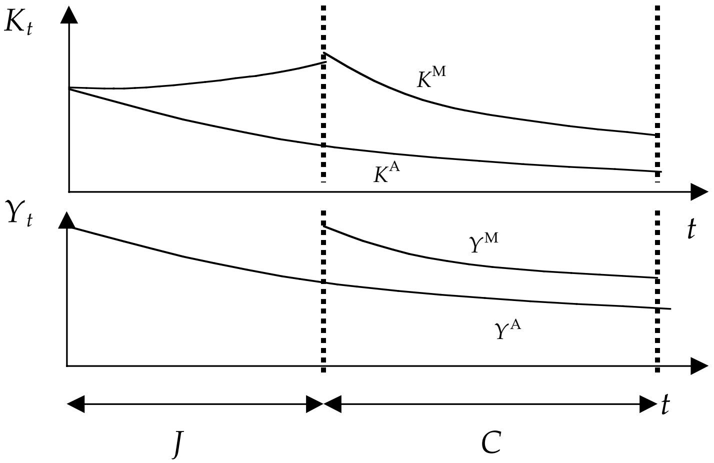
I will show that, when levels of technical parameters such as duration and regeneration rate of soil fertility by improved fallow are relevant for adoption of natural resources management technologies, one should not ignore economic and social factors as they are reflected in the discount rate, risk, information and prices of inputs and outputs.

The second section presents fallow systems as resources management technologies. Section 3 describes the theoretical model. Section 4 presents the empirical model of estimation. The results of the estimation are presented in the fifth section. Concluding remarks are presented in section 6.

2. Renewal of fallow systems as natural resources Management technologies

As the demand for greater food production becomes an ever-increasing need, while land becomes scarcer and more degraded, the only option for African farmers is the intensification of agriculture. Technological options are available such as inorganic fertilisers. However their use remains limited in Africa mainly due to rising prices and inefficient marketing systems. For example, in Benin Republic, the price of chemical fertilisers more than tripled while that of maize, a major staple, decreased, and the price of cotton, a major cash crop, hardly rose during the 1981–1993 period (MDR, 1993).

Van Der Pol *et al.* (1993) calculated that 68 per cent of the cost of soil degradation may be attributed to nitrogen deficiency in the South-West of Benin. At current prices, if nitrogen deficiency is remedied by use of imported urea fertiliser, the budget of farmers or the Benin government's would have to support an additional cost of more than US$30 million. This option is therefore out of reach of the numerous small-scale African farmers. One possibility for fertilising soils and at the same time avoiding a decline in soil productivity is to explore natural sources of fertilisers, for example, cover crops such as Mucuna fallow, used in West Africa.



K^{A} = Evolution of soil fertility without fallow
K^{M} = Evolution of soil fertility with fallow
Y^{A} = Evolution of crop yield without fallow
Y^{M} = Evolution of crop yield after fallow

Figure 1. *Evolutions of fertility and production on soil with and without fallow system during a rotation cycle*

The use of a fallow system to address soil nitrogen deficiency is appropriate at a time when greater concern is being paid to the adverse effects of nutrients transported from farms to surface and ground waters (Khanna, 2001).

A general improved fallow technology is described as follows: A farmer that decides to partially adopt the fallow system divides his land into two plots. One is planted with fallow system during a period J in order to increase soil fertility. When the fallow is mature, it is removed and the plot is farmed during a period C. During the cropping period, the soil fertility is supposed to decay. During the rotation cycle ($J + C$), the other plot is directly cropped and the initial fertility K_0 also decays.

Figure 1 presents the evolution of the stock of fertility (K_t) and production (Y_t) per unit of land on plots with and without the new technology.

Despite the potential benefits associated with fallow systems, they are not without user and opportunity costs. Those who adopt the system have to support the clearing costs of fallow, the loss of crops during the fallow time, etc. Thus, the adoption of fallow systems implies a rational process of decision making that is not adequately modelled by the relevant literature.

3. Theoretical model

The model begins with the information held by farmers, the potential adopters. It would be misleading to categorize the population of farmers into adopters and non-adopters if not all the members of the potential adoption community are informed. The adopting farmers are therefore those that are informed of the existence of the technology and find it profitable. Thus, the adoption decision is conditional on other decisions such as the need to search for information. In turn, the adoption decision affects the intensity of adoption and the choice of levels of inputs (fertilisers, labour). If those interrelations exist and they are not taken into account, the estimators obtained from econometric estimations may be biased (Saha *et al.*, 1994). This observation is similar to the problem associated with the separate analysis of the adoption of components of a technological package without recognizing the link between their adoption (Khanna, 2001).

The unified model is composed of three equations. The first relates to the process of information acquisition, the second explains the adoption decision, and the last is associated with the level of adoption intensity.

3.1. Information equation

A common procedure in adoption studies is to divide the adoption population into adopters and non-adopters without worrying about whether all members of the potential adoption population are informed about the existence and utilization of the technology under study. This usually results in inefficient and biased estimators. Then, if in a community, some potential adopters are not informed about the existence and how to use the technology, the information equation should be the first equation of an adoption model (Saha *et al.*, 1994).

Let us take a farmer with a level of information equal i^*, and let i^0 be the threshold of level of information that a farmer should have in order to be classified as informed. Then, the farmer is informed if $i^* > i^0$.

By defining the latent variable Y^{H^*} as $Y^{H^*} = i^* - i^0$, the condition to classify a farmer as informed becomes

$$Y^{H^*} = i^*(X^H) - i^0 > 0 \tag{1}$$

where superscript H stands for 'has heard that the technology exists and knows how to use it'.

$X^H =$ vector of socio-economic and demographic factors (such as age, farming experience, education, soil degradation, etc.) that could influence i^*, say the supply and demand of information.

The theoretical equation to be estimated is then

$$Y^{H^*} = X^H.\beta^{H^*} + u^{H^*} \tag{2}$$

where:

$\beta^{H^*} =$ vector of parameters to be estimated,
$u^{H^*} =$ error term.

i^*, i^0, and consequently Y^{H^*}, are not observable. To estimate the information equation, we need to construct a variable that accounts for whether the farmer is aware of the technology and how to use it. Let us denote that variable by Y^H, which takes the value 1 for a positive answer ($Y^{H^*} > 0$) and 0 for a negative or null answer ($Y^{H^*} \leq 0$).

The theoretical Probit equation to be estimated is therefore

$$Y^H = \Phi(X^H.\beta^H + u^H) \tag{3}$$

where:

β^H = vector of parameters to be estimated,
u^H = error term.

