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THE DISTRIBUTIONAL EFFECTS OF NEW TECHNOLOGY UNDER RISK

by

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I. INTRODUCTION

The postmortem on the "green revolution" has begun to concentrate on the discouragingly low rates of adoption and diffusion. A number of possible barriers to the adoption of new technologies have been identified. They include risk aversion, fixed costs of adoption, access to credit, and tenurial arrangements. While the potential role of these "barriers" has been discussed at length in the literature, a consistent conceptual framework has not been advanced which admits empirically observed behavior. Most of the work to date provides detailed descriptions of individual country and regional experiences and develops only heuristic arguments to explain observed behavior.

In addition to adoption and diffusion barriers, policymakers have become increasingly concerned with the income-distribution effects of the green revolution technologies. In some instances, larger farms adopted new technology more rapidly and received relatively more benefits. Some analysts have argued that, since higher income farms may receive relatively more benfits and low-income farms may be made worse off (either relatively or absolutely), the new technology should not have been introduced. Although average income may have increased, social adversities associated with an increased spread of income distribution may fail to outweigh expected social benefits. Unfortunately, as yet, no operational framework has been developed from which such distributional implications may be evaluated.

Empirical studies of technological adoption and technology-based rural development programs inevitably focus on the variation in adoption rates among different-size farming operations. This concern reflects the wide-spread recognition that the degree of technology divisibility influences its applicability for small landholders. In general, the evidence regarding the gross correlation between farm size and technology adoption is mixed. To be sure, because of the complexity of the relationship between size of landholding and adoption, simple statistical correlations provide limited guidance.

Empirical studies of the green revolution have concentrated on high-yielding-variety technology (HYV). The empirical results tend to suggest that, in the early stages of the adoption process, farm size plays some role; but its relationship is not significant and it tends to vary widely between crops and regions. A number of studies from India and Pakistan report a positive relationship between farm size and initial adoption [Castillo, 1973; Griffin, 1972; Schluter, 1971; von Blanckenburg, 1972; Muthia, 1971; and Rochin, 1972]. Once adoption takes place, there is evidence which suggests that owners of small- or medium-size farms plant a larger proportion of their available land to HYVs and employ a higher level of inputs than do larger farms [Schluter, 1971; Muthia, 1971; Sharma, 1973; and van Der Veen, 1975]. Schulter [1971] found an inverse relationship between farm size and the proportion of acreage allocated to HYVs in the case of rice, dajra, maize, and jowar in India and that the relationship was more significant the longer the period of time since the introduction of new varieties. Muthia [1971] found that small- and medium-size farms in south India contributed a larger share of total HYV acreage than was their share of total cultivated acreage. Sharma [1973] reported that the level of adoption of the total HYV package was higher in the case of small- and medium-size farms than for larger farms. Among Philippine farms, van Der Veen [1975] found an inverse relationship between farm size and the amount of fertilizer and labor used per hectare.[1]

Empirical investigations of use of fertilizer and pesticide per unit of land show an even more confusing pattern. While many studies indicate no significance different in chemical input use per acre between farms of different sizes [e.g., Lipton, 1978, p. 321; Singh, 1979, pp. 58 and 59; Parthasarathy and Prasad, 1978], others indicate a negative relationship between the amount of fertilizer applied per hectare and farm size. Perrin and Winkelman [1976, p. 893] report significant effects of size in nearly half of the studies covered by their survey. Similar findings are reported by Clawson [1978] and in a number of studies cited by Singh [1979, pp. 53 and 54].

The seemingly conflicting results that have been generated by empirical studies are expected because landholding size is a surrogate for a whole array of potentially important factors, such as access to credit, capacity to bear risk, access to scarce inputs (water, seeds, fertilizers, insecticides), wealth, human capital, access to information, etc. The influence of these factors varies in different areas and over time as does the relationship between landholding size and adoption behavior.

Conceptual frameworks which have been advanced to explain this behavior have concentrated upon the potential barriers to adoption and diffusion [Feder, 1980; Feder and O'Mara, 1979; Bhaduri, 1973; Newbery, 1975; Srinivasan, 1972, 1979; Scandizzo, 1979; and Hiebert, 1974]. For example, Feder and O'Mara [1979] focus on the relationship between farm size and the process of adoption over time, assuming a fixed adoption set up cost and risk aversion. Their model introduces dynamic elements through reduction of uncertainty due to both learning by doing and exogenous effects. This conceptual framework, along with the other factors mentioned above, treats behavior of a single "representative" farm. What is required, however, is a conceptual framework which can be empiricized for an entire rural region that is composed of individual farmers possessing different sets of resources, and having different attitudes toward risk, having different access to credit, etc.

In this setting, the purpose of this paper is to develop an internally consistent conceptual framework which (a) takes explicit account of the potential barriers to adoption, (b) can be employed to investigate the distributional effects of new technology, and (c) admits, as possible outcomes, the empirical evidence that has been documented for the green revolution. As noted on numerous occasions by Nobel laureate Theodore Schultz [1953], this framework will recognize that large differences in rates of return in agriculture are caused by differences in endowments of inputs, human capital, and wealth controlled by individual farmers. Explicit treatment of the distribution of these factors among farmers is necessary to explain income distribution, barriers to adoption, and available empirical evidence. Our approach is to focus upon the relationship between the adoption decision and the resource endowments and individual attitudes. Given these relationships, it is possible to relate income distribution to resource-endowment distribution and other microparameter distributions.

II. THE MODEL

Consider initially a single farm with fixed landholdings, $\bar{L}$, and a traditional technology, S_1, involving one crop which requires v_1 units of variable inputs per hectare and has a subjective distribution of quasi rents per hectare given by $\pi_1 = p_1 y_1 - w_1 v_1$ which is distributed N (μ_1, σ_1) where w_1 is the price per unit for variable inputs (which may simply represent the opportunity cost of using the inputs such as family labor elsewhere). Exogeneity of the price of the aggregate variable input per unit results from competition since the production function is assumed to be fixed proportions for a given technology. Suppose also that, under normality, the farmer's objective can be represented in a mean-variance framework with risk aversion coefficient $\phi > 0$. Where L_1 represents the amount of land allocated to the traditional technology, the decision problem is thus

(1) $$\max_{L_1} \mu_1 L_1 - \phi\sigma_1 L_1^2$$

where $E(\pi_1) = \mu_1$ and variance of π_1 is denoted by σ_1, subject to

$$L_1 \leq \bar{L}.$$

The first-order condition in the case of an internal solution implies

$$L_1 = L^*_1 \equiv \frac{\mu_1}{2\phi\sigma_1}.$$

Thus, the resulting decision, in general, is

(2) $$L_1 = \bar{L}_1 \equiv \begin{cases} 0 & \text{if } L_1^* < 0 \\ L_1^* & \text{if } 0 \leq L_1^* \leq \bar{L} \\ \bar{L} & \text{if } L_1^* > \bar{L}. \end{cases}$$

For the purpose of this paper, risk aversion is assumed to be mild enough to lead to full employment of land when only one crop is considered; hence, $L_1 = \bar{L}$ under S_1.

Now suppose a new technology, S_2, is introduced. The farmer can allocate some of his land to the traditional crop (at traditional costs) and some of his land to a new crop (or a new method of producing the same crop). The second crop, which will be referred to as the "modern crop," may be a high-yielding variety or a cash crop utilizing modern inputs. On the other hand, it may be more vulnerable to weather variations and thus carry a greater degree of uncertainty regarding the returns per hectare. Additional (and subjective) uncertainty may also accompany the modern crop due to the fact that the farmer is less familiar with the new technology. Considering this factor, the modern crop may be viewed as more risky even if, in reality, it is no more susceptible to extreme weather situations than the traditional crop.

