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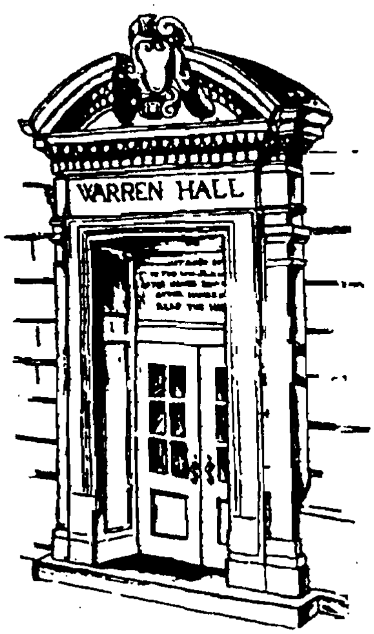

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ANALYZING ENVIRONMENTAL POLICY WITH POLLUTION ABATEMENT VERSUS OUTPUT REDUCTION: AN APPLICATION TO U.S. AGRICULTURE

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Analyzing Environmental Policy with Pollution Abatement versus Output Reduction:

An Application to U.S. Agriculture

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Abstract

A model is developed that derives optimal pollution levels and determines the welfare economics of pollution reduction, differentiating between abatement and output reduction. It is suitable to analyze alternative policy instruments aimed to reduce external costs of agricultural production. The model is applied to the U.S. corn sector and we simulate the effects of stylized environmental policies for pesticide use on social welfare and environmental quality. The simulation results indicate that across policy scenarios, fairly modest reductions in output may induce significant gains in social welfare and environmental quality.

Analyzing Environmental Policy with Pollution Abatement versus Output Reduction: An Application to U.S. Agriculture

1. Introduction

Pollution generated by a production externality can be dealt with by reducing output and/or abatement activities, or a combination thereof. Output reduction involves a loss in social surplus, while abatement involves direct resource costs. In addition to these curtailment costs, pollution also incurs the social costs of damages upon the population when released. Our objective is to develop a proper framework that determines the social optimal production and pollution levels simultaneous with the optimal combination of abatement activities and output reduction. Output/input taxes (e.g. taxes on electricity output or fuel) or direct regulations on production are examples of output reduction policies. Pollution taxes or subsidies for abatement activities (e.g. carbon taxes or tax breaks for clean production) or direct regulations on pollution levels (e.g. smokestack filter for an electrical utility plant) also induce abatement. The distinction between abatement and output reduction (and the interaction between the two) allows us to properly evaluate the welfare implications of alternative environmental policy scenarios.

The literature typically defines pollution reduction without making a distinction between abatement and output reduction or evaluates only one them (Krutilla, 1991; Anderson, 1992; Buchanan and Tullock, 1975; Baumol and Oates, 1988).[1] Helfand (1991) defines pollution as a function of pollution increasing and pollution decreasing inputs, but does not distinguish between abatement and output reduction either. An exception is Pearce and Turner (1990, ch. 6) who attempt to integrate abatement and output reduction but fail to do so appropriately. The objective of this paper is to develop a comprehensive framework that clearly distinguishes between abatement and output reduction and to operationalize it into an empirical methodology. The

[1] In chapter 5, Baumol and Oates make no distinction between abatement and output reduction. In chapter 14, they assume abatement technology is unavailable and show that subsidies for pollution reduction are inefficient relative to pollution (production) taxes in a dynamic setting due to entry/exit of firms.

significance of our framework is illustrated by an empirical example of pesticide use in U.S. agriculture. Pesticides are responsible for a variety of pollution problems causing significant social and environmental costs. However, using alternative pest control measures (abatement activities), pesticide use and hence social and environmental costs can be reduced significantly without reducing production (Pimentel, 1993b).

2. An Analytical Framework

Consider the production of a good Q generating an externality (i.e. pollution). Abatement activities A can reduce pollution levels *without* affecting production of good Q. Consider Cobb-Douglas production functions exhibiting decreasing returns to scale that describe production and abatement activities, respectively: $Q = F(N, X^i_Q)$; $A = G(X^i_A)$, where X^i_j are input quantities (i = 1, ..., n; j = Q, A).[2] Input N used in the production of a good Q generates *gross* pollution E(N). Assume a convex relationship between gross pollution generated and input N: $E_N > 0$ and $E_{NN} \geq 0$. *Net* pollution released (S) is defined as gross pollution minus abatement:

[1] $$S = E(N) - A.$$

Thus, pollution generated (referred to as gross pollution) is the sum of pollution released (referred to as net pollution) and pollution abated, all measured in identical units. Note that gross pollution may either be released in the environment inducing pollution damages or abated entailing abatement costs. Monetary external costs (damages) due to net pollution EC(S) = EC[E(N)−A] are convex in S and marginal external costs are given by $MEC(S) = EC_S(S)$. Let P denote the fixed market price of good Q. Input prices are fixed, such that cost minimization results in a convex, additively separable total (variable) cost function C(Q, A) = C(Q) + AC(A) where C(Q) are the production costs of good Q and AC(A) are abatement costs.

[2] While the assumption of Cobb-Douglas production functions is a simplification, made to keep mathematical computations and graphical representation simple, the problem is likely to generalize using other production functions with few differences.