3.2. *Adoption equation*

The income of the adopting farmer is obtained by adding discounted flows of revenues on plots with (R_f) and without (R_a) the new technology. The adoption period lasts for J and the land plots are cropped during period C. Then

$$\begin{aligned} R_f = {} & \underbrace{Mv\exp(-\delta J)}_{\text{i}} - \underbrace{\int_0^J Mz\exp(-\delta t)\,dt}_{\text{ii}} \\ & + \underbrace{\int_J^{J+C} [PK_0\exp(gJ - b(t-J)).F(M)\tilde{e}_m - wM]\exp(-\delta t)\,dt}_{\text{iii}} \\ & - \underbrace{\int_0^{J+C} lM\exp(-\delta t)\,dt}_{\text{iv}} \end{aligned}$$

and

$$R_a = \underbrace{\int_J^{J+C} [PK_0\exp(-bt)F(A)\tilde{e}_a - wA]\exp(-\delta t)\,dt}_{\text{v}} - \underbrace{\int_J^{J+C} lA\exp(-\delta t)\,dt}_{\text{vi}} \tag{4}$$

where:

K_0 = initial fertility level;
$\tilde{e}_a$ = random term, denoting the risky nature of production on plots without the new technology;
$\tilde{e}_m$ = random term, denoting the risky nature of production on plots with the new technology, $0 \leq \tilde{e}_m \leq 1$;
z = management cost (per unit of land) during the fallow period;
w = unit management cost of all plots during cropping period;
l = land rent,[1] assumed constant during the rotation cycle;
g = regeneration rate of soil fertility during the adoption period;
b = degradation rate of soil fertility during the cropping period;

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[1] For the purposes of simplification it is assumed that land rent is independent of the soil fertility. This assumption does not create a problem as the cost of land is not the focus of this paper.

J = duration of the adoption (fallow) period or fallow length;
C = duration of the cropping period or cropping length;
v = unit value of the fallow after maturation resulting from the sale of wood, shrubs, harvests, etc.;
P = unit price of the crop that succeeds the fallow. It is assumed that the same crop is cultivated on plots with and without the new technology. P is a parameter;
δ = instantaneous discount rate;
t = time;
exp = exponential function;
R_f = income with the new technology; and
R_a = income without the new technology.

Then:

> R_f is the sum of the discounted value of the matured fallow (i), minus the discounted value of the total fallow management cost (ii), plus the discounted net income from cropping after fallow (iii), minus the discounted opportunity cost of land (iv), and
> R_a is the discounted net income from the crop on a plot without fallow (v), minus the discounted opportunity cost of land (vi).

The basic assumptions underlying income flows are:

(a) F is the production function that is assumed to conform to ordinary regularity conditions such as monotonicity and diminishing marginal returns.
(b) Two controlled production factors are considered: land (farmed area) and an aggregated input standing for other factors of production. It is assumed that the production in a period is proportional to the stock of fertility.[2]
(c) There is a subjective risk associated with production on plots with the new technology. This subjective risk is assumed constant, non-Bayesian, occurring at the moment of the first adoption, not permanently revised, and vanishing after one adoption. The production function on other plots is also risky but its level of risk is assumed less than that on land with the new technology, about which little is known.
(d) The level of fertility increases exponentially during the adoption period and decreases exponentially during the cropping period.[3]
(e) M and C are supposed time invariant. That is, at time t, if the farmer decides to devote a plot of area M to the fallow system, he waits

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[2] This linearity assumption is compatible with a factor–augmenting technology with a one–degree homogeneous production function (see Stoneman, 1983).

[3] It is more realistic to model the growth of fertility capital as a logistic function of time. The assumption of exponential growth of fertility, without fundamentally modifying the theoretical results, is acceptable within a finite time horizon and has the advantage to facilitate mathematical manipulations. The exponential assumption permits us to substitute directly the state equations of soil fertility in the objective index without recurring to equations of motion and use of Pontryaguin Principle.

until J and crops during C before resorting to another adoption cycle on the same plot. When this assumption may reduce the efficiency of the solution,[4] it is conform to the agricultural risky environment of the study.

Since the conditions that determine the adoption or rejection of the resource management technologies are always changing and the adoption or rejection decision is reversible, it is better to model adoption as utilization of technology at a moment t instead of modelling adoption as a once and for all decision. This is justified by the fact that a farmer who uses a technology during one period could temporally or permanently abandon it the next period for three main reasons:

1. The dynamics of the technological change. At any moment, other performing technologies may be found and substituted for the old ones;
2. Alteration in biophysical conditions. The biophysical factors that induced the utilization of a technology such as the severity of the problem of soil fertility degradation may change, imposing a change on the farmer's
3. The socio-economic conditions of the farmer and of the farmer's environment change.

Because of the possibility that the adoption of the technology may be discontinued, we could model the informed farmer's decision to adopt or to reject a technology as a problem of inter-temporal maximization, solved at the beginning of each adoption period. The farmer's problem comes down to

$$\begin{gathered} \text{Maximize } U^E = \overset{E}{{}_{i^*}}[U(R)] \\ M^*, A^*, J^*, C^* \\ \text{subject to } M + A = S \end{gathered} \tag{5}$$

where:

E = expectation operator,
U = utility,
R = inter-temporal discounted income,
M = current land area devoted to fallow,
A = current land area devoted to other crops,
J = fallow length,
C = cropping length,
S = total farmed land area.

U^E is then the expected utility of the total discounted income.

The expectation of R is conditional on the level of information (i^*) because the subjective risk that any potential adopter associates with the new technology depends on the level of information on the performance of the technology.

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[4] This was pointed out by an anonymous referee.

Assuming $\tilde{e}_a = 1$ (that is the old technology is not risky), replacing A by $(S - M)$ in the maximization programme, and integrating, we have

$$\begin{aligned}
R = {} & Mv\exp(-\delta J) - Mz\frac{1}{\delta}(1 - \exp(-J\,\delta)) \\
& + PK_0F(M).\tilde{e}_m.\left(\frac{1}{b+\delta}\right).(\exp((g-\delta)J) \\
& - \exp((g-\delta)J - (b+\delta)C)) - wM\frac{1}{\delta}(\exp(-J\,\delta) - \exp(-(J + C)\delta)) \\
& + PK_0F(S-M).\left(\frac{1}{b+\delta}\right).(1 - \exp(-(b+\delta)(J + C))) \\
& - w(S-M)\frac{1}{\delta}(1 - \exp(-(J + C)\delta)) - lS\frac{1}{\delta}(1 - \exp(-(J + C)\delta)). \qquad (6)
\end{aligned}$$

The farmer adopts the new technology if the differentiation of R with respect to M cancels for $M^* > 0$; that is[5]

$$\begin{aligned}
U_M^E = {}^{E}_{i^*}[U'(.)[PK_0B_1.F_m(M^*).\tilde{e}_m - B_2w - B_3z + B_4v \\
- PK_0A_1F_m(S - M^*)) + A_2w]] = 0 \qquad (7)
\end{aligned}$$

where:

$U^E{}_M$ stands for differentiation of U^E with respect to M,
$U'(.)$ is the differentiation of U with respect to R,
M^* is the optimal level of land devoted to fallow system. Let us denote

$$A_1 = \left(\frac{1}{b+\delta}\right).(1 - \exp(-(b+\delta)(J + C))),$$

$$A_2 = \frac{1}{\delta}(1 - \exp(-(J + C)\delta)),$$

$$B_1 = \left(\frac{1}{b+\delta}\right).(\exp((g-\delta)J) - \exp((g-\delta)J - (b+\delta)C)),$$

$$B_2 = \frac{1}{\delta}(\exp(-J\,\delta) - \exp(-(J + C)\delta)),$$

$$B_3 = \frac{1}{\delta}(1 - \exp(-J\,\delta)),$$

$$B_4 = \exp(-\delta J)$$

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[5] Because regularity conditions (that is concavity) are assumed for the production functions, we will suppose that the first conditions are sufficient for optimality.

