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Measuring the Benefit-Cost Ratio of Public IPM Technology Transfer Programs: An Optimal Control Framework and an Application to Nepalese Agriculture

by

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Measuring the Benefit-Cost Ratio of Public IPM Technology Transfer Programs: An Optimal Control Framework and an Application to Nepalese Agriculture*

Abstract:
Despite favourable ecological and economic results, many developing countries have not yet adopted an integrated pesticide management (IPM). Given rising marginal costs and diminishing marginal benefits from IPM technology transfer, an optimal control framework is used to identify optimal rates of technology transfer. The framework is applied to Nepalese agriculture to illustrate the dynamic adoption process for IPM. The results indicate that public IPM technology transfer programs should be targeted to maintain about 50% of agricultural production in IPM. The benefit-cost ratio is approximately 7.9:1. If the educational program is financed by a tax on chemical inputs the benefit-cost ratio would be 9.1:1.

Keywords: Integrated pesticide management, cost-benefit analysis, extension, dynamic optimisation, Nepal

JEL classification: C61, D61, Q16, Q2

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1. The Problem

Recent studies (e.g. Yudelman 1994) indicate that there will be a need for a substantial increase in food production in developing countries over the next 20 to 25 years to meet food security needs for the populations of Asia, Africa, and Latin America. Yet, as the prospects for expanding acreage under cultivation are severely constrained, most of the increased food supply will have to come from the further intensification of production. This applies with special force to Asia in general and Nepal in particular.[1] In this context, the use of chemical pesticides and pesticide policies in developing countries have come under close scrutiny (see Farah 1994, Wiebers 1993, Yudelman et al. 1998 and Repetto 1985 on developing countries and MoA/Winrock International 1994a and 1994b on Nepal). While pesticides have helped increase agricultural productivity since World War II, increased pesticide use has generated a growing set of problems related to pest resistance to pesticides, pest resurgence, human health, and environmental contamination.

It is now widely believed that if farmers adopt integrated pesticide management (IPM), it could contribute substantially to the intensification of agriculture in a sustainable manner (Thrupp 1996). For example, village-level experiments with alternative crop protection strategies (zero-insecticide strategy, IPM, and current pesticide practice) for rice production in several Asian countries (China, Indonesia, Malaysia, Thailand, The Philippines, and Vietnam) showed no significant difference in the mean and variance of yields; the production response to insecticide applications is modest at best. However, farm level profits from rice production were highest in the communities that did not apply any

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[1] Aside from the Terai, there are few areas suited to large scale agricultural development in Nepal, although there is some potential in the hills for intensive horticulture (World Bank 1999: 32).

insecticides (Rice IPM Network 1995; IRRI 1996; Heong et al. 1995). Similar results are reported for developed countries. Evaluations of the economic effects of IPM on the farm in the US indicate that IPM generally decreases pesticide use and economic risk and increases yield and net returns (VCES 1987). In some parts of Europe, IPM has been successful in replacing pesticide applications with non-chemical methods while maintaining similar economic results (Reus et al. 1994). White and Wetzstein (1995) calculated the benefit-cost ratio of extending IPM in US cotton farming as 6.5:1.

Despite these favourable results, several constraints such as insecure farm tenure, risk aversion, inadequate farm size, extreme heterogeneity of production environments, lack of credit, and the subsistence nature of farm production systems still hamper the full adoption of an agricultural innovation such as IPM in developing countries (Feder et al. 1985). Byerlee and Hesse de Polance (1986) report that farmers generally adopt technological changes in a sequential manner, often accepting only a portion of the available technology. Although a few farmers may adopt the comprehensive package of available technologies, the overall consequence of constraints to adoption is that farmers do not immediately adopt a new technology. Instead, the dynamics of the system indicate that the percentage of farmers adopting a new technology increases through time, and the final equilibrium set of farmers adopting a technology may be only a subset of farmers.

By influencing the availability and exposure of technologies, the rate of farmers' technology adoption can be controlled. However, there are costs associated with influencing these variables. Given a new technology and costs of exposing the technology, the optimal path through time of farmers' availability and exposure to the technology should be determined. In the case of IPM adoption, the appropriate level of Cooperative Extension Programs designed for educating farmers concerning IPM may vary through time depending on the percentage of farmers adopting IPM and the long-run equilibrium level of adoption. More educational programs are needed in the early stages of adoption when only a few farmers have implemented the technology. When many farmers adopt the technology, the number of educational programs can be reduced and the nature of the program changed to best reach the remaining farmers.