Suppose production of the modern crop requires v_2 units of variable inputs per hectare (possibly of a different mix than used by the traditional technique) at price w_2 per unit to attain a subjective distribution of quasi rents per hectare of $\pi_2 \equiv p_2y_2 - w_2v_2$ which is distributed $N(\mu_2, \sigma_2)$. Also, suppose that both prices and yields of the traditional and modern techniques are correlated with cov $(\pi_1, \pi_2) = \sigma_{12}$, i.e.,

$$\begin{pmatrix} \pi_1 \\ \pi_2 \end{pmatrix} \sim N \left[\begin{pmatrix} \mu_1 \\ \mu_2 \end{pmatrix}, \begin{pmatrix} \sigma_1 & \sigma_{12} \\ \sigma_{12} & \sigma_2 \end{pmatrix} \right]$$

with the covariance matrix assumed to be positive definite. Note that the variances and covariance include subjective uncertainty about yields and market access (prices) and may thus be influenced by both experience and extension efforts.

While it may also be interesting to consider variation in levels of use of modern inputs with the new technology, i.e., how optimal modern input use may vary with resource endowments and behavioral parameters, Feder [1980] has shown that, in some cases (where a strictly riskless land-using activity exists with sufficiently high returns to merit use of some resources for every relevant farm size, risk aversion, etc., considered), modern input use per hectare is independent of farm size, risk aversion, uncertainty, and fixed costs of adoption.

In the context of the above problem, the objective of the farmer under the new technology is

$$(3) \qquad \max_{L_1, L_2} \; \mu_1 L_1 + \mu_2 L_2 - \phi \, (\sigma_1 L_1^2 + \sigma_2 L_2^2 + 2\sigma_{12} L_1 L_2)$$

subject to

$$L_1 + L_2 \leq \bar{L}.$$

First-order conditions for maximization imply

$$(4) \qquad \frac{\partial \Delta}{\partial L_1} = \mu_1 - 2\phi \, (L_1 \sigma_1 + L_2 \sigma_{12}) - \lambda \geq 0,$$

$$(5) \qquad \frac{\partial \Delta}{\partial L_2} = \mu_2 - 2\phi \, (L_1 \sigma_{12} + L_2) - \lambda \geq 0.$$

$$\frac{\partial \Delta}{\partial \lambda} = \bar{L} - L_1 - L_2 \geq 0,$$

$$\frac{\partial \Delta}{\partial L_1} L_1 = 0, \; \frac{\partial \Delta}{\partial L_2} L_2 = 0, \; \frac{\partial \Delta}{\partial \lambda} \; \lambda = 0,$$

where Δ is the Lagrangian of the constrainted maximization problem. Second-order conditions require $|A| > 0$ with principal minors alternating in sign [Lancaster, 1968] where

$$A = \begin{pmatrix} -2\phi\sigma_1 & -2\phi\sigma_{12} & -1 \\ -2\phi\sigma_{12} & -2\phi\sigma_2 & -1 \\ -1 & -1 & 0 \end{pmatrix};$$

these conditions are obviously satisfied given positive definiteness of the covariance matrix for (π_1, π_2)[1].

To examine behavior under the modern technology, the conditions in (4) and (5) can be solved with $\lambda = 0$ for the case where the land constraint is not binding. As in the case of the traditional technology, however, the assumption in this paper will be that land is a binding constraint. Hence, for the case of an internal solution in L_1 and L_2, the inequalities in (4) and (5) become equalities and, together with the land constraints, yield

(6) $$L_1 = L_1^* \equiv \frac{\mu_1 - \mu_2 + 2\phi \bar{L} (\sigma_2 - \sigma_{12})}{|A|}$$

(7) $$L_2 = L_2^* \equiv \frac{\mu_2 - \mu_1 + 2\phi \bar{L} (\sigma_1 - \sigma_{12})}{|A|}$$

or, in general,

(8) $$L_i = \bar{L}_i \equiv \begin{cases} 0 & \text{if } L_i^* < 0 \\ L_i^* & \text{if } 0 \leq L_i^* \leq \bar{L} \\ \bar{L} & \text{if } L_i^* \geq \bar{L}, \end{cases}$$

$i = 1, 2.$

The technology decision for an individual farmer can be made by comparing maximum expected utility under the two alternatives. Assuming the outcome with full utilization of land ($L_1 = \overline{L}$) in (2), substitution into (1) yields expected utility U_1 under S_1,

(9) $$U_1 = \mu_1\overline{L} - \phi\sigma_1\overline{L}^2.$$

Also, assuming full utilization of land, substitution of (8) into (3), and, additionally, the annualized cost of k, adopting the new technology yields expected utility, U_2, under S_2,

(10) $$U_2 = \mu_1\overline{L}_1 + \mu_2\overline{L}_2 - \phi\ (\sigma_1\overline{L}_1^2 + \sigma_2\overline{L}_2^2 + 2\sigma_{12}\overline{L}_1\overline{L}_2) - k.$$

Thus, assuming either that the farmer is myopic (or considers future periods to be like this one) or that annualized fixed costs of adoption are recurring, the farmer selects technology, S_1, if $U_1 > U_2$ and technology, S_2, when $U_2 > U_1$.

(a) The Role of Land Endowments and Risk Attitudes

To investigate income effects on farmers with different endowments and different attitudes, a first step is to consider the effects of these factors on rates of adoption. Since, under the presumed putty-clay production structure (fixed proportions for a given technology but variable proportions across technologies), the farmer's decision can be broken into two parts--first, whether or not to adopt the new technology and, second, how much land to devote to the new technique given adoption. Given adoption, the effects of changes in land endowment on intensity of adoption can be examined using equations (6)-(8). While the following three propositions are simply shown for the model considered here, they hold more generally in the case where the modern technology uses a modern input which affects both expected returns and variability of returns.

PROPOSITION 1: For a given subjective distribution of returns per hectare, larger adopting farms tend to devote more land to the traditional technology than small adopting farms if the new technology is viewed as more risky than the traditional technology. Land devoted to the traditional technology declines in absolute terms with farm size (among adopting farms) when the new technology is less risky and the correlation of yields under the two technologies is highly positive ($\sigma_{12} > \sigma_2$).

PROOF: Differentiating (4) with respect to $\bar{L}$ obtains

$$\frac{dL_1}{d\bar{L}} = \frac{2\phi}{|A|} (\sigma_2 - \sigma_{12})$$

which is positive if $\sigma_2 - \sigma_{12} > 0$. But $\sigma_1 + \sigma_2 - 2\sigma_{12} > 0$ by positive definiteness of the covariance matrix, so $\sigma_2 > \sigma_{12}$ must hold when $\sigma_2 > \sigma_1$. The second part of the proposition is proven similarly.

PROPOSITION 2: For a given subjective distribution of returns per hectare, larger adopting farms tend to devote more land to the new technology than smaller adopting farms if the correlation of yields under the two technologies is low or negative but (assuming the new technology is viewed as more risky than the old) tend to devote less land to the new technology if yields are highly correlated.

PROOF: Differentiating (7) with respect to $\bar{L}$ obtains

$$\frac{dL_2}{d\bar{L}} = \frac{2\phi}{|A|}(\sigma_1 - \sigma_{12}) \tag{11}$$

which is positive if $\sigma_1 - \sigma_{12} > 0$. This result will obtain when σ_{12} is small or negative. If the new technology is viewed as more risky than the old, then $\sigma_2 > \sigma_1$; and, as correlation gets high, $\sigma_1 - \sigma_{12}$ becomes negative so that $dL_2/d\bar{L} < 0$.

