Interactions Between Agricultural and Environmental Policies: A Conceptual Framework

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INTERACTION BETWEEN ENVIRONMENTAL AND AGRICULTURAL POLICIES: OPPORTUNITIES FOR COORDINATION AND LIMITATIONS FOR EVALUATION[†]

Interactions Between Agricultural and Environmental Policies: A Conceptual Framework

By RICHARD E. JUST AND JOHN M. ANTLE*

Agricultural policy has a well-documented impact on farmers' production decisions, and those decisions (land, water, and agricultural chemical use) may in turn affect the environment. There is a public perception that existing agricultural policies are linked to agricultural pollution, as exemplified by the conclusions of the recent National Research Council report, *Alternative Agriculture* (1989). There is only limited theoretical or empirical research addressing these linkages, however.

This paper develops a conceptual framework that can be used to analyze the interactions between agricultural and environmental policies and pollution. This framework integrates physical and economic models at a disaggregate level necessary to capture the heterogeneity of the physical environment and the economic behavior of farmers. Following E. Hochman and D. Zilberman (1978), the disaggregate units can be statistically aggregated to a level useful for policy analysis. Agricultural and environmental policies can be categorized according to their effects on the intensive and extensive margins. Combining the different policy instruments with the microeconomic heterogeneity, we find that existing agricultural and environmental policies can have either positive or negative effects of nonpoint source pollution; to infer an aggregate effect requires data that do not currently exist. Our framework provides a basis for empirical investigations of these effects, given adequate data. Moreover, we find that agricultural policy instruments can be used to mitigate pollution if used appropriately.

I. A Disaggregated Model

Consider a region defined in relation to an environmentally meaningful geographical unit, such as a watershed or aquifer. The jth acre in the region has a set of environmental characteristics ω_j, that affect both its agricultural productivity and the production of pollution. A variety of complex physical models are being developed to measure pollution caused by agricultural production, such as surface and ground water contamination. 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.

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 their land (a more general model would include a vector of farm-specific char-

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acteristics). 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 $\delta_j^i=1$ if acre j is in production and 0 otherwise, and let $\delta_i=\{\delta_j^i\}$. The vector of attributes of land in production on farm i is then $\omega(\delta_i)=(\omega_1^i\delta_1^i,\omega_2^i\delta_2^i,\ldots)$ and total acreage in production on the ith farm is $\Sigma_j\delta_j^i$.

All farms in the region face the same vectors p and q of prices and policy parameters. Define x_j^i as the input allocation of farmer i to acre j and x^i as the vector of x_j^i. The ith farmer's decision problem can then be cast as

$$(1)\qquad \max_{x^i,\delta^i}\pi\left[x^i,\omega(\delta^i)\,|\,p,\psi,\omega^i\right]$$

where π is the farmer's objective function embedding the production technology and ψ is a vector of policy parameters.

The solution to this maximization problem generates the demand functions $x_j^i=x(p,\psi,\omega_j^i)$ and $\delta_j^i=\delta(p,\psi,\omega_j^i)$. The environmental characteristic of each unit of farm land 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 the land in production, $\omega(\delta^i)$, are determined by land use decisions. 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.

II. Modeling the Joint Distribution of Inputs, Environmental Characteristics, and Pollution

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 are not important, it is possible to greatly simplify the modeling by assuming a common continuous distribution such as a joint lognormal distribution.

The implementation of an environmental policy such as a restriction on input use per acre may alter farmer behavior, and induce other changes in the distribution $\phi(x,\omega)$ in addition to its censoring. According to the optimization problem defined above, farmers jointly 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 would also be different. Suppose, for example, that ω and x are positively correlated, 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 distribution would shift toward the origin in the ω dimension and would also 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 inputs and pollution.

III. Policy Interaction at the Extensive and Intensive Margins

In another paper (1990), we apply the general model above to the analysis of 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 composed of a complex set of instruments that interact with one another in determining decisions on the extensive and intensive margins simultaneously. Indeed, the producer's choice problem is defined in Section I as the joint determination of land use and input use. Most policies that affect the economic decisions of farmers thus 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 because they tend to encourage more intensive farming practices on the acreage in production. Indeed, the analysis of input use holding land use fixed verifies that price supports will generally increase input use and pollution. The analysis of land-use decisions holding input intensity fixed, however, shows that agricultural policies do not necessarily lead to higher 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 appropriately designed and administered.

