Environmental Policy, Technology Substitution and Cross-Media Transfers

Livestock Series Report 6

Edward Osei and Bruce A. Babcock

Working Paper 96-WP 169
November 1996

Environmental Policy, Technology Substitution, and Cross-Media Transfers

Livestock Series Report 6

Edward Osei and Bruce A. Babcock

Working Paper 96-WP 169
November 1996

Center for Agricultural and Rural Development
Iowa State University
Ames, IA 50011-1070

Edward Osei is an economist at the Texas Institute for Applied Environmental Research, Tarleton State University, Stephenville; and Bruce A. Babcock is an associate professor of economics and head of the Resource and Environmental Policy Division, CARD.

The National Pilot Project on Livestock and the Environment is funded by the U.S. Environmental Protection Agency, under Cooperative Agreement #R820374-01-0.

ABSTRACT

We consider the implications of cross-media transfers for the analysis of environmental policy and technology substitution. We discuss welfare implications from the standpoint of society and of the firm. Society's solution is shown to lead to the least level of damage, output, and waste treatment costs.

Key Words: Environmental policy, isopollution, augmented isodamage, isocost, cross-media transfers, technology substitution, optimization.

ENVIRONMENTAL POLICY, TECHNOLOGY SUBSTITUTION, AND CROSS-MEDIA TRANSFERS

Livestock Series Report 6

The effects of federal and state environmental regulations are, in general, well understood. (See Baumol and Oates [1988] and Cropper and Oates [1992] for useful reviews of these effects.) Management practices are a popular regulatory tool, especially in agriculture, to reduce pollution. One advantage of relying on best management practices (BMPs) to control pollution is that once they are in place, the need for actual monitoring of discharges is reduced.

The specification of BMPs raises two important issues regarding pollution prevention. First, different technologies may change the rate of release of pollutants by different amounts. A technology that leads to lower levels of carbon monoxide in the air, for example, might result in higher levels of another pollutant, such as dust particles or smog. Such pollutant substitution among competing technologies may necessitate some value judgment in deciding what mix of pollutant concentrations is socially optimal, and hence which technology to choose. A second issue has to do with cross-media transfers. Even when there is only one pollutant, there may be tradeoffs in the level of the single pollutant among the environmental media.

In this paper we examine the issue of cross-media transfers, which was recognized also by Metcalf et al. (1984). We provide an analytical framework to help explain the concept of cross-media transfers in the context of technology substitution. And we characterize the conditions under which such transfers are socially beneficial and provide criteria for the choice of technologies as functions of the society's preferences for different environmental media. We begin by choosing technologies that are optimal for society. We then augment the analysis by considering several environmental policies. To simplify the analysis we use specific functional forms appropriately chosen to represent some general assumptions about society's preferences and the production and pollution prevention technologies.

The Cross-Media Transfers (CMT) Model

Consider a profit-maximizer who produces a single good X sold at a constant and exogenous price P. A single pollutant, N, is produced as a byproduct of the production process. The factors required for production are represented by the input vector M. The firm chooses one of the available production technologies, indexed by i. We represent the constraint on the i^{th} production process by the inequality $f_i(X, N, M) \geq 0$. The k^{th} element in the input vector, ω_k, is an exogenous price.

The process by which the single pollutant is distributed into various environmental media is partly endogenous to the operations of the firm. We refer to this endogenous action on N as the waste management technology of the firm. This endogenous action may be influenced by regulatory policy. The effect of the *waste management technology* is to convert the N units of the pollutant into N_a units in the air, N_g units in groundwater, and N_s units in surface water.[1] For simplicity we consider only air and groundwater in our analysis. We assume there are a number of waste management technologies indexed by j and that the constraint on the j^{th} waste management process is $G_j(N, N_a, N_g) = 0$. The waste management technologies have different cost structures and also result in different levels of N_a and N_g for a given amount, N of pollutant at the source.[2] The use of the j^{th} waste management technology requires a capital investment of K_j. It also entails some variable costs, which for the j^{th} waste management process, we shall represent as $C_j(N_a, N_g)$.

