The Effects of Domestic Agricultural Policy Reform on Environmental Quality

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Abstract *A general equilibrium model is developed to study the environmental implications of agricultural policies. Model results show that declines in the acreage reduction program (ARP) would reduce agricultural fertilizer use, but the return of ARP land to production would lead to an overall increase in sedimentation and offsite environmental damage. In contrast, if land and fertilizers are highly substitutable, declines in deficiency payments and other commodity price support programs would reduce offsite environmental damages by reducing fertilizer use. Agricultural policy reform would be consistent with conservation policy because it would encourage a reduction in the use of fertilizer-intensive production practices.*

Keywords *Policy reform, trade liberalization, general equilibrium, conservation reserve program, environmental quality*

Two major agricultural issues have triggered considerable public policy discussion at both the national and international level: agricultural policy reform and the environmental side effects of agricultural production. The desire to reduce market distortions, high farm program costs, and expensive surplus commodity stocks has fueled policy reform debate.

The second issue, concern over agriculture's impact on the environment, has grown from agriculture's sometimes harmful side effects. The environmental lobby became a significant player for the first time in the design of the Food Security Act (FSA) of 1985, which introduced significant new programs to protect natural resources. Environmental considerations also entered into the 1990 Food, Agriculture, Conservation, and Trade Act.

This article advances consideration of these two issues by showing how a simple specific-factor model can be empirically computed to investigate the relationships between agricultural policies, resource use, and environmental quality. We study policy reform in a general equilibrium framework, focusing on resource use and environmental implications. A unique feature of our analysis is the explicit specification of an environmental damage function, derived from the work by Ribaudo (*23*).[1]

The Model

The model is formulated as a general equilibrium system to evaluate the ultimate tradeoffs between environmental quality, production, and income. In a general equilibrium system, agricultural production is affected by cross-sectoral flows of factors of production and intermediate inputs and by the income effects of policy changes on the demand and supply of other goods. This model, although a general equilibrium system, is only modestly more complicated in its solution than a partial equilibrium system. There are three production sectors in the model: agriculture, manufacturing, and nontraded goods. Environmental degradation is modeled as a joint product in the output of agriculture. However, since there is assumed to be no market for this output, the market equilibrium is found by dropping the equation for environmental damages.

The following production functions describe the structure of the economy:

$X_1 = f_1(L_1, K_1, T, S, X_{31})$		(agriculture)
$X_2 = f_2(T, S, X_{31})$		(environmental damages)
$X_3 = f_3(L_3, K_3)$		(manufactures)
$X_4 = f_4(L_4, K_4)$		(nontraded goods)

X_j denotes the output of section j. L_j denotes the labor input into production in sector j. X_{31} represents intermediate chemical fertilizers from the manufacturing sector to the agricultural sector.[2] T and S are agricultural-specific factors that represent nonerodible land (NEL) and highly erodible land (HEL), respectively (*8*). We assume that the two types of land are highly, but not perfectly substitutable. Land is identified in this manner to facilitate modeling the conservation reserve program (CRP). This method of modeling agricultural land is conceptually similar to that of Hertel and Tsigas (*15*) and Robidoux and Smart (*24*).

K_j denotes the input of capital into the production in sector j. We assume that labor is perfectly mobile among sectors, while capital is sector specific, because we are interested in exploring policy scenarios that are consistent with the intermediate-run timeframe, and

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[1]Italicized numbers in parentheses cite sources listed in the References section at the end of this article.

[2]Pesticides are not included in our equations because their contribution to total environmental damages from agriculture is not well known.

reaffirming that farm structures and some types of capital are relatively immobile in the short run to medium run (*13*) The association of the intermediate run with capital specificity is also consistent with the trade literature on which our economic model is grounded (*17*)

To present this model as a general equilibrium system of equations, we introduce some additional variables w, r_{Ki}, r_T, and r_S, respectively, are the wage rate, the rental rate on capital in sector i, the rental rate on NEL, and the rental rate on HEL, p_j is the price of good j, and P_1^* is the world price of the agricultural goods, a_{ij} is the conditional input coefficient representing the input of factor or intermediate good i into the production of a unit of good j, D_j is the domestic consumption of good j, and I represents national income