REMARK 1: Propositions 1 and 2 are consistent with intuition since an increase in land, $\bar{L}$, leads to greater variance of profits if land is fully employed. The accompanying need to reduce variance suggests diversifying by using some of each increment of land under each technology. This opportunity is taken away, however, when yields under the two technologies are too highly correlated, in which case the farmer is inclined to lean more heavily toward the tried and proven traditional technology which entails lower subjective risk. Proposition 2 thus suggests that high correlation of yields under old and new technologies may represent a substantial barrier to adoption. On the other hand, if extension efforts are effective in reducing subjective risk for the new technology, Propositions 1 and 2 suggest ways in which intensity of adoption by farm size may be altered.

Although the above propositions explore the effects of increased land endowments on <u>absolute</u> hectarage under old and new technologies, a further analysis of relative shares serves to support much of the recent empirical evidence.

PROPOSITION 3: For a given subjective distribution of returns per hectare, the relative share of the traditional technology is increasing in farm size; the relative share of the new technology is decreasing in farm size among those farm sizes which lead to some use of both technologies so long as the new technology is subjectively more profitable (although more risky).

PROOF: Differentiating directly and using (7) and (11) obtains

$$\frac{d\,(L_2/\bar{L})}{d\bar{L}} = \frac{1}{\bar{L}}\left(\frac{dL_2}{d\bar{L}} - \frac{L_2}{\bar{L}}\right) = \frac{\mu_1 - \mu_2}{\bar{L}^2\,|A|} \tag{12}$$

which is negative if expected profits per hectare under the new technology exceed these under the old technology. The remaining assertions related to $L_1/\bar{L}$ follow since the sum of shares is unity.

REMARK 2: Proposition 3 suggests the very plausible and oft-observed relationship whereby large farmers tend to adopt new technologies by first experimenting on relatively smaller shares of their farmland than do small farmers. This result is in sharp contrast to that found by Feder and O'Mara (1979) under the questionable assumption of constant relative risk aversion.[2] It should also be noted that the case of Proposition 3 is the only plausible case under which both technologies would be used on farms of adequate size to effectively spread fixed costs. If the new technology were both more profitable and less risky, then all such farms would adopt; but if the new technology were both less profitable and more risky, no farm would adopt. Since the case with $\mu_2 > \mu_1$ corresponds to seemingly all recognized problems of technology adoption, only those cases will be considered in the remainder of this paper. Hence, cases with $\sigma_2 < \sigma_1$ are uninteresting in that no farm would or should adopt in that case regardless of farm size or risk (averse) preferences.

Finally, for completeness, note:

PROPOSITION 4: for a given subjective distribution of returns per hectare, adopting farmers with higher risk aversion will tend to devote more (less) land to the traditional technology both absolutely and relatively—which implies the reverse is true for land devoted to the modern technology—if expected profitability under the the new technology is greater (less) or, equivalently, if the new technology is less (more) risky.

PROOF: Differentiating (6) and (7) with respect to ϕ obtains

$$\frac{dL_1}{d\phi} = \frac{\mu_2 - \mu_1}{\phi|A|}, \qquad \frac{dL_2}{d\phi} = \frac{\mu_1 - \mu_2}{\phi|A|},$$

and

$$\frac{d(L_i/\bar{L})}{d\phi} = \frac{1}{\bar{L}}\frac{dL_i}{d\phi}, \qquad i = 1, 2.$$

Proposition 4 follows immediately upon noting from (8) that an internal solution implies neither technology can be both more profitable and less risky.

(b) Endogenous Technology

Based on the results of Propositions 1-3, the role of land endowments in the adoption decision can be investigated graphically. Consider first the graphical relationship of adoption rate given investment in the new technology.

Note first that, if the modern technology is adopted and all land is devoted to the new technique ($L_2 = \bar{L}$, $L_1 = 0$), then from (10)

$$U_2 = \bar{U}_2 \equiv \mu_2\bar{L} - \phi\sigma_2\bar{L}^2 - k. \tag{13}$$

Alternatively, substituting equations (6) and (7) into (10) we have

$$\begin{aligned} U_2 = \tilde{U}_2 \equiv\ & \frac{2\phi}{|A|}\left[\mu_1(\sigma_2 - \sigma_{12}) + \mu_2(\sigma_1 - \sigma_{12})\right]\bar{L} \\ & - \frac{2\phi^2}{|A|}(\sigma_1\sigma_2 - \sigma_{12}^2)\,\bar{L}^2 + \frac{1}{2|A|}(\mu_2 - \mu_1)^2 - k \end{aligned} \tag{14}$$

for the case where some of both techniques are used.

To consider $\bar{U}_2$ and $\tilde{U}_2$ graphically, note that each is quadratic in $\bar{L}$. Also, note that each has a positive first derivative with respect to $\bar{L}$ at $\bar{L} = 0$. The latter point is evident upon noting that

$$\left.\frac{d\tilde{U}_2}{d\bar{L}}\right|_{\bar{L}=0} = \mu_1\,\omega_1 + \mu_2\omega_2 \tag{15}$$

where $\omega_1 + \omega_2 = 1$ with $\omega_1 = (\sigma_1 - \sigma_{12})/(\sigma_1 + \sigma_2 - 2\sigma_{12})$. From (15), it is further apparent that

$$\left.\frac{d\tilde{U}_2}{d\bar{L}}\right|_{\bar{L}=0} < \left.\frac{d\bar{U}_2}{d\bar{L}}\right|_{\bar{L}=0}$$

since $\mu_2 > \mu_1$. Also, note that the intercept on the $\bar{L} = 0$ axis is $-k$ for $\bar{U}_2$ and is greater than $-k$ for $\tilde{U}_2$. Finally, note that both $\bar{U}_2$ and $\tilde{U}_2$

possess negative second derivatives with respect to $\bar{L}$ with $d^2\bar{U}_2/d\bar{L}^2 < d^2\tilde{U}_2/d\bar{L}^2$. This may be shown by first noting that

$$\frac{d^2\bar{U}_2}{d\bar{L}^2} = -2\phi\,\frac{\sigma_1\sigma_2 + \sigma_2^2 - 2\sigma_2\sigma_{12}}{\sigma_1 + \sigma_2 - 2\sigma_{12}}\,,\quad \frac{d^2\tilde{U}_2}{d\bar{L}^2} = -2\phi\,\frac{\sigma_1\sigma_2 - \sigma_{12}^2}{\sigma_1 + \sigma_2 - 2\sigma_{12}^2}\,,$$

and then representing the difference as a factor of $(\sigma_2 - \sigma_{12})^2$. From these observations, $\bar{U}_2$ and $\tilde{U}_2$ clearly follow inverted U-shapes such as depicted in Figure 1(a).