[2] $$C(Q,A) = Min \left\{ \sum_i p_i (X^i_Q + X^i_A) + p_N N \right\}$$

Marginal (private) production costs are C_Q = MPC(Q) and marginal abatement costs are C_A = MAC(A). Private profits are given by $\Pi = P \cdot Q - C(Q,A)$. Marginal private costs of producing Q are C_Q = MPC(Q) and marginal abatement costs are C_A = MAC(A). Without pollution policy, marginal profits $M\Pi = \partial\Pi/\partial Q = P - MPC = 0$, implying an output level of Qo and pollution level of So = E(Qo). Marginal profits gained by increasing output equal marginal profits lost by reducing output. Marginal profits lost by reducing pollution via output reduction only, termed marginal output reduction cost or MORC, are defined by

[3] $$MORC(E) = \partial\Pi/\partial E = M\Pi \,/\, [\partial E/\partial Q]$$

Thus, MORC(E) is the marginal cost of reducing pollution via output reduction only as depicted graphically in Figure 1.[3] Since abatement is negative (net) pollution, MAC(-A) is equivalent to the marginal cost of reducing pollution via abatement only as depicted in Figure 1. The marginal cost of reducing net pollution via output reduction *and* abatement simultaneously, termed marginal pollution reduction cost or MPRC, is derived by adding MORC(E) and MAC(-A) horizontally at So from right to left:[4]

[4] $$MPRC(S) = MPRC[E-A] = MORC(E) = MAC(-A)$$

[3] Note that the intercept of MORC(E) on the horizontal axis defines So, the amount of pollution corresponding to the private optimum without public policy action. The intercept of MAC(-A) on the horizontal axis is arbitrarily set at So, but could be somewhere to the right of So. If MAC(-A) crosses the horizontal axis to the left of So, then pollution abatement would imply at least some private benefits. Although not considered here, this aspect can easily be incorporated in our analysis.

[4] Note that MPRC(S) is obtained by adding pollution reduction due to less output and pollution reduction due to abatement, analogous to deriving a total supply curve by horizontal summation of two individual supply schedules. Pearce and Turner (1990, Figure 6.4) attempt to integrate abatement and output reduction, but do not obtain the total supply of pollution reduction by horizontal summation of MAC and MNPB. By their definition, abatement yields only social benefits because all private benefits are portrayed by MNPB. This implies a privately optimal pollution level where MNPB = 0 and that MAC may not cross the horizontal axis before MNPB.

Gross pollution (E = S+A) is either released into the environment inducing external costs or abated inducing abatement costs. Thus, total gross pollution costs GC(E) are external costs or pollution damages EC(S) *plus* abatement costs AC(A). Defining GC(E) as the sum of EC(S) and AC(A) is stipulated by the notion that abatement costs are a social cost analogous to the external costs of pollution released into the environment. By abating pollution, private firms deliver a social good (less pollution) with resources they would otherwise use to produce private goods. In Figure 2, marginal gross pollution costs, denoted by MGC(E), are derived by adding MEC(S) and MAC(A) horizontally, starting at the origin from left to right:

[5] $$MGC(E) = MGC[S+A] = MEC(S) = MAC(A).$$

3. Optimal Pollution and Welfare

When deriving optimal production and pollution levels, economists typically compare pollution damages and the benefits of reduced pollution (cost-benefit analysis). Alternatively, economists expand on the theory of a profit-maximizing firm imposing a marginal divergence between private and social cost of production and output reduction as the only means to reduce pollution. Many authors exclude abatement by assuming MAC(-A) *exceeds* MORC(S) over the relevant range of pollution reduction [e.g. (Krutilla, 1991); (Anderson, 1992)]. This implies that gross pollution equals net pollution (E=S) and marginal gross pollution costs equal marginal external costs from net pollution (MGC=MEC). Unlike the literature, we distinguish pollution reduction via output reduction and pollution abatement, integrating the benefits and costs of abatement into conventional partial-equilibrium welfare analysis. This allows for an appropriate assessment of the social welfare implications under alternative environmental policy scenarios.

In Figure 1, the optimal level of *net* pollution S* is determined by a standard procedure, equating marginal external costs and marginal pollution reduction costs (condition [6]). Optimal levels of abatement A* and gross pollution E* which in turn defines the optimal level of output reduction are determined simultaneously.

[6] $$\text{MPRC}(S^*) = \text{MEC}(S^*) = \text{MORC}(E^*) = \text{MAC}(-A^*)$$

In Figure 2, the optimal level of *gross* pollution E* is determined by an unorthodox rule, equating marginal gross pollution costs and marginal output reduction costs (condition [7]). Optimal levels of abatement A* and net pollution S* are determined simultaneously.

[7] $$\text{MGC}(E^*) = \text{MORC}(E^*) = \text{MAC}(A^*) = \text{MEC}(S^*)$$

Condition (7) is appropriate because MORC(E) describes the marginal cost of reducing gross pollution and MGC(E) portrays the marginal benefit of reducing gross pollution. Indeed, Figures 1 and 2 describe the same optimum because MGC(E*) = MORC(E*) = MEC(S*) = MPRC(S*).

Let us now compare the welfare implications of the equilibria depicted in Figures 1 and 2. First, consider the approach depicted in Figure 1. Area *dfgS** below MEC(S) is interpreted as the optimal reduction in pollution damages, implying that area *0gS** below MEC(S) depicts optimal pollution damages due to net pollution S*. The area *dgS** below MPRC(S) is the minimum cost of reducing net pollution via an optimal combination of output reduction and abatement. Area *dgS** is equal to the sum of output reduction costs *dcn* and abatement costs *dih*. Hence, area *dfg* depicts the maximum *net welfare gains* of reducing pollution below So. Second, consider the method depicted in Figure 2. Area *acn0* below MORC(E) depicts optimal producer surplus of pollution generating production. Area *cn0* below MGC(E) depicts the minimum social cost of pollution generating production with an optimal combination of net pollution and abatement. Optimal abatement costs are equal to area *0jA**, which equals area *dih* in Figure 1. Consequently, area *ac0* characterizes maximum social surplus attainable from pollution generating production.