Given this notation and the assumptions of constant returns to scale in production and perfect competition in all markets, we can formulate the following general equilibrium system in the tradition of the Jones model of international trade (*18*)

$$L = a_{L1}X_1 + a_{L3}X_3 + a_{L4}X_4 \quad (1)$$

$$K_1 = a_{K1}X_1 \quad (2)$$

$$K_3 = a_{K3}X_3 \quad (3)$$

$$K_4 = a_{K4}X_4 \quad (4)$$

$$T = a_{T1}X_1 \quad (5)$$

$$S = a_{S1}X_1 \quad (6)$$

$$P_1 = wa_{L1} + r_{K1}a_{K1} + r_Ta_{T1} + r_Sa_{S1} + P_3a_{31} \quad (7)$$

$$P_3 = wa_{L3} + r_{K3}a_{K3} \quad (8)$$

$$p_1 = wa_{L1} + r_{K4}a_{K1} \quad (9)$$

$$a_{L1} = a_{L1}(w, r_{K1}, r_T, r_S, P_3) \quad (10)$$

$$a_{K1} = a_{K1}(w, r_{K1}, r_T, r_S, P_3) \quad (11)$$

$$a_{T1} = a_{T1}(w, r_{K1}, r_T, r_S, P_3) \quad (12)$$

$$a_{S1} = a_{S1}(w, r_{K1}, r_T, r_S, P_3) \quad (13)$$

$$a_{31} = a_{31}(2, r_{K1}, r_T, r_S, P_3) \quad (14)$$

$$a_{L3} = a_{L3}(w, r_{K3}) \quad (15)$$

$$a_{K3} = a_{K3}(w, r_{K3}) \quad (16)$$

$$a_{L4} = a_{L4}(w, r_{K4}) \quad (17)$$

$$a_{K4} = a_{K4}(w, r_{K4}) \quad (18)$$

$$D_1 = D_1(I, P_1, P_3, P_4) \quad (19)$$

$$X_4 = D_4(I, P_1, P_3, P_4) \quad (20)$$

$$I = P_1X_1 + P_3X_3 + P_4X_4 - P_3a_{31}X_1 - (PSE)P_1^*(X_1 - D_1) \quad (21)$$

$$P_1 = P_1^* \quad (22)$$

Equations 1-6 are full-employment conditions, and equations 7-9 are the zero-profit conditions Equations 10-18 are the conditional input-output coefficient functions Because we want to focus primarily on the agricultural sector, we include equation 19, which gives the demand for agricultural goods Equation 20 is the equilibrium condition for the service, or nontraded goods sector Equation 21 defines the dollar price of national income, and equation 22 defines the domestic-currency price of the agricultural good There are 22 equations and 22 endogenous variables (X_1, X_3, X_4, D_1, w, r_T, r_S, r_{K1}, r_{K3}, r_{K4}, a_{L1}, a_{T1}, a_{S1}, a_{31}, a_{K1}, a_{L3}, a_{K3}, a_{L4}, a_{K4}, P_1, P_4, and I) The model is completely specified

From this general equilibrium model, we derive the following linearized system of equations of change

$$\lambda_{L1}\hat{X}_1 + \lambda_{L3}\hat{X}_3 + \lambda_{L4}\hat{X}_4 = -\lambda_{L1}\hat{a}_{L1} - \lambda_{L3}\hat{a}_{L3} - \lambda_{L4}\hat{a}_{L4} \quad (1b)$$

$$\hat{X}_1 = -\hat{a}_{K1} \quad (2b)$$

$$\hat{X}_1 = -\hat{a}_{K3} \quad (3b)$$

$$\hat{X}_1 = -\hat{a}_{K4} \quad (4b)$$

$$\hat{X}_1 = \hat{T} - \hat{a}_{T1} \quad (5b)$$

$$\hat{X}_1 = \hat{S} - \hat{a}_{S1} \quad (6b)$$

$$\Theta_{L1}\hat{w} + \Theta_{K1}\hat{r}_{K1} + \Theta_{T1}\hat{r}_T + \Theta_{S1}\hat{r}_S = \hat{P}_1 \quad (7b)$$

$$\Theta_{L3}\hat{w} + \Theta_{K3}\hat{r}_{K3} = 0 \quad (8b)$$

$$\Theta_{L4}\hat{w} + \Theta_{K4}\hat{r}_{K4} = \hat{P}_4 \quad (9b)$$

$$\hat{a}_{L1} = \sigma^1_{LL}\Theta_{L1}\hat{w} + \sigma^1_{LK}\Theta_{K1}\hat{r}_{K1} + \sigma^1_{LT}\Theta_{T1}\hat{r}_T + \sigma^1_{LS}\Theta_{S1}\hat{r}_S \quad (10b)$$