The objective of this paper is to analyze this adoption process for IPM in agriculture. Using an optimal control framework, IPM benefits are compared with costs of IPM technology transfer for the aggregate Nepalese agricultural sector. The impact of IPM technology on input and output prices is taken into consideration in determining the optimal rate of technology transfer in the form of an exposure rate through educational programs of the Cooperative Extension Service. The important aspect of the approach chosen here is the blending of two methodologies, a static competitive market model (Section 2) with a welfare-maximizing dynamic control model (Sections 3 and 4). This results in modeling technological change in a competitive market with consideration of producers' dynamic long-run partial adoption process. Without this dynamic consideration of adoption, a static market model would suggest instantaneous full adoption of the technology - which is counter to recent literature on technology adoption. Applying the approach to Nepal (Section 5) suggests that public technology transfer programs should be targeted to maintain about 50% of agricultural production in IPM.

2. The Competitive Market Model

Assume a competitive market model for a single agricultural output, Q, that is produced with two substitutable inputs (nonchemical inputs, X_1, and chemicals, X_2, respectively). The production function is assumed to be homogeneous of degree one. For a competitive profit-maximizing industry, the value of the marginal product of each input equals its input price (W_1 or W_2). There are a demand curve for the agricultural product and industry supply curves for the two factors of production.

(1) $Q = d(P)$ (product demand)

(2) $Q = f(X_1^F, X_2^F)$ (production function)

(3) $Pf_i = W_i^F, i = 1,2$ (derived demand for factors)

(4) $X_i^M = g(W_i^M)$, $i = 1,2$ (factor supplies)

(5) $W_i^F = (1 + t_i)W_i^M$, $i = 1,2$ (factor tax policy)

(6) $X_i^F = X_i^M$, i = 1,2 (factor market clearing)

The endogenous variables are output Q, output price P, factor use X_i, and factor price W_i. The superscripts M and F represent market and farm, respectively. Thus, W_2^M is the market price and W_2^F is the farm price for chemicals which differ by the factor tax rate t_2. The marginal product of factor i is represented by $f_i = dQ / dX_i^F$.

This basic model can be used to measure the effects of technological change on prices and quantities. The particular type of technological change considered here is factor-saving technological change associated with the first factor of production, nonchemical inputs. An example is IPM, which increases the marginal product of nonchemical inputs through improved management while not affecting the marginal product of chemicals.

Without taxes, there is one quantity variable for each input ($X_i = X_i^M = X_i^F$), and one price for each input ($W_i = W_i^M = W_i^F$). Furthermore, the supply of chemicals for agriculture is assumed to be perfectly elastic as all chemicals are imported to Nepal. With a perfectly elastic supply from abroad, the price of chemicals is exogenously determined by the world market price and domestic tax policy; the quantity of chemicals used is determined solely by demand. Making the above substitutions, totally differentiating the system of equations (1) through (6), and converting to elasticities shows how partial adoption of nonchemical-saving technological change affects quantities and prices in the free market model:

(7) $\Delta P = (1/h)\Delta Q$

(8) $\Delta Q = K_1 \Delta X_1 + K_2 \Delta X_2$

(9) $\Delta W_1 = -(K_2 / s)\Delta X_1 + \left(K_2 / s\right)\Delta X_2 + \Delta P + g$

(10) $\Delta W_2 = 0$

(11) $\Delta X_1 = e_1 \Delta W_1$

(12) $\Delta X_2 = \Delta X_1 + (K_1 / s)\Delta Q$

where Δ indicates relative changes [$\Delta x = d\log(x) = dx / x$], h is the demand elasticity, K_i is the factor share, s is the elasticity of substitution for the two inputs, e_i is the input supply elasticity, and g is the relative change in marginal product of nonchemical inputs from partial adoption of the technological change.

The system of equations (7) through (12) can be solved by forming the Jacobian matrix of partial derivatives of the endogenous variables. Inverting the Jacobian matrix and multiplying it by the vector of exogenous shifters (0 0 g 0 0 0)' yields the following solutions:

(13) $\Delta P = K_1 e_1 g \;/\; D$

(14) $\Delta Q = hK_1 e_1 g \;/\; D = h\Delta P$

(15) $\Delta W_1 = (K_1 h - K_2 s)g \;/\; D$

(16) $\Delta W_2 = 0$

(17) $\Delta X_1 = e_1(K_1 h - K_2 s)g \;/\; D = e_1 \Delta W_1$

(18) $\Delta X_2 = K_1 e_1 (h + s)g \;/\; D$

(19) $D = K_1 h - K_2 s - e_1$

where D is the determinant of the Jacobian matrix of the system of equations multiplied by $-hs$. For the free-market model, the following two conditions hold. The relative change in output is the demand elasticity multiplied by the relative change in market price ($\Delta Q = h\Delta P$). For the first factor, the relative change in factor use is the supply elasticity multiplied by the relative change in input price ($\Delta X_1 = e_1 \Delta W_1$).