Now consider comparison of $\bar{U}_2$ and $\tilde{U}_2$ to determine where some of the traditional technology will continue to be used in the event of adoption. Obviously, from (6) and (7), $L_1^* < 0$ and $L_2^* > 0$ when $\bar{L} > 0$, since the new technology is more profitable in a mean sense. Hence, it is clear from (8) that, as the land endowment expands from zero, <u>given adoption of the new technology</u>, initially $\bar{L}_2 = \bar{L}$ and $\bar{L}_1 = 0$. In other words, with $\bar{L}$ near zero, the U_2 curve is unattainable since it corresponds to negative L_1. Thus, given adoption, all land is allocated to the new technology. Only at some larger land endowment does some land begin to be allocated to the traditional technology. This point occurs where $L_1^* = 0$ since, from (8), $\bar{L}_1 > 0$ if $L_1^* > 0$ but $\bar{L}_1 = 0$ if $L_1^* \leq 0$. Thus, a critical farm size, $\bar{L}^*$, at which land begins to be allocated to both the modern and traditional technologies, given investment in the modern technology, can be determined by solving $L_1^* = 0$ using (6),

$$\text{(16)} \qquad \bar{L}^* = \frac{\mu_2 - \mu_1}{2\phi\,(\sigma_2 - \sigma_{12})}\,.$$

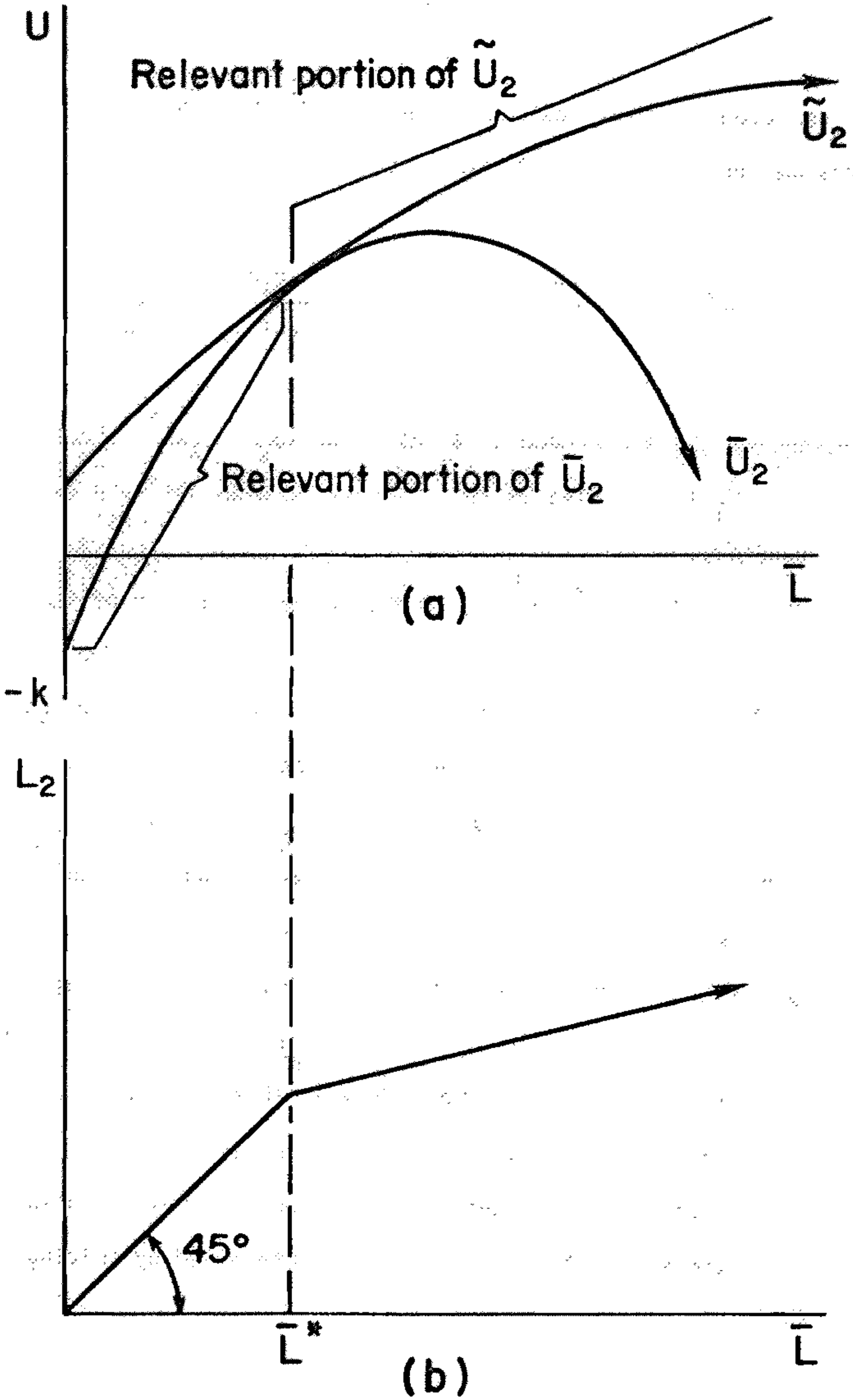

Figure 1

Determination of Adoption Rate Given Adoption

By substitution of (16) into (13) and (14), one may further verify that $\bar{U}_2 = \tilde{U}_2$ and that $d\bar{U}_2/d\bar{L} = d\tilde{U}_2/d\bar{L}$ at L*. Hence, $\bar{U}_2$ and $\tilde{U}_2$ are tangent at $\bar{L}$* as depicted in Figure 1(a).

From the above arguments, it is clear that the relevant portion of the $\bar{U}_2$ curve, given adoption, corresponds to $0 \leq \bar{L} \leq \bar{L}^*$. To the right of $\bar{L}^*$, $\tilde{U}_2$ dominates $\bar{U}_2$ and is attainable (except and unless at some larger land endowment $\tilde{U}_2$ corresponds to $L_2 < 0$). Thus, to determine the adoption rate, consider Figure 1(b). Left of $\bar{L}^*$, all land is allocated to the modern technology so L_2 as a function of $\bar{L}$ follows the 45-degree line. At $\bar{L}^*$, some land begins to be allocated to L_1 as $\tilde{U}_2$ becomes relevant. The relationship of L_2 with respect to $\bar{L}$ then follows equation (7) which is obviously linear in $\bar{L}$. Thus, L_2 follows the shape indicated in Figure 1(b) for the case where $\sigma_1 > \sigma_{12}$, i.e., for the case with $dL_2/d\bar{L} > 0$. Following this same approach, one can also consider the case with $\sigma_1 < \sigma_{12}$. If $\sigma_1 < \sigma_{12}$, then the linear segment to the right of $\bar{L}^*$ in Figure 1(b) has negative slope so that L_2 falls to zero at some larger land endowment.

To generalize the relationships in Figure 1 for the case of endogenous adoption decisions, the graphical relationships need simply be compared with that of U_1 in equation (9). Of course, U_1 is obviously also quadratic in $\bar{L}$ with an inverted U-shape but runs through the origin (with positive slope) as indicated in Figure 2. Two alternatives are of immediate importance: (a) the case where U_1 intersects $\bar{U}_2$ (from above) to the left of $\bar{L}^*$ (Figure 2a) and (b) the case where U_1 intersects $\tilde{U}_2$ (from above) to the right of $\bar{L}^*$ (Figure 2b). (Cases where U_1 lies entirely above the relevant portions of $\bar{U}_2$ and $\tilde{U}_2$ are not interesting since no farm size would lead to adoption.) The intersection point in case (a) is obtained by equating U_1 and $\bar{U}_2$ and solving $\bar{L}$; the solution is given by

