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MODELING THE EFFECTS OF POLICY ON FARMERS IN DEVELOPING AGRICULTURE
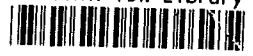
by

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1. Introduction

Over the last decade, the focus of attention in the development community has shifted from preoccupation with economic growth to some emphasis on distribution. Some recent research has cast doubt on the generality of neoclassical assumptions regarding the negative effects of redistribution on the incentives to work and save (Krishna). Some countries, particularly Yugoslavia, China, Korea, and Taiwan, have successfully reconciled growth with poverty reduction even in the early stages of development. Moreover, the Taiwanese case has demonstrated that, with a suitable growth pattern, growth and equity is most easily reconciled in the agricultural sector.

The equity impacts of selected government policies have been addressed by a number of different frameworks, most of which are based on aggregative relationships. Generally, aggregative relationships are specified for an agricultural sector and a nonagricultural sector. The microeconomic foundations of these frameworks, however, are not generally specified. As a result, the distributional consequences of development policy are unclear.

The purpose of this paper is to advance a framework for evaluating the impact of governmental policies on developing agriculture assuming that the major source of growth is technological change at the microlevel. The need for such models has been emphasized by the recent survey of Feder, Just, and Zilberman. The framework focus is on the incentives and constraints for technological adoption. The distributional consequences of various policies are shown to depend upon landownership, land utilization, and the technology associated with land assets.

Without loss of generality, a stylized model involving two technologies, traditional and modern, is specified. The framework admits a number of important features including uncertainty, varying degrees of risk aversion, both fixed and variable costs of technological adoption, and credit as well as land constraints. The model design allows the evaluation of a wide array of various policies. This set of policies includes particular instruments often pursued by developing country governments. In particular, we examine price support, credit-funding enhancement, credit subsidies, fixed crop insurance, price stabilization, input subsidies, and extension promotion.

In the determination of the distributional consequences of governmental intervention, a comparative evaluation of the above policies is performed. However, it should be noted that the model design is readily amendable to investigating the efficiency and equity consequences of integrated, comprehensive sets of policy. The latter evaluations can be most usefully achieved once the model is empirically implemented. The results suggest that egalitarian development strategies can be determined which involve an integration of various policies.

The basic microeconomic foundations of the framework are developed in section 2. Section 3 focuses on the microeconomic behavior of various farmers under alternative policies. Finally, the concluding section examines the operational use of the developed framework. Formal derivations of the important relationships are presented in the Appendix.

2. The Model

Consider initially a single farm with fixed landholdings, L, valued at price, p_L, and a traditional technology involving a subjective distribution

of net returns per hectare $\pi_0 = p_0 y_0$ with mean $E(\pi_0) = m_0$ and variance $V(\pi_0) = \sigma_0$ where p_0 and y_0 are the price and yields, respectively, under the traditional technology. Suppose a new technology is introduced under which 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 (technique), which will be referred to as the "modern crop," may be a high-yielding variety or a cash crop utilizing a modern input such as fertilizers, insecticides, and improved seeds. On the other hand, it may be more vulnerable to weather variations so that there is a relatively 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 not more susceptible to extreme weather situations than the traditional crop.

Suppose production of the modern crop requires a cost of w for the modern input per hectare to attain a subjective distribution of net returns per hectare π_1 with mean $E(\pi_1) = m_1$ and variance $V(\pi_1) = \sigma_1$. Suppose the (opportunity) cost of funds used to finance the modern input is given by r so that $\pi_1 = p_1 y_1 - w(1 + r)$ where p_1 and y_1 are the price and yield of the modern crop, respectively, and $p_1 y_1$ is normally distributed. Also, suppose that net returns of the traditional and modern crops are correlated with $\text{corr}(\pi_0, \pi_1) = \rho$.

Specifically, assume

$$\begin{pmatrix} \pi_0 \\ \pi_1 \end{pmatrix} \sim N \left[\begin{pmatrix} m_0 \\ m_1 \end{pmatrix}, \begin{pmatrix} \sigma_0^2 & \rho\sigma_0\sigma_1 \\ \rho\sigma_0\sigma_1 & \sigma_1^2 \end{pmatrix} \right]$$

with the relevant covariance matrix assumed to be positive definite; further reasonable assumptions include $m_0 > 0$, $m_1 > 0$. Also note that the variances and covariances include <u>subjective</u> uncertainty about yields and market access (prices) and may thus be influenced by both experience and extension efforts.

