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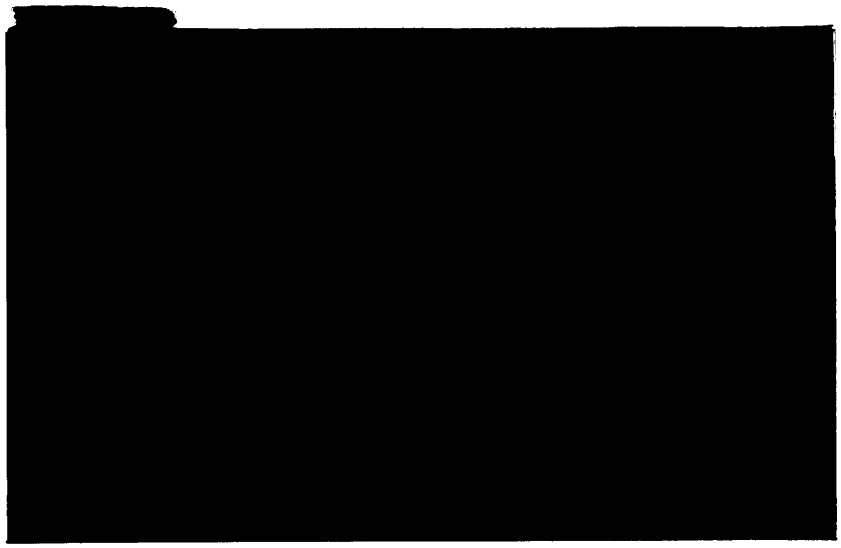

Effects of Commodity Program Structure on Resource Use and the Environment

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Effects of Commodity Program Structure on Resource Use and the Environment

Agricultural commodity policies have a direct impact on farmers' production decisions, and farmers' production decisions in turn affect the agro-ecosystem and the larger natural environment. The literature that addresses various aspects of the many potential interactions between agriculture and the environment through these linkages is diverse. The literature on soil erosion externalities and their management is the most extensively researched (see for example Loehr, Haith, Walter and Martin 1978). In this literature, agricul- tural production practices and soil transport models are linked. The fisheries literature is another area in which economic models are combined with physical and biological models. For example, Capalbo (1986) linked the neoclassical model of the firm with a fisheries population growth model to analyze common property renewable resource issues. Anderson, Opaluch and Sullivan (1985) addressed site-specific pesticide contamination of ground-water with a combination of physical and economic models. The chapters in part III of this volume also address various empirical relationships between agriculture and the environment.

Because the public is concerned about protecting the environment, agricultural policy analysts should incorporate these environmental impacts into their evaluations of alternative policies (Kramer 1986; Batie 1988). There are two reasons why commodity policy analysts have tended not to include environmental impacts. First, although research has begun to link the agricultural production process to environmental quality, no general analytical framework has been developed that combines site-specific relationships between management practices and environmental attributes of farmland that can be aggregated consistently to the regional or national level for purposes of welfare and policy analyses. Second, even if an appropriate analytical framework were available, the data needed to quantify relevant relationships are not available. Statistically valid samples that combine on a location-specific basis both management practices and environmental variables do not exist.

The purpose of this chapter is to develop an analytical framework that can be used to integrate physical and economic relationships at a disaggregated level, statistically aggregate to a level relevant for policy analysis, and show how those aggregate relationships can be used for welfare and policy analyses and how distributional detail matters. This analytical framework also suggests the kinds of data that need to be collected to make quantitative policy analysis feasible.

Beginning with an overview of the conceptual model, this chapter also includes stylized physical and economic models and a discussion of how they can be integrated into a statistical framework. The later sections include a welfare framework for policy analysis, which embodies the tradeoffs policymakers face between output and pollution, and an analysis of the relationships between policy variables and decisions at the extensive and intensive margins. Concluding this chapter is a discussion of directions for further theoretical developments and empirical research needed to incorporate resource and environmental considerations into quantitative policy models.

The Conceptual Framework

Consider classifying all policies into two basic types: (1) those that affect management decisions at the intensive margin, such as a price support that increases chemical use per unit of land, and (2) those that affect management decisions at the extensive margin, such as diversion requirements for participation in a program that affects total land use. Some policies affect incentives at both margins, as might be the case with a price support that encourages chemical use on existing cropland and also encourages farmers to bring new land into production.

A schematic representation of the conceptual framework developed in this paper is presented in Figure 1. The upper part of the figure pertains to the analysis of a unit of land at the farm level. Commodity policies affect farmers' incentives at both the extensive and intensive margins. Besides determining agricultural production, these decisions have environmental impacts through two distinct but interrelated mechanisms. Decisions at the extensive margin determine which particular acres of cropland are put into production, and thus determine the environmental attributes of the land in production. Management decisions at the intensive margin determine the application rates of chemicals, water use and tillage practices. Physical relationships between the environmental attributes of the land in production and management practices then jointly determine the agricultural output and pollution associated with a particular unit of land in production.

Based on farm-level decision model, each unit of land that is in production has management and environmental characteristics that are functions of prices, policies, and technological and other farm-specific characteristics. The distribution of farm and environmental characteristics in the region induces a distribution of management practices and environmental attributes for land units in production. This joint distribution provides the basis for aggregation of outputs, inputs, and pollution to the regional level. Based on the properties of the policy criterion or welfare function chosen, one can then proceed to analyze the tradeoffs between production and pollution that are associated with alternative policies. Hochman and Zilberman (1978) have demonstrated the importance of production and pollution microparameter distributions in analyzing environmental policy tradeoffs. Similar principles, to be demonstrated in this chapter, apply in examining the effects of commercial agricultural policy on environmental and resource depletion issues.

Various issues arise in translating this very general conceptual framework into a useful analytical model. At the disaggregated level, both the physical model and the economic model must be specified so they can be integrated into a tractable model of crop output and pollution. Numerous modeling issues arise, including the models' dynamics and the level of aggregation of inputs and outputs. For the purposes of this chapter, decisions at the intensive margin generally are short-run input decisions and are related to the intraseasonal dynamics of the production process. Decisions at the extensive margin involve placing a unit of land in production. These decisions may involve long-run considerations such as the interseasonal dynamics of crop rotations and capital investment.

While the analyses in this chapter do not consider explicit dynamics, quantitative applications will require addressing the full range of issues that arise in applied production economics research including the dynamic aspects of the economic and physical models. For example, the physical models of soil erosion and chemical transport and fate generally involve dynamic processes that relate the farmers' intraseasonal and interseasonal management decisions to environmental impacts. Since the 1970's, a variety of models have been developed and are being developed to quantify soil erosion, chemical runoff into surface water, and chemical transport through soils to groundwater (Lorber and Mulkey 1982). These models are comprised of systems of differential equations that express changes in environmental quality as functions of management actions and environmental parameters, and require detailed information regarding the timing of input decisions and location-specific environmental attributes (Donigian and Dean 1985). Similarly, models for evaluation of the effects of chemicals on humans and other species utilize dose-response relationships, which range from simple linear models to more complex models designed to account for repeated exposures (Rowe 1983). Users of quantitative applications must address a variety of methodological issues in the integration of these physical models with economic models, including level of aggregation across space and time, analytical tractability, and use of experimental and nonexperimental data (Capalbo and Antle 1989).

Another set of general issues arises in aggregating and conducting welfare analyses. A number of approaches can be taken to address the problem of analyzing the tradeoffs between crop production and pollution. First is the question of the appropriate level of aggregation. Should policy be addressed to a region associated with a particular agro-ecosystem, or is national policy at issue? In this chapter the authors focus on a regional analysis, say for a watershed or aquifer; but these regions could be aggregated into a national model as well. The second major issue is the choice of a welfare criterion. How are social costs associated with agricultural pollution or resource depletion valued in welfare and policy analyses? Is an absolute physical standard (e.g., parts per billion of contaminant in drinking water) to be met, or can crop production and pollution literally be "traded off" in the policy calculus? Economists are wont to analyze environmental policy using tradeoffs between pollution and output and to regard economic efficiency as an important aspect of policy design. The public and policymakers, however, tend not to consider tradeoffs in assessing environmental issues and most environmental policies are based on standards that usually are not considered by economists to be economically efficient.

In actual policy decisionmaking, one can view the tradeoffs illuminated by a detailed analytical framework as leading to more informed decisions--decisionmakers weigh, either explicitly or implicitly, the social benefits of agricultural production against the social costs it generates.

The Disaggregated Model

Consider a region defined in relation to an environmentally meaningful geographical unit, such as a watershed or aquifer. Each acre in the region has a set of environmental characteristics that affect both its agricultural productivity and the production of pollution. To simplify the analysis, a scalar index ω_j is used to represent the jth acre's environmental characteristics (e.g., ω_j could be an erodability index, a DRASTIC score, or a mass distribution fraction of a chemical to soil, air, or water). In this stylized analysis, this scalar index is assumed to be related to both crop productivity and pollution generation. More generally, ω_j can be specified as a vector of land quality attributes, with some elements explaining productivity and others explaining pollution.

There are two components to the analysis: (1) an economic model for making management and land use decisions as functions of prices, policies, and farm characteristics, and (2) a physical model used to determine pollution as a function of management decisions and environmental attributes of land in production. Throughout the discussion the term "pollution" is used generally to represent any physical effect of agricultural production on the environment, human health, or resource depletion.

A variety of complex physical models are being developed to measure pollution, such as surface and groundwater contamination, caused by agricultural production. The stylized physical model here is represented by the function $z_j = z(x_j, \omega_j)$ where x_j is the level of input use on the jth acre and z_j is pollution generated by production on the jth acre.[1]

The function $z(x,\omega)$ is assumed to be increasing in x and ω, i.e., the index ω is defined so that an increase in its value corresponds to more pollution for a given level of input use. The range of values of ω in the region is defined over an interval $(0,\bar{\omega}]$. Input use per acre, x, is a nonnegative real number. As will be discussed, both x and ω may be constrained by commodity or environmental policies to a particular interval of the real line. The $z(x,\omega)$ function also may exhibit certain convexity properties. For example, it may be reasonable in some cases to assume that $z(x,\omega)$ is quasi convex and monotonically increasing in its arguments. Some physical models of chemical fate in the environment posses explicit convexity properties (Yoshida, Shigeoka, and Yamauchi 1983). In some of the more sophisticated physical models, however, convexity properties are difficult to determine analytically because the models are comprised of differential equations that do not admit closed-form solutions (e.g., Carsel et al. 1985).

The economic model is based on the optimal allocation of land and other inputs in production as functions of prices, policies, and the environmental characteristics of the land managed by the farmer. To focus on the role of land quality, all farmers are assumed to be risk neutral and to produce with identical technology. Farms are differentiated only by the environmental characteristics of land.[2] In the production period, the ith farmer manages n^i acres with environmental characteristics $\omega^i = (\omega_1^i, \omega_2^i, \ldots)$. Define the indicator function δ_j^i such that

$$\delta_j^i = \begin{cases} 1 \text{ if acre } j \text{ is in production} \\ 0 \text{ otherwise,} \end{cases}$$

and let $\delta_i = \{\delta^i_j\}$. The vector of attributes of land in production on farm i is then $\omega(\delta_i) = (\omega^i_1\delta^i_1, \omega^i_2\delta^i_2, \ldots)$ and total acreage in production on the ith farm is $\Sigma_j \delta^i_j$.

All farms in the region face the same vectors p and ψ of prices and policy parameters. Yield is given by $y^i_j = y(x^i_j, \omega^i_j)$ and y^i is the vector of yields for farm i. Define x^i_j as the input allocation of farmer i to acre j and x^i as the vector of x^i_j. The ith farmer's decision problem can then be cast as

$$\max_{x^i, \delta^i} \pi[x^i, \omega(\delta^i) | p, \psi, \omega^i]$$

where π is the farmer's objective function embedding the production technology. In addition to setting prices, policy may impose a set of inequality constraints on land use. For example, a diversion requirement of λ percent imposes a constraint $\Sigma_j \delta^i_j \le n^i(1 - \lambda)$ on total acreage in production.

The solution to this maximization problem generates the demand functions $x^i_j = x(p, \psi, \omega^i_j)$ and $\delta^i_j = \delta(p, \psi, \omega^i_j)$. Note that x and δ are discontinuous functions and thus are not differentiable. Under reasonable conditions, however, the discontinuity in x occurs only when δ^i_j switches from one dichotomous value to the other. Thus, x will be treated as a conventional demand function that is twice continuously differentiable with respect to p at the intensive margin.

The environmental characteristic of each unit of farmland in the region is fixed at a point in time and can be viewed as being distributed across the acres in the region with a distribution defined by the parameter vector θ. The distribution of environmental attributes induces a joint distribution for input use x^i and land use δ^i in the region. The environmental attributes of land in production $\omega(\delta^i)$ are determined by land use decisions, and yield and pollution are functions of input use and the environmental attributes of the land in production. Thus, farmers' production decisions generate a joint distribution of output, input, environmental attributes, and pollution in the region (y, x, ω, and z). Based on this joint distribution, conditional and marginal distributions for these variables can be derived.

For example, output and pollution can be integrated out of the joint distribution to obtain the joint marginal distribution function $\phi(x,\omega|p,\psi,\theta)$ for input use and environmental attributes of the acres in production in the region. That is, if an acre j is randomly sampled from acres in production, the probability that $x_j < x_0$ and $\omega_j < \omega_0$ is

$$\int_0^{x_0} \int_0^{\omega_0} \phi(x,\omega|p,\psi,\theta)\ dx\ d\omega.$$

Similarly, a marginal distribution for pollution ϕ_z can be derived and used to determine the probability that pollution is less than or equal to a given level z_0 by calculating

$$\int_0^{z_0} \phi_z(z|p,\psi,\theta)\ dz.$$

Note that this quantity can be interpreted as the share of land on which pollution is less than or equal to z_0. Alternatively, an aggregate pollution function can be constructed by simply taking the expectation of z with respect to the joint distribution of y, x, ω, and z.