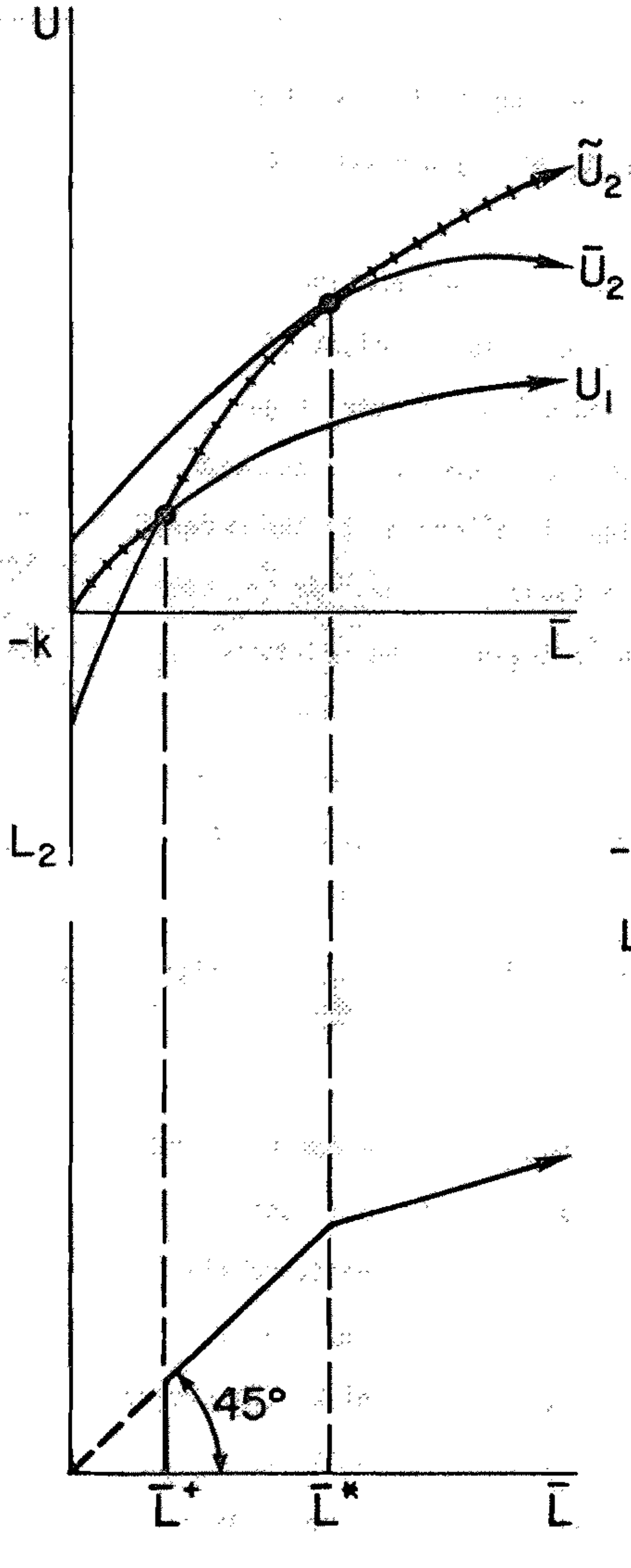

Figure 2a

Adoption with Low Fixed Cost and Low Covariance

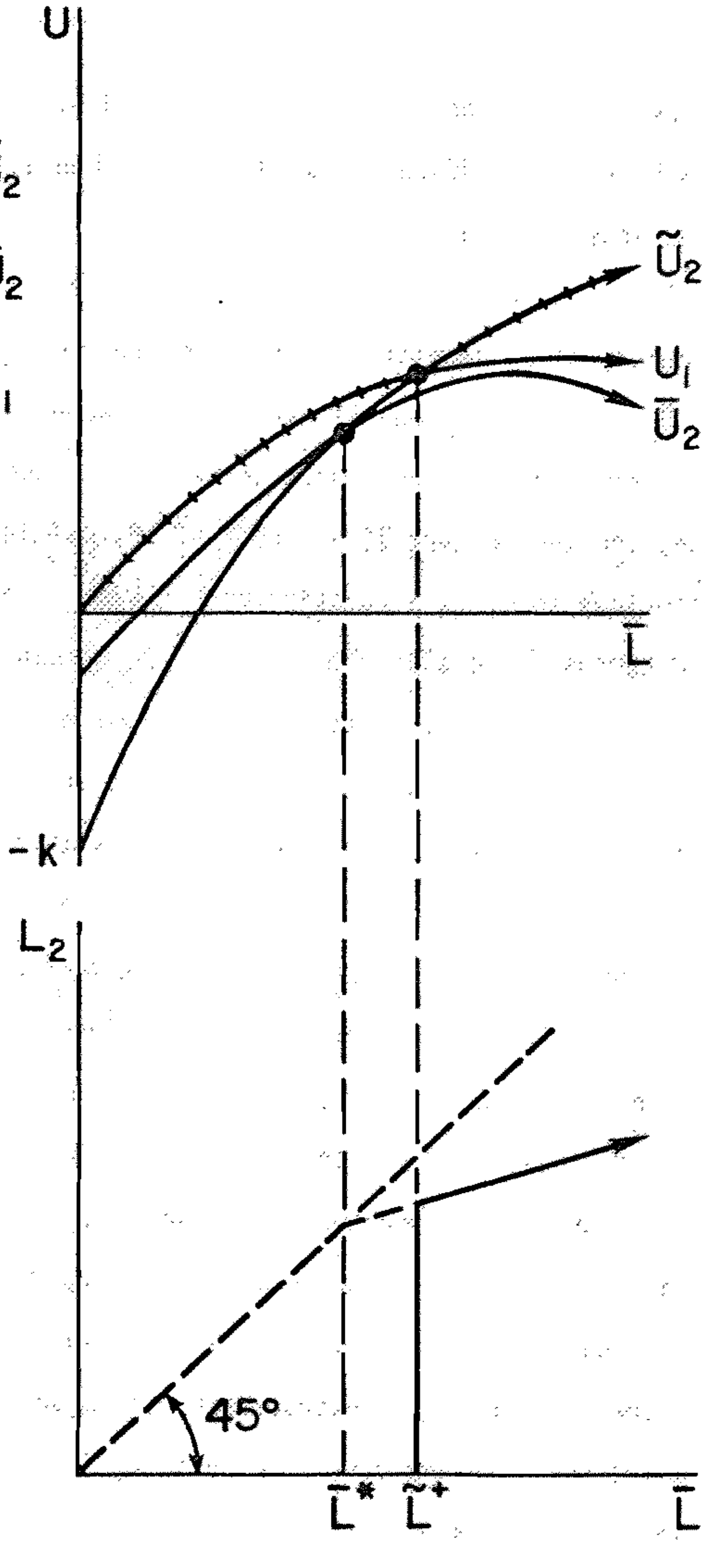

Figure 2b

Adoption with High Fixed Cost and Low Covariance

(17) $$\bar{L}^{+} = \frac{\mu_2 - \mu_1 - \sqrt{(\mu_2 - \mu_1)^2 - 4\phi k\ (\sigma_2 - \sigma_1)}}{2\phi\ (\sigma_2 - \sigma_1)} .$$

(Note that the other root corresponds either to an intersection where U_1 intersects $\bar{U}_2$ from below or to an intersection at some $\bar{L} < 0$ which occurs when $\sigma_1 > \sigma_2$.) The intersection point in case (b) is obtained by equating U_1 and $\tilde{U}_2$ and solving for $\bar{L}$; the solution is given by[3]

(18) $$\tilde{L}^{+} = \frac{\mu_1 - \mu_2 + \sqrt{4\phi k\ (\sigma_1 + \sigma_2 - 2\sigma_{12})}}{2\sigma\ (\sigma_1 - \sigma_{12})} .$$

Note that $d^2U_1/d\bar{L}^2 < d^2\tilde{U}_2/d\bar{L}^2$ so, if U_1 cuts $\tilde{U}_2$ from above as in case (b), then there is no other intersection of the two to the right of $\tilde{L}^{+}$; the second intersection is to the left of $\tilde{L}^{+}$ and corresponds either to $\bar{L} < 0$ or to the irrelevant portion of $\tilde{U}_2$. Furthermore, direct differentiation of (9) and (14) and substitution of (7) implies

$$\frac{d\tilde{U}_2}{d\bar{L}} - \frac{dU_1}{d\bar{L}} = 2\phi L_2^{*}\ (\sigma_1 - \sigma_{12})$$

so when U_1 cuts $\tilde{U}_2$ from above (where $L_2^{*} > 0$), $\sigma_1 > \sigma_{12}$ must hold. In other words, $\sigma_1 < \sigma_{12}$ can hold only when $\bar{L}^{+} < \bar{L}^{*}$ (Figure 2a) and not in the case of Figure 2b.