The presence of pollutants in the air and water is a disutility to society. We capture this disutility by a damage function D given as $D = D(N_a, N_g)$. For our analytical purposes we impose the following structure on the damage function: $D_l > 0$, $D_{ll} \geq 0$, $l = a, g$; $D_{ag} \leq 0$ where subscripts denote partial derivatives. Similarly we assume that for each waste management system j, $G_l > 0$, $G_{ll} < 0$, $l = a, g$; $G_{ag} > 0$, $G_{ga} > 0$, $G_N < 0$. Thus, when there is an increase in total pollution at the source, the levels of pollution in both air and groundwater increase at a decreasing rate. For the production transformation function we shall require $f_X < 0$, $f_N > 0$, $f_M > 0$. Finally, we impose the following restrictions on the

---

[1] In the absence of a waste management system, pollutants generated end up in the various environmental media in different proportions. Presumably the use of an appropriate waste treatment system would result in magnitudes and relative proportions of the pollutant in the different media that are less harmful to society.

[2] We distinguish between total pollution produced at the source, N, and total pollution resulting in the environment, $N_a + N_g$. From a strict mass balance perspective these may be considered equal. However, we allow for the possibility that the total level of pollution in the environment will be different from (typically less than) the level of pollution produced, due to some characteristics of the waste management process. For example, any recycling process could result in a level of pollution in the environment less than the amount of pollutant generated. Furthermore, if the portion of the environment we are concerned with is restricted, as we have done here, to say air and ground water, the distinction between the two becomes more apparent.

variable cost of the waste management technology: $C_l > 0$, $C_{ll} \geq 0$, $l = a, g$; $C_{ag} \leq 0$. In the ensuing analysis, we maximize both the firm's and society's welfare, which are defined by net benefit functions. The net benefit function of the profit maximizing firm is revenues less production costs and waste management costs. Thus, the problem of the entrepreneur can be formulated as the maximization of an appropriate Lagrangian as follows:

$$\max_{i}\left\{\max_{j}\left[\max_{\substack{X,M,N_a,\\N_g,N}} L = pX - \sum_{k}\omega_k M_k - C_j(N_a, N_g) - K_j + \lambda_j G_j(N, N_a, N_g) + \mu_i f_i(X, N, M)\right]\right\} \qquad (1)$$

where L is the Lagrangian function and λ_j and μ_i are Lagrange multipliers.

Society takes into account the damage caused pollutants in various environmental media and also imputes the costs of waste treatment. To adequately understand the problems facing society and the entrepreneur, it is useful to introduce some concepts.

We define a cross-media transfer as the transfer of some amount of a given pollutant from one medium, say groundwater, to another, such as air. To explain this concept we define two curves: an isopollution curve and an isodamage curve. An isopollution curve is the locus of the combinations of N_a and N_g that result from a given level of total pollution, N. Similarly, an isodamage curve is the locus of the combinations of N_a and N_g that result in the same level of damage to society. By the assumptions governing the first and second derivatives of the damage function it can be shown readily that the isodamage curve is concave to the origin in the $N_a - N_g$ plane. On the other hand, the isopollution curve is convex to the origin in the $N_a - N_g$ plane. An additional construct that is useful in the analysis of the firm's optimization problem is the familiar isocost curve. It is the locus of combinations of N_a and N_g that entail the same cost to the firm.

Suppose that the optimal solution from the perspective of the firm as well as society implies the adoption of production technology i^0 and waste management technology j^0. Let us further simplify things by assuming that there is only one input ($k = 1$) in the production process. Then the firm's optimization problem reduces to

$$\max_{\substack{X,M,N_a,\\N_g,N}} L = pX - \omega M - C(N_a, N_g) - K + \lambda G(N, N_a, N_g) + \mu f(X, N, M) \qquad (2)$$

where the subscripts i^0 and j^0 have been dropped for simplicity. It is straightforward to show, with the aid of Figure 1, that the optimal solution for the firm occurs at the tangential intersection of an isopollution locus and an isocost curve, for if the firm chooses any other point on that pair of isopollution and isocost loci, there would be unnecessary losses in net revenue.