$$\hat{a}_{K1} = \sigma^1_{KL}\Theta_{L1}\hat{w} + \sigma^1_{KK}\Theta_{K1}\hat{r}_{K1} + \sigma^1_{KT}\Theta_{T1}\hat{r}_T + \sigma^1_{KS}\Theta_{S1}\hat{r}_S \quad (11b)$$

$$\hat{a}_{T1} = \sigma^1_{TL}\Theta_{L1}\hat{w} + \sigma^1_{TK}\Theta_{K1}\hat{r}_{K1} + \sigma^1_{TT}\Theta_{T1}\hat{r}_T + \sigma^1_{TS}\Theta_{S1}\hat{r}_S \quad (12b)$$

$$\hat{a}_{S1} = \sigma^1_{SL}\Theta_{L1}\hat{w} + \sigma^1_{SK}\Theta_{K1}\hat{r}_{K1} + \sigma^1_{ST}\Theta_{T1}\hat{r}_T + \sigma^1_{SS}\Theta_{S1}\hat{r}_S \quad (13b)$$

$$a_{31} = \sigma^1_{3L}\Theta_{L1}\hat{w} + \sigma^1_{3K}\Theta_{K1}\hat{r}_{K1} + \sigma^1_{3T}\Theta_{T1}\hat{r}_T + \sigma^1_{3S}\Theta_{S1}\hat{r}_S \quad (14b)$$

$$\hat{a}_{L3} = \sigma^3_{LL}\Theta_{L3}\hat{w} + \sigma^3_{LK}\Theta_{K3}\hat{r}_{K3} \quad (15b)$$

$$\hat{a}_{K3} = \sigma^3_{KL}\Theta_{L3}\hat{w} + \sigma^3_{KK}\Theta_{K3}\hat{r}_{K3} \quad (16b)$$

$$\hat{a}_{L4} = \sigma^4_{LL}\Theta_{L4}\hat{w} + \sigma^4_{LK}\Theta_{K4}\hat{r}_{K4} \quad (17b)$$

$$\hat{a}_{K4} = \sigma^4_{KL}\Theta_{L4}\hat{w} + \sigma^4_{KK}\Theta_{K4}\hat{r}_{K4} \quad (18b)$$

$$D_1 = e_{11}\hat{P}_1 + e_{14}\hat{P}_4 + \eta_1(\hat{I} - v_1\hat{P}_1 - v_4\hat{P}_4) \quad (19b)$$

$$\hat{X}_4 = e_{41}\hat{P}_1 + e_{44}\hat{P}_4 + \eta_4(\hat{I} - v_1\hat{P}_1 - v_4\hat{P}_4) \quad (20b)$$

$$P_1 = E_1(\hat{X}_1 - D_1)\hat{P}^*_1 \quad (22b)$$

The circumflex signifies a proportional rate of change ($\hat{X}_i = dx_i/x_i$). λ_{ij} denotes the proportions of factor i used in sector j, Θ_{ij} denotes the share of factor i in the output of sector j, σ^j_{ik} is the Allen partial elasticity of substitution between inputs i and k in sector j, e_{ij} is the price j, compensated elasticity of demand for good i, η_i is the income elasticity sector-j demand, v_j is the share of good j in consumption, and E_1 in equation 22b is the price elasticity of export demand for agricultural commodities. Inclusion of equation 22b shows that the United States, with respect to world agriculture, has some market power and, therefore, affects world agricultural prices. The appendix contains the derivation of the change in the real income of the economy ($\hat{I} - v_1\hat{p}_1 - v_4\hat{p}_4$) and the sources of the share and elasticity parameters.

Policy Reform and the CRP

To this model, two policy shocks are introduced: increased Conservation Reserve Program (CRP) participation and commodity policy reform. The CRP is a voluntary long-term program initially aimed at withdrawing 40-45 million acres of highly erodible land from production. It is the most ambitious agricultural conservation program to date. Enrollment in the program has been relatively constant since February 1989 at about 31 million acres, or 7.6 percent of total 1989 cropland (*30*). The primary objectives of this program include controlling offsite damages of erosion, protecting longrun agricultural productivity by reducing soil erosion, and promoting wildlife habitat. The CRP enters our model as an exogenous change in the endowment of land resources. Commodity policy reform is defended by proponents primarily for the desirability of removing production distortions and reducing the burden of agricultural commodity programs on the Federal budget.