However, why do we distinguish Figures 1 and 2? While Figure 1 is appropriate in illustrating net welfare gains attainable from reducing pollution below So (area *dfg*), Figure 2 is appropriate in depicting net welfare gains attainable from pollution generating production (area *ac0*). Consequently, Figure 2 conforms directly and intuitively with customary producer surplus analysis which measures net welfare gains from (pollution generating) *production*. In contrast, it is less intuitive to depict net welfare gains from pollution generating production with Figure 1 (area *ab0+bdg*) as well as net welfare gains from reducing pollution below So with Figure 2 (area *bdf+ch0*).[5]

Moreover, Figures 1 and 2 allow for a simple comparative-static analysis of relative changes (shifts) in the overall cost structure. For example, pivotal shifts, i.e. a percentage rise (fall) in MEC implies, ceteris paribus, an increase (decrease) in area *dfg*, but a decrease (increase) in area *ac0*. Thus, net welfare gains from reducing pollution below So (area *dfg*) and net welfare gains from pollution generating production (area *ac0*) adjust in opposite directions. Table 1 summarizes the effects for relative (ceteris paribus) changes in MEC, MORC and MAC.

Table 1: Qualitative welfare effects if MEC, MORC, or MAC rise (↑) or fall (↓)

	MEC		MORC		MAC	
	↑	↓	↑	↓	↑	↓
area *dfg* (Figure 1)	+	–	–	+	–	+
area *ac0* (Figure 2)	–	+	+	–	–	+

The next step is to integrate the costs and benefits of abatement into conventional partial-equilibrium welfare analysis. Pollution generating production implies external costs, part of which are abated. Hence, we define total social costs of production as private costs of production

[5] Note that pollution reduction without abatement (i.e. no MAC curves) implies that Figures 1 and 2 are identical such that optimal net welfare gains from reducing pollution below So are equal to area *bdf* and optimal net welfare gains from pollution generating production are equal to area *ab0*.

C(Q) *plus* abatement and/or external costs GC(Q). Net welfare gains from non-polluting production (=producer surplus) are defined as producer revenue minus social (=private) costs of production.[6] Analogously, we define net welfare gains attainable from pollution generating production as producer revenue minus social (≠private) costs of production.

In Figure 3, pollution generating production Q is depicted on the horizontal axis, scaled assuming that $E(N) = kN(Q)$, where N(Q) is the conditional input demand function for the polluting input needed to produce Q *without* abatement and k is a scalar describing the intensity of gross pollution. This scaling assumption simplyfies to separate pollution reduction via output reduction (which involves using less of input N) from abatement activities which presumably reduce pollution (and the use of input N) without reducing output, but is not fundamental to the model itself. Without abatement, S=E(N) such that we transfer MEC according to $MEC[E(N)] = MEC[kN(Q)] \equiv MEC(Q)$ into Figure 3 and then use this scaling procedure to obtain MGC(Q).[7]

In Figure 3, no abatement activity implies that marginal private costs MPC and marginal external costs MEC must be added *vertically* to obtain the marginal *social* costs of pollution generating production. Without abatement activity, the (optimal) production level Q' is defined by $P = MPC(Q') + MEC(Q')$ such that (optimal) pollution is given by $S' = E(N') = Q'$.

The next step is to incorporate abatement activities into Figure 3. With abatement, net pollution no longer equals gross pollution: $S \neq E$. It follows that marginal private costs MPC and marginal gross pollution costs MGC must be added *vertically* to obtain the marginal social cost of pollution generating production. In Figure 3, the optimal production level Q* is determined by: $P = MPC(Q^*) + MGC(Q^*)$ such that optimal net pollution and abatement levels are given by $MGC(Q^*) = MEC(S^*) = MAC(A^*)$.

[6] Private production costs exclude costs of abating socially damaging pollution since producers would earn nothing in return. However, private production costs include costs of abating privately damaging pollution for which producers would earn positive returns.
[7] Note that a Cobb-Douglas production function with decreasing returns to scale implies that MEC(Q) will be concave in Figure 3. Moreover, constant (increasing) returns to scale imply that MEC(Q) will be linear (convex).

Next, we discuss the welfare implications related to Figure 3 where all applicable areas are marked in order to correspond with Figure 2. Area *ac0* defines maximal social welfare attainable from production when pollution is reduced optimally via abatement and output reduction. It corresponds to area *ac0* in Figure 2, which depicted maximum net welfare gains attainable form pollution generating production. Area *ab0* describes maximum social welfare attainable if pollution is reduced via output reduction only and corresponds to area *ab0* in Figure 2. Area *acn0* depicts optimal producer surplus from a pollution generating good. Area *0cn* portrays minimum gross pollution costs via an optimal combination of pollution released and pollution abated. Area *cdn* shows the corresponding output reduction costs, implying that area *bc0* is the net welfare gain from optimal abatement. Thus, Figure 3 integrates pollution abatement into conventional partial-equilibrium welfare analysis with output on the horizontal axis, while the approach depicted in Figure 2 is equivalent but has pollution on the horizontal axis.