The farmer must either allocate all his land to the traditional technology or incur a fixed set-up cost, k, for the new technology in which case he can allocate his land in any proportion between the two technologies. Thus, the investment decision is a discrete choice whereas the land-allocation decision is a continuous choice. In addition to the fixed set-up cost, k, for which the annualized cost is rk, the farmer also incurs a variable cost, w per hectare, for adoption. Both of these costs must be considered in the context of available credit, K, in making the adoption decision. The credit constraint is

$$I(k + wL_1) \leq K$$

where $I = 0$ if the modern technology is not adopted, $I = 1$ if the modern technology is adopted, and L_1 is the amount of land allocated to the new technology.

Now assume that the farmer is risk averse with utility function $U(\cdot)$ defined on wealth, $U' >$, $U'' \leq 0$. Suppose that wealth, W, at the end of each season is represented by the sum of land value, $p_L L$, and the net return from production. Where L_0 is the amount of land allocated to the traditional technology, the decision problem is thus

$$\max_{\substack{I = 0, 1 \\ L_0, L_1}} EU[p_L L + \pi_0 L_0 + I (\pi_1 L_1 - rk)] \qquad (1)$$

subject to

$$L_0 + IL_1 \leq L$$

$$I(k + wL_1) \leq K$$

$$L_0, L_1 \geq 0.$$

The results below assume that risk aversion is not so great or returns so poor as to prevent use of all available land. Thus, the land constraint can be replaced by a strict equality.

To solve this decision problem, first consider the choice of land allocation given the adoption decision. Assuming full utilization, the optimal decision with $I = 0$ is $L_0 = L$. Thus, expected utility is

$$U_0 (L) = EU[(p_L + \pi_0) L]. \qquad (2)$$

Alternatively, given adoption, the objective of the decision problem in (1) becomes

$$\max_{L_0, L_1} EU[p_L L + \pi_0 L_0 + \pi_1 L_1 - rk] \qquad (3)$$

subject to

$$L_0 + L_1 \leq L$$

$$k + wL_1 \leq K$$

$$L_0, L_1 \geq 0.$$

The solution to this problem is approximated by (see the Appendix):

$$
L_1 = \bar{L}_1 \equiv \begin{cases} 0 & \text{if } L_1^* < 0 \text{ or } k > K \\[4pt] L_1^* & \text{if } 0 \le L_1^* \le L \text{ and } (K - k)/w > 0 \\[4pt] (K - k)/w & \text{if } L > L_1^* > (K - k)/w > 0 \\[4pt] L & \text{if } (K - k)/w > L \text{ and } L_1^* > L \end{cases}
\tag{4}
$$

and $L_0 = \bar{L}_0 \equiv L - \bar{L}_1$

where

$$
L_1^* = \frac{E(\Delta\pi)}{\phi V(\Delta\pi)} + L R
\tag{5}
$$

$$
R = \frac{\sigma_0^2 - \rho\sigma_0\sigma_1}{\sigma_0^2 + \sigma_1^2 - 2\rho\sigma_0\sigma_1}
\tag{6}
$$

$$
\Delta\pi = \pi_1 - \pi_0
\tag{7}
$$

$$
\phi = \frac{-U''(\bar{W})}{U'(\bar{W})}
\tag{8}
$$

$$
W = p_L L + m_0 L + E(\Delta\pi) L_1 - rk.
\tag{9}
$$

Note that ϕ is the coefficient of absolute risk aversion at expected wealth.

This result is intuitively clear from Figure 1 upon noting that (3) is a concave programming problem with linear constraints. Assuming full utilization of land, the optimal solution must lie on the line ac. For mathematical convenience, the Appendix derives L_1^* as the optimal solution for L_1 when

negative choices for land quantities are possible (corresponding to the broken lines in Figure 1). Thus, by concavity of the objective function, the optimum is at point c if $L_1^* < 0$. If the credit is abundant (e.g., $K = K_1$ in Figure 1), then the optimum is at point a if $L_1^* > L$. However, if credit is insufficient to allow complete adoption such as if $K = K_0$ in Figure 1, then the segment ab is infeasible because of credit limitations. Thus the optimum is at point b if $L_1^* > (K - k)/w$.