Let us now assume that 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 into production those acres that are more profitable than g, while meeting or exceeding the diversion requirement. We assume there is a monotonic relationship between input use and profitability as environmental attributes are varied. 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

$$\bar{x}(g,\lambda) \equiv \min\Big\{ x_j^* | \pi_j \le g \\ \text{or } \textstyle\sum_j (1-\delta_j) \ge n\lambda \Big\}.$$

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. If x and z are positively correlated, removing land with $x < \bar{x}$ also removes land associated with low pollution levels. If x and z are negatively correlated, the opposite tends to be true. Formally, for a binding diversion requirement λ,

$$(2)\quad E(z) = (1-\lambda)^{-1} \times \int_0^\infty \int_{\bar{x}}^\infty z f(x,z)\, dx\, dz \equiv Z$$

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

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

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

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 follows that if λ is not binding then changes in g can also have either positive or negative effects on expected pollution depending on the correlation between x and z.

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

The combined effects of a price support/acreage diversion policy and an input restriction on pollution can now be analyzed. The land diversion induces farmers to remove land with $x < \bar{x}$ from production, and thus to truncate the distribution at $\bar{x}$. 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. The combined effects of the policies are thus 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, the preferred policy is to reduce pollution (and production), whereas if x and z are negatively correlated, the preferred policy is an acreage diversion. Conversely, if x and z are positively (negatively) correlated, a diversion (standard) may increase (not reduce) pollution.

The preceding analysis applies to farms that participate in programs. A complete analysis also needs to address the program participation decision. From equation (1), farmer i on acre j earns profit $\pi[p, \varphi, \omega_j^i]$ given prices p, policy parameters φ, and attributes ω_j^i. A farmer that chooses to comply with program rules faces policy parameter vector φ_c, and those who do not, face φ_n. Expected returns on the ith farm are

$$E[\pi|\varphi_k, \theta^i] = \int \pi[p, \varphi_k, \omega] \phi(\omega|\phi^i)\, d\omega,$$

$$k = c, n.$$

We can define a compliance frontier as those combinations of φ and θ giving $E[\pi|\varphi_n, \theta^i] = E[\pi|\varphi_c, \theta^i]$. Given policy parameters, for example, it is possible to examine the relationship among elements of θ along the frontier. To obtain an expression for aggregate variables, define the distribution of environmental parameters across farms as $f(\theta|\varphi_k)$, so that the proportion of complying and noncomplying farms is $p_k = \int f(\theta|\varphi_k)\, d\theta$, $k = c, n$. Now expected pollution, for example, can be expressed as $E(z) = p_n \int\int z f(x, z)\, dx\, dz + p_c Z$, where Z is defined as in (2).

IV. A Simple Model Combining Extensive and Intensive Margin Effects of Policy

The results of the previous section can be illustrated using a simple example. Let A_i be the total acreage of farm i and let y_i be the average yield on farm i. Suppose yield follows $y_i = a_i(1 - e^{-x_i}) + b_i$ where x_i is the quantity of the polluting (environmentally degradating or resource depleting) input used, and a_i and b_i are constants associated with farm i. Where p_m is the market price for output, v is the price of the input, and c_i is the cost per acre of any other inputs embodied in a_i and b_i, profit on farm i under noncompliance with a voluntary program is

$$\pi_i = A_i[p_m a_i(1 - e^{-x_i}) + p_m b_i - v x_i - c_i].$$

The condition for profit maximization in this case is

$$\partial \pi_i / \partial x_i = A_i(p_m a_i e^{-x_i} - v) = 0$$

which implies an optimal input per acre under noncompliance of $x_i^n = \ln(p_m a_i/v)$ if $\pi_i^1 \geq \pi_i^0$, and 0 otherwise, where π_i^1 is the optimal profit when optimal input use is positive,