4. Analyzing Environmental Policy

Now we employ the framework developed in Figure 3 and analyze the social welfare effects of stylized environmental policies. Any policy designed to reduce pollution and resulting damages will affect private and/or social costs of production and in turn social welfare. Social welfare gains attainable (pollution generating) production are defined as producer revenue minus social costs of production. Figure 3 also illustrates the social welfare gains for a small exporter. The elasticity of excess demand is infinity, implying an exogenous world market price at P such that consumer surplus remains constant. Assuming free trade, we discuss four stylized environmental policy scenarios (no policy, production tax, pollution tax, abatement subsidy).

Without any policy designed to reduce pollution, the optimality condition is MPC = P such that production is determined at point *d*. Consequently, area *ad0-0fd* = *ab0-bdf* illustrates (maximum) social welfare gains attainable from production or producer surplus net of gross pollution costs with no environmental policy.

With a tax imposed on pollution generating production, firms will reduce pollution via physical output reduction only, because there exists no private incentive to reduce pollution via abatement. Accordingly, the optimality condition is MPC + MEC = P with a tax rate of *mb* and production given at point *b*. Area *ab0* depicts (maximum) net welfare gains attainable from production or producer surplus net of remaining pollution damages.

With a tax levied on net pollution, private firms will reduce pollution via output reduction and are given an incentive to abate. Hence, the optimality condition is MPC + MGC = P with a tax rate of *nc* = tp* and production at given point *c*. Area *ac0* depicts the maximum social welfare gain attainable from production or producer surplus net of remaining pollution damages. Area *0bc* is the net welfare gain attainable from socially optimal abatement.

With a subsidy compensating for abatement activities, private firms will reduce pollution via abatement only. No incentive to reduce pollution via output reduction exists because firms would suffer a profit loss without receiving compensation. From Figure 2, it follows that social welfare improving subsidization of abatement is possible *without* output reduction up to when MAC(A) = MGC(So) = MGC(Qo) which implies a subsidy rate equal to *de*, an abatement level As, and a net pollution level given by S=So–As. In Figure 3, area *ad0-0de* = *ab0+0bc-cde* depicts (maximum) social welfare gains attainable from production or producer surplus net of remaining pollution damages with a subsidy compensating for abatement activities.

A welfare ranking of all four policy scenarios is possible depending on the relative size of area *0bc* versus area *cde* in Figure 3. If *0bc* > *cde*, the maximum social welfare attainable with an abatement subsidy exceeds the maximum social welfare attainable with an output tax, while the opposite is true if *0bc* < *cde*. A net pollution tax is optimal, while no pollution policy is worst. Table 2 summarizes the welfare effects of the policy scenarios discussed.

Table 2: Social Welfare Implications of Four Environmental Policy Instruments

Policy Instrument	Social Welfare
No Policy	*ab0-bdf*
Production tax	*ab0*
Net Pollution tax	*ac0*
Abatement subsidy	*ab0+0bc-cde*

5. An Empirical Example in U.S. Agriculture

In this section, we assess the social welfare effects of alternative environmental policies affecting pesticide use in U.S. corn production. Pesticides enhance agricultural productivity, but associated environmental and health effects are the subject of an ongoing societal debate about regulating pesticide usage (Zilberman et al., 1992). To examine the issue, we assess productivity and costs of corn production and abatement strategies which allow for a reduction in pesticide use without reducing crop yields. Several studies suggest that it is technologically feasible to significantly reduce pesticide use in the United States without reducing production (NAS, 1989; Pimentel et al., 1993b). The challenge is to determine relevant functional relations required to simulate social welfare and environmental effects. In particular, it is necessary to evaluate the external costs as well as the cost of abatement strategies associated with pesticides.

The total value of corn production ranks first among all crops in the United States (Ali and McBride, 1994). Corn is planted on over 75 million acres, with an average yield of about 109 bushels per acre. Currently, U.S. farmers apply an estimated 320 million kg of pesticides each year, costing them roughly $4.1 billion. Pesticide use in corn production exceeds that for any other crop totaling about 125 million kg or about 39% of annual pesticide use. About 89% of all pesticides used to grow corn are herbicides and 11% are insecticides (Pimentel et al., 1993b). Over 90% of corn grown is treated with herbicides and on average over 3 kg of herbicides are sprayed per hectare of corn (Pimentel et al., 1993a). Fifty years ago, very little insecticide was applied to corn. Since then, insecticide use in corn has increased more than 1,000-fold, primarily due to insufficient crop rotation. Currently, about 40% of U.S. corn is grown without rotation.

Pesticides make an important contribution to maintain world food production. In general, each dollar invested in pesticide control measures returns approximately $4 in crops saved. Crop losses would increase by an average of 10% if no pesticides are used at all (Pimentel et al., 1992). However, most benefit estimates of pesticide usage are based on direct crop returns and do not include indirect social and environmental costs associated with pesticides. These indirect costs must be incorporated in order to facilitate a sound analysis of public policy aimed to alter the use of pesticides. Pimentel et al. (1992) attempt to estimate total social and environmental costs resulting from pesticide use in the United States. Their analysis includes a monetary assessment of human health effects, domestic animal poisonings, losses due to reduced natural resistance of crops, losses due to pesticide resistance, crop pollination problems and honeybee losses, crop losses, fishery and bird losses, groundwater contamination, and the costs of government programs to regulate pesticides. They estimate that environmental and social costs due to pesticide use in the United States total *at least* $8 billion annually. A significant proportion of this is due to corn production where 39% of all pesticides are applied.