The problem is conditional on the acquired information level (i^*). The farmer adopts the technology if $R'(0) > 0$;[6] that is[7]

$$Y^{A^*} = P.K_0B_1.F_m(0).E(\tilde{e}_m) + B_4v + A_2w - PK_0A_1F_m(S) - B_2w - B_3z > 0 \tag{8}$$

or

$$P.K_0B_1.F_m(0).E(\tilde{e}_m) + B_4v - B_2w - B_3z > PK_0A_1F_m(S) - A_2w \tag{9}$$

Assuming that $E(\tilde{e}_m)$ is a function of i^* (the subjective risk is determined by the level of information), that is $E(\tilde{e}_m) = \bar{e}(i^*)$, the first term of inequality (9) is the net marginal value of adoption expected by the farmer with level of information i^*; the second term is the net marginal cost of adoption.

The message brought by the inequality (9) is summarized as proposition 1.

Proposition 1

The farmer adopts the fallow system if the net marginal expected value is greater than the net marginal cost.

The first interesting point relating to the model is that the adoption decision is independent of the degree of risk of the technology (that is, independent of moments of $\tilde{e}_m$ of order greater than 1) and of the attitude of the farmer towards risk[8] (see Saha *et al.*, 1994). The result does not refer to any measure of risk aversion (through utility function), but to the mean of risk discount. This means that what influences the decision to adopt is not the degree of risk aversion of the adopter but the mean subjective risk discount. As I demonstrate later in the paper, the degree of risk aversion does intervene when the farmer must decide on the intensity of adoption. A second interesting remark is that the adoption decision is independent of the level of the land rent in the study area.[9]

Y^{A^*} is not observable because i^* and possibly, δ are not. Let us include the observable variables X^H (recall that $i^* = i(X^H)$), S, P,[10] z, w and K_0 as elements of vector X^A. We obtain the following theoretical model

$$Y^{A^*} = X^A.\beta^{A^*} + u^{A^*} \tag{10}$$

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[6] Because $U^E_{MM} < 0$. There is full adoption if $U^E_{M^*} > 0$ for all M^*. It is reasonable to assume that second differentiation of G with respect to M is non–increasing in M because more adoption means that more and more fertile land is devoted to the technology. That should result into lesser and lesser marginal returns.

[7] A necessary condition for $M^* > 0$ (adoption) is $U^E_M(0) > 0$. $E(U_M)\,|_{M=0} = E(U_R.R_M)\,|_{M=0} = [E(U_R).E(R_M)]\,|_{M=0} + \mathrm{COV}(U_R, R_M)\,|_{M=0} > 0$. With $M = 0$, the income is non–stochastic, and $\mathrm{COV}(U_R, R_M)\,|_{M=0} = 0$. Since $U_R > 0$, the necessary condition becomes $R_M > 0$ and the proposition is easily demonstrated.

[8] This is due to the assumption of non–risky F.

[9] Unless the land rent is too high, leading the farmer to sell his land instead of either cropping or adopting soil fertility enhancing technologies. The soil fertility is recovered to improve productivity, not for land rent. Moreover, the model should be valid in a community where land is not traded.

[10] P may be a vector of output prices because the land may be split and sown with more than one crop.

where:

β^{A^*}, vector of parameters to be estimated,
u^{A^*}, the error term,

the latent Y^{A^*} is defined by its proxy Y^A taking the value 1 for adopters and the value of 0 for non-adopters for the sub-sample of informed framers ($Y^H = 1$).

The conditional Probit model to estimate is then

$$Y^A = \Phi(X^A.\beta^A + u^A) \tag{11}$$

Putting aside the risky nature of the new technology and differentiating the total discount income with respect to C and J. We get results similar to those embodied in proposition 1.

The differentiation with respect to C gives

$$\begin{aligned} R_C = {} & PK_0F(M).\exp[(g-\delta)J-(b+\delta)C]-wM\exp(-(J+C)\delta) \\ & + PK_0F(S-M).\exp[-(b+\delta)(J+C)]-w(S-M).\exp(-(J+C)\delta)) \\ & - lS.\exp[-(J+C)\delta)] = 0 \end{aligned}$$

Arranging terms, we have

$$\underbrace{PK_0[F(M).\exp(gJ-bC)+F(S-M).\exp[-b(J+C)]}_{1} = \underbrace{(w+l)S}_{2} \tag{12}$$

Then, equation (12) interprets as: the farmer will crop his plots until the total revenue (1) equals total opportunity cost (2).

In the case of full adoption, $M = S$, equation (12) becomes

$$PK_0F(S).\exp(gJ-bC) = (w+l)S \tag{13}$$

As shown by equation (13), in the case of complete adoption, the farmer will exhaust all the accumulated soil fertility ($gJ = bC$) before resorting to another adoption cycle only if $PK_0F(S) = (w+l)S$. He will crop indefinitely and refuse to further adopt only if the opportunity cost (management cost plus land rent) is nil.

This result is very important and means that in agro-systems where the opportunity costs of land and labour are insignificant, adoption will be impeded.

The differentiation of R with respect to J gives

$$\begin{aligned} R_J = {} & -\delta Mv\exp(-\delta J)-Mz.\exp(-J\delta)+PK_0F(M).\frac{g-\delta}{b+\delta}.[\exp((g-\delta)J) \\ & -\exp((g-\delta)J-(b+\delta)C))]-wM[-\exp(-J\delta)+\exp(-(J+C)\delta)] \\ & + PK_0F(S-M).\exp(-(b+\delta)(J+C))-w(S-M).\exp(-(J+C)\delta)) \\ & - lS.\exp(-(J+C)\delta)) = 0 \end{aligned}$$

Arranging terms, we have

$$\begin{aligned}
&PK_0F(M).\frac{g-\delta}{b+\delta}.[\exp((g-\delta)J-(b+\delta)C))]\\
&+PK_0F(S-M).\exp(-(b+\delta)(J+C))+wM[\exp(-J\delta)-\exp(-(J+C)\delta)]\\
&\qquad=\delta Mv\exp(-\delta J)+Mz.\exp(-J\delta)+w(S-M).\exp(-(J+C)\delta))\\
&\qquad\quad+lS.\exp(-(J+C)\delta))
\end{aligned}\tag{14}$$

All things equal, equation (14) interprets as: The fallow will be kept on the adoption plots until the marginal income equals marginal cost.