A Log-Linear Model

A simple log-linear model is a useful example to illustrate the effects of policy on output, input use, land use, and pollution. The physical model is

$$z = x^{\alpha}\omega^{\beta},\ \ \alpha,\ \beta > 0,$$

and the yield function is

$$y = x^{\eta}\omega^{\nu},\ \ 0 < \eta < 1.$$

Note that the parameters α, β and η are assumed to be positive, but the sign of ν is not restricted. The parameter ν is positive when the environmental attribute that is positively associated with pollution also is positively associated with productivity, as would be the case when rich alluvial soils are in proximity to surface water or shallow groundwater and thus high yields are associated with water pollution. The parameter ν is negative when environmentally sensitive conditions, such as highly erodible land, are associated with both high levels of pollution and low productivity. Note also that for log-linear model, both pollution and crop output are zero when the input x is zero. This property makes the log-linear model unsuitable for inputs such as chemicals that are not essential in the production process. Alternatively, the function can be used for nonessential inputs by respecifying it in the form $y = (x + \varepsilon)^{\eta}\omega^{\nu}$, where $\varepsilon > 0$ is a model parameter.

The relationships between yield, pollution, and input per acre generated by these functions when the input x is held constant and the environmental attribute ω is varied are presented in Figure 2 for different values of the parameters. The curves in Figure 2(a) are derived by inverting the z-function and substituting it into the yield function to obtain

$$\ln y = (\eta - \frac{\alpha\nu}{\beta})\ln x + (\frac{\nu}{\beta})\ln z.$$

This equation represents the relationship between y and z that is obtained by varying ω while x is held constant. Since $\beta > 0$, the sign of this relationship is positive or negative depending on the sign of ν. When ν is positive an increase in the environmental attribute's value increases both output and pollution for any level of input; the converse is true when yield is decreasing in the value of the environmental attribute. Thus, increased output is not necessarily associated with higher pollution, <u>ceteris paribus</u>.

The relationships between profit maximizing input use x^* and pollution as the environmental attribute is varied are presented in Figure 2(b). Solving for x^* gives

$$\ln x^* = \ln k + \nu \ln (p/v) + \rho \ln \omega,$$

where k is a constant, ν depends on the parameters of the two functions, and $\rho = \nu/(1 - \eta)$. Substituting the inverted z function into x^* gives

$$\ln x^* = \ln k^* + \nu^* \ln (p/v) + \tau \ln z$$

where $\tau = \rho/(\beta + \rho\alpha)$. As in the output-pollution relationship, it is possible for the input-pollution relationship generated by varying the environmental attribute to be either positive or negative depending on the sign of ν. Note that $\nu > 0$ is sufficient for $\tau > 0$ while $\tau < 0$ occurs for some values of $\nu < 0$. Thus, a negative value of ν can generate a negative relationship between pollution and input use, because an increase in ω can increase z and reduce x^*.

The relationships between input per unit of output, $\tilde{x}$, and pollution per unit of output, $\tilde{z}$, in the case of fixed proportions pollution and yield functions are shown in Figure 2(c). This special case is of interest because it allows decisions at the extensive margin to be analyzed independently of decisions on the intensive margin. This case will be investigated in the section "Policy Interaction on the Extensive Margin." Observe that

$$\tilde{z} = z/y = x^{\alpha-\eta}\omega^{\beta-\nu}$$

and

$$\tilde{x} = x/y = x^{1-\eta}\omega^{-\nu}.$$

Thus, $\alpha = \eta = 1$ is the case of fixed proportions. Note that the pollution-output and input-output ratios are fixed for a given value of the environmental attribute ω. This does not means that proportions are fixed at the farm level, however, because total input use and total acreage vary according to which acres are brought into production.

Assuming fixed proportions, inverting the $\tilde{x}$ equation and substituting into the $\tilde{z}$ equation gives

$$\ln \tilde{z} = (1 - \frac{\beta}{\nu})\ln \tilde{x}.$$

As the environmental attribute is varied it is possible to generate either a positive or negative relationship between input and pollution per unit of output depending on the relative magnitudes of the parameters and the sign of ν. If ν is positive and less than β, an increase in ω reduces $\tilde{x}$ but increases $\tilde{z}$; a negative value of ν means that an increase in ω reduces y and ensures a positive relationship between $\tilde{x}$ and $\tilde{z}$.

The relationships in Figure 2 determine the properties of the distributions of output, input use, and pollution. Variations in environmental attributes induce variations in input use, output, and pollution through these functional relationships.

Modeling the Joint Distribution of x, ω, and z

Policy may impose restrictions on the distribution of x and ω that must be taken into account in analysis and estimation. When land use restrictions limit the range of environmental attributes available for production, the distribution will be truncated in the ω dimension. The distribution of x and ω also may be censored, as when there is a positive probability that input use occurs at zero. This occurs, for example, when pesticide use decisions may be zero with a positive probability. Similarly, the distribution may be censored at a positive limit, as when policy limits water or chemical use. When truncation or censoring is not important, it is possible to greatly simplify the modeling by assuming a common continuous distribution such as a joint lognormal distribution. It is worth noting that the lognormal is one of the distributions that has been used in recent Monte Carlo simulations of physical models (Carsel et al. 1988), and has long been used in economic production modeling. This section first uses the standard lognormal model, and the following sections discuss generalizations to truncation and censoring.

Assume that x and ω are distributed in the population such that

$$\begin{bmatrix} \ln x \\ \ln \omega \end{bmatrix} \sim N(\mu, \Sigma | p, \psi, \theta),$$

where μ is a (2 x 1) vector of means and Σ is a (2 x 2) covariance matrix. Letting $\gamma = (\alpha, \beta)'$, it follows that

$$\ln z \sim N(\gamma'\mu, \gamma'\Sigma\gamma) = N(\mu_z, \sigma_z^2),$$

so that

$$z \sim LN[\exp(\mu_z + \sigma_z^2/2), \exp(2\mu_z + 2\sigma_z^2) - \exp(2\mu_z + \sigma_z^2)].$$

The moments of the distribution of x and ω are functions of policy parameters so the moments of the joint distribution of z and x also are functions of policy parameters, and

$$\partial E(z)/\partial\psi = \exp(\mu_z + \sigma_z^2)[\gamma'(\partial\mu/\partial\psi) + \gamma'(\partial\sigma/\partial\psi)\gamma/2].$$

Since α and β are positive, a positive relationship between the policy parameter and the mean input or the mean environmental attribute implies the policy change has a positive effect on mean pollution. By the properties of the lognormal distribution, it also follows that an increase in the variances or covariance of x and ω shift the distribution of z in the positive direction and increase its mean.

Using the definition of the covariance, cov(z,x) = E(zx) - E(z)E(x), and the fact that $xz = x^{\alpha+1}\omega^{\beta}$, it can be shown that

$$E(x) = \exp(e'\mu + e'\Sigma e/2)$$

$$E(z) = \exp(\gamma'\mu + \gamma'\Sigma\gamma/2)$$

$$E(zx) = \exp((\gamma+e)'\mu + (\gamma+e)'\Sigma(\gamma+e)/2)$$

where $e = (1,0)'$. The correlation between z and x is therefore

$$\sigma_{zx} = \exp(\alpha\sigma_x^2 + \beta\sigma_{x\omega}) - 1.$$

Since α and β are positive, σ_{zx} is positive unless $\sigma_{x\omega}$ is sufficiently negative to cause $\alpha\sigma_x^2 + \beta\sigma_{x\omega} < 0$. Thus, using the lognormal model demonstrates the central role that the covariance between input use and environmental attributes plays in determining the relationship between pollution and input use in the population.

The effect of policy on the correlation between input use and pollution is

$$\partial\sigma_{zx}/\partial\psi = \exp(\alpha\sigma_x^2 + \beta\sigma_{x\omega})[\alpha(\partial\sigma_x^2/\partial\psi) + \beta(\partial\sigma_{x\omega}/\partial\psi)].$$

The effect of policy on σ_{zx} thus depends on the effects of policy on the variance of input use and on the covariance of input use and environmental attributes.

This lognormal example is an illustration of the importance of some basic relationships between farmers' management and land use decisions, and the effects of policy on those relationships and agricultural pollution. These relationships are utilized in the policy analyses in the following sections.

The joint distributions of x and ω and of x and z can be represented graphically using confidence regions as illustrated in Figure 3 for an elliptical distribution such as the normal (note these ellipsoids are defined for the logarithms of the variables in the lognormal model). In Figure 3 95 percent ellipsoids are shown for the case of positive correlation between the variables. As shown in the previous section for the lognormal case, a positive correlation between ω and x usually translates into a positive correlation between z and x, and the converse is to be expected for negative correlations. A change in a policy variable such as a support price would be expected to increase input use on each acre in production, thus shifting the joint distribution $\phi(x,\omega)$ to the right. Such a shift in $\phi(x,\omega)$ would in turn shift the joint distribution of z and x in the northeast direction and could also alter its shape as revealed in the ellipsoids.

Truncation of Distributions

When there is an acreage diversion requirement so that farmers produce only on land with input levels $x > \bar{x}$, the distribution $\phi(x,\omega)$ is truncated in the x dimension. The percentage of land idled is

$$\lambda = \int_0^\infty \int_0^{\bar{x}} \phi(x,\omega)\ dx\ d\omega.$$

The truncated density function is therefore $(1 - \lambda)^{-1}\phi(x,\omega)$, for $x \in [\bar{x},\infty)$ and $\omega \in (0,\infty)$.

The truncation of the distribution changes its shape and the shape of the corresponding confidence region. To illustrate how the distribution changes, consider the distribution of x for a given value of ω with truncation on the left-hand tail as illustrated in Figure 4(a). The truncation causes the density to shift upwards as illustrated by the broken line. Before truncation the α_0 critical level for the right-hand tail is given by x_c, where by

$$\alpha_0 = \int_{x_c}^\infty \phi(x,\omega)\ dx.$$

Thus after truncation,

$$\alpha_0 < (1 - \lambda)^{-1}\alpha_0 = \int_{x_c}^\infty \phi(x,\omega)/(1 - \lambda)\ dx.$$

It follows, therefore, that the α_0 critical level for the truncated distribution is $\bar{x}_c > x_c$, as illustrated in Figure 4(a). Truncation from the left thus shifts the mass of the distribution rightward and shifts the confidence interval to the right.

A similar analysis can be conducted for a confidence region defined in the left-hand tail. Obviously, if $\bar{x} > x_c$ the α_0 critical value for the truncated distribution must be at some $\bar{x}_c > \bar{x}$. The other possible case in which $\bar{x} < x_c$ is illustrated in Figure 4(b). Note that the area under $\phi(x,\omega)$ between $\bar{x}$ and x_c is

$$\int_{\bar{x}}^{x_c} \phi(x,\omega)\ dx = \alpha_0 - \lambda,$$

and therefore the corresponding area under the truncated distribution is

$$\int_{\bar{x}}^{x_c} \frac{1}{1 - \lambda}\ \phi(x,\omega)\ dx = \frac{\alpha_0 - \lambda}{1 - \lambda} < \alpha_0.$$

The inequality follows from the fact that α_0 and λ are numbers between zero and one so that $\alpha_0 - \lambda < \alpha_0 - \alpha_0\lambda = (1 - \lambda)\alpha_0$. Therefore, the α_0 critical value for the truncated distribution is at $\bar{x}_c > x_c$, as illustrated in Figure 4(b).

Combining the relationships in Figures 4(a) and 4(b) gives the confidence region for the truncated joint distribution in 4(c). According to Figures 4(a) and 4(b) for each value of ω, limits of the confidence region move to the right by an amount determined by the amount of mass that is shifted rightward. It is left to the reader to consider the various other possible cases, such as a left-tail truncation with a negative correlation between ω and x, a right-tail truncation, or a truncation in the ω dimension. In each case the truncation shifts the mass of the distribution and therefore also shifts the confidence region.

<u>Censoring of Distributions</u>

Environmental regulations that restrict the maximum amount of input used per acre may cause farmers to apply that maximum amount on the acres that would have received a larger amount if input use was unrestricted. This would be the case, for example, if nitrogen use was restricted to a level less than the profit maximizing level to control groundwater contamination. Such policies cause the mass of the $\phi(x,\omega)$ distribution to "pile up" at the point of the restriction. If the maximum input use allowed is x_0 and the profit maximizing input is $x^* > x_0$, the joint distribution of ω and x is defined as

$$\phi(x^*,\omega) = \phi(x,\omega) \text{ for } x < x_0$$

$$\phi(x^*,\omega) = \int_{x_0}^{\infty} \phi(x,\omega)\, dx \text{ for } x \geq x_0.$$

The censoring of the distribution thus leaves the distribution shape unchanged for values of x less than x_0, and the mass of the distribution to the right of x_0 is accumulated at x_0. This phenomenon is illustrated in Figure 5 by the shading of the vertical line at x_0.