To determine the technology choice, let

$$U_1 (L, \overline{L}_1) = EU[p_L L + \pi_0 (L - \overline{L}_1) + \pi_1 \overline{L}_1 - rk].$$

Assuming either that the farmer is myopic (or considers future periods to be like the current one), the farmer selects the traditional technology if $U_0 > U_1$ and selects the new technology if $U_1 > U_0$.

3. Behavior of Individual Farmers Under Alternative Policies

Based on the model of individual farmers in section 2, the Appendix investigates the mathematical properties of farmer behavior under several alternative development policies. This is done by first examining the effects of alternative policies on farmers given the adoption decision and then investigating effects on adoption decisions. The results are summarized in the propositions of this section. The policies considered are price support, credit-funding enhancement, credit subsidy, fixed crop insurance, price stabilization, modern input subsidy, cost subsidy extension, promotion, and land reform. Price support, crop insurance, and price stabilization are considered both in cases where the new technology is associated with a new and
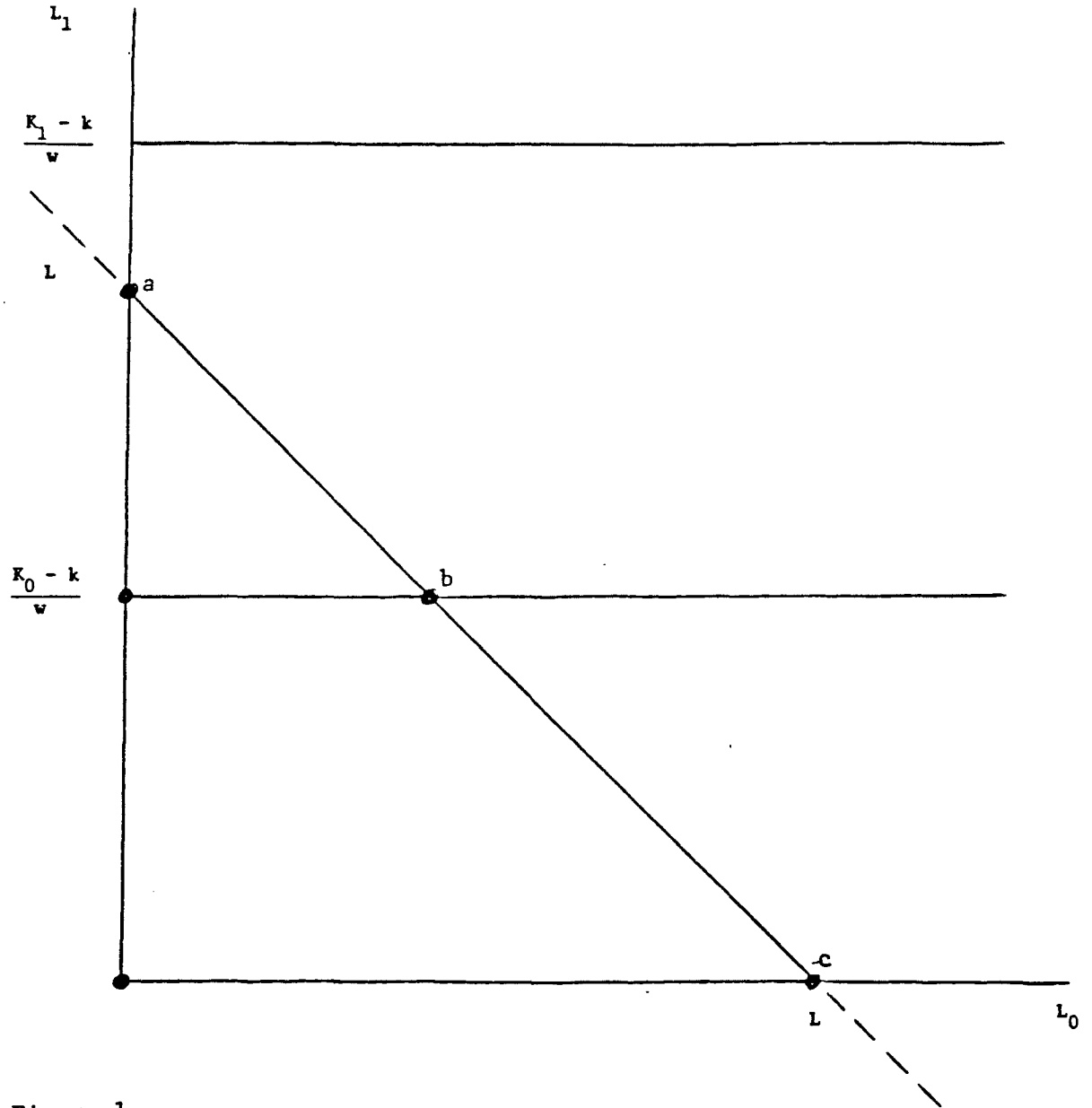
Figure 1