To consider the remaining relevant case with $\sigma_1 < \sigma_{12}$, note that $dL^{*}/d\bar{L} < 0$ from equation (7) which, with linearity, implies that $\bar{L}_2$ goes to zero for sufficiently large $\bar{L}$; hence, some land endowment $\hat{L}$ with $\hat{L} > \bar{L}^{*}$ must exist such that no larger land endowment leads to adoption. This case is depicted in Figure 2c. This second critical land endowment can be found by equating U_1 and $\tilde{U}_2$ and solving for $\bar{L}$,

$$(19) \qquad \hat{L} = \frac{\mu_2 - \mu_1 - \sqrt{4\phi k\ (\sigma_1 + \sigma_2 - 2\sigma_{12})}}{2\phi\ (\sigma_{12} - \sigma_1)}.$$

The other root corresponds to the second intersection where U_1 cuts $\tilde{U}_2$ from above; this intersection is irrelevant since it corresponds to negative L_2 as can be verified by substitution into equation (7).

These results thus prove the following propositions.

PROPOSITION 5: The indirect expected utility function as a function of land endowment is piecewise quadratic with either 2, 3, or 4 connected segments: (i) if $\tilde{L}^+ > \bar{L}^*$, then expected utility follows U_1 for $0 \leq \bar{L} \leq \tilde{L}^+$ and $\tilde{U}_2$ for $\bar{L} \geq \tilde{L}^+$; (ii) if $\sigma_1 < \sigma_{12}$, then expected utility follows U_1 for $0 \leq \bar{L} \leq \bar{L}^+$, U_2 for $\bar{L}^+ \leq \bar{L} \leq \bar{L}^*$, $\tilde{U}_2$ for $\bar{L}^* \leq \bar{L} \leq \hat{L}$, and U_1 for $\bar{L} \geq \hat{L}$; and (iii) if $\sigma_1 > \sigma_{12}$ and $\bar{L}^+ < \bar{L}^*$, then expected utility follows U_1 for $0 \leq \bar{L} \leq \bar{L}^+$, $\bar{U}_2$ for $\bar{L}^+ \leq \bar{L} \leq \bar{L}^*$, and $\tilde{U}_2$ for $\bar{L} \geq \bar{L}^*$.

PROPOSITION 6: The quantity of land devoted to the modern technology as a function of land endowment is piecewise linear and discontinuous with 2, 3, or 4 segments: (i) if $\tilde{L}^+ > \bar{L}^*$, then $L_2 = 0$ for $\bar{L} < L^+$ and $L_2 = a + b\bar{L}$ for $\bar{L} > \tilde{L}^+$; (ii) if $\sigma_1 < \sigma_{12}$, then $L_2 = 0$ for $\bar{L} < \bar{L}^+$, $L_2 = \bar{L}$ for $\bar{L}^+ < \bar{L} < \bar{L}^*$, $L_2 = a + b\bar{L}$ for $\bar{L}^* < \bar{L} < \hat{L}$, and $L_2 = 0$ for $\bar{L} > \hat{L}$; and (iii) if $\sigma_1 > \sigma_{12}$ and $\bar{L}^+ < L^*$, then $L_2 = 0$ for $0 < \bar{L} < \bar{L}^+$, $L_2 = \bar{L}$ for $\bar{L}^+ < \bar{L} < \bar{L}^*$, and $L_2 = a + b\bar{L}$ for $\bar{L} > \bar{L}^*$. In each case

$$(20) \qquad a = \frac{\mu_2 - \mu_1}{|A|}, \qquad b = \frac{\sigma_1 - \sigma_{12}}{\sigma_1 + \sigma_2 - 2\sigma_{12}}.$$