Agricultural programs provide support for producers through a broad range of policies. Most important are direct payments, market price support, input subsidies, marketing subsidies, State programs, and taxation policies. We consider here only the effect of reducing the level of support programs that act as output wedges, that is, the programs that distort the level of production primarily by inducing farmers to produce a larger quantity of output than would otherwise be the case. The most important programs in this category include price supports/quotas and deficiency payments. We do not consider the economic effects of reducing input subsidies (commodity loans, Farmers Home Administration programs, subsidies for land improvements), which create primary factor wedges.

The producer subsidy equivalent (PSE) has been used as a measure of output and primary factor wedges (*25, 26*). It is defined as the level of producer subsidy that would be necessary to compensate producers for the removal of government programs affecting commodities.[3] The average PSE during 1982-86 for 12 commodities (wheat, corn, rice, sorghum, barley, oats, soybeans, dairy, sugar, beef, veal, and poultry), not including input subsidies, was 21.4 percent of total producer value, or $23.2 billion (*32*). Since this transfer accounts for the vast majority of total U.S. agricultural policy transfers, we use it to derive a PSE for all U.S. agriculture. We find the average PSE for all agricultural commodities during 1982-86 to be 17.2 percent by dividing $23.2 billion by the average value of U.S. agricultural output ($135 billion) over the same period (*33*).

The PSE enters our model through equation 22 as an *ad valorem* price subsidy to agriculture. Equation 22 now becomes

$$P_1 = P^*_1(1 + PSE)$$

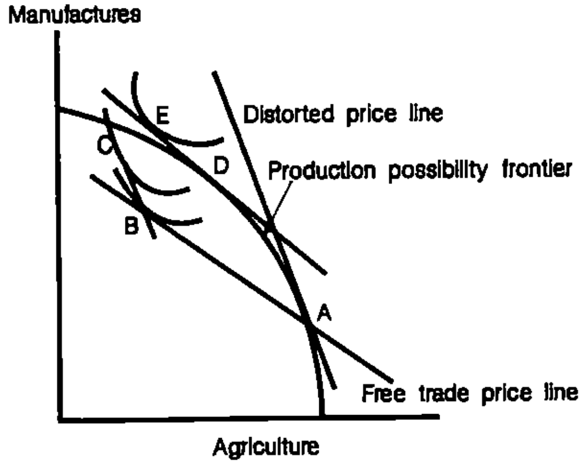
Equation 22b becomes

$$\hat{P}_1 = E_1(\hat{X}_1 - \hat{D}_1)\hat{P}^*_1 + dPSE/(1 + PSE)$$

Figure 1 shows how the price wedge introduced by commodity price supports and export subsidies affects our model. With subsidies, production takes place at point A, the tangency of the domestic (distorted) price line with the production possibilities frontier. Consumers, however, face world prices and would consume at point B, but the subsidy distorts consumption and production. Thus, point C is the distorted consumption point. With removal of the agricultural price wedge, production and consumption move to points D and E. Exports of agricultural goods are reduced, while exports of manufactures increase. The economy is better off when it operates on a higher community indifference curve (CIC). In our model, the income equation (equation 21) reflects the fact that it is not

[3]For a more complete definition of PSE's, see (*32*).

Figure 1
Removal of commodity price supports and export subsidies



possible to increase economywide income by subsidizing exports

Not captured in the PSE, but closely linked with it, is the Acreage Reduction Program (ARP), the Federal Government's largest annual cropland retirement program It is designed to reduce total planted acres when national supplies of agricultural commodities are projected to be high The 1982-86 average ARP participation level was 38 6 million acres (*30*) ARP participation is required of agricultural producers if they are to maintain eligibility for Federal agricultural support program benefits Like the CRP, the ARP enters our model as an exogenous change in the endowment of land resources