3.3. Equation of adoption intensity

After taking the decision to adopt, the farmer should choose the intensity of adoption that is the proportion of the available land to devote to fallow.

Let us denote by Y^I the adoption intensity (knowing that $Y^A = 1$, that is, the farmer decided to adopt). That variable is truncated at 0.

X^I is the vector of the measurable variables that may determine Y^I (some elements of X^H, X^A and other variables that may determine the adoption risk).

The theoretical conditional model to estimate is

$$Y^I = X^I.\beta^I + u^I \tag{15}$$

where:

β^I = vector of parameters,
u^I = the error term.

Y^I is observable and measured by the percentage of the total farm (S) devoted to the technology, that is, $Y^I = \frac{M^*}{S} * 100$. Then we have $Y^I = 0$ for no adoption and $Y^I = 100$ for full adoption.

The message embodied in proposition 1 is that the model developed so far may be used by a rational farmer in deciding whether to adopt or how intensively to adopt. But one may wonder to what extent the model could help to:

1. predict the impact of risk on adoption intensity;
2. sketch the interplay between biophysical and socio-economic factors on the one hand, and the soil degradation process on the other.

The latter investigation is worth developing because, as Baland and Platteau (2000) pointed out: 'clearly, the biophysical characteristics of the resource matter interact with economic parameters to determine whether conservation is a profitable strategy'. Among those characteristics and parameters, the initial soil fertility, minimum subsistence constraint, and discount rate were explicitly mentioned.

The answers to the above-mentioned queries are summarized as propositions 2 through 6.

Proposition 2

A decrease in subjective risk degree associated with adoption of fallow-based technology raises adoption intensity if the farmer's utility is characterized by a constant absolute risk aversion coefficient (CARA).

The proof of proposition 2 is based on Rothschild and Stiglitz (1970) (see appendix).

From this proposition, one could infer that anything that increases the acquired level of information about the technology has a positive impact on adoption intensity. That result was also found by Saha *et al.* (1994). and confirms the analysis by Feder and Roger (1984) of the impact of information on the adoption of innovations. Thus, we infer that any increase in extension effort and promotion of information exchange between farmers that ultimately amounts to an increase in information level, should increase adoption intensity of a technically relevant natural resource management technology.

Proposition 3

For a farmer with a CARA utility function, adoption intensity increases with management costs of cropping plots.

This result is demonstrated by using the theorem of implicit functions (Chiang, 1992). The proof is proposed in the appendix.

Proposition 3 interprets as follows: when exhausted land plots become more weedy and more costly in labour, farmers will be more inclined to increase adoption intensity of fallow-based technology. This is a consistent result because, when land management costs increase, short-term farm profits decrease, resulting in a decrease in the weight of short-term loss associated with a greater adoption intensity of a fallow system.

Definition

An adoption level M^* *is high if* $M^*/S > 0.5$. *This adoption intensity level completely exhausts the comparative advantage of yield associated with the fallow-based technology.*[11]

Proposition 4

For a farmer with a CARA utility function and at a high level of adoption intensity, output prices and the initial soil fertility level have a positive impact on the adoption intensity if $g = \delta$. *At a low level of adoption intensity, the impact of output prices and the initial fertility level could not be predicted unambiguously.* g *and* δ *are, respectively, the regeneration rate of soil fertility under fallow and instantaneous discount rate.*

The output price P and the initial fertility level K_0 enter in total farm income equation (R) in the same way. The proof for the case of P is also valid for K_0 (see the appendix).

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[11] If production was not linear in fertility, the high level of adoption would be defined as $F'(M) < F'(A)$.

This result is very important and shows that the debate between Repetto (1987) and Lipton (1981) (see Barrett, 1997)[12] on the contradictory impact of price policy on soil protection cannot be solved without considering the technical parameters of natural resource management technology. The net impact resulting from the effects of enhancement of future production and present forgone production due to adoption depends on how easily the soil is degraded as a result of increased exploitation, the consequent effect on soil productivity, the cost of additional conservation, and the discount rate (Baland and Platteau, 2000).

Proposition 5
For a farmer with a CARA utility function, there is a positive relationship between land availability and adoption intensity.

The proof of this proposition is given in the appendix.

It is easy to see the potential difficulty associated with the diffusion of natural resource management technologies. Land is usually severely degraded under land shortage. However, as proved through proposition 5, it is precisely that situation which makes it difficult for smallholding farmers to adopt land management technologies.

Proposition 6
Under CARA, an increase in unit value (v) of direct products from the mature fallow, or a reduction in specific unit management cost (z), increases adoption intensity.

The results established by proposition 6 and proved in the appendix are intuitive and do not require further elaboration. But they validate the adoption model by predicting a positive impact of any policy that decreases user or opportunity costs (free of charge seeds, purchase of fallow direct products) on the diffusion of natural resource management technologies (see also Baland and Platteau, 2000).

Because the farmer requires a minimum length of time in order to put the land in fallow and to harness the increase in crop production associated with the accumulation of soil fertility in a rotation cycle, we may intuitively infer that there is a positive relationship between adoption intensity and duration of land contracts. McConnell (1983) obtained similar results for anti-erosive devices. But the result here is different from that of McConnell in one major aspect. He obtained the positive impact of time horizon on adoption by making land resale values endogenous, whereas in our model, land rent is assumed constant.

Nevertheless, one question remained unsolved: which of C or J will be extended when the land contract permits the farmer to increase $J + C$?

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[12] Repetto (1987) suggested a positive relation and Lipton (1981) the contrary. It is worth mentioning that Barrett (1997) resolved the contradiction by resorting to different production functions. But, in a same community where the adoption behaviour of individual farmers may also be diverse, this argument is questionable since the tradition in econometrics is to assume that the mean production function is the same.

The answer to that question depends on the marginal effects of the variables C and J (that is R_C and R_J).

Let us take the case of corner solutions leading to full adoption. Then, we have

$$\begin{aligned} R_C - R_J = {} & PK_0F(S).\exp[(g-\delta)J-(b+\delta)C] \\ & + \delta Sv\exp(-\delta J) + Sz.\exp(-J\delta) - PK_0F(S).\frac{g-\delta}{b+\delta}.[\exp((g-\delta)J) \\ & - \exp((g-\delta)J-(b+\delta)C))] - wS\exp(-J\delta) \qquad (16) \end{aligned}$$

The sign of the quantity $(R_C - R_J)$ is not clear-cut, but if $g \leq \delta$, then, $R_C - R_J \geq 0$, and the farmer will be prone to extend the cropping length.