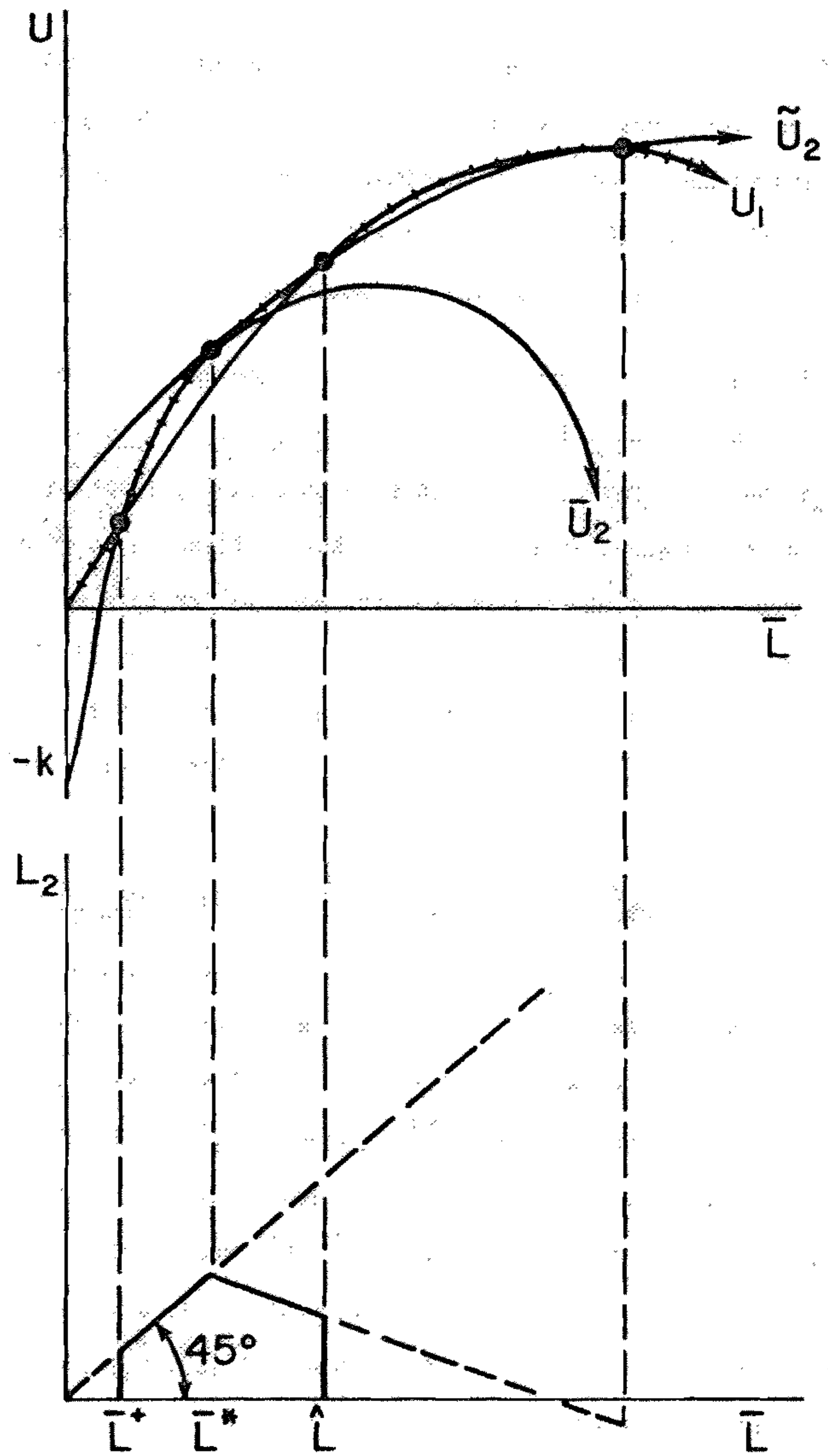

Figure 2c

Adoption with High Covariance

To develop further results with respect to the distribution of risk attitudes and other parameters among farmers, the results in Table 1 are useful. These results can be confirmed by simple differentiation of equations (16), (17), (18), (19), and (20). On this basis, some rather peculiar results are obtained depending on the distribution of farm sizes among farms.

PROPOSITION 7: Farmers with greater risk aversion do not necessarily adopt the modern technology at a lower rate even though it is viewed as more risky, <u>ceteris paribus</u>. In case (i) of Propositions 5 and 6, adopting farms with higher risk aversion adopt at a lower rate; but if fixed costs of adoption are high, farmers with greater risk aversion and smaller farm sizes may adopt when less risk-averse farmers would not. In cases (ii) and (iii), adopting farms with higher risk aversion adopt at a lower rate; but if fixed costs are low, farmers with greater risk aversion and smaller farm sizes may adopt when others would not.

PROOF: Comparing two levels of risk aversion, ϕ_0 and ϕ_1, on a given farm size ($\phi_1 > \phi_0$), let $\overline{L}_i^*$, $\overline{L}_i^+$, $\tilde{L}_i^+$, and $\hat{L}_i$ represent the critical levels in (16) through (19) with risk-aversion parameter, ϕ_i. Then using Table 1, case (i) implies lower rates of adoption for farm sizes $\overline{L}$ $(\tilde{L}_0^+, \infty)$ under ϕ_1 than under ϕ_0, but adoption occurs for $\overline{L}$ $(\tilde{L}_1^+, \tilde{L}_0^+)$ under ϕ_1 if k is high, whereas it does not under ϕ_0. Case (iii) implies lower rates of adoption under ϕ_1 for $\overline{L}$ $(\overline{L}^*, \hat{L}_0)$, but farm sizes with $\overline{L}$ $(\overline{L}^+, \overline{L}^+)$ adopt under ϕ_1, whereas they do not under ϕ_0 if k is low. In case (iii), adoption rates are lower under ϕ_1 for L $(\overline{L}_1^*, \infty)$; but farms with $\overline{L}$ $(\overline{L}_1^+, \overline{L}_0^+)$ adopt under ϕ_1, whereas they do not adopt under ϕ_0 if k is low.

TABLE 1.

COMPARATIVE STATIC RESULTS FOR SWITCH POINTS

Y	X			
	$\bar{L}^*$	$\bar{L}^+$	$\tilde{L}^+$	$\hat{L}$
	sign of dX/dY			
ϕ	−	+ for k large − for k small	− for k large + for k small	−
$\mu_2 - \mu_1$	+	−	−	+

REMARK 3: Propositions 6 and 7 imply that the distribution of resource endowments and behavioral attitudes among farmers is essential in determining aggregate as well as distributional impacts associated with the introduction of new technology. For example, consider two distributions where all farmers have the same risk aversion with land sizes concentrated at $\bar{L}^*$ in the first case but with many below $\bar{L}^+$ (and above $\hat{L}$) in the second case. Then in cases (ii) or (iii) of Proposition 6, aggregate adoption will be much higher with the first distribution than with the second depending on the level of fixed costs. Alternatively, consider two situations with the same marginal distributions of farm size and risk aversion. But suppose in the first, farms with sizes near $\bar{L}^+$ have high risk aversion relative to the second case. Then aggregate adoption could be much greater in the first situation if either case (ii) or (iii) of Proposition (6) applies. These results thus imply that, because of discontinuities in adoption behavior at points $\bar{L}^+$, $\bar{L}^*$, $\tilde{L}^+$, or $\hat{L}$, distributional considerations are absolutely necessary in studying even aggregate behavior.

III. DISTRIBUTIONAL CONSEQUENCES OF NEW TECHNOLOGY

In addition to allowing adequate study of aggregate behavior, the framework of this paper is useful for studying the distributional consequences of new technology. As suggested in the introduction, some concern has been expressed in the literature that new technology may be undesirable regardless of aggregate effects if income distribution is adversely affected. In the context of this paper, the appropriate concept of income is expected utility rather than simply profit or expected profit since changes in the measure of expected utility used above reflect compensating (equivalent) variation, i.e., of willingness to pay or receive in lieu of the changes. That is, risk is an economic bad in the context of risk aversion, and those who bear higher risk are worse off in terms of "real" income.

The distributional effects of new technology can be examined under a variety of assumptions depending on the size of the associated sector, i.e., the extent to which adoption affects the prices of inputs and outputs. For the case where prices are unaffected, one finds

PROPOSITION 8: If demands for products and supplies of inputs are perfectly elastic, then incomes for small farmers with farm sizes below $\bar{L}^+$ in cases (ii) and (iii) or below $\tilde{L}^+$ in case (i) are unaffected <u>absolutely</u>, while incomes for larger farmers increase with the introduction of new technology except for farm sizes above $\hat{L}$ in case (ii) which are also unaffected. Thus, income distribution tends to widen in cases (i) and (iii), and small farmers become <u>relatively</u> worse off in any case. Large farmers may also be relatively worse off in the high covariance case (ii).

PROOF: Immediate upon comparing the cross-hatched utility curve with U_1 in Figures 2a, 2b, and 2c.

Turning to the more interesting cases where price impacts of adoption are realized, suppose the new technology is, say, a high-yielding variety and, thus, following a usual Green Revolution scenario, is labor using. In this case, allocation of more land to the new technology causes greater labor use (recall that fixed proportions production is assumed); hence, the greater demand for labor causes wage rates to increase. Since the new technology uses more labor per hectare, this will cause μ_2 to fall by more than μ_1 so that $\mu_2 - \mu_1$ falls. Thus, one finds

PROPOSITION 9: If new technology is labor using and thus drives wage rates up, then small <u>nonadopting</u> farmers are worse off both relatively and absolutely. The smaller <u>adopting</u> farmers can also be worse off both relatively and absolutely. Larger farmers may be either better off or worse off depending on the extent of wage rate adjustments except in the high covariance case where the largest farmers are worse off in both senses without question.

