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Do Rich or Large-Scale Farmers Choose a High Type of Production Technology?: The Case of IPM Adoption

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ABSTRACT

By using a two-period model in which farmers must choose one of two alternative production technologies I analyze the relationship between farm scales of farm income and the adoption of new technology. A high type of production techniques yields higher returns but also demands a bigger fixed implementation cost. I find that these fixed implementation costs imply threshold effects in the selection process of production techniques–farmers above a critical level of the first period income select a high type of production techniques while farmers below the threshold select a low type of production techniques.

I. Introduction

Recently, Integrated Pest Management (IPM[1]) has received considerable

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[1] The Office of Technology Assessment(OTA) defines IPM as "the optimization of pest control in and economically and ecologically sound manner, accomplished by the coordinated use of multiple tactics to assure stable crop production and to maintain pest damage below the economic injury level while minimizing hazards to human, plants, and the environment." IPM is likely to play a lead role in the transition from a chemical-intensive to a low-input sustainable agriculture. Briefly, the essence of IPM is that it substitutes other inputs for chemical pesticides, notably (1) information about the state of the crop ecosystem, including the pest and predator population sizes (e.g., through scouting); (2) mechanical control methods (crop rotation, trap cropping, source reduction); and (3) biological controls(introduced predators or pest diseases, resistant crop varieties).

attention in the economic literature as a means of reducing the negative effects of chemical pesticides on the environment, commonly referred to as environmental externalities. As IPM techniques were designed to meet some of the health and environmental concerns of pesticides as well as the problems of pest resistance to pesticides, many governments have recommended the use of IPM to their farmers.[2]

There are rich literatures on the adoption of technological innovations in agriculture. Early researches focused on the diffusion process: after a slow start in which only a few farmers adopt the innovation, adoption expands at an increasing time rate. Later, the rate of adoption decreases as the number of adopters begins to exceed the number of farmers who have not yet adopted. Finally, adoption asymptotically approaches its maximum level, until the process ends. This process results in an s-shaped diffusion curve, first discussed by rural sociologists and introduced to economics by Griliches in 1957.

Other researchers have examined the influence of farmers' attributes of the adoption of agricultural innovations (e.g., Rahm and Huffman, Caswell and Zilberman). The adoption of IPM techniques has recently been analyzed by Kovach and Tette (1988) for New York apple producers. However, there are few theoretical studies on the relationship between farming scales or individual income and the adoption of IPM, and moreover these studies show somewhat different results. Based on the farm-level survey data, Kovach and Tette (1988) shows that large operations are more likely to be using IPM techniques. However, this result is different from evidence available for other types of low-input farming where the literature suggests a greater tendency for smaller operations to adopt (McDonald and Glynn).[3] Is there any difference in adoption of IPM between large-scale farmers and

[2] For example, the USDA sets a goal for the use of IPM on 75 percent of U.S. farmland by the end of this century. See Jorge Fernandez-Cornejo(1996)

[3] See Mcdonald and Glynn (1994) wrote. "... This suggests that smaller operation are more likely to be using cultural controls in a manner which is compatible with IPM procedure."

small scale ones? Or do rich farmers prefer IPM to conventional tools as a pest control method?

This study is intended to answer to the above questions. The selection process of new production technology as a two-period utility maximization problem is modeled. Farmers as consumers maximize their lifetime utility while farmers as producers choose a their preferred type of production technology between two types of production techniques — high type and low one. A high type of production techniques produces higher yields but demand higher implementation costs than does a low type of production techniques. In this sense, the choice of production techniques by farmers is essentially a choice among two alternative time profiles of their income: low income today and high income tomorrow under a high type of production technology versus the reverse profile under a low type of production technique.

In this model, increases in first period income have two important effects on costs as a proportion of income. First, for a given production type, the unit cost of implementing techniques declines. Second, the incremental cost of a high type of production techniques also falls. Loosely speaking, as an income rises, production techniques become less expensive; and rich farmers find high type of production techniques more affordable.

The next section presents the model and a central planning solution. Section III discusses how production techniques are chosen under complete information. Conclusions are in section IV and proofs are collected in an appendix.