Since the investment cost of waste treatment technologies is independent of the levels of N_a and N_g the isocost curve can be derived directly from the variable cost function $C(N_a, N_g)$. Suppose that the variable cost of waste treatment is fixed at a value, say $\overline{C}$. Then the isocost locus, $N_a(N_g)$, is the solution to the equation $C(N_a, N_g) - \overline{C} = 0$, with corresponding slope $\frac{dN_a}{dN_g} = -\frac{C_g}{C_a}$. Similarly, the isopollution locus, $N_a(N_g)$, is the solution to the equation $G(\overline{N}, N_a, N_g) = 0$. The slope of this locus is $\frac{dN_a}{dN_g} = -\frac{G_g}{G_a}$. Thus the solution to the firm's problem will satisfy $C_g / C_a = G_g / G_a$. This occurs at point A in Figure 1.

The optimal solution in the case of society takes a form similar to the preceding. Since the net benefit function of society includes the cost of the waste treatment technology, the isocost curve is of relevance here as well. However, society is also concerned about the damage caused by pollution. Thus, the total cost to society is captured by an augmentation of the isodamage locus by the profile of isocost. The optimal solution to society occurs at the tangential intersection of the resulting augmented isodamage locus[3] and the isopollution locus. The slope of the augmented isodamage locus is $\frac{dN_a}{dN_g} = -\frac{D_g + C_g}{D_a + C_a}$ so that the solution to society's problem will satisfy $(D_g + C_g)/(D_a + C_a) = G_g / G_a$.

The left hand side of this equation represents the marginal rate of substitution in the augmented damage function. The right hand side represents the marginal rate of cross-media substitution in waste management technology. Thus for the optimal solution to be achieved, the marginal rate of cross-media substitution in the waste management technology must be set equal to the marginal rate of substitution in the augmented damage function. The optimal solution occurs at point B in Figure 1 where the augmented isodamage locus and the isopollution curve are tangential to each other. The figure has been drawn to reflect a scenario where society would choose less overall damage, involving a higher ratio of air to goundwater pollution than the firm. In order to obtain more specific and useful information from this model, we will presently impose additional structure on the functions defined here.

Let us first assume that the production technology of the firm is given as

---

[3] We shall refer to the total cost to society as an augmented social damage function, defined as the sum of social damage due to pollution and the waste treatment costs incurred by the firm.

$$f(X,N,M)=X^{\gamma_0}M^{\gamma_M}N^{\gamma_N}-A,\ \gamma_0<0<\gamma_N,\ \gamma_M>0,\ \gamma_0+\gamma_M+\gamma_N=0,\ A>0.$$

Thus, all technologies suitably captured by this Cobb-Douglas form can be indexed by the levels of the parameters γ_0, γ_N and γ_M. The waste management technology is defined more specifically as

$$G(N,N_a,N_g)=\alpha_a \ln N_a+\alpha_g \ln N_g-\ln N,\ \ \alpha_a+\alpha_g=1,\ \alpha_a>0,\ \alpha_g>0.$$

With this specification the waste management technology can be indexed by α_a. We specify the variable cost of the waste management process as $C(N_a,N_g)=\sigma_a N_a{}^2+\sigma_g N_g{}^2,\ \sigma_a>0,\ \sigma_g>0.$ Finally the damage to society due to the pollutant is assumed to be captured by $D(N_a,N_g)=\beta_a N_a{}^2+\beta_g N_g{}^2$, $\beta_a>0,\ \beta_g>0.$

Assuming an interior point, the optimal solution to society's problem is more specifically given as:

$X^{*s}=\mu^{*s}(\gamma_N+\gamma_M)A/p\ X^{*s}=\mu^{*s}(\gamma_N+\gamma_M)A/p\ X^{*s}=\mu^{*s}(\gamma_N+\gamma_M)A/p$,

$N^{*s}=\sqrt{\mu^{*s}\varepsilon^s\gamma_N A}$, $N_a{}^{*s}=\sqrt{\mu^{*s}\gamma_N A\alpha_a/(\sigma_a+\beta_a)}$

$N_g{}^{*s}=\sqrt{\mu^{*s}\gamma_N A(1-\alpha_a)/(\sigma_g+\beta_g)}$, $\lambda^{*s}=\mu^{*s}\gamma_N A$ and $\mu^{*s}=\eta\varepsilon^s$ where