This censored distribution can be used to compute the moments of the distribution of the random variables. For example, expected pollution is

$$\text{(1)} \qquad E(z) = \int_0^{\infty} \int_0^{x_0} z(x^*,\omega)\, \phi(x^*,\omega)\, dx^* d\omega$$

$$= \int_0^{\infty} \int_0^{x_0} z(x,\omega)\, \phi(x,\omega)\, dx\, d\omega + \int_0^{\infty} z(x_0,\omega) \int_{x_0}^{\infty} \phi(x,\omega)\, dx\, d\omega.$$

This representation of the distribution can be used to investigate the impact of changes in the policy parameter x_0 on moments such as E(z). This kind of analysis will be conducted in subsequent sections of this chapter.

The implementation of an environmental policy such as a restriction on input use per acre may alter a farmer's behavior and induce other changes in the distribution $\phi(x,\omega)$ in addition to its censoring. According to the optimization problem defined in the section "The Disaggregated Model," farmers choose which acres to place in production and the inputs used on those acres as functions of environmental attributes of the land. If the jth acre is profitable at $x_j > x_0$ but not at $x_j = x_0$ then that acre would not be put in production under a restriction at x_0 . Hence, the resulting joint distribution $\phi(x,\omega)$ for acres in production also would be different. Suppose, for example, that ω and x are positively correlated as in Figure 5, and all acres with $\omega > \omega^*$ were unprofitable with $x = x_0$. The policy would thus result in the truncation of the distribution at ω^* for values of $x > x_0$. As a result, the section of the confidence region below ω^* would shift downward, and the distribution also would be truncated at x_0. It can be concluded, therefore, that policies can have complex effects on the joint distribution of x and ω. Similar conclusions can be drawn for the joint distribution of x and z. In the section "Policy Interaction at the Extensive and Intensive Margins," the joint effects of policies on both the extensive margin and the intensive margin are examined further.

Policy and Input Use on the Intensive Margin

The discussion now will be focused on input use at the intensive margin. In this section land use is assumed to be constant so the distribution of environmental attributes also is held constant at the farm level. The only behavioral response by farmers to policy is to adjust input use. Input adjustments, in turn, affect yield and pollution. Because pollution is increasing in input use for a given value of the environmental attribute, an increase in mean input use causes an increase in mean pollution whether there is a positive or a negative correlation between ω and x. Two types of relationships may exist between the distributions of x and ω and between x and z when a policy change, such as an increase in a support price, causes an increase in mean input use (Figure 3). Holding the mean land attribute constant at ω_1, an increase in the support price increases mean input use from x_1 to x_2, increases mean pollution from z_1 to z_2, and the confidence regions shift to the right as illustrated in Figure 3. Similarly, mean yield is increasing in mean input use. These relationships can be derived with the lognormal model introduced earlier, for example.

Social welfare (or alternatively, the relevant policy criterion) is assumed to be a function of aggregate (mean) production, input use, and pollution, $W = W(Y,X,Z)$. Aggregate input use is included in this function, because of the partial nature of the analysis here, to represent the value to society of inputs drawn away from other sectors of the economy. Alternatively, the welfare criterion could be defined as a function of producer surplus, consumer surplus, and the benefits of environmental preservation. With either approach, the function could be specified numerically see (Gardner 1990).

When there is no adjustment at the extensive margin, a policy change affects welfare through its effects on input use. Assuming appropriate curvature conditions to assure a unique global maximum, the socially (or politically) optimal level of input use can then be defined as X^* satisfying

$$dW/dX = W_y Y_x + W_x + W_z Z_x = 0,$$

where subscripted variables denote partial derivatives, and Y, X, and Z are aggregate (mean) input, yield, and pollution per acre. According to this equation, the marginal social benefit $W_y Y_x$ is equated to the marginal social cost $-W_x - W_z Z_x$ at the social optimum level of input use X^*.

As noted, $Z_x > 0$ when the land in production is fixed. Given their land in production, profit maximizing farmers use inputs so that the value of the marginal product is equal to the input price. Thus, at the population mean, farmers overuse the input relative to the social optimum because they ignore the social cost of the pollution they create. In other words, profit maximizing farmers behave as if $W_z = 0$. This behavior is analogous to the behavior of profit maximizing farmers at the extensive margin discussed in the previous section.

Agricultural Policy on the Intensive Margin

The demand for inputs is an increasing function of output price, so for a binding support price p_s, profit maximizing farmers increase input per acre as the support price is increased. Thus, a price support intensifies the application of inputs to land, increases pollution, and moves input use farther away from the social optimum X^* defined with $Z_x > 0$. With a fixed land endowment in production, therefore, the conventional wisdom that price supports increase pollution is justified. Similar conclusions can be drawn for any other kind of policy, such as credit subsidies or crop insurance subsidies, that effectively lower the price of inputs relative to outputs.

Since the 1970's commodity programs have combined a support price and a target price with an acreage diversion requirement. Whether or not acreage diversion is required, it should be noted that the maximum of the support price and the market price is the relevant price for farmers' decisions on the intensive margin. When there is no diversion, and the target price is greater than the market price, profit per acre is

$$\pi_j = \max(p_s, p_m)y_j + \{p_t - \max(p_s, p_m)\}y_p - vx_j - c,$$

where p_m is the market price, p_t is the target price, y_p is the program yield, and c is fixed cost per acre. Given y_p, which is used to determine the government payment associated with the target price, the farmer's input choice decisions thus depend on the support or market price. Thus, given the current program design, the higher target price does not exacerbate environmental problems on the intensive margin.

Environmental Policies and Behavior on the Intensive Margin

In principle, socially optimal input use could be induced through a pollution tax, although this policy solution is not practical since most agricultural pollution is nonpoint and costly to monitor. Assuming output and input prices are not otherwise distorted, with a pollution tax t the profit-maximizing level of input use satisfies

$$\partial\pi_j/\partial x_j = p\partial y_j/\partial x_j - v - t\partial z_j/\partial x_j = 0.$$

Thus, the appropriate tax will induce farmers to equate the value of the marginal product with the marginal social cost of production, and the social welfare-maximizing input-use level will be achieved on each acre. Figure 3 is an illustration of the kinds of shifts in the distribution of input and pollution that might occur in response to a pollution tax. Generally, high levels of input use would be discouraged, mean input use would decline from x_2 to x_1, and the distribution would tend to be shifted towards the origin with lower mean pollution levels.

An input tax also could be used to approximate the social optimum. The profit-maximizing input choice on acre j would satisfy

$$\partial\pi_j/\partial x_j = p\partial y_j/\partial x_j - v - t = 0.$$

Unless pollution is proportional to input use, the input tax generally would not achieve the efficient level of input use on each acre. This is because the differences in the marginal damage $\partial z_j/\partial x_j$ across acres with different environmental attributes would not be taken into account. Nevertheless, in the aggregate an input tax could be socially preferred to no policy intervention.

Most environmental policies are based on standards, not taxes. If the pollution function $z(x,\omega)$ were known, it would be possible to impose a standard $x_s(\omega)$ that would achieve the socially optimal level of pollution on each type of acre. This type of site-specific standard is illustrated in Figure 6(a) for the case in which ω and x are positively correlated. The left-hand figure shows the effects of the standard on the distribution of ω and x. The imposition of the standard causes the distribution to be censored along the $x_s(\omega)$ curve. The shape of the distribution is altered as indicated by the shaded area representing the accumulation of the mass of the distribution along $x_s(\omega)$. The censoring also alters the shape of the distribution of z and x, as indicated in the right-hand figure.

In practice, uniform standards typically are used. The case of a uniform standard is illustrated in Figure 6(b). The left-hand figure shows the censoring of the distribution of ω and x at the value x_0. The right-hand figure shows the effect on the distribution of z and x. The censoring of the distribution of ω and x at the value x_0 causes the confidence region of the distribution of z and x to shift leftward. Uniform standards are inefficient because they force all acres to conform to a standard regardless of how much pollution they cause or their productivity. For this reason uniform standards generally cost more forgone output to attain a particular amount of pollution reduction than site-specific standards or taxes.

Combining Commodity and Environmental Policies at the Intensive Margin

When land in production is fixed, commodity policy that transfers income to farmers by subsidizing production generally increases the intensity of input use, and thus increases pollution. With a commodity policy, therefore, there are distortions on two margins that lead to socially suboptimal input use: (1) output is overvalued relative to inputs, and (2) pollution is undervalued (assuming that market prices are efficient so that support prices are not designed to fix some distortion). The first-best solution, as always, is to correct the distortions on the corresponding margins. If this cannot be done, then second-best solutions can be devised. Thus, if commodity policies cannot be eliminated, a pollution tax, input tax, or standard can be used to move closer to the social optimum.

Given a particular commodity policy, such as a support price above the market price, input use is higher than with the market price and is a function of the marginal product of the input and the support price. Unless the marginal effect of the input is the same on output and pollution, a uniform tax on pollution is not able to achieve the social optimum on each acre, although it could be an improvement over no intervention. The same reasoning holds _a fortiori_ for the analysis of the input tax and pollution standards. They generally will not achieve the social optimum except under highly restrictive conditions.

There is an important difference between taxes and standards that should be mentioned, however. If the objective of price supports is to transfer income to farmers (however inefficiently), pollution or input taxes obviously work directly against this objective. Pollution standards, although usually less efficient than taxes, provide a means of combining commercial and environmental policy to address both income distribution and environmental concerns. It must be emphasized, however, that both of these policy tools are inefficient means to these ends. Income transfers unrelated to input use would achieve the income distribution objectives without distorting input use. Such lump-sum transfers, if feasible, could be combined with either taxes or standards to more closely approximate the social optimum than a price support would.

Policy Interaction on the Extensive Margin

In this section a simple model of the interaction of agricultural and resource policies whose adjustments occur on the extensive margin will be developed. Adjustments on the intensive margin are not addressed. In other words, input use per acre does not respond to prices or policy changes. Many representations of production in agricultural economics follow fixed-proportion relationships. For example, programming models include production activities whereby input use and production vary proportionally with the acreage allocated to an activity and the proportions do not respond to prices. Since these applications have proven useful in many contexts, the results of this section should provide a useful abstraction. Note, however, that the framework of this section allows for variations in the input application rates with respect to characteristics of land and operator.

Following the general framework presented in the section "The Disaggregate Model," let ω_j represent the characteristics of acre j and let x_j represent the quantity of productive inputs used on land with characteristics ω_j when it is used to produce. Then pollution (or resource depletion) on acre j is $z_j = z(x_j,\omega_j)$. Similarly, let production on land with characteristics ω_j follow $y_j = y(x_j,\omega_j)$. To simplify the presentation for this case, variables are redefined so that $\tilde{x}_j = x_j/y_j$ is the input-output ratio and $\tilde{z}_j = z_j/y_j$ is the pollution-output ratio on land with characteristics ω_j.

Next, let output price be given by p and input price by v. Following competition, these prices are assumed to apply to all acreage. Profit from production on land with characteristics ω_j is then given by $\pi_j = py_j - v\tilde{x}_j y_j$. Assuming profit maximization, this land will be used for production if and only if $\pi_j > 0$ which implies $\tilde{x}_j < p/v \equiv x^*$.

The use of land for production is illustrated in Figure 7. All land is classified by the input-output ratio $\tilde{x}$ and the pollution-output ratio $\tilde{z}$ with the domain of all available land included in the rectangle defined by $\bar{x}$ and $\bar{z}$. For given prices defining x_0^*, only land to the left of x_0^* is used for production under profit maximization as in panel (a). Less productive land to the right of x_0^* is idled. Alternatively, environmental concerns suggest eliminating production on land with higher pollution-output ratios such as land above z_0^* in panel (b). A general extensive margin frontier combining both environmental and production concerns is of the form $z^*(\tilde{x})$ where all land left and below is used to produce and land above and right is idled as in panel (c).

Now let the joint probability density function for $\tilde{x}$ and $\tilde{z}$ across the entire region of interest follow $f(\tilde{x},\tilde{z})$. (This distribution is more basically induced by the spatial distribution of characteristics across the region.) Then aggregate production, input use, and pollution can be found by integration,

$$(2) \qquad Y = \int_0^{\bar{x}} \int_0^{z^*(\tilde{x})} y \; f(\tilde{x},\tilde{z}) \; d\tilde{z} \; d\tilde{x}$$

$$(3) \qquad X = \int_0^{\bar{x}} \int_0^{z^*(\tilde{x})} \tilde{x}y \; f(\tilde{x},\tilde{z}) \; d\tilde{z} \; d\tilde{x}$$

$$(4) \qquad Z = \int_0^{\bar{x}} \int_0^{z^*(\tilde{x})} \tilde{z}y \; f(\tilde{x},\tilde{z}) \; d\tilde{z} \; d\tilde{x}.$$

Recall from the section "Policy and Input Use on the Intensive Margin" that the welfare function is defined as $W = W(y,x,z)$. The form of the optimal policy is found by substituting (2)-(4) into the welfare function W, differentiating with respect to z^* for each level of $\tilde{x}$, and setting the result equal to zero,

$$\frac{\partial W}{\partial z^*} = W_y\, yf(\tilde{x}, z^*) + W_x\, \tilde{x}yf(\tilde{x}, z^*) + W_z\, z^* yf(\tilde{x}, z^*) = 0.$$

This is a condition that must hold for all $\tilde{x}$ and z^* along the optimal extensive margin frontier $z^*(\tilde{x})$. Dividing through by $yf(\tilde{x}, z^*)$ simplifies the condition to

(5) $$W_y + \tilde{x}W_x + z^*W_z = 0.$$

The shape of the optimal policy can be found by comparative static analysis of this condition which yields $dz^*/d\tilde{x} = -W_x/W_y < 0$. Since W_x and W_y are determined at the aggregate level, they are constant along the optimal extensive margin frontier. This implies that $dz^*/d\tilde{x}$ is constant along the optimal frontier or, in other words, that $z^*(\tilde{x})$ is a straight line with a negative slope as in panel (d) of Figure 7 with production occurring for $\tilde{x} < -(W_y + z^*W_z)/W_x$. Given this result, various forms of agricultural and environmental policies will be evaluated to determine their potential to achieve or approximate optimum conditions.