PROOF: To conserve space, only a heuristic proof will be given. First, note that in all three cases (Figures 2a, 2b, and 2c), U_1 and $\bar{U}_2$ shift down by a difference which is linear and increasing in $\bar{L}$ (due to fixed proportions production) but greater in the case of $\bar{U}_2$. Also, U_2 shifts down similarly to maintain tangency with $\bar{U}_2$. Where <u>ex ante</u> critical points (before the wage increase) are represented by "0" subscripts and <u>ex post</u> critical points were represented by "1" subscripts, it is clear from Table 1 that $\bar{L}_1^* < \bar{L}_0^*$, $\bar{L}_1^+ > \bar{L}_0^+$, $\tilde{L}_1^+ > L_0^+$, and $\hat{L}_1 > \hat{L}_0$. Hence, farmers are clearly worse off if $L < L^+$ in cases (ii) and (iii), $\bar{L} < \tilde{L}^+$ in case (i), and $\bar{L} > \bar{L}_0$ in case (ii). Farms of other sizes may be better off; but if wage impacts are sufficiently great, then the <u>ex post</u> relevant portion of $\bar{U}_2$ and $\tilde{U}_2$ may lie below the <u>ex ante</u> U_1. However, farmers would not return to the old technology because the <u>ex post</u> U_1 may be even less than the <u>ex post</u> relevant portions of $\bar{U}_2$ and $\tilde{U}_2$.

REMARK 4: Proposition 9 suggests that, under certain conditions, new technology may indeed have an adverse impact on income distribution; furthermore, aggregate farm income, as well as income for every individual farmer, can even decline. This disturbing result is due partly to the phenomena of unfulfilled expectations and partly to competition. With unfulfilled expectations, farmers can realize less income than they expect with adaptive or extrapolative expectations because wage increases are not adequately forecasted. In this case, some farmers with $\overline{L}$ $(\overline{L}_0^+, \overline{L}_1^+)$ in cases (ii) and (iii), with $\overline{L}$ $(\tilde{L}_0^+, \tilde{L}_1^+)$ in case (i), or with $\overline{L}$ $(\hat{L}_1, \hat{L}_0)$ in case (ii) may actually adopt and find later that they would have been better off in an ex post sense if they had not adopted. For other adopting farm sizes, however, even perfect foresight on the part of an individual farmer may not save him from adverse effects. If wage rates adjust because of other farmer's behavior, then a farmer may find his ex post $\overline{U}_1$, $\tilde{U}_2$, and U_2 all below his maximum attainable ex ante utility; and, except in the above intervals, the relevant portions of U_2 and U_2 would dominate U_1 indicating adoption also at ex post prices. If all farmers have perfect foresight, then it is not possible for all farmers to be worse off; but if only some farmers are better off in an ex post sense with adoption, their actions will influence wage rates making nonadopters worse off. It is clear from the directional movement of critical points, however, that greater adjustment of wage rates (more inelastic labor supply) with fulfilled expectations (foresight) leads to less adoption than imperfect foresight (or prior to attainment of fulfilled expectations equilibrium) in cases (i) and (iii) and a contraction of the set of adopting farms in every case regardless of farm size distribution.

PROPOSITION 10: Suppose input prices are unaffected but product demand is not perfectly elastic.

a. If the new technique produces essentially the same crop as the traditional technique so that increased production depresses both prices, then small nonadopting farms are worse off both relatively and absolutely than without introduction of the new technology. If covariance is high, then some large farms may also be worse off in both senses.

b. If, on the other hand, the new technique produces an essentially different crop than the traditional technique (with zero or negative cross-price elasticity of demand), then increased adoption depresses price of the modern crop; but as land is shifted away from the traditional crop, the price of the traditional crop increases. Hence, nonadopting farmers (small or large) are better off in an absolute sense.

PROOF: From Proposition 5, small farms with $\bar{L} < \bar{L}^+$ in cases (ii) and (iii) or $\bar{L} < \tilde{L}^+$ in case (i) and large farms with $\bar{L} > \hat{L}$ in case (ii)--with inequalities holding for both <u>ex ante</u> and <u>ex post</u> critical points--have expected utility following introduction of the new technology as specified by the <u>ex post</u> U_1. However, if p_1 falls (for every state of the environment), then these farms must be worse off, whereas if p_1 rises, these farms are better off in an absolute sense.

REMARK 5: Proposition 10 suggests that some types of new technologies may be more desirable than others not so much because of increased profit expectations but because of economic relationships of new products with existing ones. In point of fact, Green Revolution technologies associated with high-yielding varieties of existing crops would seem, on the basis of Proposition 10, to lead to more adverse effects on income distribution than if similarly profitable alternative crops could have been developed. Only in this case could extensive adoption of the new technology (extensive enough to cause product price adjustment) avoid adverse impacts on even absolute incomes of small farmers.

Propositions 9 and 10 are developed here merely to give a flavor of the type of distributional consequences that can be examined in the framework of this paper. Lack of space prevents analysis of a host of other issues and cases. It is clear, however, that Proposition 9 can be reformulated for the case of an input-saving new technology, i.e., a laborsaving capital innovation, or the case where a new technology uses other inputs than employed by the traditional technology. In these cases, traditional input prices would fall and nonadopters would be absolutely better off as in the case of independent products in Proposition 10. This suggests that technologies should be sought which intensively use inputs available in elastic supply or which use different inputs or use labor in different seasons than the traditional technology. Proposition 10 can also be generalized along the lines of Proposition 9 and Remark 4 to consider consequences of fulfilled versus unfulfilled expectations. In each case, myopic (unfulfilled) expectations can cause a small group of farm sizes to be worse off with adoption than nonadoption. Over time, such farmers would eventually return to the old technology or learn by doing to the point of being better off under the new technology. Other issues which could be usefully investigated are the effects of subsidies on adoption, extension activities, and adoption over time that might take place with learning.

IV. CONCLUSIONS

The results in this paper show that the distribution of resource endowments and behaviorial parameters among farmers is crucial and necessary in determining both the aggregate and distributional impacts of introducing new technology. While the framework has been kept quite simple for the purpose of demonstrating these results, extensions (e.g., consideration of credit constraints) are possible along the same lines.

Furthermore, empirical implementation of the framework is feasible. The rate of adoption relationships in Figures 2a, 2b, and 2c are piecewise linear with well-specified "knots" between linear segments. Thus, spline function regression methods should provide a useful approach to estimation. Aggregation can then be carried out by integration with respect to a distribution of resource endowments and other parameters among farmers. Such a distribution can be either estimated or observed depending on data availability. For example, suppose $F(\overline{L})$ denotes the distribution of land endowments among decision-makers and $L_2(\overline{L})$ is the piecewise linear and discontinuous response function depicted in Figures 2a, 2b, or 2c. Then the aggregate adoption of the new technology in terms of land area is given by $N = \int L_2(\overline{L})dF(\overline{L})$ where N is the number of farms. Where $U(L)$ is the associated piecewise quadratic expected utility function, the income distribution is given by $F(U^{-1}(U))$ where U^{-1} is the inverse function which satisfies $U^{-1}(U_0) = \overline{L}_0$ when $U_0 = U(L_0)$.

One of the most important characteristics of most all technology problems has to do with asset fixity and fixed costs attached to change. Asset fixity and high fixed costs of adoption, whether pecuniary or not, cause significant discontinuities in behavioral response. Only by considering the distribution of individual decision-makers around those discontinuities can either aggregate or distributional consequences of new technology be investigated in terms of an operational model.

NOTES

1. van Der Veen attributed the inverse relationship to (a) land on small farms was utilized more intensively to meet subsistence needs, (b) generally, smaller farms have better irrigation facilities, and (c) more low-cost family farm labor per unit of land is available on small farms. It should be noted that van Der Veen did not conduct a formal empirical analysis to support or deny the importance of these potential emplanatory factors.
2. Moreover, the empirical results of Schluter (1971), Sharma (1973), and van Der Veen (1975) verify that larger farmers devote smaller shares of their land to the newer technology.
3. For the sake of brevity, the peculiar cases where $\sigma_1 = \sigma_2$ or $\sigma_1 = \sigma_{12}$, which suggest modifications of equations (17) and (18), will not be considered.

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