In evaluating the social welfare impacts of environmental policies, we neglect market distortions due to pre-existing government programs (e.g. target price support), but include the environmental and social costs of pesticides (external costs) as well as the cost of abatement technologies associated with pesticide use. In analyzing a pesticide ban, Lichtenberg and Zilberman (1986b) evaluate the welfare bias when pre-existing government programs are neglected. However, such policy distortions are not crucial in order to distinguish pollution abatment and output reduction. Moreover, relative to their estimates, the welfare effects of environmental policies including the external costs as well as the cost of abatement strategies associated with pesticides are significantly higher as our analysis will prove.

Data and Model Calibration

The assessment of total social and environmental costs resulting from pesticide use by Pimentel et al. includes an array of associated environmental and health problems. Therefore, it is virtually impossible to define and/or measure associated pollution levels. Some form of pollution index is needed, based on how much pollution is generated by pesticides used in corn production and how much pollution damage can be abated using alternative pest control measures. We conjecture that gross pollution is linearly related with pesticide use when there is no abatement: $E(N) = kN$. Consequently, the analysis to follow assumes a relation between net pollution, input use, and abatement activities given by $S = kN - A$. Thus, abatement A is the reduction in the use of input N relative to producing a given quantity of Q without abatement.

However, what exactly is abatement? Abatement may be considered as implementing alternative production techniques (i.e. pest control measures that decrease pesticide use) without reducing production. Pimentel et al. (1993b) list a variety of feasible techniques available to reduce pesticide application rates *without* reducing corn production. For example, instituting crop rotation and planting more resistant corn varieties can achieve great reductions in insecticide use. Similarly, avoiding total weed elimination and the use of mechanical cultivation combined with crop rotation can reduce herbicide use substantially. However, farmers implementing alternative pest control measures to reduce pesticide application rates accrue added costs which we have defined as abatement costs. The raw data used to calibrate the model is listed in the appendix.

The estimates of Pimentel et al. indicate that corn's contribution to total pesticide damages of $8 bil. per annum is less than proportional (less than 39%) because many high-valued crops (e.g. fruits, vegetables) are treated with relatively high doses of pesticides per acre such that their contribution to total pesticide damages is more than proportional (Pimentel et al., 1993a). As an approximation, we assume that corn's contribution to total damages is defined by its share of pesticides usage (= 39%) discounted by a proportional damage factor (= 0.6).[8]

Suppose pesticide damages EC(S) are quadratic in S with EC(0) = 0 and imply a linear marginal external cost function MEC(S) = c∗S intercepting at the origin in Figures 1 and 2. Thus, increases in corn production due to pesticide use or a decline in abatement activities increase total pesticide damages at an increasing rate. Parameter c is determined such that corn's contribution to total pesticide damages EC(So) at the base level of corn production Qo is represented by the area below MEC(S) at So.

Suppose that corn production is characterized by $Q = B(K_Q)^{\alpha} N^{\beta}$, while abatement is defined by $A = R\,(K_A)^{\gamma}$. K_i (i = Q, A) is the farmer owned input whose quantity is now fixed such that $K = K_Q + K_A$.[9] N is the purchased pesticide input. The shares of farmer owned input and pesticides in total corn production costs are used to determine parameters α and β in an initial calibration step. Suppose $\gamma = 0.5$ such that abatement costs $AC(A) = p_K\, K_A(A)$ are quadratic in A such that marginal abatement costs are linear represented by MAC(A) = d∗A and $d = (p_K/\gamma)R^{-1/\gamma}$. Because marginal external cost MEC(S) and marginal abatement costs MAC(A) are both linear, their horizontal summation defines a linear marginal gross pollution cost function for pesticides: MGC(E) = g∗E. The slope of MGC is defined by g = 1/[(1/c)+(1/d)].

When calibrating the model, the input price p_K varies such that abatement costs (= added alternative control costs) accrued by adapting pesticide damage reducing pest control methods are measured by the area below MAC(A) at the remaining pollution level. For corn, Pimentel et al. (1993b) estimate an annual total of $530.5 million in added alternative control costs could reduce pesticide application rates by 62.4% *without* reducing overall production. However, it is

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[8] Pimentel, D. (1994) personal communication. Cornell University, Ithaca, NY.

[9] Limiting the availability of the farmer owned input K adds a general equilibrium feature to the model. It implies input price adjustments such that the MORC and MAC curves will shift in response to policy changes, generating interaction effects between output reduction and abatement activities not analyzed in Figures 1-3.

controversial, just how much reduction in corn's contribution to total pesticide damages can be accomplished using less pesticides. As an approximation, we conjecture that for each percent reduction in pesticide use, a one percent reduction in corn's contribution to total pesticide damage is accomplished. Thus, a 62.4% reduction in pesticide use for corn implies to an abatement level of 0.624*No (where No is the initial level of pesticide use) and results in a 62.4% reduction in corn's contribution to total pesticide damages such that remaining damages are 0.376*EC(So).