different crop and where the new technology is simply a new production method or variety of the same crop (in which case the controls may also directly affect farmers who are using the old technology).

The parameters through which these policies are reflected in the model are m_1, σ_1, w, K, k, r, L, m_0, and σ_0. Specifically, a price support is assumed to cause the expected returns per hectare under the new technology, m_1, to increase, and the variability of returns per hectare under the new technology, σ_1, to decrease. If the price support also applies to the existing crop, then similar effects are assumed for the old technology except that the effect on both expected returns and variability of returns per hectare under the old technology is relatively less ($dm_0 = \beta_m \, dm_1$ where $0 < \beta_m < 1$ and $d\sigma_0 = \beta_\sigma \, d\sigma_1$ where $0 < \beta_\sigma < 1$).[1]

Credit funding enhancement (for example, through an additional public source of funds) is assumed to increase the farmer's credit limit, K, at the same cost of capital as otherwise. Credit subsidy, either directly or through loan guarantees, is assumed to lower the effective cost of capital, r.

Crop insurance is assumed to be actuarially fair and lower the variability of returns per hectare under the new technology, σ_1, without affecting expected returns per hectare. If the new technology applies to the same crop as the old technology (crop insurance applies in both cases), then similar assumptions apply to the old technology except that the effect on the variability of returns per hectare under the old technology is relatively less (as suggested by the assumption that the new technology is viewed as relatively more risky). The effect of price stabilization is thus the same as for crop insurance.

A subsidy on modern input use is reflected by a reduction in variable input costs per hectare, w. A subsidy on the fixed cost incurred in adoption is reflected by a reduction in k.

Several types of extension effects are considered. Extension contacts can cause a farmer to increase his subjective expectations of returns per hectare under the new technology, m_1, and/or to reduce his subjective variability of returns under the new technology, σ_1. In addition, extension contact can reduce some of the fixed costs (search and learning) associated with adoption as reflected in k. Finally, land reform is reflected by a change in farm size L. Given the above preliminaries, it is possible to derive a number of propositions which admit testable hypotheses on the behavior of individual farmers. These propositions focus on technology adoption choices under each of the various policies.

Proposition 1: Price Support. If the new technology pertains to a new crop, then a price support will cause adopting farmers to increase intensity of use of the new technology unless they have already fully adopted or have exhausted their credit (in which case, there is no intensity effect); also, the tendency to adopt is increased among nonadopting farmers for whom credit permits. If the new technology pertains to the existing crop, then a price support will cause adopting farmers to increase intensity of use of the new technology unless they have already fully adopted or have exhausted their credit if the correlation of returns under the two technologies is high $(\rho > \beta_\sigma)$ and the expected per hectare gains from adoption are high $(\beta_m < L_1/L_0)$. However, intensity of use will decrease in the same case if the correlation of returns is low $(\rho < \beta_\sigma)$ and the expected increase in returns per hectare is low $(\beta_m$ close to 1).

To determine the effects of price support policies, we clearly need data on adopting and nonadopting farmers; the availability of credit across each of these two groups of farmers; and the correlation among the returns under the two technologies. Proposition 1 suggests the price support policies cannot be pursued independently of credit market conditions. In particular, a well-designed price support policy which neglects the availability of credit may not have the intended effect on technological adoption.

Proposition 2: Credit Funding. The effect of a public credit program that increases credit availability at the market interest rate is to increase the intensity of adoption for adopting farmers who have exhausted their credit limit; the intensity of adoption is unaffected for other adopting farmers. In addition, the tendency to adopt among nonadopting farmers increases but only among those for whom credit is initially insufficient to finance adoption.