4. Empirical estimation of the adoption model

The three steps of decision making are presented in a unified model to estimate as follows

$$\begin{cases} Y^H = \Phi(X^H.\beta^H + u^H)\text{(a)} \\ Y^A = \Phi(X^A.\beta^A + u^A)\text{(b)} \\ Y^I = X^I.\beta^I + u^I\text{(c)} \end{cases} \qquad (17)$$

where:

(a) = information equation,
(b) = adoption equation and,
(c) = adoption intensity equation.

The variables and parameters of the model are defined earlier.

Three cases are distinguished:

(i) The farmer is not informed; in such a case, it is not possible to consider adoption or adoption intensity.
(ii) The farmer is informed but has not adopted ; it is not possible to consider adoption intensity for this category of farmers.
(iii) The farmer has adopted the technology.

Then, the model (17) is a model of sequential selection.

This model of sequential adoption of one technology based on information acquisition is in essence different from that of Khanna (2001) of sequential adoption of components of a technological package. Nevertheless, the statistical implication for econometric analysis of adoption and impact evaluation are quite similar. As in Khanna (2001), and just making the substitution of technological components for decisions, it is possible to say that: since decisions (information, adoption, intensity of adoption) are interrelated, single equations are inefficient because they ignore the correlation in the error terms of equations that explain each decision. This correlation arises because the same unobserved characteristics may influence all inter-related decisions.

For the empirical estimation, I assume that (u^H, u^A, u^I) has a tri-normal distribution. That is

$$(u^H, u^A, u^I)\ TVN\,(0,0,0;1,1,\sigma^2;\rho,\psi^H,\psi^A) \qquad (18)$$

where:

ψ^H, ψ^A and ρ are respectively the correlation coefficients between u^H and u^I, u^A and u^I and, u^A and u^H.

Under the above assumptions, the conditional probability of the adoption decision is given by equation (19) (see Saha *et al.*, 1994; Fuglie and Bosch, 1995; Maddala, 1983)

$$\begin{aligned}&\mathrm{Prob}(Y^A = 1/Y^H = 1)\\ &\quad = E[Y^A/(i^* - i^0) > 0] = \Phi(X^A.\beta^A) + \rho.\frac{\phi(-X^H.\beta^H)}{1 - \Phi(-X^H.\beta^H)}\end{aligned} \qquad (19)$$

Note $\alpha = -X^H.\beta^H$ *and* $\lambda(\alpha) = \frac{\phi(\alpha)}{1-\Phi(\alpha)}$; $\lambda(\alpha)$ is the inverse of Mills' ratio. Then, we have

$$\mathrm{Prob}(Y_A = 1/Y_H = 1) = \Phi(X_A.\beta_A) + \rho.\lambda(\alpha) \qquad (20)$$

Φ and ϕ are the functions of normal cumulative distribution and normal probability density respectively.

For traditional Probit and Logit estimations, only element $\Phi(X^A.\beta^A)$ is considered in equation (20), resulting in inconsistent estimators β^A. More importantly, application of traditional Probit and Logit estimations that ignore self-selection would result in biased estimates of marginal effect on probability of adoption of a variable x_j that is common to vectors X^H and X^A.

From (20), we have

$$\frac{\partial \mathrm{Prob}(Y^A = 1/Y^H = 1)}{\partial x_j} = \Phi(X^A.\beta^A)\beta_j^A + \rho.\beta_j^H.(\lambda\alpha - \lambda^2) \qquad (21)$$

If the possibility of self-selection is ignored, the second element of the right side of equation (21) will be omitted.

For all parameters to be identified, X^H and X^A should differ at least in one independent variable.

After the estimation of parameters, they are used to form an augmented model of adoption intensity (Greene, 1995). That is

$$Y^I = X^I.\beta^I + \hat{\lambda}^H.\theta^H + \hat{\lambda}^A.\theta^A + \eta \qquad (22)$$

where

$\eta =$ error term

$$\hat{\lambda}^H = \frac{\phi(-X^H.\hat{\beta}^H).\Phi\left[(-X^A.\hat{\beta}^A - \hat{\rho}.Y^H)/(1-\hat{\rho}^2)^{1/2}\right]}{\Phi_2(-X^H.\hat{\beta}^H, -X^A, \hat{\beta}^A, \hat{\rho})}$$

and

$$\hat{\lambda}^A = \frac{\phi(-X^A.\hat{\beta}^A).\Phi\left[(-X^H.\hat{\beta}^H - \hat{\rho}.Y^A)/(1-\hat{\rho}^2)^{1/2}\right]}{\Phi_2(-X^H.\hat{\beta}^H, -X^A, \hat{\beta}^A, \hat{\rho})}$$

Φ_2 is a cumulative bivariate normal probability distribution.

In the analysis of the quantities of factors' used after adoption, the last two non-error elements of equation (22) reflect the fact that those who heard about the technology and adopted may behave differently with the same socio-demographic, socio-economic, and biophysical characteristics if they were not informed and had not adopted (Fuglie and Bosch, 1995).

If a technology (as in the case of our study) is not adopted to a great extent, we can increase the proportion of adopters in our sample. If the empirical model is estimated, ignoring the sampling bias, the estimators obtained are inconsistent (Maddala, 1983). Maddala suggests that the likelihood function be weighted, taking as weights

$$W(J) = Q(J)/H(J)$$

where:

$Q(J)$ = proportion of the population with choice J and
$H(J)$ = proportion of the sample with choice J.

Since the sample used to test the theoretical comparative results is purposively selected, the appropriate weighting process is performed before estimation. For group 1 made of non-informed farmers, we have, $Q(1) = 13$ per cent, $H(1) = 13$ per cent, and $W(1) = 1$; for group 2 made of non-adopting informed farmers, we have, $Q(2) = 80$ per cent, $H(2) = 61$ per cent, and $W(2) = 1.31$ and for group 3 made of adopters, we have $Q(3) = 7$ per cent, $H(3) = 26$ per cent, and $W(3) = 0.27$.

5. Data and empirical results

5.1. Study area and data

Data on the adoption of Mucuna fallow systems will be used to empirically test some of the comparative theoretical results.

Mucuna Fallow (MF) is an emerging Natural Resource Management Technology used to restore poor soil fertility in southern Benin. It is a cover crop that produces an organic biomass that may reach 6 tons per hectare and accumulates up to 160 kg N/ha for a vegetation cycle of about 240 days (Carsky and Ndikawa, 1998).

Empirical data were collected during the first semester of 1998 in three southern provinces of Benin. The southern provinces represent about 10 per cent of the country's area. However they contain about 70 per cent of the Benin population. With a population density of about 220 inhabitants/km^2, southern Benin is one of the most densely populated zones of Sub-Saharan Africa (MDR, 1993).