II. Model

Farmers as consumers maximize the present discounted value of their utility from consumption, that is,

(1) $V = U(C_1) + \delta\, U(C_2)$,

Where U is a twice differentiable, increasing, and concave function, C_t denotes consumption in period $t=1$, 2, and $\delta\,(>0)$

is a discount rate. Let's assume that $U(C)$ is homothetic throughout, current and future consumption are normal goods, and $-CU''(C)/U'(C) < 1$ for all $C > 0$, which makes first and second period consumption gross substitutes.

Each farmer is assumed to have an endowment vector $(E_1, E_2) \geq 0$ of a single perishable consumption good in periods 1 and 2. Farmers use the endowment to consume and pay costs associated with their production activity as producers. The individual farmer's budget constraint in the first period is,

$$(2) \quad C_1 = (1 - \tau) E_1,$$

where $\tau \in [0, 1]$ denotes the cost rate of production activity on the first period income.

Farmers as producers invest an amount, denoted by g, in their production activities. However, they must decide to how to produce agricultural goods. In other words, they have to select one type of production technique. Technology types are indexed $i = H, L$, where H denotes a high type of production technique and L a low type.

Technology types differ in two respects. First, a type i technique is able to convert g units of investment into $m_i g$ units of profits where $m_H > m_L > 0$. This is compatible with survey results such that gross revenue and profits tend to be higher for IPM users than non-users.[4] Second, in terms of its cost the type i technique requires fixed costs, denoted by W_i, for its proper implementation, where $W_H > W_L > 0$. This is aimed to reflect survey results such that IPM user received some special training about IPM or took Extension service course of programs provided by the government or by private agencies.[5] Consequently, IPM

[4] See *The National Evaluation of Extension's IPM programs* by Rajotte, Kazmierczak, Norton, Lambur, and Allen (1987) and papers of Kovach and Tette (1988) and McDonald and Glynn (1994).

[5] In general, successful implementation of IPM needs an understanding of agricultural ecosystem. IPM relies on close monitoring of pest populations and scientific interpretation of souting in order to determine when a population has reached an economically damaging threshold.

technique yields more profits ($=m_H g_H$) but requires higher operation cost ($=g_H+W_H$) than pesticides. Thus, the operational constraint for type i technique is

(3) $\tau E_1 \geq g_i + W_i$, $i=H, L.$

In period 2 the farmer as a consumer has an endowment E_2 and receives a transfer $m_i g_i$ from the farmer as a producer (himself). Thus, the period 2 budget constraint of the farmer as a consumer is

(4) $C_2 = E_2 + m_i g_i$, $i=H, L.$

The farmer's problem is to maximize his life time utility, equation (1), subject to the first and second period budget constraints, equation (2) and (4) respectively, and operation constraints for type i, equation (3). Note that g_i is control variable in the model since W_i is automatically determined according to g_i.

(5) $\underset{g}{Max}\ V = U(C_1) + \delta U(C_2) = U(E_1 - g_i - W_i) + \delta U(E_2 + m_i g_i)$

If there exists an interior solution, say g^*, it satisfies the usual first-order condition

(6) $U'(E_1 - g_i - W_i) = m_i\ \delta U'(E_2 + m_i g_i)$.

In general, the solution for g_i is given by the saving function

(7) $g_i^* = g_i(m_i, E_1 - W_i, E_2)$

defined for a farmer as consumer with income vector ($E_1 - W_i$, E_2) and interest yield m_i. Then, farmer's maximal lifetime utility when a type i production technique is selected equals

(8) $V_i = v(E_1 - W_i, E_2, m_i)$

where $v(E, m_i)$ is the indirect utility function corresponding to life-cycle income E and interest yield m_i. When the utility function is homothetic, the saving function is linearly homogeneous in the income vector ($E_1 - W_i, E_2$). Hence, the equation (7) can be written as

$$(9)\quad g_i^* = (E_i - W_i)z(m_i, \frac{E_2}{E_1 - W_i}).$$

What happens to the selection of g_i as the scale of endowment increases under a type i technique? Suppose that we expand (E_1, E_2) by the common factor $\lambda > 0$. Then equation (9) says that the proportion of investment in the first period income is

$$(10)\quad \frac{g_i}{\lambda E_1} = \frac{\lambda E_1 - W_i}{\lambda E_1} z(m_i, \frac{\lambda E_2}{\lambda E_1 - W_i}) = (1 - \frac{W_i/\lambda}{E_1})z(m_i, \frac{E_2}{E_1 - W_i/\lambda}).$$