Figure 2 shows that an increase in land available for agricultural production shifts the production possibility frontier of agriculture and manufactures outward (from PPF_1 to PPF_2) along the agricultural axis The initial production point, where the price line is tangent to the initial frontier, is point A Consumption occurs at point B, the tangency of the price line with the initial community indifference curve (CIC_1) The initial production and consumption equilibrium illustrates that, in this model, agriculture is considered the export good, while manufactures are considered the import good The production and consumption points, with an increase in agricultural land, are given by C and D, respectively The economy is better off—it operates on a higher community indifference curve (CIC_2)—and agricultural exports (production less consumption) rise

Environmental Damages

To assess the direct and indirect effects of the CRP and policy reform on environmental quality, we specified an agricultural environmental damage equation

The proportional change in environmental damages (ED) is given by the sum of proportional changes in the use of HEL, NEL, and fertilizers, weighted by each factor's contribution to total agricultural environmental damage

$$\hat{ED} = D_{HEL}\hat{S} + D_{NEL}\hat{T} + D_{CHEM}\hat{X}_{31},$$

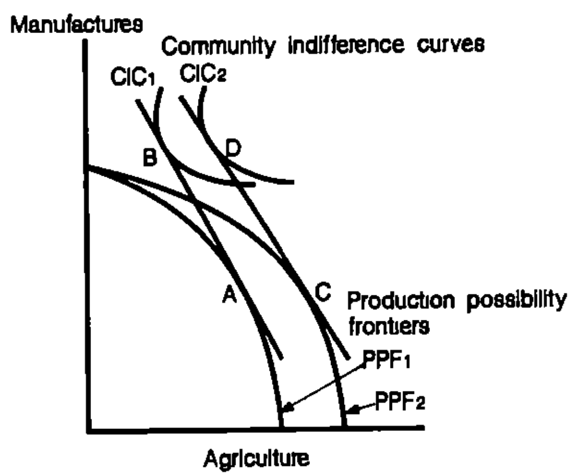
where D_{HEL}, D_{NEL}, and D_{FERT} are the contribution of HEL, NEL, and fertilizer to total agricultural environmental damages

Because our focus is on the environmental effects of farm policy changes, the environmental damage function reflects only damages from farming It does not consider environmental damage from the manufacturing and service sectors We think it is reasonable to consider only agri-environmental damages related to agricultural policy changes because farm agriculture accounts for only about 2 percent of the total economy Consequently, agricultural policy changes have little effect on production and pollution emissions in the manufacturing and service sectors

Ribaudo (*23*) provides estimates of offsite environmental damages from agricultural emissions of nitrogen, phosphorus, and suspended sediment, which harm freshwater and marine recreation, water storage, navigation, flooding, roadside and irrigation ditches, freshwater and marine commercial fishing, municipal water treatment, municipal and industrial use, and steam power cooling We used Ribaudo's damage estimate to determine that the contribution of agricultural chemicals to total agricultural environmental damage is 23 percent

The share of highly erodible land and nonerodible land in the remaining 77 percent of total agricultural environmental damages is estimated from the fact that

Figure 2
Removal of ARP land constraints



highly erodible land accounts for 63 percent of the cropland sheet, rill, and wind erosion (*31*). Highly erodible land's contribution to damage is 63 percent of 77, or 48.5 percent. Nonerodible land's contribution is, consequently, 28.5 percent.

Although the damage function is crude, it contains the best information available on specific environmental damage due to sediment delivered from cropland. We believe that it is sufficiently robust to provide some preliminary and meaningful indications of the relative magnitudes and directions of change of surface water environmental damages from the introduction of policy shocks, in this case of policy reform and increased CRP participation. Additional work in measuring the environmental consequences of agricultural production would be useful.

Policy Experiments

Two CRP scenarios are considered: no change from the present enrollment of about 31 million acres and an increase in enrollment to 45 million acres. Under the first scenario, two levels of simultaneous ARP and PSE commodity policy reform (20-percent and 40-percent reductions in the base level), and the separate impact of a 40-percent reduction in the ARP and the PSE are considered. The 1982-86 average PSE and ARP in the United States (17.2 percent and 38.6 million acres, respectively) are used as the benchmarks for the PSE and ARP levels. The second scenario assesses the effect of an increase in the CRP without any other changes in policy.