3. Economic Welfare Effects

The economic welfare effects of factor-saving technological change can be measured by the combined effect on consumer and producer surplus. The consumer surplus is the difference between what consumers would be willing to pay for each unit of a commodity and what they actually pay. Thus, the change in consumer surplus resulting from a technological change is graphically measured by the area under the demand curve and between the two equilibrium prices, with and without technological change. Likewise, the producer surplus is defined as the payment that need not be made in order to induce producers to supply additional output. Graphically, the change in producer surplus resulting from technological change is measured by the area above the supply curve and between the two equilibrium prices (Just, Hueth, and Schmitz 1982). IPM is modeled as a shifter of the marginal product of nonchemical inputs. The change in consumer surplus (ΔCS) is given by:

(20) $\Delta CS = PQ(-\Delta P)(1 + 0.5\Delta Q)$

Technological change is assumed only for the first factor, while the second factor is assumed to have perfectly elastic supply. Thus, the change in producer surplus (ΔPS) is given by:

(21) $\Delta PS = W_1 X_1 \Delta W_1 (1 + 0.5\Delta X_1)$

Substituting the solutions for ΔP and ΔQ from equations (13) and (14) into equation (20) yields the following solution for the change in consumer surplus:

(22) $\Delta CS = [-g\, PQK_1 e_1 / D][1 + 0.5g\, hK_1 e_1 / D]$.

Likewise, substituting equations (15) and (17) into equation (21) gives the following expression for the change in producer surplus:

(23) $\Delta PS = [g\, W_1 X_1 (K_1 h - K_2 s) / D]\,[1 + 0.5g\, e_1 (K_1 h - K_2 s) / D]$.

From (22) and (23), the change in economic welfare (ΔEW) can be calculated as the sum of changes in consumer and producer surplus. A relative measure of economic welfare $(\Delta EW = \Delta EW / PQ)$ will be used for ease of interpretation of subsequent results. The relative change in economic welfare resulting from the relative change in marginal product of nonchemical inputs, g, is given by

$$(24) \qquad \Delta EW = a_1 g^2 + a_2 g + a_3$$

with symbolic representations for a_i, $i = 1,2,3$, for technological change with and without taxes reported in Table 1. Consideration of a chemical input tax (t_2) results in a modification of the a_i parameters denoted as a_1' in Table 1. The vector of exogenous variables is now (0 0 g t_2 0 0)'. Multiplying the inverted Jacobian matrix by this vector of exogenous variables yields the solution for the parameters reported in the bottom half of Table 1.

Table 1 - Parameters of the Welfare Functions

Without chemical input tax:

$$a_1 = [-K_1^2 e_1^2 h + K_1(K_1 h - K_2 s)^2 e_1] / 2D^2$$

$$a_2 = [-K_1 e_1 + K_1(K_1 h - K_2 s)] / D$$

$$a_3 = 0$$

With chemical input tax (at rate t_2):

$$a_1' = a_1$$

$$a_2' = a_2 + 2K_1 K_2 e_1 t_2 [-hs - he_1 + K_1 h^2 + K_1 hs - K_2 hs - K_2 s^2] / 2D^2$$

$$a_3' = t_2 K_2 [-s - e_1 + K_1(h + s)] / D + t_2^2 K_2^2 [-h(s + e_1)^2 + K_1 e_1 (h + e_1)^2 / 2D^2$$

$$a_4' = K_1 K_2 e_1 (h + s) t_2 / D$$

$$a_5' = K_2 t_2$$

Note: $T_2 = a_4' g + a_5'$, where T_2 denotes the relative tax on chemicals.

4. Comparative Dynamics[2]

So far, it has been assumed that the rate of farmers' technology adoption and hence the nonchemical-saving technical change (IPM) is exogenous to the competitive market model. Yet, by influencing the availability and exposure of IPM technology, the rate of farmers' technology adoption can be controlled by the government. But there are costs associated with influencing these variables.