Policy Simulations

Once calibrated, the model is used to simulate welfare and pollution effects of six stylized environmental policy instruments (none, production tax t_Q, pollution tax t_S, abatement subsidy s_A, pesticide tax t_N, and an input subsidy s_K for K_A). The policy simulations were carried out using the mathematical programming package GAMS©. For simplicity, we assume that the U.S. is a small, social welfare maximizing exporter of corn facing an exogenously given world market price. The simulation results are listed in Table 3 where social welfare gains are calculated relative to the no policy scenario. The policy simulations imply that [10]

(1) an optimal production tax raises social welfare by $955 M by reducing net pollution via output reduction by 46% and external costs by 70%;

(2) an optimal pollution tax raises social welfare by $ 1.25B by reducing net pollution by 66% (37% due to output reduction and 29% due to abatement) and external costs by 88%;

(3) optimal abatement subsidies raise social welfare by $ 1.03B which reduces net pollution by 61% and external costs by 84%;

(4) production levels decline between 3.6% (abatement subsidy) and 9.4% (production tax).

[10] Note that production and pesticide tax as well as abatement and K_A input subsidy for yield identical welfare effects which is due to fixing the farm input level K and assuming a one input production function for A.

----- Insert Table 3 here-----

6. Concluding Remarks

The model developed in this paper derives optimal pollution levels and the welfare economics of pollution reduction, differentiating between abatement and output reduction. In Figure 2, we discuss a unique cost/benefit approach to derive optimal pollution levels regarding abatement costs as a social cost. We defined the total social costs of a polluting production activity as private production costs plus gross pollution costs. This approach illustrates best the net welfare gains attainable from pollution generating production, which is appropriate for policy and welfare analysis of a polluting good, because it conforms directly and intuitively with customary producer surplus analysis. In Figure 1, we discuss the standard cost/benefit approach which illustrates best the net welfare gains attainable from reducing pollution below the private optimum. As Figures 1 and 2 have demonstrated, when output reduction is the *only* means to reduce pollution, such a distinction does not matter, but when abatement as well as output reduction may reduce pollution, it does. In Figure 3, we integrate the costs and benefits of abatement into conventional partial equilibrium analysis with pollution generating production depicted on the horizontal axis.

The significance of our model is illustrated by an application to pesticide pollution in the U.S. corn market. Several stylized environmental policies are simulated to evaluate their effects on social welfare and environmental quality. Comparing policies, one can conclude that a significant reduction in external costs can be achieved with relatively little reduction in overall production. In order to further improve the empirical analysis, it is necessary to specify relevant functional relations in more detail (including to endogenize the domestic price level P) and to quantify the results that emanate from our analytical framework under alternative scenarios, including existing commodity policies such as deficiency payments, export subsidies, and acreage diversion programs. In order to determine exact properties of the MORC and MAC functions, a more detailed specification of production and abatement cost functions is required. Several micro studies evaluating a combination of MORC and MAC exist (Lichtenberg and Zilberman, 1986a) and their conclusions have to be incorporated to ascertain the components of MAC and MORC specific to the case of corn and other agricultural commodities. Because the social welfare benefits of optimal pollution policies are significant, the empirical analysis needs to be refined and extended not only to other agricultural commodities, but to other sectors as well where pollution is a problem and the distinction between output reduction and abatement is relevant (for example, electrical utilities).

Table 3: Environmental Policy Simulation Results

Environmental Policy Instrument	Social Welfare Gains ($M)	External Costs ($M)	Production (M bus.)	Abate-ment	Net Pollution	Price p_K ($)	Policy Parameter
None	0	1,904	8,000	---	5,023	1.000	---
Production tax	955	564	7,251	---	2,734	0.544	$t_Q = 0.963$
Pollution tax	1,250	222	7,428	1,460	1,714	0.816	$t_S = 0.334$
Abatement subsidy	1,030	296	7,714	2,029	1,980	1.002	$s_A = 0.570$
Pesticide tax	955	564	7,251	---	2,734	0.906	$t_N = 0.666$
Input subsidy for K_A	1,030	296	7,714	2,029	1,980	1.002	$s_K = 1.002$