When consumption goods are normal, the saving rate z is decreasing in the second argument which, in turn, is increasing in λ. Since the implementation cost of production techniques is unaffected by the scale change, the effective saving rate increases with the scale of endowment. This proves

Proposition 1. *Assume* $g_i > 0$ *for a given type of production techniques* $i = H, L$. *Then the ratio of investment to initial income,* g_i / E_1 *rises as* (E_1, E_2) *expand in proportion.*

The intuition for the positive scale effect of the saving propensity z is simple. A proportionate rise in incomes tilts the time profile of the farmer's effective endowment towards period 1 since the first period endowment, $E_1 - W_i$, rises faster than the second period endowment E_2. Note that a rise in E_1 reduces the implementation cost of production techniques as a proportion of E_1. The desire to smooth consumption causes farmers to increase their desired investment g.

The key assumption which derives the result is the constancy of W_i and more broadly, the **non-convex nature of implementation costs of production techniques.** What is essential here is that the cost rises less than proportionately with income.

III. Selection of Production Types

Now consider the farmer's selection preference for a production technology. The actual selection of production techniques can be inferred by comparing farmer's welfare levels under each type. Suppose that at the beginning of period 1 the farmer as a producer chooses types of production techniques according to the following simple rule:

Choose type H if $V_H \geq V_L$

Choose type L otherwise.

Equation (7) reduces this rule to choosing the type H technique if, and only if

$$(11) \quad v(E_1 - W_H, E_2, m_H) \geq v(E_1 - W_L, E_2, m_L)$$

Figure 1 illustrates the factors that affect farmer's selection. The effective consumption possibility frontier (CPF) facing the farmer is the kinked contour given by ACB, the outer envelope of the two CPF's corresponding to high and low type of techniques. If the tangency point of the effective CPF with the farmer's highest indifference curve lies on the CPF of the high type technique, then the farmer selects $i=H$. Otherwise, a low type of techniques is chosen. Note that the flatter the indifference map, the greater the chance that the tangency point lies on the high type's CPF. Thus, farmers with a high value of δ are likely to select a high type of techniques.

The issue that concerns us most in this study is how wealth, or the scale of farming, biases the choice of production types. In particular, are rich farmers more likely to have high type of production techniques? To answer this issue the following iso-elastic utility function is assumed.

$$(12) \qquad U(C) = \begin{cases} \dfrac{C^{1-\theta}}{1-\theta} & \text{if } \theta \in [0,1] \\ \ln C & \text{if } \theta = 1 \end{cases}$$

Without further loss of generality, we normalize the income vector (E_1, E_2) to (*1*, *E*), the fixed costs for the proper implementation of production techniques (W_L, W_H) to (*0*, *W*). Under this homothetic structure, g_i^* is

$$(13) \qquad g_*^i = \frac{R(E_1 - W_i) - E_2}{R + m_i},$$

where $R = (\delta m_i)^{-1/\theta}$. Thus, the indirect utility function of the farmer, V_i, is

$$(14) \qquad (1-\theta)V_i = \left(E_1 - W_i - \frac{R(E_1 - W_i) - E_2}{R + m_i}\right)^{1-\theta} + \delta\left(E_2 - W_i - \frac{R(E_1 - W_i) - E_2}{R + m_i}\right)^{1-\theta}$$

$$= \left(\frac{m_{i(E_1} - W_i) + E_2}{R + m_i}\right)^{1-\theta} + \delta\left(\frac{m_i(E_1 - W_i) - E_2}{R + m_i}\right)^{1-\theta}$$

$$= (E_1 - W_i + E_2/m_i)^{1-\theta} G(m_i),$$

where $G(m_i) = \left(\dfrac{m_i}{R + m_i}\right)^{1-\theta} + \delta\left(\dfrac{Rm_i}{R + m_i}\right)^{1-\theta}$.

From this indirect utility function we readily obtain the farmer's life-cycle utility under each type of production techniques, given the normalized vectors(λ, λE) and (*0*, *W*). The relevant expressions are

$$(15a) \qquad (1-\theta)V_L(\lambda) = \left(\lambda + \frac{\lambda E}{m_L}\right)^{1-\theta} G(m_L)$$

$$(15b) \qquad (1-\theta)V_H(\lambda) = \left(\lambda - W + \frac{\lambda E}{m_H}\right)^{1-\theta} G(m_H),$$

where λ is the scale parameter. The initial scale of the farmer corresponds to $\lambda = 1$.