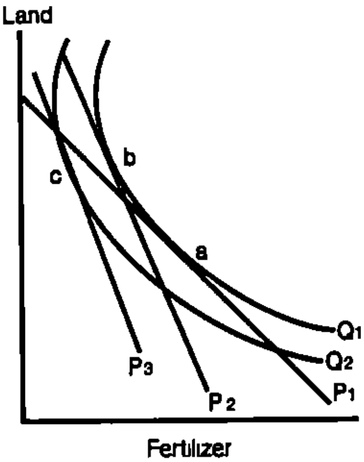
Reductions in the ARP reduced agricultural fertilizer use, but the return of ARP land to production leads to an increase of offsite environmental damages (table 1). This result is consistent with the empirical efforts of Shoemaker and Offutt, who find a historical positive bias associated with chemicals and acreage control programs (*29*). In contrast, declines in the PSE reduce offsite agricultural environmental damages by reducing fertilizer use. The positive environmental effect of a reduction in the PSE dominates the negative environmental effect of an equivalent percentage reduction in the ARP. In fact, the positive environmental effect of simultaneous PSE and ARP reduction is so strong that even modest policy reform (20 percent) generates environmental benefits nearly as great as an increase in the CRP to 45 million acres. This suggests that policy reform is consistent with conservation policy because it encourages a reduction in the use of fertilizer-intensive production practices.

Reduced fertilizer use is a result of two effects: the output effect and the substitution effect (fig. 3). Economic optima are provided when the ratio of resource prices (P_1) equals the marginal rate of substitution of fertilizers for land (point *a*). The substitution effect is reflected in the movement from *a* to *b* caused by changes in input prices (from P_1 to P_2). In our analysis, both ARP and PSE reform increase the price of fertilizer relative to land and, consequently, reduce the fertilizer/land ratio in production. ARP reform places more land in production, reducing the marginal physical product and returns to land. With land cheaper and fertilizer prices unchanged, farmers

Table 1—Percentage change in endogenous variables

Variables	Scenario one: CRP = 31 million acres				Scenario two: CRP = 45 million acres
	Simultaneous reduction in both ARP and PSE of		Reduction in ARP of 40 percent	Reduction in PSE of 40 percent	No policy reform
	20 percent	40 percent			
Environmental damages (ED)	-4.30	-8.50	2.60	-11.20	-5.40
Output					
Agriculture ($\hat{X}_i$)	-3.50	-6.90	1.90	-8.80	-1.70
Manufactures ($\hat{X}_i$)	.06	.10	-.01	.10	.10
Services ($\hat{X}_i$)	.04	.09	-.01	.09	.01
Fertilizer inputs					
Agriculture ($\hat{X}_{3i}$)	-25.10	-50.10	-1.70	-48.50	1.50
Labor inputs					
Agriculture ($\hat{L}_i$)	-10.40	-20.70	1.90	-22.60	-1.67
Manufactures ($\hat{L}_i$)	.09	.15	-.02	.15	.01
Services ($\hat{L}_i$)	.07	.13	-.01	.15	.01
Wage rate ($\hat{w}$)	-.05	-.09	.01	-.10	-.01
Returns to capital					
Agriculture ($\hat{r}_{ki}$)	-21.60	-43.30	.80	-44.10	-.70
Manufactures ($\hat{r}_{ki}$)	.10	.30	-.02	.30	.02
Services ($\hat{r}_{ki}$)	.09	.20	-.02	.20	.01
Returns to land					
Highly erodible land ($\hat{r}_S$)	-20.50	-41.00	-2.70	-38.00	4.20
Nonerodible land ($\hat{r}_F$)	-20.50	-41.00	-2.70	-38.00	1.70

Figure 3
Substitution and output effects of policy reform



shift away from fertilizers, which are a land substitute PSE reductions also reduce the return to land and, consequently, the fertilizer/land ratio in production

Agricultural policy not only creates static distortions in input markets, represented by the movement from *a* to *b*, but it also distorts the nature of longrun research and development Ruttan (*27*), Reichelderfer (*21*), and the National Research Council (*19*) observed that scientific and technical innovation in both the public and private sectors have been overly biased toward the development of land substitutes—plant protection chemicals and crop varieties and management systems that reflect the overvaluation of land and undervaluation of the social costs of the disposal of residuals from agricultural production practices

The output effect is represented by the inward shift of the production isoquant (from Q_1 to Q_2) and the movement from equilibrium point *b* to *c* At point *c*, the new isoquant (Q_2) is tangent to the adjusted factor price ratio (P_3) In our analysis, the production isoquant shifts inward as a result of the simultaneous reduction of the PSE and ARP (although reducing the ARP increases agricultural output, the output-reducing effect of an equivalent percentage reduction in the PSE dominates)