$\eta=(p/[\gamma_N+\gamma_M])^{2+\frac{2\gamma_M}{\gamma_N}}(\gamma_M/\omega)^{\frac{2\gamma_M}{\gamma_N}}\gamma_N A^{-(1+\frac{\gamma_N}{2})}$, $\varepsilon^s=(\alpha_a/[\sigma_a+\beta_a])^{\alpha_a}([1-\alpha_a]/[\sigma_g+\beta_g])^{1-\alpha_a}$

and the superscript *s* denotes society's solution values as opposed to those of the firm. The solution to the firm's problem is of a similar form, except that we now have

$N_a{}^{*f}=\sqrt{\mu^{*f}\gamma_N A\alpha_a/\sigma_a}$, $N_g{}^{*f}=\sqrt{\mu^{*f}\gamma_N A(1-\alpha_a)/\sigma_g}$, and

$\varepsilon^f=(\alpha_a/\sigma_a)^{\alpha_a}((1-\alpha_a)/\sigma_g)^{1-\alpha_a}$

Having identified the optimal solutions in such specific terms, we are able to obtain some useful inferences about the differences between society's solution and that of the firm, as well as the implications for environmental policy. We begin with an examination of the firm's and society's solutions with the aid of Figure 2. In that figure, the solution to the firm's problem is depicted as point A, where the isocost and isopollution loci are tangential to each other. Society's solution, as is apparent from above, entails lower levels of all the variables. Furthermore, depending on the relative magnitudes of the parameters of the damage and cost functions, society's solution might involve much lower levels of N_g relative to N_a or vice versa. In Figure 2, we have assumed that it involves a much lower level of N_g relative to N_a. Society's solution is at point B where the augmented isodamage function is tangential to an isopollution locus.

Decomposition of the Optimal Solution

It is useful, at this stage. to decompose the difference between society's solution and that of the firm into two components. We refer to these as a *substitution effect* and a *pollution reducing effect.* The substitution effect of society's decision relative to that of the firm is the cross-media transfer of pollution that brings the relative levels of N_a and N_g in line with society's preferences. This is depicted in Figure 2 as a movement from point A to C where a scalar translation of the augmented isodamage locus is tangential to the isopollution locus relevant to the firm's problem. The substitution effect thus entails an adjustment of the levels of N_a and N_g to reflect society's relative preferences for air and groundwater pollution, while maintaining the total level of pollution generated according to the firm's optimal solution. We refer to point C as the compensated solution, as opposed to point A, which is the firm's solution and point B, which is society's optimal solution. The pollution reducing effect refers to the reduction in the level of total pollution that comes as a result of society imputing a positive cost to the damage inflicted on society by the pollutant, while holding unchanged the relative levels of N_a and N_g. The pollution reducing effect is illustrated in Figure 2 as a movement from point C to point B, society's optimal solution. The compensated levels of air and ground water pollution can be readily derived from the above. We obtain $N_a^c = N_a^f / [\theta^{(1-\alpha_a)/2}]$ and $N_g^c = N_g^f \theta^{\alpha_a/2}$ where $\theta = [(\sigma_a + \beta_a)\sigma_g] / [(\sigma_g + \beta_g)\sigma_a]$.

The solutions to these problems enable us to derive expansion paths from the perspectives of society and the firm. Given our technology specifications, the expansion paths are straight lines through the origin. They are defined as $N_a^f = \sqrt{\sigma_g \alpha_a / [\sigma_a(1-\alpha_a)]} N_g^f$ for the firm and $N_a^s = \sqrt{(\sigma_g + \beta_g)\alpha_a / [(\sigma_a + \beta_a)(1-\alpha_a)]} N_g^s$ for society. It is clear, that just as for the optimal solution, the expansion path of society coincides with that of the firm if and only if $\sigma_a / \sigma_g = \beta_a / \beta_g$; that is, the relative weights society attaches to air and groundwater pollution are in the same ratio as the relative weights of the media-specific pollutants in the cost of the waste management process of the firm.

Welfare Implications

Let us maintain, without loss of generality, the assumption that society cares more about groundwater pollution than air pollution. More specifically, let us say that the weight society attaches to groundwater relative to air pollution is greater than the ratio of marginal cost of groundwater to that of air pollution in the waste treatment process. Then the isocost, isodamage, and augmented isodamage loci are as depicted in Figure 2. We have drawn the relevant isopollution loci to show the three solution points. Given our assumptions, we can arrive at the following proposition.