In order to simplify the notation, let's define the payoff ratio:

$$(16) \quad \varphi(\lambda) \equiv V_H(\lambda)/V_L(\lambda).$$

Since both V_H and V_L are positive by assumption, the farmer chooses the high type of production technique if $\varphi(\lambda) \geq 1$, the low type one otherwise. To see how scale of endowment of scale of farming influences the choosing prospects of two alternative types of production technique, let's consider some properties of the function $\varphi(\lambda)$ in the following lemma.

Lemma 1. *$\varphi(\lambda)$ is monotonically increasing in λ for all $\lambda \geq \frac{W}{1+(E/m_H)}$.*

The proof is obvious. Lemma 1 says that an increase in the scale of farming weakens the low-cost advantage of a low type of production techniques and undermines its attractiveness to the farmer relatively to a high type of production techniques. This occurs because a rise in λ causes the life-cycle income net $[\lambda - W + (\lambda E/m_H)]$ under a type H technique to rise by more than the corresponding increase under a type L. From this Lemma we also obtain a definition of critical scale λ^* above which the high type of production techniques is selected.

Lemma 2. *Define* $\alpha = \left(\frac{G(m_L)}{G(m_H)}\right)^{1/(1-\theta)}$ *and assume that*

$E < \frac{(1-\alpha)m_H m_L}{\alpha m_H - m_L}$. *Then, there exists a critical scale of farming, λ^*, such that $\varphi(\lambda) \geq 1$ for all $\lambda \geq \lambda^*$*

Proof. See Appendix.

Lemma 2 shows that all farmers whose endowment ratio

E_2/E_1 is sufficiently skewed toward the first period have a critical size λ^* above which they select the high type of production technique. This leads directly to the second proposition.

Proposition 2. *All farmers with scale greater than the critical endowment vector* $(\lambda^* E_1, \lambda^* E_2)$ *select the high type of production techniques which requires a greater fraction of the first period income as its implementation costs than the low type of production techniques. Farmers below the critical scale choose a low type of production techniques.*

Proposition 2 is key to this paper. It shows that the income of a farmer has one kind of major influences on the adoption of new production techniques – large scale or rich farmers are more likely to select the high type of production techniques because the implementation costs of the high type one absorbs a smaller fraction of farmer's income. It is important to reiterate that these scale or threshold effects derive from decreasing incremental costs of high type of production costs. Also this proposition predicts that farmer's investment would behave as in Figure 2. In Figure 2 investment is very low until $E_1 = E^*$. Once reaching the threshold, farmers select high type of production techniques which causes investment to jump up.

IV. Conclusions

By using a two period utility maximization problem it is derived that farmers above a critical level of the first period income choose the high type of production techniques such as IPM while farmers below the threshold select the low type technique. The insight in this study is that implementation costs for high type technique per unit income is decreasing and the selection process has a threshold property. For farmers with low income-levels a high type of production techniques is too expensive relative to low type one. As income grows, high types of production techniques become relatively cheaper since the associated implementation costs do not typically grow in proportion to income. Since income growth is itself a function of the level and productivity of investment, farmers already above the threshold grow faster than those below the threshold. The model, thus, suggests an explanation for poverty traps and the continued disparities in income across the globe.

The result is however, based on a strong assumption of full information and the constancy of W_i. In other words, since there are uncertainty problems in the adoption process of a new technology, we have to interpret these results with care. one suggestion about incomplete information is that at the end of the