Price Support

The most common agricultural policy instrument used in the United States over the last half century has been price support. When a price support is provided unconditionally, it simply puts a floor under the market price thus raising the producer price if the support is effective. The condition for producing on land with characteristics ω_j is $\pi_j = p_s y_j - v\tilde{x}_j y_j > 0$, which implies $\tilde{x}_j < p_s/v = x_s^*$. This results in a vertical extensive margin frontier such as in panel (a) of Figure 7 where the frontier shifts further right and brings more land into production with higher support levels. Clearly, this control reaches the social optimum only when environmental concerns play no role in social welfare ($W_z = 0$). Interestingly, this is the type of agricultural policy that prevailed during most of the first few decades of agricultural intervention when environmental concerns received little attention. For example, wheat production enjoyed unconditional price supports until 1954, except for 1950, and feed grains also did until 1961. Clearly, however, excess production and stock accumulation rather than environmental concerns were initial reasons for revising programs and adding conditions to price supports.

Production Controls

To avoid excessive overproduction when farm prices have been supported, various forms of production controls often have been imposed. These have taken the form of mandatory production quotas, voluntary participation in allotments, voluntary diversion and acreage reduction programs (ARP's), and conservation reserve programs (CRP's). Following the framework introduced by Rausser, Zilberman, and Just (1984), all of these controls have the effect of bidding up the returns to land at the extensive margin.

Let g be the payment per acre for diversion under a voluntary diversion or conservation reserve program or, alternatively, let g represent the shadow value of the land constraint associated with an allotment or minimum diversion requirement.[3] The condition for producing on land with characteristics ω_j is then $\pi_j = p^* y_j - v\tilde{x}_j y_j > g$ where p^* is the higher of the market, support, or target prices associated with the program. This implies that production occurs on land with characteristics ω_j if and only if

$$(6) \quad \tilde{x}_j < \frac{p^* Y_j - g}{vY_j} = \frac{p^*}{v} - \frac{g}{vY_j} .$$

Thus the performance of a production control program depends on the type of environmental or resource depletion problem of concern. If higher yielding land has a higher pollution-output ratio, then applying equation (6) will cause an upward sloping extensive margin frontier as Figure 8. This is directly contrary to the optimal policy form and causes land to be diverted from production that has a lower pollution-output ratio than land remaining in production. Thus, an acreage reduction program interacts very poorly with resource or environmental considerations that tend to result only with intensive farming practices. These results apply when pollution represents the depletion of water for irrigation because irrigation tends to use more variable inputs per unit of output. The same also may be true when pollution represents insecticide and fungicide exposure for farm workers, because proportionally more labor per acre is used on high input crops such as fruits and vegetables that rely heavily on such pesticides. However, such crops do not have production controls.

If higher yielding land has a lower pollution-output ratio, then equation (6) implies that the extensive margin frontier is downward sloping as in panel (c) of Figure 7. This frontier is more in line with the optimal policy. However, the slope of the resulting extensive margin frontier will not be constant as under social optimality unless the yield is inversely proportional to the pollution-output ratio. This implies that the level of pollution per acre does not vary with yield. In this case, the optimum can be achieved by appropriate choice of the target price, which determines p^* (when effective) and the diversion level, which determines g. This case appears to be more appropriate for certain kinds of low-till herbicide use problems whereby pollution represents the environmental exposure necessary to control weeds (particularly prior to the growing season) and may not depend heavily on other factors that affect yields. On the other hand, when pollution represents soil erosion and the more erodible soils are the poorer soils, a relationship whereby higher yielding land has a lower absolute level of pollution per acre is suggested. In this case, an acreage reduction program can provide too much incentive to reduce use of poor soils. However, with moderate target prices and production controls, this case may approximate the social optimum.

Based on these results related to extensive margin considerations alone, current agricultural policies appear to be poorly suited to water policy needs and, in fact, exacerbate them. However, the addition of production controls to price supports for major agricultural commodities over the last 30 years appears to be moving in a general direction consistent with environmental concerns related to soil erosion and pesticide use.

Pollution Tax

Consider next the set of policies typically proposed to deal with resource and environmental concerns. A policy with desirable properties in many contexts, but rarely used in practice, is a pollution tax. Suppose a tax t is imposed on each unit of pollution. Then short-run profit per acre on land with characteristic ω_j is $\pi_j = py_j - v\tilde{x}_j y_j - t\tilde{z}_j y_j$. Thus, only land with $p - v\tilde{x}_j - t\tilde{z}_j > 0$ or, equivalently, with $\tilde{x}_j < (p - t\tilde{z}_j)/v$ will be used to produce. This results in a straight-line extensive margin frontier with a negative slope as in panel (d) of Figure 7. Comparing to the optimal frontier condition in equation (5), one finds that the optimum is achieved if $p = W_y$, $v = W_x$, and $t = W_z$. This is the traditional result whereby the social optimum is achieved by simply setting the pollution tax equal to the marginal social cost of pollution if market prices are not distorted. In this analysis the ability of a single pollution tax instrument to transmit appropriate signals simultaneously to producers in many and varied circumstances is emphasized.

Interaction of a Pollution Tax with Agricultural Policy

The interaction of agricultural and resource policies will now be considered. This is done first by considering the interaction of pollution taxes with the agricultural policies discussed earlier. Second, pollution standards and how they interact with agricultural policies will be discussed.

For the case of a pollution tax, it is clear that agricultural policy, which distorts output prices upward, can undermine efforts to impose optimal resource policy. Subsidizing output prices raises the extensive margin frontier such as $z^*(x)$ in Figure 7(d) in a vertically parallel fashion. This problem cannot be corrected by imposing a higher pollution tax since that rotates the extensive margin frontier. Apparently, however, some cases exist whereby a combination of price support, production control, and taxing pollution beyond the marginal social cost of pollution approximates the social optimum. For example, in the water resource depletion case cited earlier, production controls tended to rotate the extensive margin frontier clockwise whereas a water use charge (the pollution tax) tends to rotate the extensive margin frontier counterclockwise. By using the price support level to counter-balance the disincentive to produce caused by a water use charge beyond the social cost, the social optimum may be achieved or approximated in some cases. However, this could be achieved only by careful coordination of agricultural and resource policies.

Pollution Standards

Pollution taxes are difficult or impossible to impose because of nonpoint source problems or costs of monitoring. Alternatively, pollution standards have been the most common policy instrument of resource and environmental policies. For example, quotas frequently are used to allocate water. Pesticide policies frequently impose application standards or reentry restrictions.

Pollution standards can take a variety of forms. For example, a pollution standard could be imposed in the form of a limitation on the pollution-output ratio, $\tilde{z}_j < z_0^*$. This would attain a result as in panel (b) of Figure 7. For most resource and environmental problems in agriculture, pollution-output standards are difficult to impose because output is stochastic and pollution often is related more closely to input use. One example is the case of a standard on pesticide residuals on fruit and vegetable produce. Comparing the pollution standard with the optimal policy of equation (5), environmental concerns are allowed to determine the outcome and production efficiency is disregarded. Of course, this situation does not occur in the case of pesticides used for preservation after harvest for which use is not related to local or land characteristics that also may be correlated with agricultural productivity.

The most widely used form of standards used in agriculture are standards on pollution-land ratios, e.g., $\tilde{z}_j y_j < s$. Water quotas are usually in acre-feet. Pesticide application standards are in terms of application per acre. Because these standards do not necessarily relate to output, they can be either consistent or inconsistent with production efficiency and social optimality criteria. Consistency depends on the joint distribution of y_j, $\tilde{x}_j$, and $\tilde{z}_j$.

Consider first the case where higher pollution per acre occurs on land with higher pollution per unit of output regardless of input use intensity. In this case, the standard imposes a extensive margin frontier as in panel (b) of Figure 7. Thus, comments similar to the case of a standard on the pollution-output ratio apply. A possible example is the case of water use quotas. Viewed across a region of varied natural rainfall circumstances, higher water use per acre tends to be associated with higher water use per unit of output.

Consider next the case where higher pollution per acre occurs on land with higher input-output ratios irrespective of the pollution-output ratio. In this case, the standard imposes a extensive margin frontier as in the case of panel (a) of Figure 7. Thus, for this case a pollution-per-acre standard is efficient from a production standpoint, but quite inefficient from a pollution standpoint. This case apparently applies to many problems of pesticide leaching into groundwater. The amount of pesticides reaching groundwater tends to be correlated highly with the quantity of pesticide use, which is correlated with the quantity of other production inputs as well.

Alternatively, pesticide contamination of the environment may tend to be greater on a per-acre basis on either land with a higher pollution-output ratio or a higher input-output ratio. For example, more irrigation may tend to carry more pesticides into groundwater. In this case, the extensive margin frontier may tilt as in panel (c) of Figure 7 so that some approximation of the social optimum results. The problem in this case is that both the slope and location of the extensive margin frontier is controlled by the choice of a single policy instrument. The relationship of the slope and location is the result of physical relationships that cannot be controlled by the policy instrument. Thus, any correspondence to the social optimum would be a coincidence.[4]

Furthermore, more adverse consequences are possible. Suppose, for example, that higher pollution per acre occurs on land with either a higher pollution-output ratio or a lower input-output ratio. This could be the case with sodbusting considerations where more soil erosion occurs on marginal land that is farmed with low input use. It also could be the case where some land characteristics lead to use of low-till technologies that are associated with lower input-output ratios in general but higher pesticide use in lieu of cultivation. In this case, a pollution per-acre standard tends to limit the use of practices with low input-output ratios leading to a extensive margin frontier of the form in Figure 8. Clearly, policies of this type can be highly inconsistent with social optimization in certain circumstances.

Interaction of Pollution Standards with Agricultural Policy

Unlike the case of a pollution tax, pollution standards do not alter the extensive margin frontier prescribed by agricultural policy because price incentives are not altered. Rather, pollution standards impose an additional frontier that further removes some types of land from production.[5] The combination of effects can be examined by simply superimposing the pollution standard extensive margin frontier on the agricultural policy extensive margin frontier. Except for the case where one of the two policies is redundant, both pollution-standard and agricultural policies need to approximate the social optimum individually. The important point here is that, with pollution standards, commercial and pollution policies can be set independently without coordination of the two sets of policy instruments. Hence, separation of policy implementation efforts among different agencies is appropriate. However, both sets of policies need to be determined with both production efficiency and environmental concerns in mind. The implication is that both sets of policies must be implemented with common values attached to environmental and production efficiency concerns. To do this, the legislation adopted at the congressional level must clearly convey these values to the separate agencies.

Conclusions with Respect to Policy Interaction on the Extensive Margin

Considering policy interactions only on the extensive margin, the need for coordination of agricultural and resource policies may not be serious in the case where pollution taxes are not used. However, both sets of policies must be set to balance production and environmental concerns appropriately . For some problems the general features of both agricultural and resource policies can seriously detract rather than improve social welfare if both are of concern because of the distributional differences in responses to such controls. For other problems, neither can be set to appropriately balance production and environmental concerns without basic information about the joint distribution of productive efficiency and pollution generation (characterized here as the joint distribution of the input-output ratio, the pollution-output ratio, and yield). Apparently, common agricultural policy instruments have somewhat more flexibility for this purpose than the resource policies that have been implemented.

As a general rule, agricultural policies combining price and production controls appear to be fairly well suited to environmental problems related to soil erosion, low-till technologies, and pesticide contamination of groundwater. These policies, however, are not suited to water depletion and the exposure of farm workers to pesticides . Resource policies are not well suited to handling water depletion problems but at least do not exacerbate the problem as do agricultural policy controls. Pesticide policies appear to have reasonable effects in some cases and unreasonable effects in others. These specific conclusions, are tentative and will remain somewhat speculative until the necessary data are generated to support the distributional analysis illustrated here.

Policy Interaction at the Extensive and Intensive Margins

The analysis presented to this point is based on simple stylized models indicating some of the general effects of major agricultural and resource policy instruments while focusing on extensive and intensive margin effects independently. In reality, agricultural policies are comprised of a complex and interactive set of instruments used to determine extensive and intensive margins simultaneously. Indeed, the producer's choice problem was defined earlier as the joint determination of land use and input use. Most policies that affect the economic decisions of farmers affect decisions at both the extensive and intensive margins.

In this context, it is interesting to note that major current agricultural policies are structured so as to allow control over both margins. This is important from a resource or environmental policy perspective for the following reason. Agricultural price supports have been criticized from a resource or environmental perspective because they tend to encourage more intensive farming practices on the acreage remaining in production, and more intensive farming practices typically are associated with more pesticide use, erosion, water use, and so forth. Indeed, the preceding analysis of input use, holding land use fixed, verified that price supports generally will increase input use and pollution. The analysis of land use decisions holding input intensity fixed, however, showed that agricultural policies do not necessarily lead to higher levels of pollution. This can be true in those cases in which agricultural productivity and the environmental attributes associated with pollution are negatively related. The point of this section is to demonstrate that current agricultural policies are structured so that undesirable environmental effects can be mitigated if policies are designed and administered appropriately.

Consider the farmer's choice problem defined as profit maximization. Acres diverted from production receive a payment of \$g per acre, and there is a diversion requirement of λ percent, or of $n\lambda$ acres. If an acre is put into production, input use is x_j^*. The solution to the land use problem is obtained by selecting for production those acres that are more profitable than g, while meeting or exceeding the diversion requirement. For stage II production, there is a monotonic relationship between input use and profitability.