$$\pi_i^1 = A_i[p_m(a_i + b_i) - v - v\ln(p_m a_i/v) - c_i],$$

and π_i^0 is the optimal profit when optimal input is zero, $\pi_i^0 = A_i(p_m b_i - c_i)$. Here, one finds

$$\pi_i^1 - \pi_i^0 = A_i[p_m a_i - v - v\ln(p_m a_i/v)] \gtreqless 0 \quad \text{as } p_m a_i \gtreqless v$$

so optimal profit under noncompliance is

$$\pi_i^n = \begin{cases} A_i[p_m(a_i + b_i) - v - v\ln(p_m a_i/v) - c_i], & \text{if } p_m a_i > v \\ A_i(p_m b_i - c_i) & \text{otherwise.} \end{cases}$$

Now consider behavior under compliance with a voluntary government program such as the wheat and feed grain programs that employ the following policy instruments: a target price p_t, a support price p_s, a diversion requirement λ, a government payment per acre for diversion g, and a program yield y_p. Define $p^* = \max(p_s, p_m)$. Then, under the provisions of these programs whereby farmers are entitled to at least the target price on production up to the program yield, and to at least the support price on all their production, profit for farm i is

$$\pi_i = A_i(1-\lambda)\left[\max(p_t, p_m)\cdot y_p + p^*\cdot\max(y_i - y_p, 0) - v x_i - c_i\right] + A_i\lambda g.$$

The first-order condition for profit maximization is $\partial\pi_i/\partial x_i = A_i(1-\lambda)(p^* a_i e^{-x_i} - v) = 0$, if $y_i > y_p$ and $\partial\pi_i/\partial x_i = A_i(1-\lambda)(-v) < 0$ if $y_i < y_p$. Thus, the optimal input use per acre under compliance is $x_i^c = \ln(p^* a_i/v)$ if $p^* a_i > v$ and $y_p < a_i + b_i - v/p^*$, and 0 otherwise.

The optimal profit under compliance is

$$\pi_i^c = \begin{cases} A_i(1-\lambda)[p_t y_p - c_i] + A_i\lambda g & \text{if } y_p \geq a_i + b_i - v/p^* \\ A_i(1-\lambda)\left[(p_t - p^*)y_p + p^* b_i - c_i\right] + A_i\lambda g & \text{if } y_p < b_i,\ p^* a_i \leq v \\ A_i(1-\lambda)\left[(p_t - p^*)y_p + p^*(a_i + b_i) - v - v\ln(p^* a_i/v) - c_i\right] + A_i\lambda g & \text{otherwise.} \end{cases}$$

Comparing π_i^c and π_i^n, it is clear that compliance can be induced by a sufficiently high target price and diversion payment regardless of how low the support price is and how high the diversion requirement is. On the other hand, more intense use of the polluting input is not induced by a high target price and diversion payment if the program yield is sufficiently high, and/or the support price is sufficiently low. For example, more intense use is not induced if the support price is at or below the market price, and the program yield is not below the yield that occurs with market price under noncompliance.

The important point of these results is that current agricultural policies are sufficiently general to permit independent control of the extensive and intensive margins. The extensive margin, (i.e., the choice of diverted and producing acreage) can be controlled through the target price, the diversion requirement, and the diversion payment. The intensive margin can be controlled within certain bounds by the choice of support price and program yield.

V. Conclusions

There are a number of directions in which the framework presented here needs to be extended. The disaggregate model needs to be aggregated so that market equilibrium implications can be analyzed. Dynamic aspects of these issues need to be considered, especially the implications for investment behavior. Empirical research must address the technical detail involved in integrating physical and economic models.

Both agricultural production and environmental impacts depend on highly location-specific environmental conditions. Reality is far too complex to allow generalizations about the environmental impacts of agricultural policies. Our analysis points to the kinds of data that are needed to make valid inferences. Statistically reliable field-specific production data and environmental data would make possible measurement of key parameters (such as the correlation between production decisions and environmental attributes of land) that are needed to assess the aggregate relationships between agricultural policy, environmental policy, and the environment.

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