Proposition 1

When society's net benefit function accounts for damage caused by pollution as well as cost incurred by the firm in waste treatment, the firm disregards the damage caused by pollution, and once the production and waste treatment technologies have been specified, society's solution involves less social damage as well as less cost to the firm than the firm's outcome. However, this comes with less total pollution and less output than the firm's solution. Under these conditions, if the firm were allowed to choose the level of output and total pollution generated, society would be better off if the firm followed society's expansion path so that the levels of media-specific pollutants are in a ratio that reflects society's preferences. The resulting output-compensated solution leads to a higher cost to the firm than if it followed its own preferences. However, the associated reduction in social damage outweighs the increase in cost to the firm.

It is important to note that the our result may not hold true if society did not account for the firm's waste treatment costs.

Proposition 2

Given the conditions in Proposition 1, society's solution entails less air as well as less groundwater pollution than the firm's solution. Thus, the pollution reducing effect of society's decisions outweigh the cross-media substitution effect.

This is a very strong result since it is true regardless of the values of the parameters. It is primarily because society considers both the damage caused by pollution and the cost incurred by the firm.

The Role of Technology in the CMT model

So far we have assumed that the production and waste management technologies were exogenously given. In this section we investigate the role of technology choice in the model. We consider technology choice from the perspective of society since that of the firm is a special case where essentially $\beta_a = \beta_g = 0$. Before proceeding, we introduce some terminology. We consider a waste management technology to be adequately defined by the double log form specified above and the duplex (α_a, α_g). A technology is said to be of class α if $\alpha_a + \alpha_g = \alpha$. In most of the preceding discussion, we have assumed a technology of class $\alpha = 1$. A production technology is completely defined by the Cobb-Douglas transformation function specified and the triplet $(\gamma_0, \gamma_M, \gamma_N)$. Let us now consider some implications of technology choice, assuming that $\alpha = 1$ and $\gamma_0 + \gamma_M + \gamma_N = 0$, unless otherwise specified.

Pollution Minimizing Technologies

Considering society's optimal solution, we observe that all the choice variables are increasing in μ^{*s}. Hence they are all increasing in ε^s. The expression for ε^s thus provides us with an opportunity to analyze the effects of different waste management technologies on the levels of the choice variables. Recall that as far as the levels of pollutants in the environment are concerned, we can index the waste management technologies by the parameter α_a. A technology with a higher value of α_a leads to more air pollution and less ground water pollution than one with a lower value, given the same level of total pollution, $\overline{N}$. Recall also that β_a and β_g represent the weights attached to air and groundwater pollution by society in the damage function, while σ_a and σ_g are the respective weights in the cost function of the firm.

Differentiating ε^s with respect to α_a we obtain

$$\frac{d\varepsilon^s}{d\alpha_a} = \varepsilon^s \ln\left[\frac{\alpha_a(\sigma_g+\beta_g)}{(1-\alpha_a)(\sigma_a+\beta_a)}\right] \gtrless 0 \text{ as } \frac{\alpha_a}{1-\alpha_a} \gtrless \frac{\beta_a+\sigma_a}{\beta_g+\sigma_g} \Leftrightarrow \frac{\alpha_a}{\beta_a+\sigma_a} \gtrless \frac{1-\alpha_a}{\beta_g+\sigma_g} \text{ and}$$

$$\frac{d^2\varepsilon^s}{d\alpha_a{}^2} = \varepsilon^s \left\{ \frac{\sigma_a+\beta_a}{\alpha_a(\sigma_g+\beta_g)(1-\alpha_a)} + \left(\ln\left[\frac{\alpha_a(\sigma_g+\beta_g)}{(1-\alpha_a)(\sigma_a+\beta_a)}\right]\right)^2 \right\} > 0.$$

Thus the level of α_a that minimizes ε^s is the one that solves

$$\frac{d\varepsilon^s}{d\alpha_a} = 0 \Leftrightarrow \frac{\alpha_a}{1-\alpha_a} = \frac{\beta_a+\sigma_a}{\beta_g+\sigma_g}. \qquad (3)$$

The implied value of α_a is $\alpha_a{}^* = (\sigma_a+\beta_a)/(\sigma_a+\beta_a+\sigma_g+\beta_g)$. Proposition 3 follows directly.