Ten villages were purposively selected. Practical reasons guided their choice: use of Mucuna and chemical fertiliser, road accessibility, geographic coverage and implication of women in agriculture.

A census of the farmers' population was conducted in the selected villages. All the households were stratified into four groups based on use or non-use of Mucuna and chemical fertilisers as follows: users of Mucuna only, users of chemical fertilisers only, users of both Mucuna and chemical fertilisers, and non-users of either technology. Four hundred households were then randomly selected – 40 households per village. The number of selected households per strata in each village was proportionate to the total number of households in the strata. Then every farmer in each selected household became a potential respondent for the survey. In total, 335 out of 400 randomly selected households and 580 farmers finally participated in the survey.

A structured questionnaire was administered to collect quantitative and qualitative data such as socio-economic characteristics of the farmers, land use systems, type of resource management technologies, and the biophysical and institutional environment.

The adoption of the resource management technologies was assessed using data collected during the population census. Adoption of Mucuna fallow was limited at a rate of 7 per cent of farmers. Thus, it is worth identifying the constraints to the diffusion of the technology.

5.2. Results

Table 1 describes the data.

The variables denoted by Credit, Livestock, Off-farm income, Farm size–consumer ratio are included in the model to cope with adoption risk. Inclusion of presence of small trees on plots and percentage of available land planted with small trees is linked to the nature of Mucuna technology. In fact, Mucuna is a creeper and pervasive plant that is difficult to mix with other crops. Percentage of land invaded by Imperata and the presence of the spear grass on plots are included in the model because the technology is supposed to fight this noxious weed. Agricultural wage rate and fertiliser price is included in the model because labour and fertiliser are substitutes of Mucuna fallow. Maize is the staple food in the villages surveyed. As suggested by the theoretical analysis, producers' prices are a determinant of adoption. Details on the inclusion of other variables in the model may be found in Honlonkou (1999).

It is worth noting that the values of certain variables contrast greatly in size with other variables which may induce heteroscedasticity. To correct for this, the natural log of values of certain variables are included in the model (Madalla, 1983). See table 1.

The Probit estimations of the information and adoption models at the farmer's level give results that are globally statistically significant. The McFadden pseudo-R^2 are 0.12 and 0.60, and rates of correct predictions are 87 per cent and 74 per cent respectively (table 2).

Nevertheless, the self-selection hypothesis seems not to be operative, leading to the conclusion that each level of the process of adoption decision making may be analysed separately. This is certainly due to the widespread dissemination of the information through formal and informal channels within the potential adoption population analysed. In fact, only 13 per cent of farmers stated that they were not informed about the existence of the technology.

The results reveal that the demand and supply of information relating to the fallow system are significantly explained by the farmer's age, the active participation of the farmers in the acquisition of informal information, the effort of official extension services, and the agricultural wage rate.

Table 1. *Descriptive statistics*

Variables	*Units*	*Minimum*	*Maximum*	*Mean*	*Std. deviation*
Acquisition of informal information (I)	1 if information acquired from informal sources and 0 if not	0	1	0.73	0.45
Adult education (I)	1 if adult education and 0 otherwise	0	1	.27	0.44
Age (I)	Number of years	14	91	39.66	13.05
Agricultural wage rate (III)	In FCFA per kanti. In natural log	400.00	2,000.00	943.13	424.01
Consumer–worker (I)	Number of consumers divided by the number of workers in the household	1.00	32.00	3.18	3.32
Credit obtained (I)	In FCFA per year. In natural log	0.00	2,300,000.00	18,102.74	124,906.24
Farm size (I)	In natural log of units of kanti (1 kanti = 0.04 hectare).	0.25	676.00	43.08	57.39
Farm size–family size ratio (I)		0.14	454.00	22.36	44.39
Fertility dummy (II)	1 if plot not fertile and 0 otherwise	0	1	0.41	0.49
Flood proneness dummy (II)	1 if prone to floods and 0 if not	0	1	0.16	0.37
Gross off-farm income (I)	In FCFA per year. In natural log	0.00	57,060,000.00	419,799.61	2,655,976.94
Gross value of (i) livestock	In FCFA. Current stock. In natural log	0.00	1,064,100.00	47,950.08	99,940.77
Land property rights dummy (II)	1 if own plot and 0 otherwise	0	1	0.41	0.49
Official extension effort (I)	1 if contact with extension agents and 0 otherwise	0.00	1.00	0.70	0.46
Participation in informal mutual financial systems (I)	In FCFA per year ($1 = CFA 650). In natural log	0.00	1,494,762.00	43,599.54	119,463.67
Percentage area planted with trees (I)	In natural log of % of available land	0.00	100.00	3.76	15.10
Percentage of degraded land (I)	In natural log of % of available land	0.00	100.00	44.80	45.10
Percentage of land devoted to Mucuna (1996, 1997)	In natural log of % of available land. That is the dependent of the adoption intensity	0.00	100.00	10.46	22.92
Percentage of land infested by imperata, a very noxious weed (I)	In natural log of % available land	0.00	100.00	54.98	45.08
Percentage of land planted with small trees (I)	In natural log of % of available land	0.00	100.00	29.04	41.07
Percentage of land prone to floods (I)	In natural log of % of available land	0.00	100.00	17.52	34.46

Continued overleaf

Table 1. *Descriptive statistics (continued)*

Variables	*Units*	*Minimum*	*Maximum*	*Mean*	*Std. deviation*
Percentage of land property rights (I)	In natural log of % of 0.00 available land	100.00	49.2	45.64	
Presence of imperata dummy (II)	1 if imperata present and 0 if not	0	1	0.45	0.50
Presence of small trees dummy (II)	1 if small trees present on the plot and 0 if not	0	1	0.23	0.42
Price of chemical fertiliser (III)	In FCFA per kg. In natural log	91.67	466.67	246.04	40.71
Price of maize (III)	In FCFA per kg. In natural log	66.67	500.00	244.59	90.34
Prior utilization (I)	Number of prior utilizations	0	5	0.29	0.65
School (I)	1 if at least six years at school and 0 otherwise	0.00	1.00	0.13	0.34
Sex (I)	1 for male and 0 for Female	0	1	0.59	0.49
Squared farm size–family size ratio (I)	Total land available divided by the number of consumers in the household	0.02	206,116.00	2,466.50	14,473.66

Note: The variables noted I are the farmer's characteristics; those noted II are the biophysical orplot's characteristics, and those noted III include the characteristics of the economic environment. \$1 = CFA 650.

Source: Author's survey, 1997.

The influence of the farmer's age is negative; revealing that younger farmers are more active in gathering information related to the natural resources management technologies (D'Souza *et al.*, 1993). The influence of access by farmers to official services and non-official means of information are positive, revealing the synergistic effects of both variables in acquisition of information. The wage rate has a positive impact on information acquisition.