Ordering all acres from least to most profitable is equivalent to ordering them from low to high values of x_j^*. The farmer will divert the jth acre if profit π_j does not exceed g, or if it is the least profitable acre with $\pi_j > g$ that must be diverted to meet the requirement. The acreage diversion thus determines a minimum level of input use $\bar{x}$ formally defined as

$$\bar{x}(g,\lambda) \equiv \min\{x_j^* | \pi_j \leq g \text{ or } \Sigma_j(1 - \delta_j) \geq n\lambda\}.$$

Note that if the marginal acre meeting the diversion requirement is more profitable than the diversion payment, the farmer will stop diverting land at that point. But if the marginal acre is not profitable, the farmer will exceed the diversion requirement up to the break-even point or a payment or diversion limitation. Thus, the diversion requirement defines a lower bound on $\bar{x}$, but as g increases holding λ constant, $\bar{x}$ may increase as more profitable land is diverted.

Truncating input use through land diversion will have an impact on the joint distribution of input and pollution and thus on expected pollution. The effect on expected pollution depends on the correlation between input and pollution (Figure 9). If x and z are positively correlated, as in Figure 9(a), removing land with $x < \bar{x}$ also removes land associated with low pollution levels. If x and z are negatively correlated, as in Figure 9(b), the opposite tends to be true. Formally, for a binding diversion requirement λ,

$$E(z) = (1 - \lambda)^{-1} \int_0^\infty \int_{\bar{x}}^\infty z\, f(x,z)\, dx\, dz \equiv Z$$

where f(x,z) is the joint distribution of input and pollution and

$$\lambda = \int_0^\infty \int_0^{\bar{x}} f(x,z)\, dx\, dz.$$

It follows that

$$d\lambda/d\bar{x} = \int_0^\infty f(\bar{x},z)dz$$

and

$$\partial Z/\partial\lambda = (1 - \lambda)^{-1} Z - (1 - \lambda)^{-1} (d\bar{x}/d\lambda) \int_0^\infty z\, f(\bar{x},z)\, dz$$

$$= (1 - \lambda)^{-1} [Z - E(z|x = \bar{x})].$$

If z and x are positively correlated, $Z = E(z|x > \bar{x}) > E(z|x = \bar{x})$ and therefore $\partial Z/\partial\lambda > 0$. Conversely, $\partial Z/\partial\lambda < 0$ if z and x are negatively correlated. Observing that the effect on $\bar{x}$ of an increase in g is the same as an increase in λ, it can be demonstrated that if λ is not binding then changes in g also can have either positive or negative effects on expected pollution depending on the correlation between x and z.

A price support and land diversion policy often is combined with various forms of environmental policies. For example, pesticide restrictions often are imposed in the form of a uniform standard. To determine the effect of a change in an input restriction x_0 on expected pollution, differentiate equation (1) with respect to x_0:

$$\partial E(z)/\partial x_0 = \int_0^\infty \partial z(x_0,\omega)/\partial x_0\ \phi(x,\omega)\ dx\ d\omega.$$

It follows that the effect of x_0 on expected pollution is determined by the magnitude and sign of the effect of x on z holding ω constant. If the partial derivative of z with respect to x has the same algebraic sign for all values of ω, then its expectation over ω will have that sign. This property is exhibited, for example, by the log-linear model presented in "The Disaggregated Model" section and by Figure 2. Intuitively, this property means that as the environmental attribute of the land is varied, the marginal impact of input use on pollution does not change qualitatively. It is difficult to imagine a case in which this property would not be satisfied.

The combined effects of a price support/acreage diversion policy and an input restriction on the distribution of z and x are illustrated in Figure 9. The solid ellipsoid represents the confidence region without policy and the broken lines and shaded areas represent the effects of the policies on the shape of the confidence region. The land diversion induces farmers to remove land with $\bar{x} < \bar{x}$ from production and thus to truncate the distribution at $\bar{x}$. The truncation shifts the confidence region as shown by the broken lines.

The restriction on input use greater than x_0 censors the distribution at x_0, so the mass of the distribution accumulates at x_0 as illustrated by the shaded areas. The combined effects of the policies are thus to eliminate the two ends of the ellipses in Figure 9 and to concentrate the mass of the distribution in the interval $[\bar{x}, x_0]$. If x and z are positively correlated, removing the lower end of the domain of x increases the mean level of pollution and removing the upper end of the domain reduces mean pollution. The opposite occurs if x and z are negatively correlated. These two types of policy therefore work in opposite directions. It can be concluded that if x and z are positively correlated, a standard is the preferred policy to reduce pollution (and production), whereas if x and z are negatively correlated the preferred policy is an acreage diversion. Similar conclusions could be drawn regarding the combination of an acreage diversion and a site-specific standard.

Generalizations and Extensions of the Analytical Framework

The discussion thus far has been focused on a simple, stylized disaggregated model in which prices are determined exogenously. There are a number of directions in which the analysis could be extended. In this section the generalization of the disaggregated model to include multiple environmental attributes and the market equilibrium implications of the resulting aggregated model are considered.

The disaggregated model was specified with a single input x and a single environmental attribute ω. In reality there are many inputs and environmental attributes. Some of these environmental attributes, such as soil fertility, affect only crop productivity and not pollution; some attributes such as subsoil properties may affect only pollution; and some such as field slope may affect both productivity and pollution. Empirical researchers will need to take this kind of technical detail into account in modeling work.

To illustrate the directions a more general analysis could take, let there be two environmental attributes (or vectors of attributes), ω_y and ω_z, such that crop yield is a function $y(x,\omega_y)$ and pollution is a function $z(x,\omega_z)$. As discussed in previous sections of this chapter, agricultural commodity policy may truncate the joint distribution $\phi(x,\omega_y,\omega_z|p,\psi,\theta)$ in the x dimension through acreage diversions, and it may change the distribution's position in the x-ω_y-ω_z space through price policies. Environmental policies may censor the distribution in the x dimension by imposing restrictions on input use, and may truncate the distributions in the ω dimensions by restricting land use. These policy actions generally will have an effect on aggregate production and thus will affect market equilibrium. The way that market equilibrium will be affected will depend on the structure of the joint distribution of x, ω_y, and ω_z and on the type of policy.

For analysis of market equilibrium, let the demand side of the market be given by $Y = D(p_y, I)$ where I represents income and other variables in the demand function besides the crop price p_y. Consider the case in which the environmental attributes ω_z are unrelated to x and ω_y so that $\phi(x,\omega_y,\omega_z|p,\phi,\theta)$ $= \phi_1(x,\omega_y|p,\psi,\theta)\phi_2(\omega_z)$. The aggregate output without environmental regulations is

$$Y(p,\psi,\theta) = \int_0^\infty \int_0^\infty y(x,\omega_y)\ \phi_1(x,\omega_y|p,\psi,\theta)\ dx\ d\omega_y.$$

Market equilibrium is determined by the condition that supply must equals demand, or

(7) $\quad Y(p,\psi,\theta) = D(p_y, I).$

Now suppose that an environmental restriction on land use is imposed that forces farmers to take out of production land with $\omega_z > \bar{\omega}_z$. The proportion of land removed from production is

$$\rho(\bar{\omega}_z) = \int_{\bar{\omega}_z}^\infty \phi_2(\omega_z)\ d\omega_z,$$

so $\partial\rho/\partial\bar{\omega}_z < 0$. Thus, with the environmental regulation, aggregate output is $Y_z = (1 - \rho)Y$ and $\partial Y_z/\partial\bar{\omega}_z > 0$. The environmental policy parameter $\bar{\omega}_z$ affects market equilibrium by shifting the supply curve in proportion to the amount of land idled by the environmental land-use restriction. The more restrictive the policy, the smaller is $\bar{\omega}_z$, the larger is ρ, and the higher is the market equilibrium price, by virtue of equation (7).

More generally, when ω_z is not independently distributed from x and ω_y, the relationship between $\bar{\omega}_z$ and the market equilibrium is more complicated. The proportion of land idled by the policy is

$$\rho = \int_0^\infty \int_0^\infty \int_{\bar{\omega}_z}^\infty \phi(x,\omega_y,\omega_z|p,\psi,\theta)\ d\omega_z\ d\omega_y\ dx,$$

and

$$\partial\rho/\partial\bar{\omega}_z = -\int_0^\infty \int_0^\infty \phi(x,\omega_y,\bar{\omega}_z)\ d\omega_y\ dx < 0.$$

Expected output under the restriction $\omega_z < \bar{\omega}_z$ is

$$Y_z = (1 - p)^{-1} \int_0^\infty \int_0^\infty \int_0^{\bar{\omega}_z} y(x,\omega_y)\phi(x,\omega_y,\omega_z|p,\psi,\theta) d\omega_z\ d\omega_y\ dx.$$

The effect of a change in $\bar{\omega}_z$ on aggregate output is

$$\partial Y_z/\partial\bar{\omega}_z = (1 - \rho)^{-1}(\partial\rho/\partial\bar{\omega}_z)Y_z$$

$$+ (1 - \rho)^{-1} \int_0^\infty \int_0^\infty y(x,\omega_y)\ \phi(x,\omega_y,\omega_z|p,\psi,\theta)\ d\omega_y\ dx.$$

$$= (1 - \rho)^{-1}(\partial\rho/\partial\bar{\omega}_z)[E(y|\omega_z < \bar{\omega}_z) - E(y|\omega_z = \bar{\omega}_z)].$$

Noting that $\partial\rho/\partial\bar{\omega}_z < 0$, the implication is that the effect of $\bar{\omega}_z$ on output is determined by the difference between the conditional mean of output under the restriction, $E(y|\omega_z < \bar{\omega}_z)$, and the conditional mean of output at the point of the restriction, $E(y|\omega_z = \bar{\omega}_z)$. If larger values of ω_z are associated with higher levels of output, then $[E(y|\omega_z < \bar{\omega}_z) - E(y|\omega_z = \bar{\omega}_z)] < 0$. The implication is that the environmental regulations idle some of the more productive land and aggregate output is therefore increasing in $\bar{\omega}_z$. The converse will be true if ω_z is negatively correlated with productivity so that $[E(y|\omega_z < \bar{\omega}_z) - E(y|\omega_z = \bar{\omega}_z)] > 0$.

It can be concluded that the market equilibrium impacts of environmental regulations will depend on the structure of the environmental regulations and the relationships between environmental attributes of the land and agricultural production. Just as it is not possible to reach general conclusions about the impact of commodity policies on agricultural pollution, neither does it appear possible to generalize about the market equilibrium effects of environmental regulations.

Conclusions

To investigate the interactions of commodity and environmental policies as they relate to concerns of both production efficiency and environmental quality, an analytical framework was developed. The major implications are as follows:

1. Commodity policy and environmental policy either can be complementary or in conflict depending on the joint distribution of input use, site-specific environmental characteristics, productivity, and pollution and the types of policy instruments imposed. There are many examples of each type of situation.
2. In cases where it is possible to set commodity policy structure so as to complement environmental goals, the practicality of doing so needs to be investigated. Relevant concerns include the distributional implications and informational requirements.
3. Disaggregated location-specific data on environmental characteristics and farming practices are critical for understanding and modeling commodity and environmental policy interactions. To develop empirical information, data must be collected to identify cases in which the environmental characteristics of agricultural lands and the input uses with which they are associated are positively and negatively correlated or uncorrelated. Some work has begun along these lines, e.g., Heimlich (1989) who investigated correlations between corn yields and soil erosion.
4. Better linkage of economic and physical models is needed to quantify and predict the environmental impact of policy changes. In developing better linkages, the structure of the decision problem needs to be taken into account. These linkages should be sensitive to truncation and censoring of distributions, and details of program structure.
5. Considerable generalization is needed to quantify and explore further the joint extensive-intensive margin decision problem. Needed generalizations include dynamics; differences in farmer attributes (technology, management ability, risk attitudes) and the associated distributional implications;

and analyses of market equilibrium effects of commodity and environmental policies.

Endnotes

1. Random weather often is an important component of physical models of soil erosion, chemical runoff, and chemical leaching into groundwater. This aspect of physical models could be included in the analysis by adding a random variable to the pollution function. This is not done here to preserve analytical simplicity, but would be important for empirical applications.
2. The model can be generalized by defining a vector of farm-specific characteristics, such as risk attitudes and technology, which are distributed in the population of farms according to a well-defined probability distribution. This generalization is not incorporated here to preserve analytical simplicity, but should be a consideration in empirical applications.
3. For the purposes of this analysis, land markets are assumed to adjust so that the poorest land is used for diversion on a regional basis as well as on a farm basis. Rausser, Zilberman, and Just (1984) show that this is an equilibrium response to a diversion program or acreage limitation.
4. By comparison, in the case that has agricultural policy consisting of both price and production controls, both the slope and location of the extensive margin frontier can be controlled.
5. In reality, imposing pollution standards also would alter the technology used on some types of land. In the framework of this section, which is an examination of only the extensive margin, however, these responses are not considered.