Proposition 3

For all technologies suitably represented by $G(N, N_a, N_g) = \alpha_a \ln N_a + \alpha_g \ln N_g - \ln N$, with α_a α_a as index,

(a) the technology that minimizes ε^s is $\alpha_a{}^* = (\sigma_a + \beta_a) / (\sigma_a + \beta_a + \sigma_g + \beta_g)$.

(b) From the solutions to the first-order conditions this same technology leads to the minimum level of output (X*), input use (M*) and total pollution produced at the source (N*).

We thus refer to (3) as the *minimum pollution criterion.*

Our analysis does not guarantee the existence of such a technology. Therefore, a relevant issue is how to compare two or more technologies that do not exactly meet the minimum pollution criterion. Fortunately, an alternative criterion of comparison emerges from the above derivations. From these we know that ε^s is strictly convex in α_a with a minimum at $\alpha_a{}^* = (\sigma_a + \beta_a) / (\sigma_a + \beta_a + \sigma_g + \beta_g)$. Thus, we conclude that the closer α_a is to $\alpha_a{}^*$, the closer is ε^s to $\varepsilon^s_{\min} = \varepsilon^s(\alpha_a{}^*) =$ $1/(\sigma_a + \beta_a + \sigma_g + \beta_g)$. We may summarize these conclusions in the next proposition.

Proposition 4

a. The closer is a technology's ratio, $\alpha_a / (1 - \alpha_a)$ to the ratio of society's weights, $(\sigma_a + \beta_a) / (\sigma_g + \beta_g)$, the better is that technology in a pollution minimizing sense.

b. The best available technology in a pollution minimizing sense is the solution to

$$\arg\min_{\alpha_a} |\alpha_a - \alpha_a{}^*|,$$

where α_a in this case is an index of all available technologies and $\alpha_a{}^*$ as defined above, is the pollution minimizing technology.

Environmental Policy in the CMT Model

We next augment our analysis with two types of technology standards. The first alternative places a ceiling on α, say $\alpha \leq t < 1$ while α_a and α_g are allowed to take any values satisfying $\alpha_a + \alpha_g = \alpha$. As ε is increasing in α we expect that in the absence of any other restrictions, a profit maximizing entrepreneur will prefer to have $\alpha = t$. Furthermore, since profit is given by $\pi = pX - \omega M - K_j = \eta \varepsilon \gamma_N A - K_j$, referring to Figure 3, the producer will choose $\alpha_a{}^* = \arg\min_{\alpha_a} \{K_0, K_t\}$ where K_0 is the overhead cost of the technology $(\alpha_a = 0, \alpha_g = t)$, and K_t is the overhead cost of the technology $(\alpha_a = t, \alpha_g = 0)$. If the situation depicted in Figure 3 prevails, society would be better off if $K_0 > K_t$ since in that case $\alpha_a = t$ will be the chosen technology and total damage will be less than that accompanying the other technology. However, if $K_0 < K_t$, the entrepreneur would choose $\alpha_a = 0$ and there would be more pollution.

The second technology policy places a more relaxed ceiling on α so that now $\alpha \leq 1$ but it restricts the choices of α_a and α_g to $\alpha_a / \alpha_g = (\beta_a + \sigma_a)/(\beta_g + \sigma_g)$, the pollution minimizing criterion for a given class. Clearly in this case the entrepreneur chooses $\alpha = 1$ and hence $\alpha_a = (\sigma_a + \beta_a)/(\sigma_a + \beta_a + \sigma_g + \beta_g)$ with $\varepsilon^s = 1/(\sigma_a + \beta_a + \sigma_g + \beta_g)$. Which of these technology policies is better from the standpoint of society or the firm is clearly an empirical issue. If *t* is close enough to 1, the second technology leads to less social damage and also less profit to the firm than the first. Note also that regardless of the value of *t*, we can conclude that if $K_0 < K_t$, then the first standard leads to more groundwater pollution and less air pollution than the second. Similarly, if $K_0 > K_t$, the first standard leads to less groundwater pollution than the second. Suppose the situation depicted in Figure 3 prevails. Then if $K_0 < K_t$, the second technology policy would also result in less pollution damage to society. However, if $K_0 > K_t$, the first technology policy ($\alpha_a \leq t < 1$) would result in less pollution damage.