Proposition 3: Credit Subsidy. The effect of a credit subsidy or public loan guarantee which lowers effective interest rates for farmers is to increase the intensity of adoption among adopting farmers unless they have already fully adopted or exhausted their credit (in which case there is no intensity effect); in addition, the tendency to adopt increases among all nonadopting farmers.

Effective evaluations of credit funding requires data on the profiles of nonadopting farmers, particularly their credit availability and degree of risk aversion. Once again, a combination of policies may prove to be more effective in achieving desired results. The effect of a credit subsidy on lowering the effective cost of capital may be minimal due to the exhaustion of available credit.

Proposition 4: Crop Insurance or Price Stabilization. If the new technology pertains to a new crop, then the effect of actuarially fair crop insurance or mean-preserving price stabilization is to increase the intensity of adoption among adopting farmers unless they have already fully adopted or have exhausted their credit (in which cases there is no intensity effect); in addition, the tendency to adopt is increased among nonadopting farmers for whom credit permits. If the new technology pertains to the existing crop, then among adopting farmers who have not already fully adopted or exhausted their credit, crop insurance or price stabilization causes an increase in the intensity of adoption if the correlation of returns under the two technologies is low ($\rho < \beta_\sigma$), while the intensity decreases if the correlation is high ($\rho > \beta_\sigma$); the intensity of adoption is unaffected for other adopting farmers.

A well-designed crop insurance or price stabilization policy may not have the intended intensity effect unless sufficient financial credit is available. Simply lowering the variability of returns under the new technology through crop insurance or some other means may not have any effect on the rate of adoption.

Proposition 5: Modern Input Subsidy. The effect of a subsidy on the modern input is to increase the intensity of adoption among adopting farmers who have not already fully adopted. In addition, the tendency to adopt increases among all nonadopting farmers except those who have insufficient credit to finance the initial outlay.

Proposition 6: Fixed Cost Subsidy. The effect of a subsidy on the fixed cost of adoption (a one-time subsidy for adoption) is to increase the intensity of adoption among adopting farmers who have not already fully adopted. Also, the tendency to adopt increases among all nonadopting farmers.

As one would expect, the effects of input subsidies or fixed cost subsidies are qualitatively equivalent. Each of these two policies in effect expands the credit constraint and, thus, the intended effects may be more easily accomplished.

Proposition 7: Extension. (a) The effect of extension activities that improve farmers' subjective distributions of returns under the new technology is to cause adopting farmers to increase the intensity of adoption if they have not already fully adopted or exhausted their credit (intensity of adoption for other adopting farmers is unaffected). In addition, the tendency to adopt increases among nonadopting farmers for whom credit permits. (b) The effect of extension activities that reduce perceived search and learning costs connected with adoption is to increase the intensity of adoption among adopting farmers who have not already fully adopted. Also, the tendency to adopt increases among all nonadopting farmers except for those who have insufficient credit to finance the initial unavoidable pecuniary costs.

Effective extension programs can simultaneously operate on the perceived probability distribution of returns under the new technology as well as the transaction cost associated with learning about the effective utilization of the new technology. This latter effect, through the measure of fixed costs, reduces the demand on available credit. Nevertheless, the most effective extension program will not achieve the intended effects if credit is simply unavailable.

Proposition 8: Land Reform. The effect of an increase in land endowment among adopting farmers with nonbinding credit is to increase the intensity of adoption if a farmer is fully adopted (all new land is allocated to the new technology) or if the intensity of adoption is low relative to the correlation

of yields among the two technologies and to decrease the intensity of adoption if the intensity of adoption is high relative to the correlation of yields. The effect among adopting farmers with binding credit is to reduce the intensity of adoption since all new land is allocated to the old technology.

Obviously, land reform without corresponding policies related to credit funding, credit subsidies, input subsidies, or fixed cost subsidies may prove to be totally ineffective. Tight credit or its unavailability will, in fact, reduce the adoption rate of the more modern technology under a land reform policy.

4. Conclusions and Implications for Equity and Efficiency

The results in Propositions 1-8 show that the effects of policies on adoption of new technology can differ widely among farmers with different characteristics and that the distribution of effects can differ widely depending on the type of policy used. Furthermore, the results imply that a mix of policy instruments may be necessary to attain equitable impacts. For example, Proposition 1 implies that a price support improves the rate of adoption except for farmers with binding credit constraints. Thus, equitable effects may require a combination of price supports with credit funding or loan guarantees. Proposition 5 implies that a modern input subsidy in the absence of credit funding policies can suffer from similar problems.