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Figure 1. The Conceptual Framework

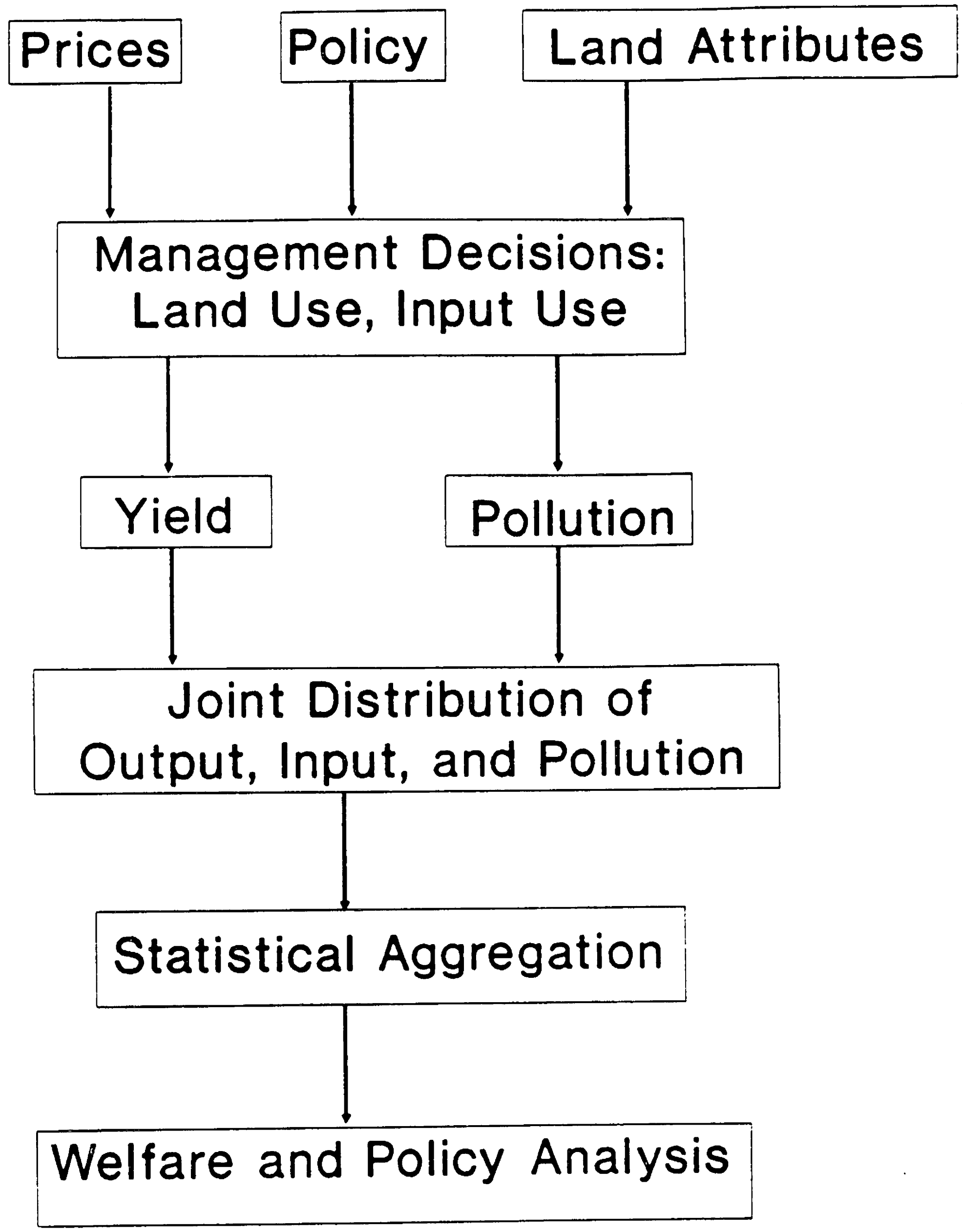


Figure 2. The Physical Model

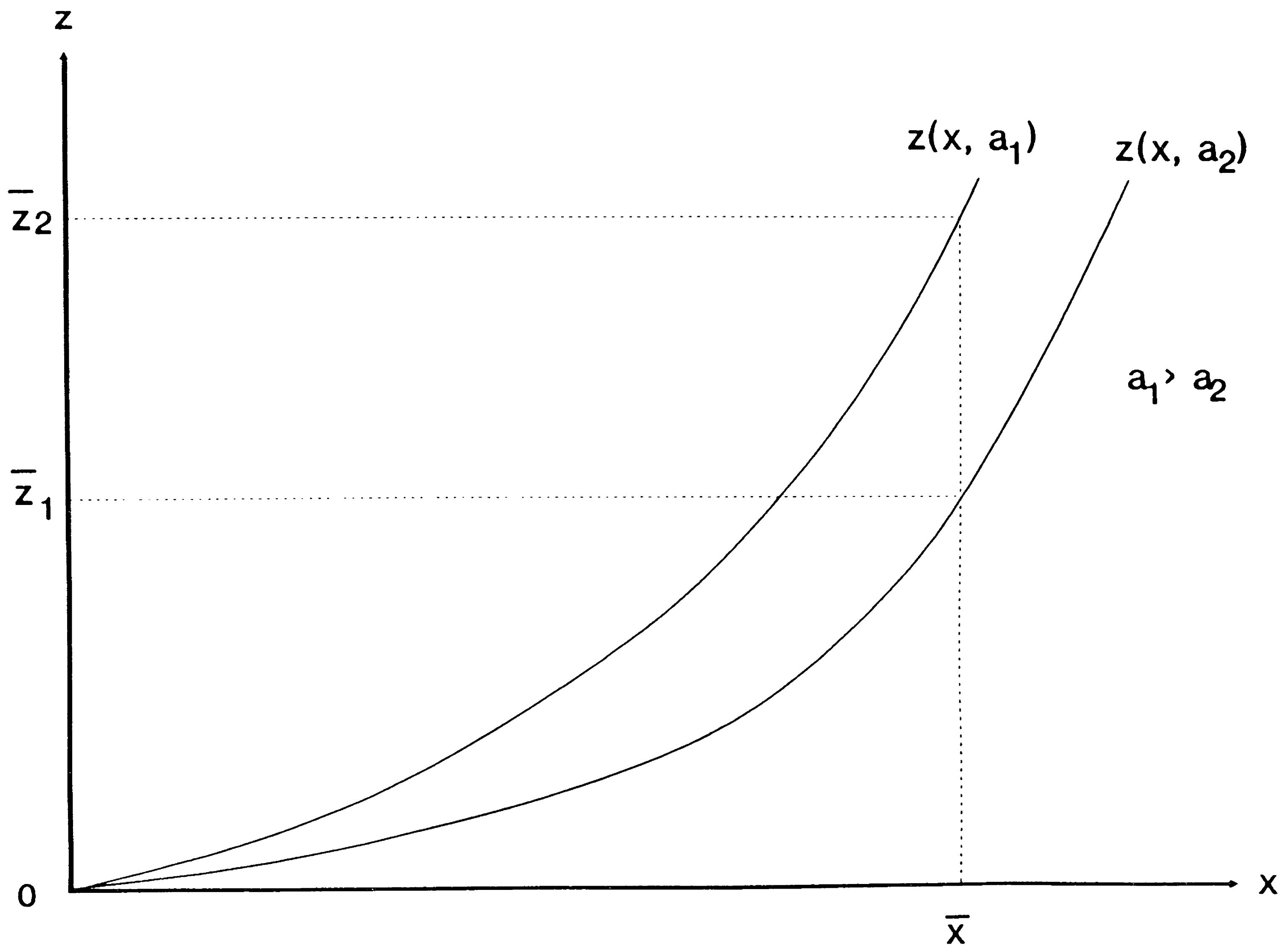


Figure 3. Output, Input and Pollution Relationships in the Integrated Log-Linear Physical Production Model