The factors that determine the adoption of Mucuna Fallow are prior utilization, farm size–family size ratio (FFR), squared farm size–family size ratio (SFFR), livestock value while considering farmer's level estimation, presence of imperata (a very noxious weed) and property rights status at plot level.

The influence of prior utilization, farm size–family size ratio, livestock value, presence of imperata, and property rights status are positive. The result obtained for the presence of imperata confirms those of Houndékon and Gogan (1996) and Manyong *et al.* (1996).

The positive impact of FFR and negative impact of SFFR show that food security determines opportunity cost of land in southern Benin and negatively impacts on the adoption decision. The adoption probability increases with FFR up to a level at which the relationship reverses. This means that at higher level of FFR, farmers prefer other fertility-improving

Table 2. *Empirical results of Mucuna fallow adoption model: Southern Benin, 1996/1997*

Dependent variables	*Information*	*Adoption*		*Adoption intensity*
Models	*PROBIT*	*PROBIT*	*PROBIT*	*SELECTION*
Levels	*Farmer's level*	*Farmer's level*	*Plot level*	*Farmer's level*^{a}
Constant	−7.44(−2.58)**	−6.99(−1.72)*	−1.88(−8.99)**	−1.30(−0.10)
Age	−0.39(−1.72)*	0.18(0.56)	–	−0.87(−1.40)
Sex	−0.19(−1.07)	0.34(1.30)	–	−0.70(−1.20)
Years at school	−0.15(−0.46)	0.41(1.48)	–	−0.33(−0.48)
Adult education	0.23(0.99)	0.13(0.60)	–	0.30(0.68)
Farm size	0.13(1.47)	–	–	–
Percentage of land infested by imperata	0.007(0.19)	0.06(1.12)	–	−0.09(−0.99)
Presence of imperata dummy	–	–	0.55(2.84)**	–
Acquisition of informal information	0.38(2.44)**	−0.09(−0.37)	–	1.00(2.71)**
Official extension effort	0.75(3.96)**	−0.30(−1.30)	–	0.20(0.43)
Percentage of degraded land	0.033(0.99)	−0.03(−0.74)	–	0.18(2.06)**
Fertility dummy	–	–	−0.20(−1.04)	–
Agricultural wage rate	1.004(5.41)**	0.12(0.51)	–	−0.006(−0.02)
Price of chemical fertiliser	0.45(1.04)	0.09(0.13)	–	0.48(0.53)
Price of maize		0.43(1.47)	–	0.89(1.15)
Area planted with trees		−0.04(−0.42)	–	0.13(0.60)
Prior utilization		0.63(4.33)**	–	0.10(0.14)
Consumer–worker ratio		−0.25(−0.64)	–	−0.05(−0.70)
Farm size–family size ratio		3.42(2.24)**	–	−3.51(−0.61)
Squared farm size–family size ratio		−4.55(−2.44)**	–	4.05(0.49)
Percentage of land property rights		−0.021(−0.42)	–	−0.09(−0.92)
Land property rights dummy		–	0.38(2.05)**	–
Credit obtained		−0.04(−1.04)	–	−0.04(−0.43)
Gross value of livestock		0.074(1.79)*	–	0.06(0.47)
Gross off-farm income		0.023(0.92)	–	−0.10(−1.96)*
Participation in informal mutual financial systems		−0.02(−0.68)	–	0.12(2.81)**
Percentage of land planted with small trees		−0.02(−0.39)	–	0.12(1.50)
Presence of small trees dummy		–	0.32(1.54)	–
Percentage of land prone to floods		0.082(1.53)	–	−0.11(−0.83)
Flood proneness dummy		–	0.06(0.23)	–
N	539	470	406	140
σ	–	–	–	1.29(2.66)**
ρ	–	–	–	−0.37(−0.32)
R^2 (McFadden)	0.12	0.60	0.47	–
X^2 (likelihood ratio)	50.51**	346.07**	186.27**	−612.82
% of correct predictions	87	74	81	–
% of positive responses	87	30	19	–

Notes: ^{a} Aggregate level, assuming that a farmer can devote many plots to the technology. Numbers in parentheses are Student t statistics. * and ** mark coefficients respectively significant at 10% and 5% levels. *N* = number of observations.

Source: Author's estimations from survey data.

technologies to Mucuna fallow. This confirms the hypothesis of double thresholds of Vissoh *et al.* (1998).

The positive impact of prior utilization of Mucuna technology means that farmers generally persist in using Mucuna fallow, and confirms that incentives for the first adoption are important and that farmers are 'learning by doing'. One can infer from suca result that short-term action by public and private organizations (such as free-of-charge seeds, purchase of harvests after first utilization) may have a multiplier effect in the long run.

The positive impact of a land right dummy at plot level means that security and duration of land contracts are determining factors for the adoption of Mucuna fallow. This also confirms the results obtained by Houndékon and Gogan (1996) and Buckles *et al.* (1998) for the same technology in Benin and Honduras respectively.

The positive influence of livestock value may be explained by the role of cash liquidity or its substitutes as insurance against innovation risks (Sanders and Vitale, 1997).

The coefficients of agricultural labour wage, informal and formal efforts in information acquisition are not significant in the adoption equation, demonstrating that, while those variables are determining factors of information acquisition, they have no impact on the adoption decision.

The adoption intensity is determined positively by effort to acquire informal information, the percentage of degraded land in the land portfolio, and participation in informal financial mutual systems, and negatively by gross off-farm income.

While the positive impact of informal acquisition of information, does not determine adoption, it does encourage the farmer to devote a larger fraction of his land to the technology. This leads to the conclusion that informal channels of diffusion of information are more effective than official ones. The percentage of the degraded land also positively impacts on adoption intensity.

To honour dates of payment to financial mutual associations, some farmers cultivate seasonal vegetables (like tomatoes) that generally require land rich in organic matter. Mucuna provides conditions appropriate for the success of such crops and also contributes to crop diversification. This is undoubtedly the reason why participation in informal financial associations positively determines adoption intensity.

The impact of gross off-farm income is negative, leading us to infer that the more farmers are involved in off-farm activities the less they are concerned by problems of arable land degradation and the less they are active in searching for information about and adopting technologies that restore soil fertility.

6. Concluding remarks

The theoretical results derived from the model of adoption showed that technical parameters such as duration and regeneration rate of soil fertility by natural resource management technologies are relevant for development of improved fallow. Nevertheless, one should not ignore the economic and social factors such as social rate of discount, risk, information and prices of inputs and outputs as these factors are as important as technical parameters.

I also prove that estimating the adoption equation without taking account of the issue of self-selection might result in biased estimators.