Summary

In this paper we provided a framework to analyze environmental policy when the transfer of pollutants from one medium to another is deemed important. Such cross-media transfers could occur when an environmental policy consisting chiefly of technology standards results in the adoption of a technology with relative rates of pollution retention that differ markedly from the status quo. Thus a policy that leads to the adoption of an "air-friendly" technology might lead to more groundwater pollution. We derive conditions for a pollution minimizing technology and show that for such a technology the rates of media-specific pollutant retention are in the same relative proportions as society's weights on pollutants in the respective media augmented by costs of controlling pollutants in those media.

Our analysis was augmented by considering two types of technology standards. One standard requires the entrepreneur to adopt a waste management system that retains much of the generated pollutant, regardless of which proportions end up in the different environmental media. Another standard requires no significant retention of total pollutants. However, the entrepreneur was expected to adopt a waste management system that distributes pollutants in the various environmental media in proportions similar to society's weights. If the amount of retention required in the first standard is small, the second policy, in general, leads to lower social damage and lower net returns to the entrepreneur than the first.

Some welfare implications of society's solution, the firm's solution, and an output-(or total pollution) compensated solution were examined. We concluded that society's optimal solution leads to the least level of social damage, cost to the firm of waste treatment, and all the other choice variables including the levels of output and total pollution generated.

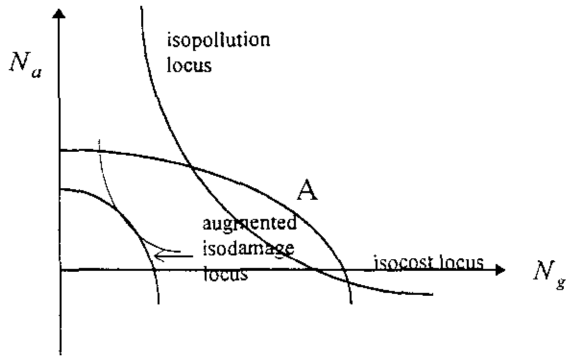

Figure 1. Iso-pollution, -damage, and -cost curves

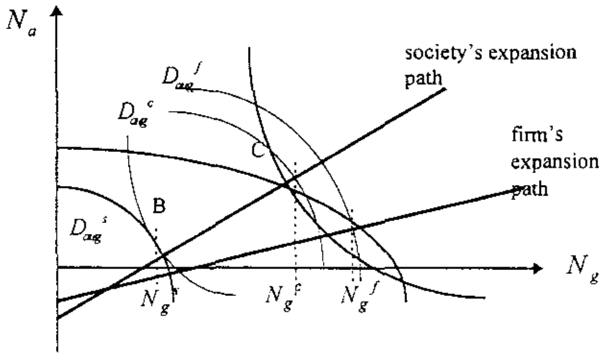

Figure 2. Optimal level and distribution of pollution.

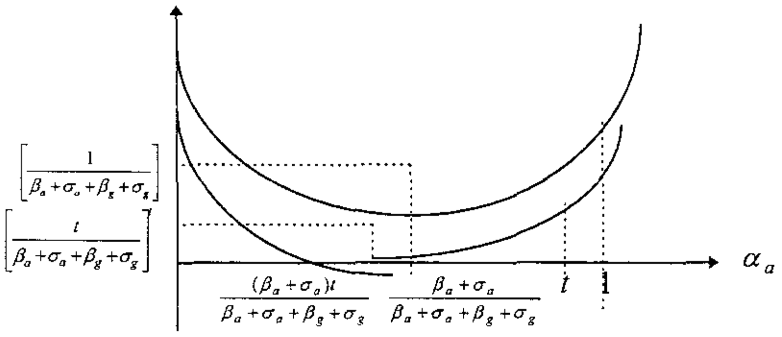

Figure 3. Optimal distribution of pollution under alternative policies