Assume the objective of the government is to maximize the discounted stream of net economic welfare from IPM technology transfer programs, including those of the Cooperative Extension Service. The maximum technological change, n, is reached if all chemical users totally adopt IPM technology. However, the dynamic nature of technology adoption implies that producers' actual level of adoption is $g(t) < n$ throughout. IPM technology adoption generates gross economic welfare changes (see above) $\Delta EW(g)$, where $\Delta EW(0) = 0$, $\Delta EW' > 0$, and $\Delta EW'' < 0$. Farmers learn about IPM technology through educational programs. At a cost $C(m)$ (where $C(0) = 0$, $C' > 0$, and $C'' > 0$), the government influences the exposure rate $m(t)$, the rate at which farmers are exposed to IPM technology through educational programs. The level of exposure results in $g(t)m(t)$ of technology change exposed to farmers, of which only a fraction $[1 - g(t)/n]$ will be newly adopted.[3] Finally, farmers knowledge about IPM technology depreciates at a constant proportionate rate d.

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[2] A general description of the optimal control problem discussed in this section is given in Kamien and Schwartz 1991: 174ff.

[3] To illustrate the relationships among the variables, consider the following example. If a new technology would increase productivity by 4% ($n = 0.04$) but only a quarter of the technology was adopted after one period $[g(t) = (1/4)n = 0.01]$, then 75% would remain unadopted $[1 - g(t)/n = 0.75]$. If educational programs result in 40% of the unadopted in the second period $[g(t)m(t)(1 - g(t)/n) = 0.003]$.

The program that maximizes the present value of net economic welfare is expressed by

$$(25)\quad \max \int_0^\infty e^{-rt}\left[a_1 g^2(t) + a_2 g(t) + a_3 - Cm^2(t)\right]dt$$

$$(26)\quad \text{subject to } \dot{g} = -dg(t) + g(t)m(t)\left[1 - g(t)/n\right], \qquad 0 < g(0) < n$$

where r is the discount rate and C are the cost of the IPM technology transfer program, measured relative to the market size (PQ). The exposure rate enters equation (25) in the quadratic form to reflect the higher marginal cost of extending IPM to farmers who are presently still using chemicals. In comparison to current IPM users, users of chemicals have characteristics which tend to limit participation.

An optimal solution for maximizing equation (25) subject to equation (26) is based on the current-value Hamiltonian (Chiang 1992: 210)

$$H = a_1 g^2 + a_2 g + a_3 - Cm^2 + l(-dg + gm - g^2 m/n).$$

The first-order conditions are denoted by equation (26) and by the following equations (27) and (28):

$$(27)\quad \P H/\P m = 0 \qquad \Rightarrow \qquad 2Cm = lg(1 - g/n)$$

$$(28)\quad \dot{l} = rl - \P H/\P g \qquad \Rightarrow$$

$$\dot{l} = l(r + d - m) + 2lgm/n - 2a_1 g + a_2$$

As demonstrated in Kamien and Schwartz (1991: 181), totally differentiating equation (27) and using equations (26), (27), and (28) to eliminate $\dot{g}, l$ and $\dot{l}$, respectively, yields

(29) $$\dot{m} = \left[r + \frac{dg}{n-g} \right] m - \frac{\left(2a_1 g^2 + a_2 g\right)\left(1-g/n\right)}{2C}.$$

For phase diagram analysis, a solution to equation (26) where $\dot{g} = 0$ is

(30) $$m = \frac{dn}{n-g}$$

and a solution to equation (29) for $\dot{m} = 0$ is

(31) $$2cm = \frac{\left(2a_1 g^2 + a_2 g\right)\left(1-g/n\right)}{r + \dfrac{dg}{(n-g)}}.$$

Considering a chemical input tax, the cost to society of exposing producers to the technological change may be reduced by the amount of the taxes collected. Defining relative tax (T_2) as the total amount of taxes collected divided by the cash receipts (PQ), and noting that $\Delta W_2 = 0$, results in $T_2 = K_2\left(1 + \Delta X_2\right)t_2$. Substituting equation (18) for ΔX_2 yields $T_2 = a_4' g + a_5'$, where expressions for a_4' and a_5' are reported in Table 1. Relative cost of exposure is then $C_2(g) = C - T_2$, where $C_2(g)$ is a general representation of the cost function. Reducing the cost of exposure by the tax revenues results in modifying the first-order conditions. Specifically, equation (29) is now written as

(29’) $$\dot{m} = \left[r + \frac{dg}{n-g} - \frac{a_4 dg}{C_2(g)} \right] m + \frac{g\left(1-g/n\right)m}{2C_2(g)} \left[a_4 m - \frac{\left(2a_1 g + a_2\right)}{m} \right].$$