Analysis of adoption of Mucuna fallow suggests that any agricultural policy aimed at efficiently promoting adoption should encourage first utilization of the technology. This can be done by reducing opportunity costs (free of charge seeds, purchase of harvests of Mucuna), promoting exchange of information among adopters and non-adopters, intensifying official extension effort, clarifying land property rights, and encouraging the development of official and informal financial institutions.

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Appendix

Proof of proposition 2

The proof of proposition 2 is based on Rothschild and Stiglitz (1970). Let us assume that an increase in a parameter γ_e is a mean-preserving spread of risk. γ_e is such that $\frac{\partial \tilde{e}(i)}{\partial i}$ has the same sign as $\frac{\partial \gamma_e}{\partial i}$ To show that M is a decreasing function of γ_e it is sufficient to demonstrate that U_M^E is concave in $\tilde{e}_m$(Laffont, 1985).

We have

$$U_M^E = \underset{i*}{E}[U'(R).(R_m)] = 0 \tag{1A}$$

where

$R_m = P.K_0 B_1.F_m(M^*)\tilde{e}_m - B_2 w - B_3 z + B_4 v - P K_0 A_1 F_m(S - M^*) + A_2 w;$
$U_{Me}^E = E_{i^*}[U''(R).R_e.(R_m) + U'(R).(R_{me})]$
$R_e =$ differentiation of R with respect to e.

From

$$R_e = P.K_0 B_1.F_m(M^*) \quad and \quad Rme = P.K_0 B_1.F_m(M^*)$$

we have

$$U_{Me}^E = \underset{i*}{E}[U'.[[[\mathrm{U}''(R)/\mathrm{U}'(R)].R_e.(R_m) + (R_{me})]]] \tag{2A}$$

Let h be the Arrow–Pratt absolute coefficient of risk aversion. We have

$$h = -U''(R)/U'(R)$$

Then, from (2A), we have

$$U_{Me}^E = \underset{i*}{E}[U'.[-h.R_e.(R_m) + (R_{me})]]$$

that is

$$U_{Me}^E = -h.\underset{i*}{E}[U'.[R_e.(R_m)]] + \underset{i*}{E}[U'.(R_{me})] \tag{3A}$$

But, according to (1A), the first element of the second side of equality (3A) cancels

$$U_{Me}^E = \underset{i*}{E}[U'.(R_{me})] \tag{4A}$$

As R_e and R_{me} are independent of e, from (4A), we obtain

$$U_{Mee}^E = \underset{i*}{E}[U''.(R_{me})] = (R_{me}).\underset{i*}{E}[U''] \tag{5A}$$

As R_{me} is positive, U_{Mee}^E is strictly negative according to CARA assumption. Then, U_M^E is strictly concave in e.

It is reasonable to assume that the subjective risk is a decreasing function of information; that is

$$\frac{\partial \gamma e}{\partial i} < 0.$$

If we put together the above assumption and proposition 2, we infer result (6A)

$$\frac{\partial M}{\partial i} = \frac{\partial M}{\partial \gamma e}\frac{\partial \gamma e}{\partial i} > 0. \tag{6A}$$

Proof of proposition 3
This result is demonstrated by using the theorem of implicit functions (Chiang, 1992).

According to that theorem, with an implicit function Y defined by $U^E(Y, X) = 0$ and under existence conditions of an explicit function of Y in X, we can infer the sign of $\frac{\partial Y}{\partial X}$; precisely, $\frac{\partial Y}{\partial X} = -\frac{\partial U^E}{\partial X} / \frac{\partial U^E}{\partial Y}$.
Thus, to infer the sign of $M_x = \frac{\partial M^*}{\partial X}$, where M^* is the land area devoted to fallow system, we should find the sign of $-\frac{U^E_{Mx}}{U^E_{MM}}$. As U^E_{MM} (second differentiation of U^E with respect to M) is negative, M_x has the sign of U^E_{Mx}, the differentiation of U^E_M with respect to X.

To prove proposition 3, it is sufficient to show that $U^E_{Mw} > 0$, with w standing for management costs of cropping plots

$$U^E_{Mw} = \underset{i^*}{E}[U''(R).R_w.(R_m) + U'(R).R_{mw})] \tag{7A}$$

$$U^E_{Mw} = \underset{i^*}{E}[U''(R).R_w.(R_m)] + \underset{i^*}{E}[U'(R).(R_{mw}) \tag{8A}$$

Under CARA assumption and condition (1A), the first element of the second side of equation (8A) cancels. As $U'(R) > 0$ and $U^E_{Mw} = A_2 - B_2 > 0$, we have $U^E_{Mw} > 0$.

Proof of proposition 4
From (1A), we have

$$U^E_{Mp} = -h.\underset{i^*}{E}[U'.[R_p.(R_m)]] + \underset{i^*}{E}[U'.(R_{mp})] \tag{9A}$$

Under the assumption of CARA, $U^E_{Mp} = (R_{mp}).\ E_{i^*}[U]$.
As $E(U') > 0$, the sign of U^E_{Mp} depends on that of R_{mp}.

$$R_{mp} = K_0 B_1.F'(M^*) - K_0 A_1 F'(S - M^*) \tag{10A}$$

If $g = \delta$, then

$$A_1 = \left(\frac{1}{b + \delta}\right).(1 - \exp(-(b + \delta)(J + C)))$$

and

$$B_1 = \left(\frac{1}{b + \delta}\right).(1 - \exp(-(b + \delta)C))$$

Thus $B_1 < A_1$.
For $M^*/S > 0.5, M^* > A$ and $F'(M^*) < F'(A)$.
Then, we deduce that

$$R_{mp} = K_0 B_1.F'(M^*) - K_0 A_1 F'(S - M^*) < 0 \tag{11A}$$

Proof of proposition 5
From (1A)
$U^E_{Ms} = -h.\ E_{i^*}[U'.[R_s.(R_m)]] + E_{i^*}[U'.(R_{ms})]$, S is the total land available.
Under CARA assumption, U^E_{Ms} has the same sign as R_{ms}.

$$R_{Ms} = -PK_0A1F''(S - M^*)$$

Under the usual regularity conditions of production functions, there is diminishing marginal returns, that is $F''(.) < 0$. Thus, $R_{ms} > 0$.

Proof of proposition 6
From (17), we have

$$U^E_{Mv} = -h.\ \underset{i^*}{E}[U'.[R_v.(R_m)]] + \underset{i^*}{E}[U'.(R_{mv})]$$

U^E_{Mv} has the same sign as R_{Mv}.
$R_{Mv} = B_4 > 0$, which proves the first part of proposition 6.
$U^E_{Mz} = -h.\ E_{i^*}[U'.[R_z.(R_m)]] + E_{i^*}[U'.(R_{mz})]$ has the same sign as R_{mz}.
$R_{mz} = -B_3 < 0$, which proves the second part of proposition 6.