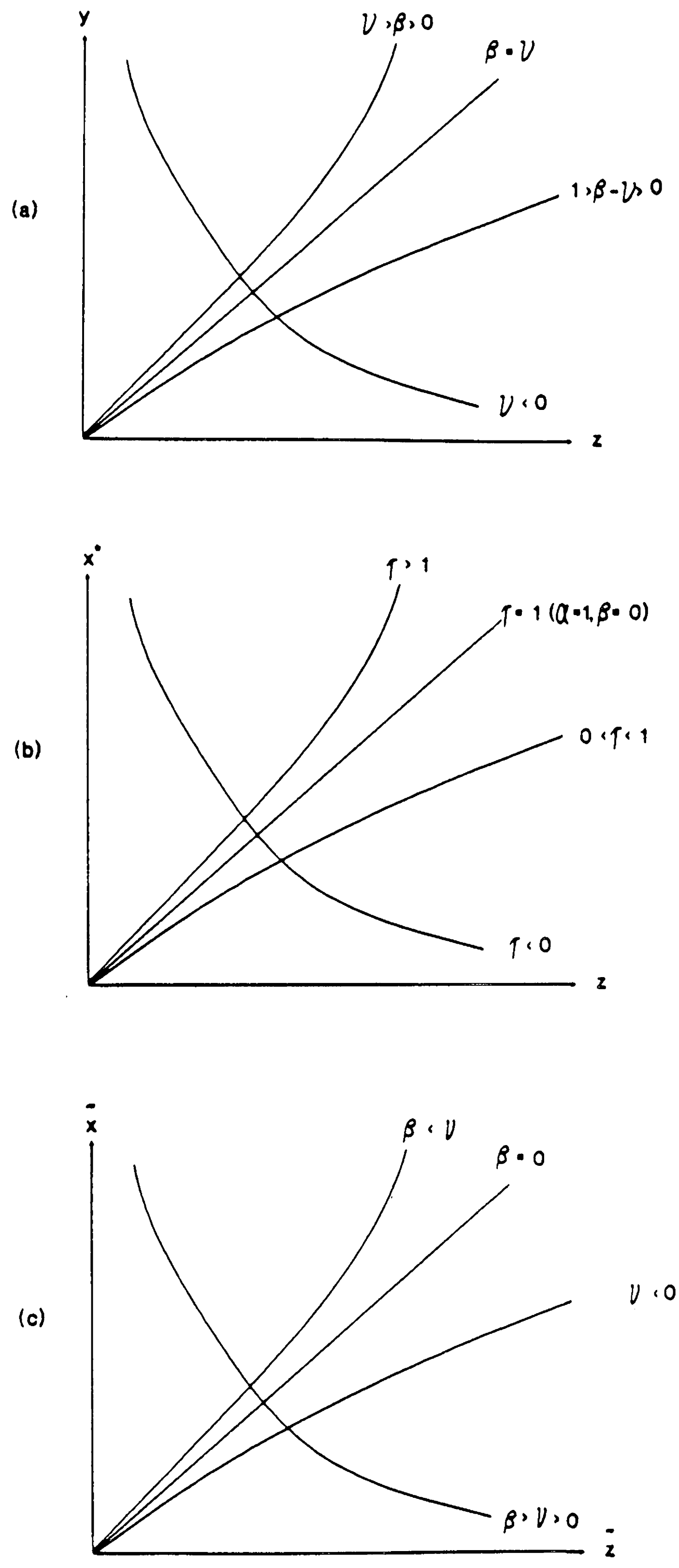


Figure 4. Use of Land for Production

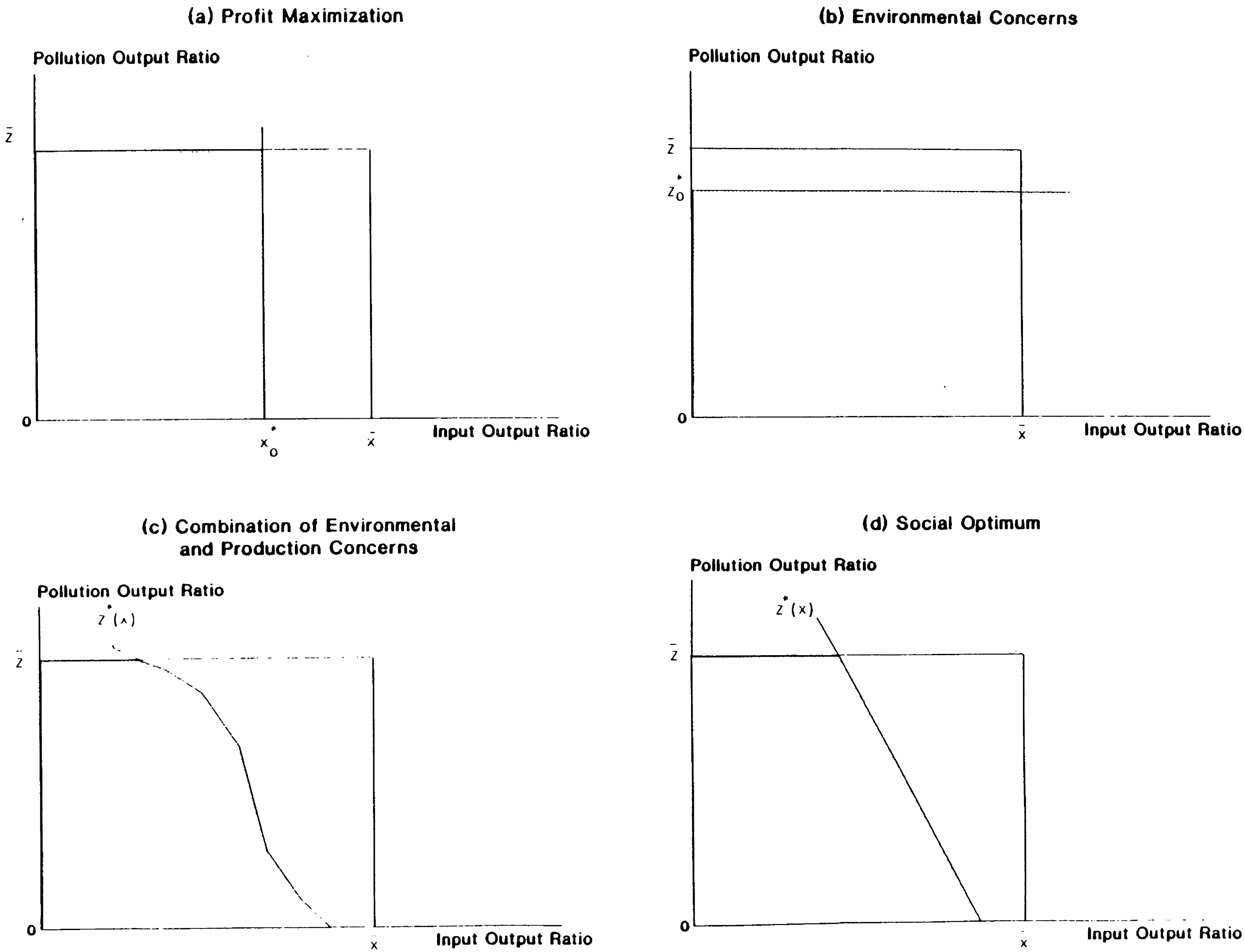


Figure 5. Use of Land for Production with Agricultural Poliy

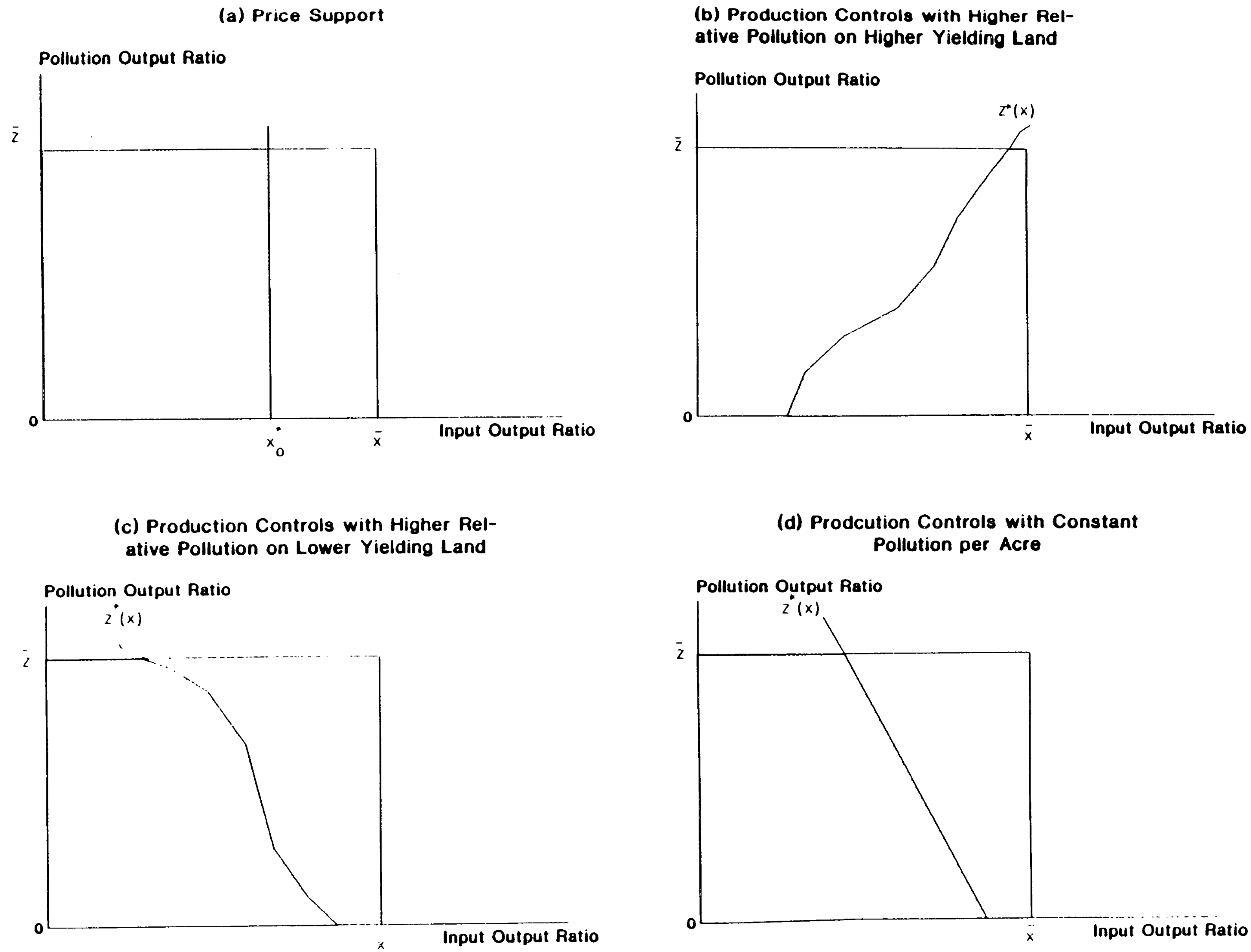


Figure 6. Effects of a Pollution per Acre Standard When Low Input-Output Ratios are Associated with High Pollution per Acre

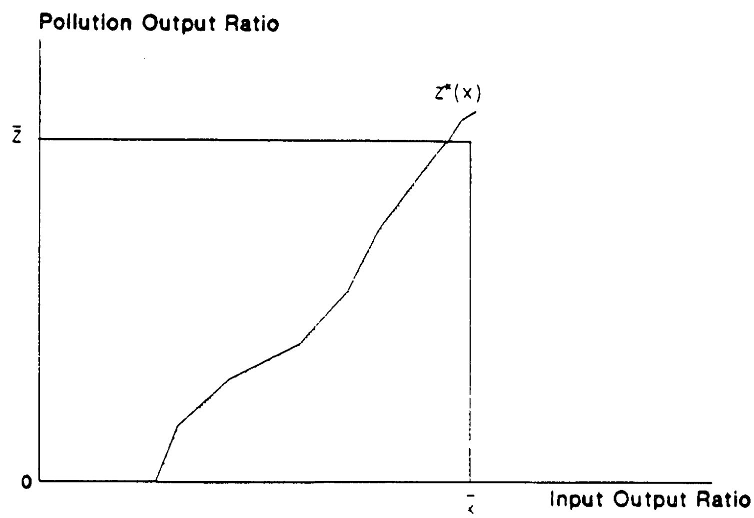
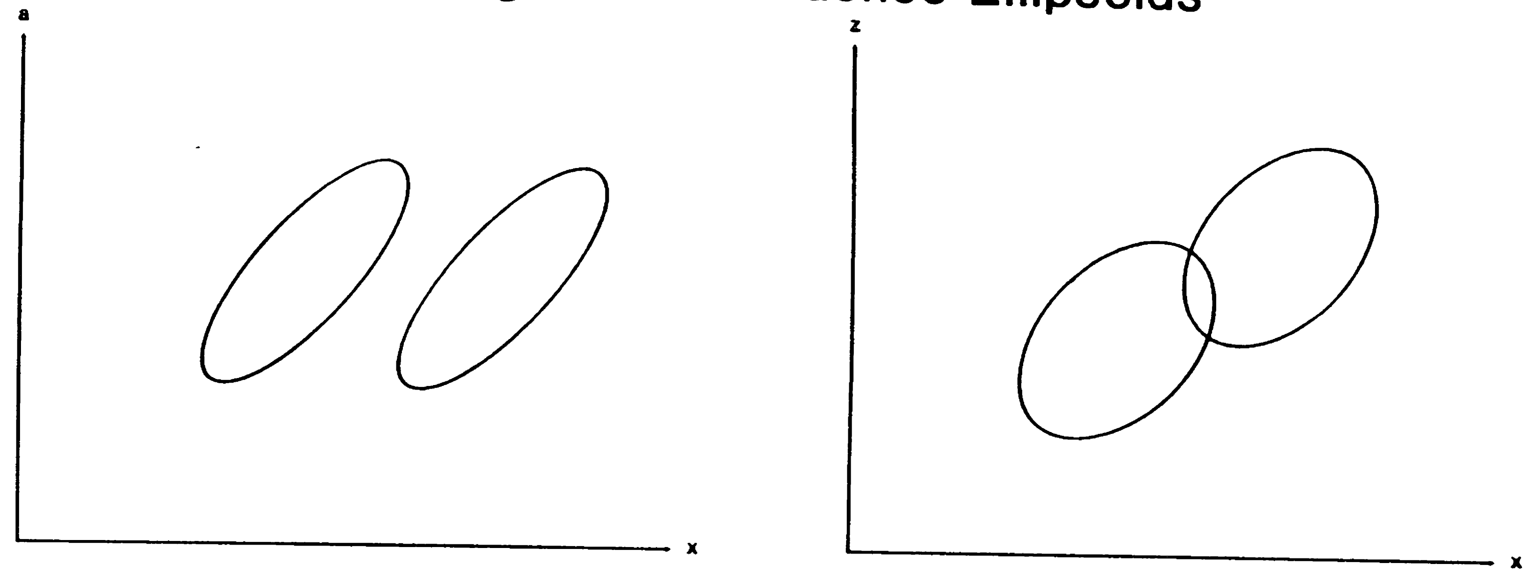
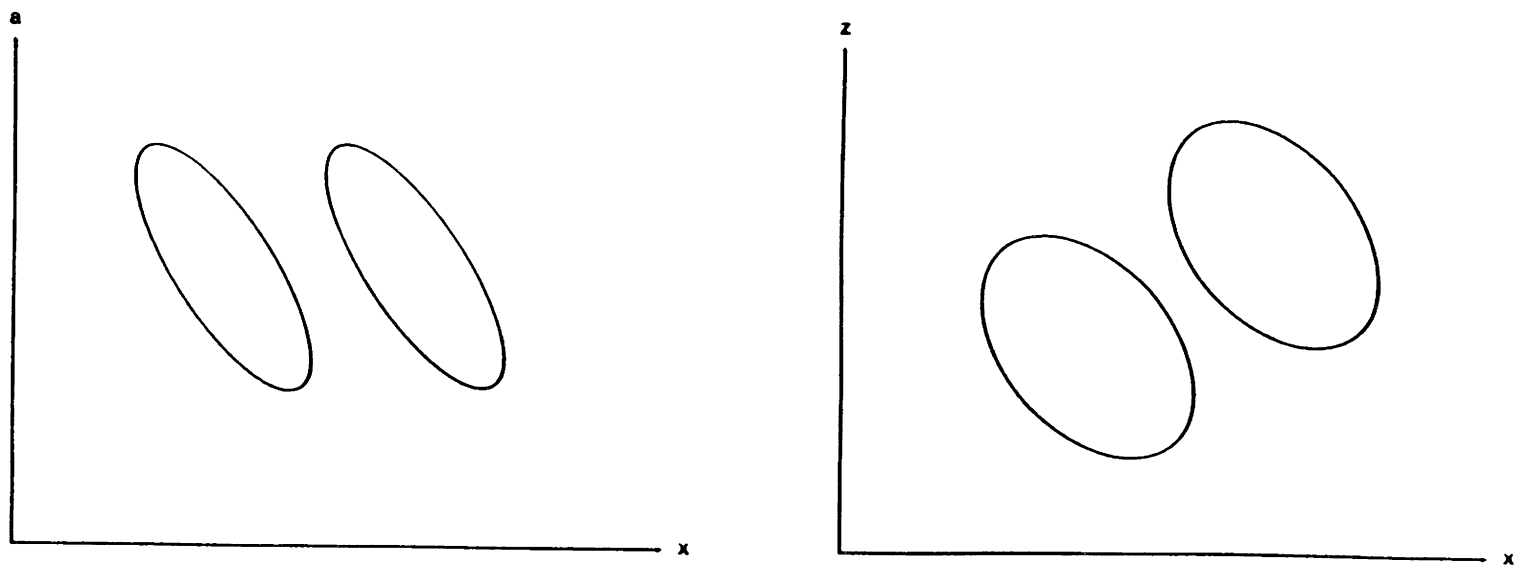


Figure 7. Effect of Price Support on the Intensive Margin
Using 95% Confidence Ellipsoids