5. Application: IPM Technology Transfer in Nepalese Agriculture

Equations (30) and (31) may be investigated empirically given elasticity estimates and factor shares for agriculture or individual crops. In the following, the model is applied to IPM technology transfer in Nepalese agriculture.[4] The supply and demand elasticities estimates listed in Table 2 are based on previous research on other developing countries. Scandizzo and Bruce (1980) offer a vast number of estimates of direct price elasticities of demand that serve as guidelines for what is expected to be found in econometric studies for Nepal and for the parameterization of the model developed above. The short-run price elasticities of demand for food, foodgrains, and total cereals are generally inelastic, with most of the statistically significant estimates clustering below -0.50. In this study, price elasticities of demand are assumed to be -0.50 in the short run and 40 percent higher, or -0.70, in the long run. In previous studies, short-run price elasticities of aggregate agricultural supply were generally in the range of 0.1 and 0.3 and long-run elasticities between 0.4 and 0.5 (Sadoulet, de Janvry 1995). Supply elasticities for this study are assumed to be at the upper bounds. In the model, factors of production are grouped into two broad categories of chemicals and other inputs. The data sources are annual sales and sales prices of chemicals as well as agricultural GDP from Agricultural Statistics Division (1999). For the fiscal years 1990/91-1998/99, chemical costs averaged about 2 percent of agricultural GDP at factor costs. This figure implies that the factor share for chemicals (K_2) equals 0.02, and the factor share for other inputs (K_1) equals 0.98. Previous literature does not provide an elasticity of substitution for the input categories used in this study. Therefore, it has been assumed that this elasticity is 1.5. The elasticity of supply for chemicals is assumed to be perfectly

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[4] Given appropriate data, the methodology may also be applied to markets for individual agricultural products.

elastic as all chemicals are imported. The elasticity of supply for other inputs is derived analytically from the model as follows: $e_1 = K_1 e - K_2 s$. Substituting the parameter estimates from Table 2 into the above equation implies that the elasticity of supply for other inputs is 0.264 in the short run and 0.46 in the long run.

Table 2 - Model Parameters Used in Analysis

Variables	Symbol	Estimates
Elasticities of demand	h	
Short run		-0.5
Long run		-0.7
Elasticities of supply	e	
Short run		0.30
Long run		0.50
Elasticities of supply for chemicals	e_2	
Short run		∞
Long run		∞
Elasticities of supply for other	e_1	
Short run		0.264
Long run		0.460
Elasticities of substitution between chemicals and other inputs	s	1.5
Factor shares		
Chemicals	K_2	0.02
Other inputs	K_1	0.98

Phase diagram analysis is conducted for a technological change representing IPM in Nepalese agriculture. The application is based on the long-run elasticities in Table 2 and expressions for a_i, i = 1,...,5 in Table 1. The analysis assumes a depreciation rate (d) of 0.10, a maximum level of technology (n) of 0.01, i.e. overall productivity would increase 1 % if all current chemical users totally adopt the IPM technology.[5] The discount rate (r) is 0.05. The cost of the educational programs (c) is assumed to be 0.004, which is 0.4 % of total agricultural market receipts.

Numerically solving equations (30) and (31) results in the steady-state solution $(g^* = 0.008, m^* = 0.5)$, illustrated in Figure 1. As indicated in Figure 1, equation (30) is an increasing convex function that grows without bound as g approaches n. The directionals defining the movement of a point (g, m) over time indicate that above (below) the locus, g is increasing (decreasing). Equation (31) is a concave function, with m increasing (decreasing) above (below) the locus, $\dot{m} = 0$. The separatrix traces the trajectory to the steady state. As the level of technology employed increases, the optimal exposure rate at first increases. This high level of exposure generates increased adoption of the technological change. The optimal exposure rate then gradually declines toward the steady-state solution.

Figure 2 illustrates the effects of technological change with and without a chemical tax. The chemical tax has the effect of reducing the cost associated with producers' exposure to technological change. Specifically, a 5 % chemical tax results in a new steady state (g', m'), with $m' = 0.55$ and $g' = 0.0084$. The tax increases the steady-state level of technological change by 5 %, with an associated increase in the rate of exposure.

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[5] Note that pesticides are not as extensively used in Nepal as in other countries in Asia or in developed countries. Thus a shift to IPM is not expected to increase overall agricultural productivity drastically. However, pesticides are heavily used in few parts of the country, particularly the Kathmandu valley and the Terai. Pesticide use is also very high on a few specific crops, especially vegetables (MoA/Winrock International 1994b). For these crops, a technological change towards IPM may induce higher increases in productivity.