Assuming the output price effects of adoption are minor, adoption or an increase in the extent of use of the new technology can be further translated into an increase in expected utility. In this context, the results of Propositions 1-8 hold important implications about the trade-off between equity and

efficiency among farmers. To see this, suppose that microparameters, such as land holdings and risk aversion, vary among farmers. Then, for example, from Proposition 1, if the new technology pertains to a new crop, then a price support will cause aggregate farm income to increase since some farms are made better off while others are unaffected. However, only full adopters and partial adopters become better off while poor farmers who cannot afford to adopt are unaffected thus widening the income distribution.

Alternatively, if the new technology pertains to the existing crop, then a price support will cause the well-being of every individual farmer to improve. But in the case where the major barriers to adoption are credit and set-up costs, adoption is unaffected so efficiency does not improve even though the minimum income level is elevated.

From Proposition 2, both equity and efficiency can be increased in the latter case by a public credit program that increases credit availability at the market interest rate. A simple credit subsidy, on the other hand, would not improve efficiency when the major barrier to adoption is the credit limit. Since poor farmers rather than rich farmers are likely limited by credit availability, a credit subsidy by itself likely widens income distribution (if poor farmers have insufficient credit to adopt, they gain no benefit from a credit subsidy).

From Proposition 5, the effect of a subsidy on the modern input is to increase aggregate farm income. However, nonadopting farmers are unaffected, while the welfare of both fully adopting and partially adopting farmers is improved. Thus, income distribution is again adversely affected even though adoption is encouraged. Only by combining credit policies with modern input subsidies would it be possible to insure that smaller farmers benefit.

The propositions of this paper thus reveal the varying qualitative effects that can be achieved by different policies. They demonstrate the importance of different types of barriers to adoption and, perhaps more importantly, the need to operate with more than a single policy regime. In other words, positive equity effects can be achieved more readily by operating with a mix of policies rather than a single policy.

Appendix

Using equation (4), this appendix derives the properties of the optimal solution to (3) as functions of the control variables, m_1, σ_1, w, K, k, r, and L. For these purposes, assume

$\phi > 0$

$\sigma_0^2 + \sigma_1^2 - 2\rho\sigma_0 \sigma_1 > 0$

$m_0 = \beta_m m_1 < m_1$

$\sigma_0 = \beta_\sigma \sigma_1 \leq \beta_m \sigma_1$

$\rho \geq 0$

$0 \leq \eta \equiv -\phi' \overline{W}/\phi \leq 1.$

Note that η is elasticity of risk aversion. As shown by Just and Zilberman, $\eta \geq 0$ corresponds to nondecreasing absolute risk aversion and $\eta \leq 1$ corresponds to nonincreasing relative risk aversion.

Under the assumption of full utilization of land ($L_0 + L_1 = L$), the problem in (3) can be rewritten as

$$\max_{L \geq L_1 \geq 0} \quad EU[(p_L + \pi_0) L + (\pi_1 - \pi_0) L_1 - rk] \tag{A1}$$

subject to

$$k + wL_1 \leq K.$$

Just, Zilberman, and Rausser show that the objective function in (A1) is strictly concave. Thus, the optimum must either be attained internally and be equivalent to the unconstrained optimum or the optimum must be attained at one of the points where constraints are binding. The first-order condition for maximization of the unconstrained problem is

$$\frac{dEU}{dL_1} = E[U'(\pi_1 - \pi_0)] = 0$$

and, as shown by Just and Zilberman, is approximated by

$$E(\Delta\pi) - \phi[L_1 V(\Delta\pi) + L(\rho\sigma_0 \sigma_1 - \sigma_0^2)] = 0 \qquad (A2)$$

The solution, L_1^*, is given by (5) using (6)-(9). Thus, based on the graphical argument related to Figure 1, the solution to the constrained problem is given by (4).