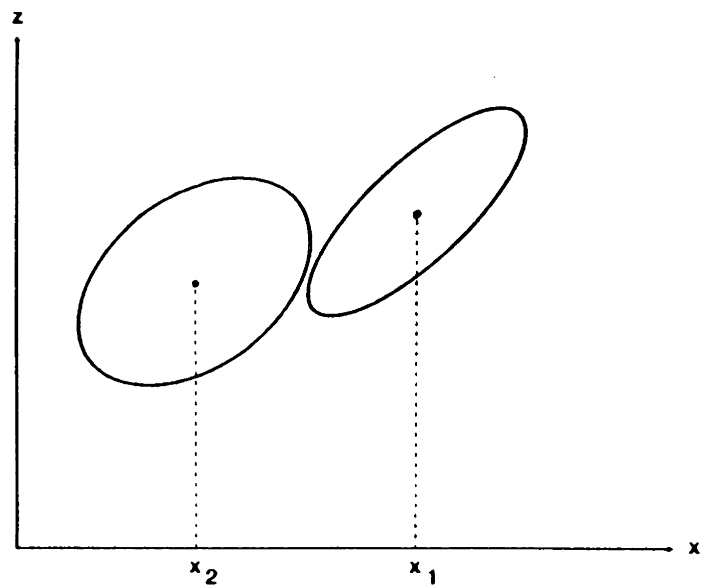


(a) Positive Correlation between a and x, z and x

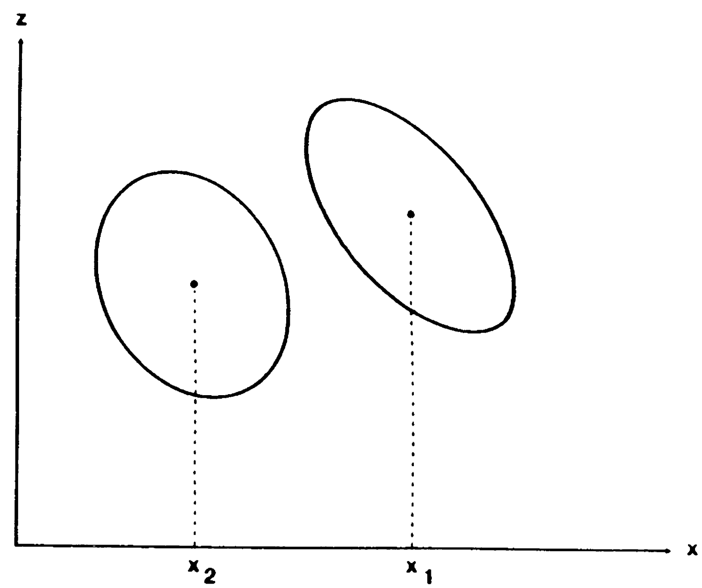


(b) Negative Correlation between a and x, z and x

Figure 8. A Pollution Tax on Input Use
95% Confidence Ellipsoids

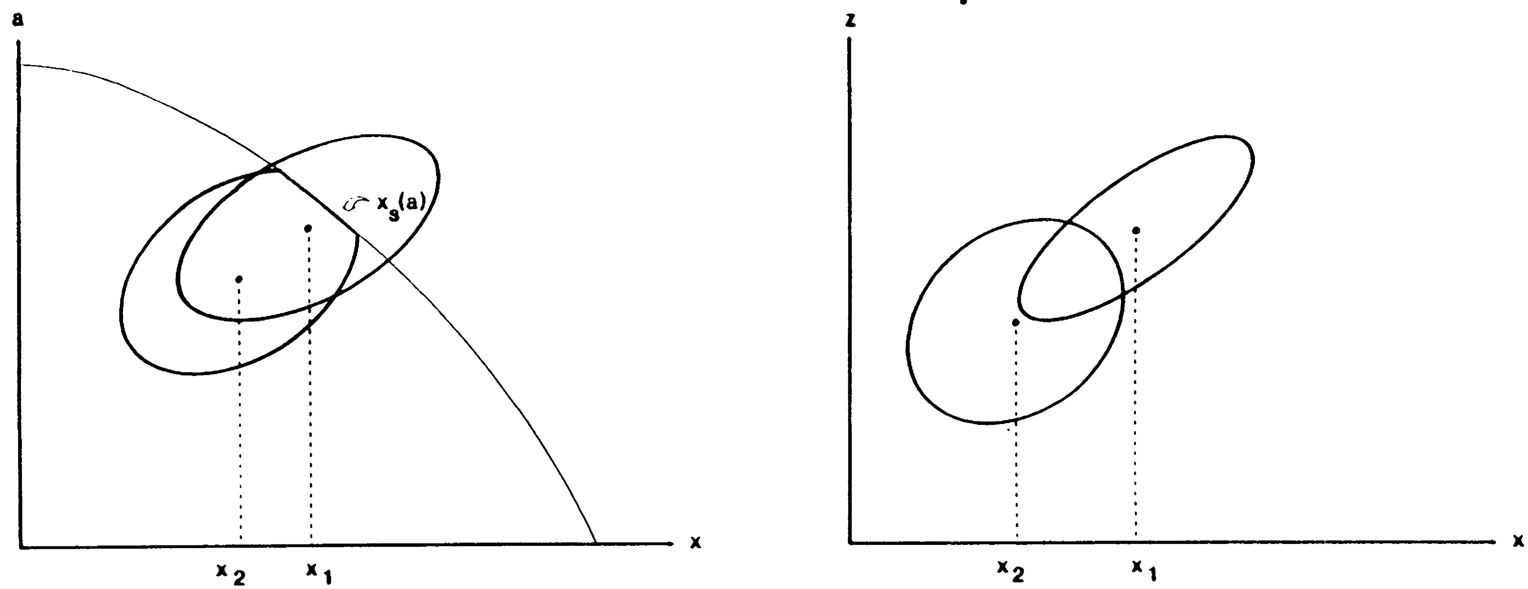


(a) Positive Correlation

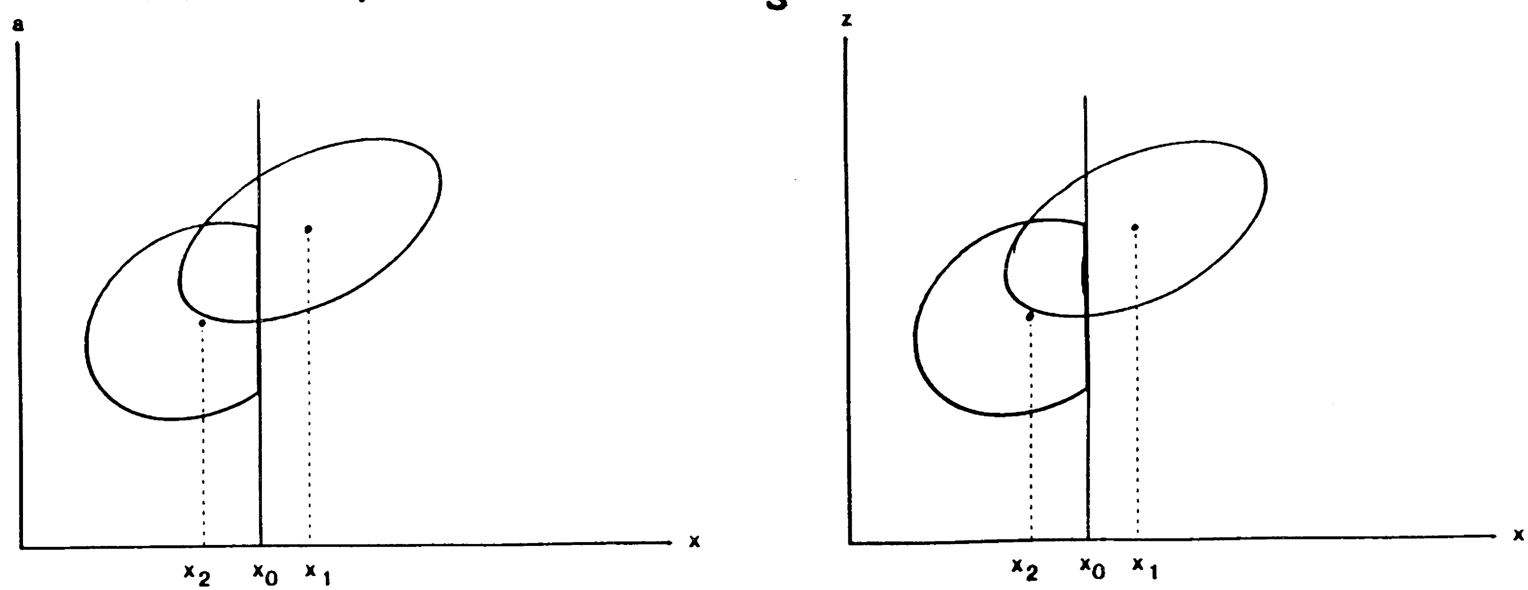


(b) Negative Correlation

Figure 9. Site Specifc and Uniform Input Standards
95% Confidence Ellipsoids

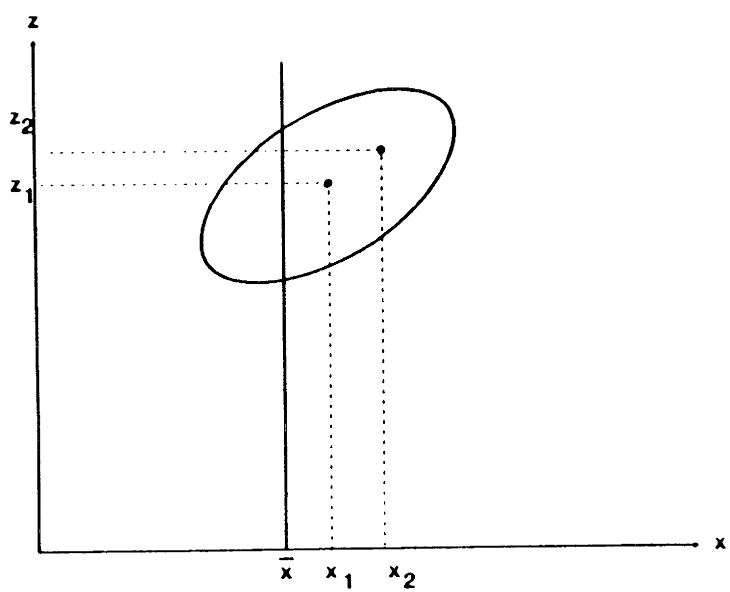


(a) Site-Specific Standard $x_s(a)$ with Positive Correlation

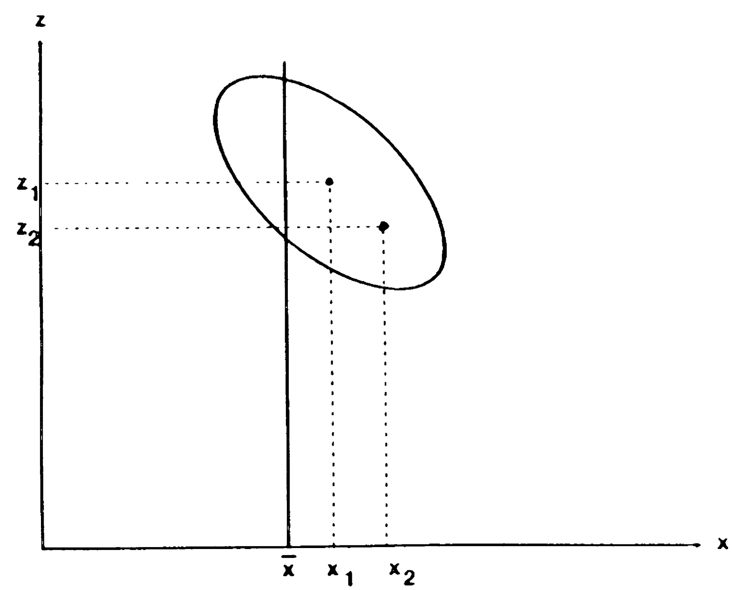


(b) Uniform Standard with Positive Correlation

Figure 10. Effect of Land Diversion on Input Use and Pollution

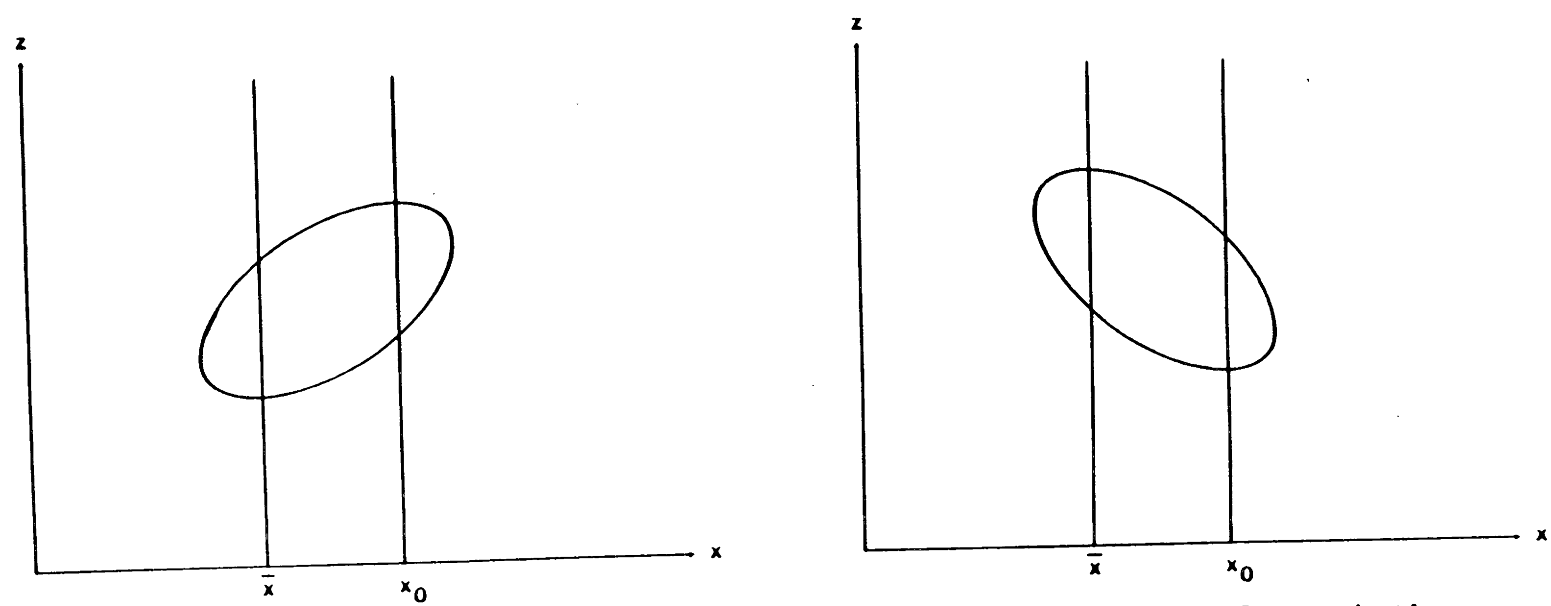


(a) Positive Correlation



(b) Negative Correlation

Figure 11. Combination Land Diversion and Uniform Input Standard



(a) Positive Correlation

(b) Negative Correlation

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