Figure 1 - Phase diagram for technological change without a chemical tax

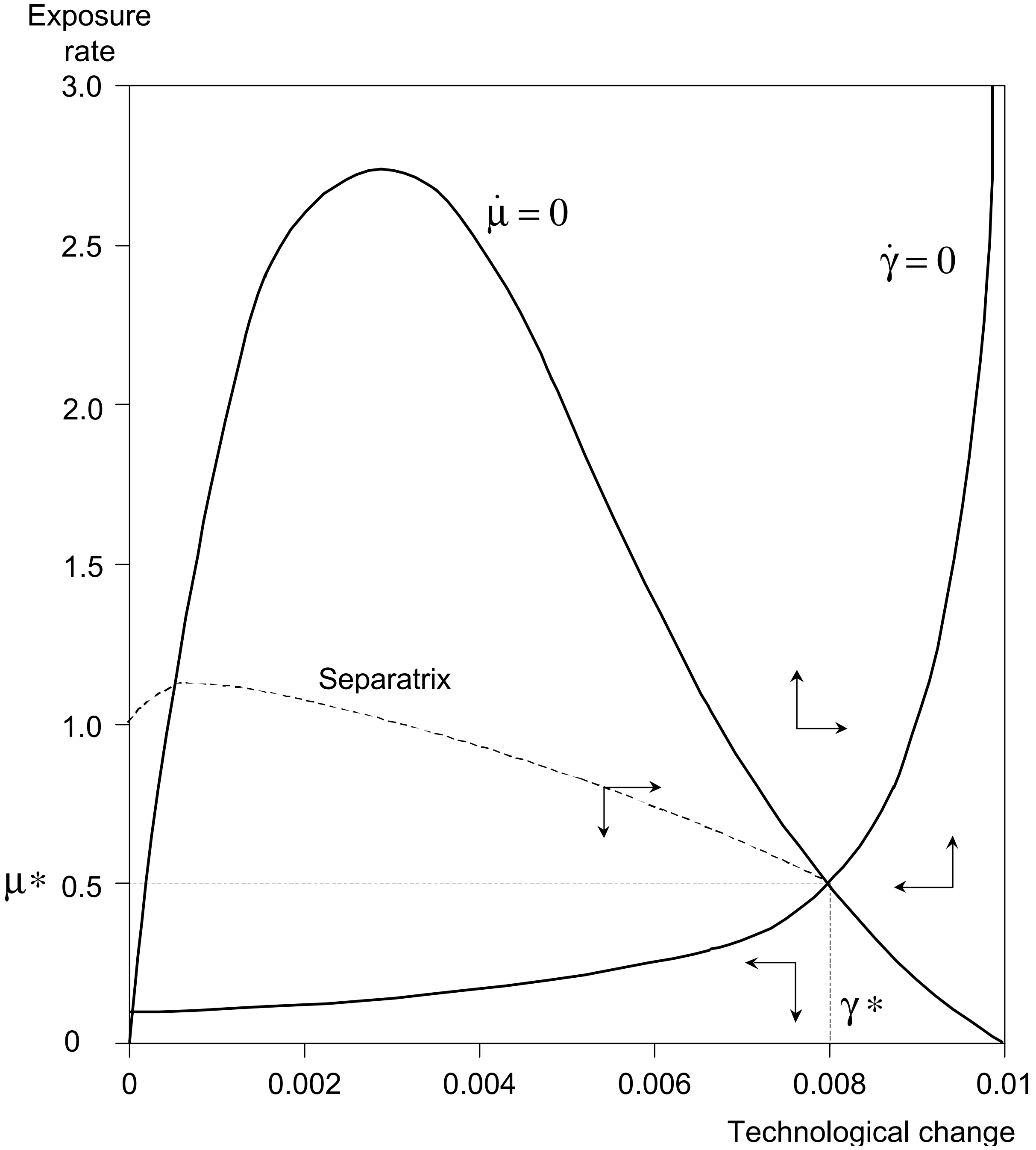
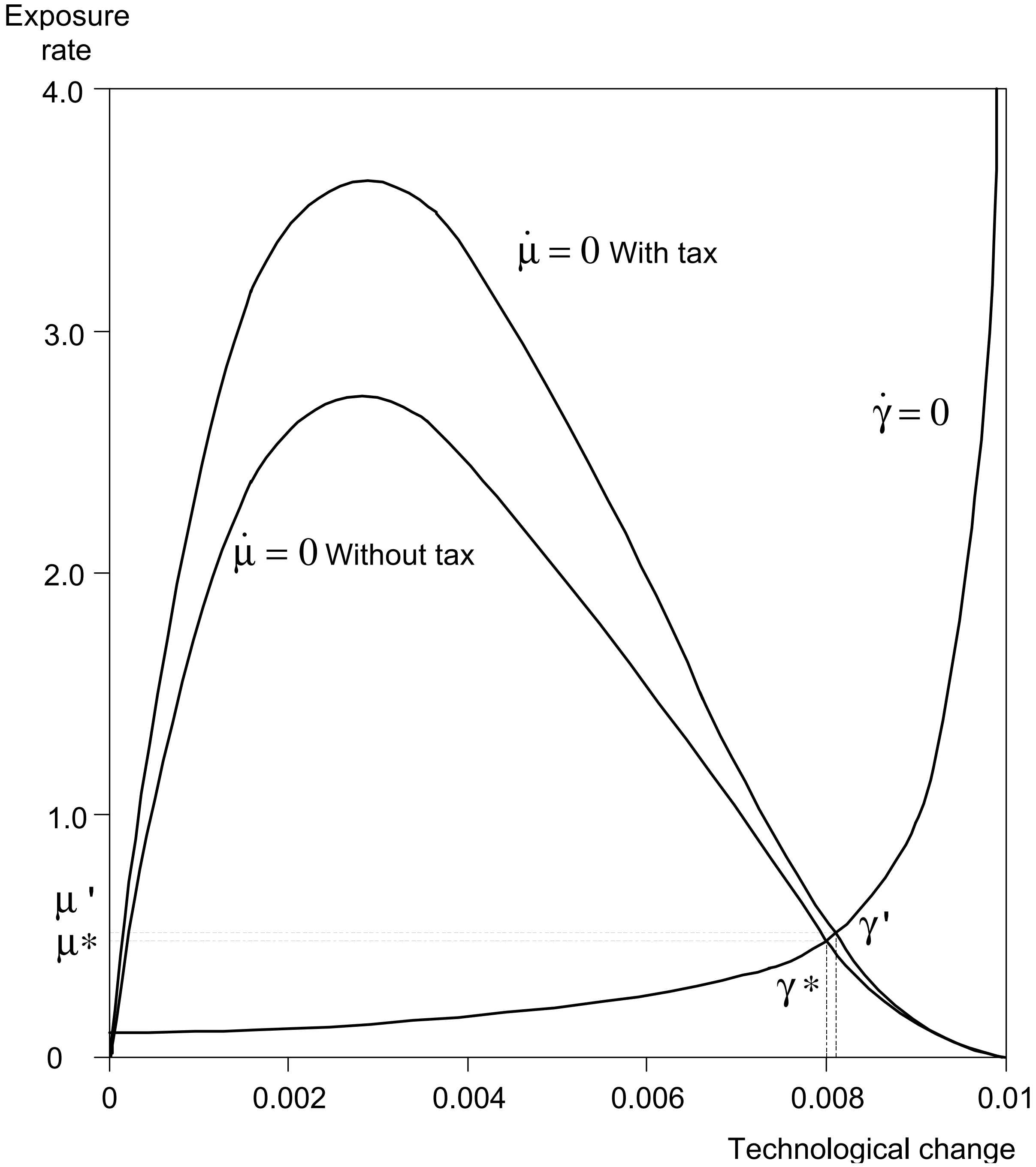