From (A2), second-order conditions require

$$- \phi V(\Delta\pi) \left[1 - \eta \frac{E(\Delta\pi)}{\phi L V(\Delta\pi)} \frac{L E(\Delta\pi)}{\overline{W}} \right] < 0.$$

To see that this condition holds, note that $L_1 \leq L$ implies from (5) that any internal solution must satisfy

$$\frac{E(\Delta\pi)}{\phi L V(\Delta\pi)} \leq 1 - R = \frac{1}{1 + \dfrac{\sigma_0(\sigma_0 - \rho\sigma_1)}{\sigma_1(\sigma_1 - \rho\sigma_0)}} \leq \frac{\sigma_1}{\sigma_1 - \sigma_0} \leq \frac{1}{1 - \beta_m} .$$

Hence,

$$D = 1 - \eta \frac{E(\Delta\pi)}{\phi L V(\Delta\pi)} \frac{L E(\Delta\pi)}{\overline{W}} \geq 1 - \eta \frac{m_1 \overline{L}}{\overline{W}} \geq 0 \qquad (A3)$$

assuming perceived average income is less than expected wealth at the end of the production period (which includes perceived income).

Because of the nature of the solution in (4), the effects of the controls tend to differ according to the four conditions in the right-hand side of (4). Thus, for simplified notation, let the case of a lower bound (LB) solution denote $L_1^* < 0$ or $k > K$; let the case of an internal solution (IS) denote $0 \leq L_1^* \leq L$ and $(K - k)/w > 0$; and let the case of a binding credit (BC) solution denote $L \geq L_1^* > (K - k)/w > 0$; and let the case of an upper bound (UB) solution denote $(K - k)/w > L$ and $L_1^* > L$.

Using (4) and (A3), one finds

$$\frac{dL_1}{dm_1} = \begin{cases} \dfrac{1}{\phi DV(\Delta\pi)} \left[1 + \eta \; L_1 \; \dfrac{E(\Delta\pi)}{\overline{W}} \right] > 0 & \text{if IS} \\[3em] 0 & \text{if LB, BC, or UB} \end{cases} \tag{A4}$$

$$\frac{dL_1}{d\sigma_1} = \frac{dL_1}{d\overline{\sigma}} = \begin{cases} - \dfrac{1}{DV(\Delta\pi)} \left[L_1 \; (2\sigma_1 - \rho\sigma_0) + L \; \rho\sigma_0 \right] < 0 & \text{if IS} \\[3em] 0 & \text{if LB, BC, or UB} \end{cases} \tag{A5}$$

$$\frac{dL_1}{dw} = \begin{cases} - \dfrac{(1 + r) \; L_1}{\phi DV(\Delta\pi)} \left[1 + \eta \; \dfrac{E(\Delta\pi)}{\overline{W}} \right] < 0 & \text{if IS} \\[2em] - \dfrac{K - k}{w^2} < 0 & \text{if BC} \\[2em] 0 & \text{if LB or UB} \end{cases} \tag{A6}$$

$$\frac{dL_1}{dK} = \begin{cases} \dfrac{1}{w} > 0 & \text{if BC} \\ \\ 0 & \text{if IS, LB, or UB} \end{cases} \tag{A7}$$

$$\frac{dL_1}{dk} = \begin{cases} -\dfrac{\eta r\ E(\Delta\pi)}{\phi D\ \bar{W}\ V(\Delta\pi)} < 0 & \text{if IS} \\ \\ -\dfrac{1}{w} < 0 & \text{if BS} \\ \\ 0 & \text{if LB or UB} \end{cases} \tag{A8}$$

$$\frac{dL_1}{dr} = \begin{cases} -\dfrac{w\ L_1\ \bar{W} + \eta k\ E(\Delta\pi)}{\phi D\bar{W}\ V(\Delta\pi)} < 0 & \text{if IS} \\ \\ 0 & \text{if LB, BC, or UB} \end{cases} \tag{A9}$$

$$\frac{dL_1}{dL} = \begin{cases} \dfrac{R}{D} + \eta\ \dfrac{1}{D}\ \dfrac{p_L + m_0}{\bar{W}}\ \dfrac{E(\Delta\pi)}{\phi V(\Delta\pi)} & \text{if IS} \\ \\ 1 & \text{if UB} \\ \\ 0 & \text{if LB or BC} \end{cases}$$

$$\overset{\bullet}{=} \begin{cases} \dfrac{1}{D}\left[(1-\eta)\ R + \eta\ \dfrac{L_1}{L}\right] \gtreqless 0 \text{ as } R \gtreqless \dfrac{\eta}{\eta-1}\dfrac{L_1}{L} & \text{if IS} \\ \\ 1 & \text{if UB} \\ \\ 0 & \text{if LB or BC} \end{cases} \tag{A10}$$