Figure 1: Net Welfare Gains from Reducing Pollution

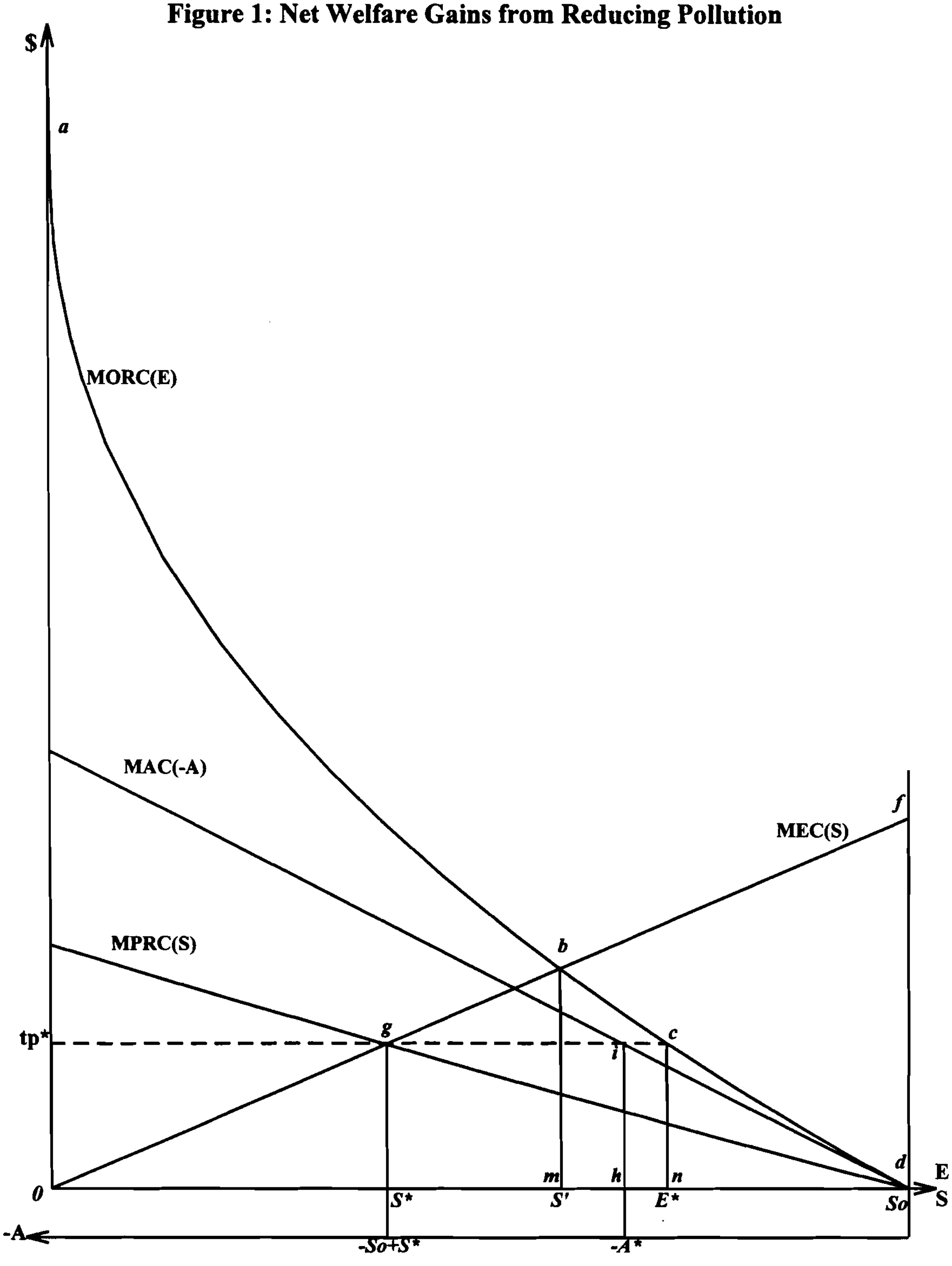


Figure 2: Net Welfare Gains from Generating Pollution

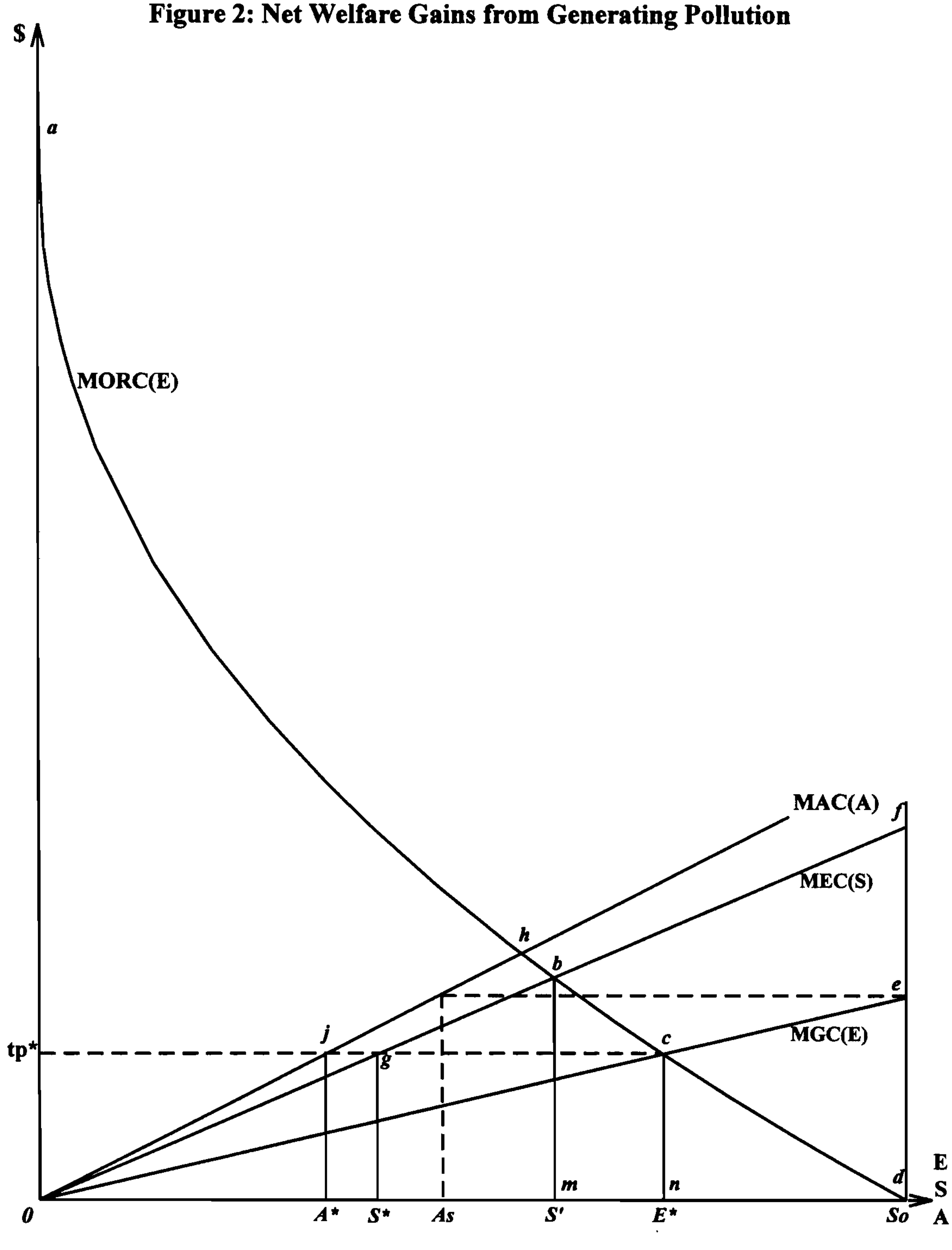
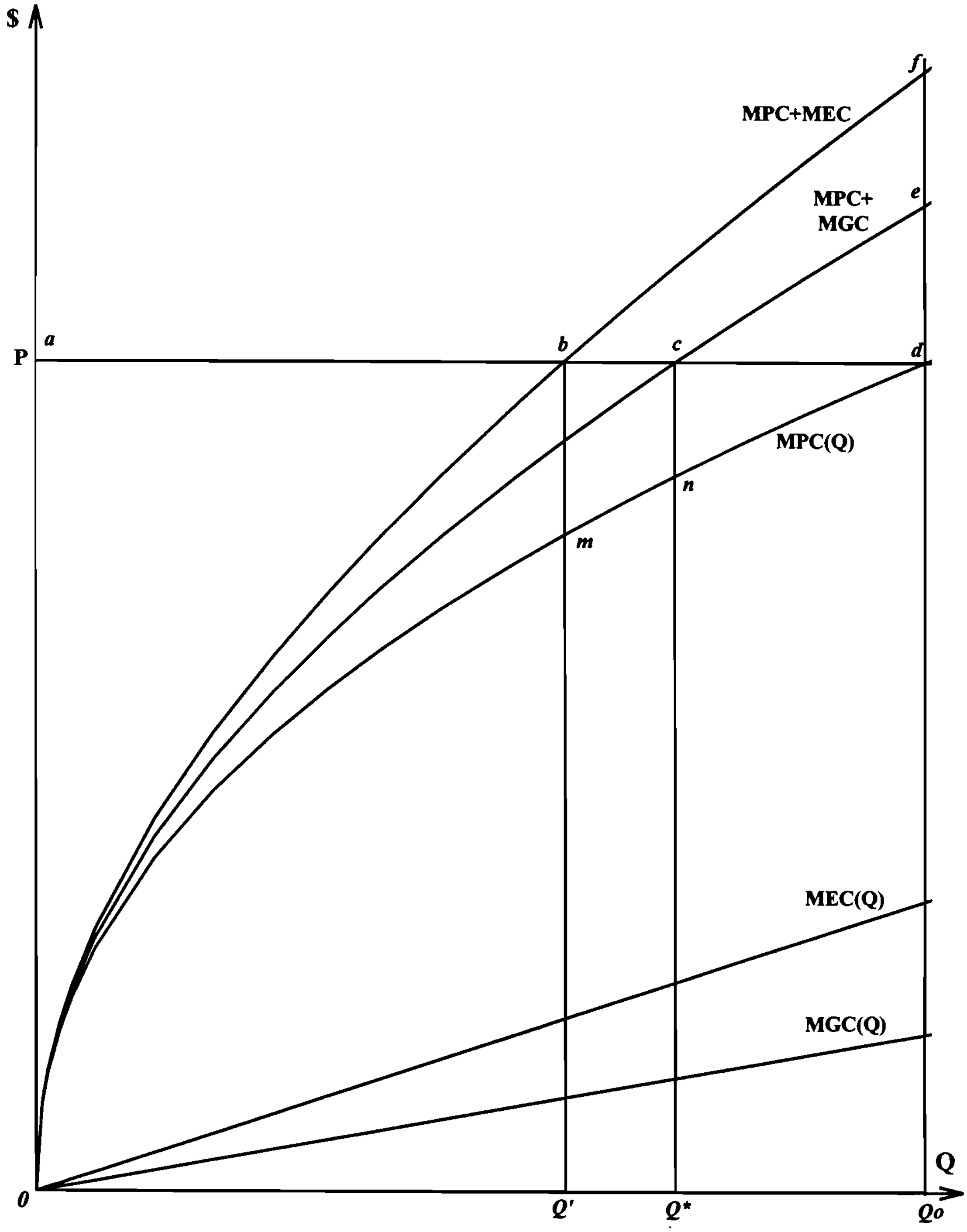


Figure 3: Social Welfare Gains from Production



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Appendix: Raw Data Used to Calibrate the Model

Corn production base (M bus.)	8,000 [a]
Base market price ($/bus.)	2.41 [a]
Cost Share of Farmer Owned Input	0.83 [b]
Cost Share of Pesticides	0.17 [b]
Total pesticide damages ($M)	8,123 [c]
Corn's share of pesticide use (%)	39.06 [c]
Proportional damage factor	0.6 [d]
Corn's contribution to total damages ($M)	1,904 [c,d]
Pesticide application reduction (%)	62.4 [c]
Added alternative control cost ($M)	530.5 [c]

Sources:
[a,b] Ali and McBride (1994);
[c] Pimentel et al. (1993b);
[d] Pimentel, D. (1994) personal communication, Cornell University, Ithaca, NY.

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