Figure 2 - Phase plane diagram for technological change with and without a chemical tax



The cost (v) of implementing the technological change is $v = Cm^2 PQ$. However, as economic welfare was described relative to the size of the market the comparable measure of cost would be the cost of implementing the technology relative to the size of the market; that is, $v^* = v \,/\, PQ = Cm^2$. Hence, v^* can be considered as the proportion of agricultural receipts spent on technological change exposure. For C = 0.004 and m^* = 0.5, v^* = 0.001, indicating approximately 0.1 % of gross receipts would be spent on IPM education.

Now, consider the steady-state solution of 0.8 % for g^* without a chemical tax. This represents a 0.8 % increase in the productivity of nonchemical inputs resulting from IPM adoption in Nepalese agriculture. The impact of this technological change is reported in Table 3. Agricultural production would expand by 0.21 % and the agricultural price index would decline by 0.31 %. The usage of nonchemical inputs would increase by 0.22 % and the aggregate price of nonchemical inputs would increase by 0.49 %. This price increase is dependent on the inelastic supply of nonchemical inputs. In the current model, the demand for agricultural products is more elastic than the supply of nonchemical inputs. There would be a reduction in chemical use of 0.25 %. The reduction in chemical use resulting from IPM is dampened by the fact that agricultural production expands.