$$\frac{dL_1}{dm_0} = \begin{cases} -\dfrac{1}{\phi DV(\Delta\pi)} \left[1 + \eta \dfrac{(L - L_1)\, E\,(\Delta\pi)}{\bar{W}} \right] < 0 & \text{if IS} \\[4em] 0 & \text{if LB, BC, or UB} \end{cases} \tag{A11}$$

$$\frac{dL_1}{d\sigma_0} = \begin{cases} \dfrac{2\sigma_0 - \rho\sigma_1}{DV(\Delta\pi)}\,(L - L_1) \gtreqless 0 \text{ as } \rho \lesseqgtr 2\,\dfrac{\sigma_0}{\sigma_1} & \text{if IS} \\[4em] 0 & \text{if LB, BC, or UB} \end{cases} \tag{A12}$$

$$\frac{dL_1}{d\bar{p}} = \begin{cases} \dfrac{dL_1}{dm_1}\dfrac{dm_1}{d\bar{p}} + \dfrac{dL_1}{d\sigma_1}\dfrac{d\sigma_1}{d\bar{p}} \geq 0 & \text{if IS} \\[4em] 0 & \text{if LB, BC, or UB} \end{cases} \tag{A13}$$

$$\frac{dL_1}{\tilde{dp}} = \begin{cases} \left[\dfrac{dL_1}{dm_1} + \dfrac{dL_1}{dm_0}\,\beta_m\right]\dfrac{dm_1}{\tilde{dp}} + \left[\dfrac{dL_1}{d\sigma_1} + \dfrac{dL_1}{d\sigma_0}\,\beta_\sigma\right]\dfrac{d\sigma_1}{\tilde{dp}} & \text{if IS} \\[2em] 0 & \text{if LB, BC, or UB} \end{cases} \qquad (A14)$$

$$\frac{dL_1}{\tilde{d\sigma}} = \begin{cases} \left[\dfrac{dL_1}{d\sigma_1} + \dfrac{dL_1}{d\sigma_0}\,\beta_\sigma\right]\dfrac{d\sigma_1}{\tilde{d\sigma}} \gtreqless 0 \text{ as } \rho \lesseqgtr \beta_\sigma & \text{if IS} \\[2em] 0 & \text{if LB, BC, or UB} \end{cases} \qquad (A15)$$

where (A10) follows from (9) assuming $[E(\Delta\pi)\,L_1 - rk]/W$ is near zero, i.e., the expected change in wealth after one period is small relative to total expected wealth.

Note that definite results are obtained in all cases except (A14) where, in the case of IS,

$$\frac{dL_1}{\tilde{dp}} = \frac{1}{\phi DV(\Delta\pi)}\left[1 - \beta_m + \eta\,\frac{E(\Delta\pi)}{\tilde{W}}\,(L_1 - \beta_m L_0)\right]\frac{dm_1}{\tilde{dp_0}}$$

$$- \frac{1}{DV(\Delta\pi)}\left[(2\sigma_1 - \rho\sigma_0)\,L_1 + \rho\sigma_0 L - \beta_\sigma(2\sigma_0 - \rho\sigma_1)\,L_0\right]\frac{d\sigma_1}{\tilde{dp_0}}\,.$$

The second component in brackets in the second term has the same sign as $\rho - \beta_\sigma$ as obtained in (A15). The first term is clearly positive if $\beta_m <$ L_1/L_0. On the other hand, if β_m gets close to 1, then the first term becomes negative if $\beta_m > L_1/L_0$. Furthermore, if β_m is close to one, then the expected gain from adoption is small while variability increases with adoption so L_1/L_0 tends to be low, i.e., $\lim_{\beta_m \to 1} L_1/L_0 = 0$. Thus, $dL_1/d\tilde{p} > 0$ if $\rho >$ β_σ and $\beta_m < L_1/L_0$ while $dL_1/d\tilde{p} < 0$ if $\rho < \beta_\sigma$ and $\beta_m \to 1$.

Footnotes

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[1]In addition, the mathematical derivation requires $\beta_\sigma \leq \beta_m$ which is consistent with the assumption that the new technology is viewed as relatively more risky by the farmer.

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