Figure 1. The Consumption Possibility Frontier in Each Type

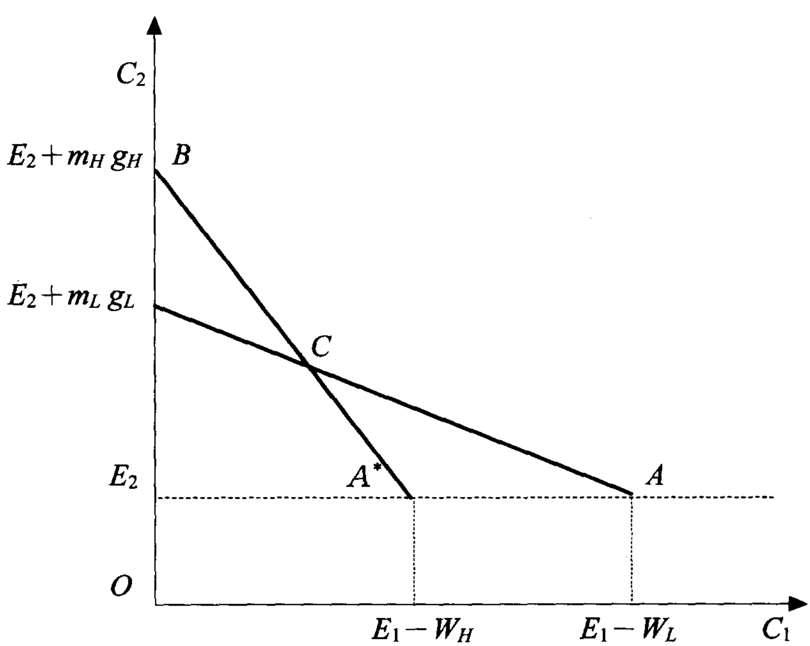
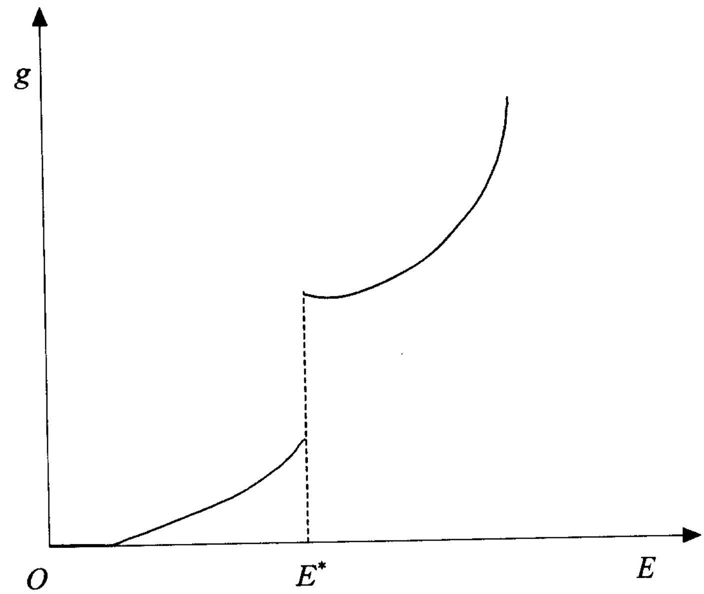


Figure 2. Investment with a Threshold Effect



period 1 farmers observe some noisy signal of their profits, $m_i g_i$ itself. For example, farmers are assumed to observe some noisy s_i which is given by $s_i = m_i g_i + \varepsilon$, where ε is a certain random variable. In this case the signal s_i would be directly correlated with the production types selected. The solution method for this problem is similar to the complete information case which this study analyzes. This case is left for the future study.

Appendix

Proof of Lemma2

The proof is straightforward once we note that λ^* solves $\varphi(\lambda) = 1$. From $\varphi(\lambda) = 1$ of the equation (16), $V_H(\lambda) = V_L(\lambda)$.

$$\left(\lambda - W + \frac{\lambda E}{m_H}\right)^{1-\theta} G(m_H) = \left(\lambda + \frac{\lambda E}{m_L}\right)^{1-\theta} G(m_L)$$

$$\left[\left(\lambda - W + \frac{\lambda E}{m_H}\right) / \left(\lambda + \frac{\lambda E}{m_L}\right)\right] = [G(m_L)/G(m_L)]^{1/(1-\theta)} = \alpha$$

$$\left(\frac{\lambda m_L(m_H + E) - W m_H m_L}{\lambda m_H(m_L + E)}\right) = \alpha \Rightarrow \lambda(m_L(m_H + E) - \alpha m_H(m_L + E)) =$$

$$m_H m_L W \Rightarrow \lambda(m_L m_H(1-\alpha) + E(m_L - \alpha m_H)) = m_H m_L W$$

For the existence of a positive λ, we need $m_L m_H (1-\alpha) > E(\alpha m_H - m_L)$. That is, $E < \frac{m_L m_H(1-\alpha)}{(\alpha m_H - m_L)}$ under assumption of $\alpha m_H > m_L$.

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