The welfare impacts of using IPM are also reported in Table 3. Relative changes in producer and consumer surpluses are 0.48 % and 0.31 %, respectively. These are relative terms with the denominator being total receipts from marketings (PQ). Thus, over 60% of the gross benefits accrue to producers. The government costs of IPM, which were discussed above, are 0.10 % of total agricultural receipts. Net economic welfare from IPM is 0.69 % of total receipts. A benefit-cost ratio can be calculated by dividing gross economic welfare,

$\Delta CS + \Delta PS$, by government costs, $v*$. Using this approach, the benefit-cost ratio for IPM in Nepalese agriculture is 7.9 to 1.

Table 3 - Welfare Effects Resulting from IPM Technology Transfer in Nepalese Agriculture

Variable Description	Variable Name	Without Tax $g = 0.8$ (%)	With Tax $g = 0.84$ (%)
Agricultural output			
Price	ΔP	-0.31	-0.32
Quantity	ΔQ	0.21	0.23
Nonchemical inputs			
Price	ΔW_1	0.49	0.51
Quantity	ΔX_1	0.22	0.24
Chemical inputs			
Price	ΔW_2	0.00	0.00
Quantity	ΔX_2	-0.25	-0.26
Consumer surplus	$\Delta(CS)^a$	0.31	0.32
Producer surplus	$\Delta(PS)^b$	0.48	0.50
Government cost	$(\mathrm{C}-\mathrm{T}_2)m^2$	0.10	0.09
Economic welfare	$\Delta(NEW)^c$	0.69	0.73

[a] $\Delta(\mathrm{CS}) = \Delta\mathrm{CS} / \mathrm{PQ}$
[b] $\Delta(PS) = \Delta PS / PQ$
[c] $\Delta(NEW) = \Delta(CS) + \Delta(PS) - (C - T_2)m^2$.

Next, consider the steady-state solution of 0.84 % for g, resulting from a chemical tax. The impacts of technological change with a chemical tax are reported in the second data column of Table 3. Agricultural production would increase 0.23 % and the price index would decline 0.32 %. Consumer surplus would increase 0.32 % and producer surplus would increase 0.50 %. The revenue generated by the chemical tax would be

$T_2 = K_2(1+\Delta X_2)t_2 = 0.02(1-0.0026)(0.05) = 0.0001$ or 0.01 % of agricultural sales. Costs of the educational programs would be $v' = (C - T_2)m^2 = (0.004 - 0.001)(0.55)^2 = 0.0009$, or 0.09 % of farm marketings. Ignoring the cost of the educational program financed by a chemical tax, the benefit-cost ratio would be 0.82/0.09 = 9.1, or 9.1 to 1. Accounting for all costs, the benefit-cost ratio would be $0.82/(0.4)(0.55)^2 = 6.8$ or 6.8 to 1.

6. Conclusions

Increasing the use of IPM can reduce aggregate chemical use, which in turn can reduce some of the environmental and health problems associated with high chemical use in agricultural production. Adoption of IPM is dependent on its effectiveness in increasing net returns. On a case-study basis, crop farmers using IPM do experience lower chemical costs and lower costs associated with chemical applications, leading to higher net returns, ceteris paribus. However, at the aggregate level, as net returns are increased, total crop acreage increases. Placing more production on the market with an inelastic demand would reduce total receipts from marketings. Hence, the marginal producer benefits from adoption of IPM tend to decline as more and more farmers adopt IPM. Moreover, the marginal costs of extending IPM technology to more and more farmers will increase as those farmers with small acreages and other characteristics (contributing to low propensities to participate in IPM) are brought into the programs.

A dynamic analytical framework was used in this study to examine the adoption process of IPM. The steady-state solution showed the optimal adoption rate and the optimal government effort through technology transfer programs such as those offered by Cooperative Extension Services. The framework has been applied to Nepalese agriculture. The base solution indicated, that for total agriculture in Nepal, technolology transfer programs should be targeted to maintain about 50% of agricultural production in IPM. Technology transfer in IPM should be an ongoing process, because pesticide management strategies continue to change. The findings indicate that chemical usage declines with the adoption of IPM. However, this reduction in chemical use is dampened by the expanded production that results from IPM.

The benefit-cost ratio for IPM is approximately 7.9:1. The benefits measured in this study are only market effects, resulting from changes in prices and quantities. Accounting for the externalities of health and environmental benefits from IPM would result in a socially optimal adoption rate that would be higher than the optimal rate indicated solely by market forces.

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