The effect of policy reform in reducing the return to land illustrates the fact that government commodity support payments are largely capitalized in asset values (land), negating the shortrun policy-induced increases in agricultural income (*6, 12, 25*) Land values represent the present value of the expected net returns to agricultural production, reducing or eliminating support programs reduces expected future returns

Increasing the CRP to 45 million acres, in contrast, takes highly erodible land out of production and reduces agricultural output and economywide income With constant prices and an increase in the marginal physical product of highly erodible land, the return to land rises For the zero profit condition to hold, the return to agricultural capital and labor must fall Labor migrates out of agriculture, and fertilizer inputs are substituted for land inputs as the employed endowment of land is reduced With the CRP at 45 million acres, and assuming no policy reform, the return to highly erodible land rises by 4 2 percent Under the paid diversion feature of the CRP, farmers must receive this rental increase on highly erodible land to induce them to participate in the program

The reduction in fertilizer use with policy reform rests strongly on the elasticity of substitution between land and fertilizers The more substitutable they are, the greater the reduction in fertilizer use As shown in the appendix, we set the Allen elasticity of substitution between fertilizers and land at 2 9 It is not clear whether this should be considered an overly optimistic estimate of land and fertilizer substitutability, or a low estimate Most estimates of substitution elasticities do not specify land and fertilizer (*3, 4, 20*) However, in a comparative study of agricultural development, Hayami and Ruttan (*10*) suggest that land and fertilizer are strongly substitutable Hertel and others, however, have estimated the Allen elasticity between land and fertilizer to be 0 68 for the United States (*14*) To test the sensitivity of environmental damages to this critical elasticity parameter, we reduced the elasticity of substitution between fertilizers and land to 1 and imposed a 40-percent reduction on the PSE and ARP Again, policy reform produced environmental benefits, but in this case only marginally ($\hat{E}D$ = –0 4)

Conclusions

Our stylized model illustrates some important relationships among agricultural policies, resource use, and environmental quality Given the structure of the present model and its parameters, policy reform (of the ARP and other agricultural support programs) tends to reduce the negative environmental externalities from cropland production Although policy reform ameliorates undesirable environmental effects, it cannot be a complete solution to an environmental problem associated with agricultural production, because agricultural programs are not the root source of the problem The root source derives from the lack of markets for the use of the environment Pollution control programs independent of government support programs are required to attain an "optimal" level of environmental quality

The linkages between agriculture and the environment are complex Our analysis has uncovered some important relationships, and our policy experiments have led to some interesting observations, but we also realize the strong need for further research. For example, we noted the importance of some critical parameters, such as the elasticity of substitution between fertilizer and land.

Other efforts might further disaggregate the agricultural sector to better capture the complexities of agricultural commodity programs and changes in the composition of agricultural production—changes that have important environmental implications since some crops are more "pollution intensive" than others. The principal difficulty in new research involves the construction of an environmental social accounting matrix that describes environmental effects associated with different agricultural activities. The matrix would form the framework for estimating total environmental damages stemming from agricultural production.

Because it is not possible to measure directly emissions from agricultural nonpoint sources of pollution, estimating total agricultural environmental damages through the construction of damage equations is critical for policy modelers seeking to compare the efficacy of measures to reduce environmental damage from agricultural production. We have assumed in this article a linear and separable damage function where the damage from each input is independent of the level of the other inputs. Future research might relax these assumptions.

Appendix

Income Effects

The production possibilities of the economy are given by

$$p_1 dX_1 + p_3 dX_3 + p_4 dX_4 - p_3 dX_{31} = r_T dT + r_S dS \quad \text{(A-1)}$$

The income of the economy is given by

$$I = P_1X_1 + P_3X_3 + P_4X_4 - P_3a_{31}X_1 - (PSE)P_1^*(X_1 - D_1) \quad \text{(A-2)}$$

By totally differentiating equation A-2 and imposing equation A-1, we obtain

$$dI = X_1dP_1 + X_4dP_4 - (PSE)P_1^*dX_1 + (PSE)P_1^*dD_1 - P_1^*(X_1 - D_1)dPSE + r_TdT + r_SdS - (PSE)(X_1 - D_1)dP_1^* \quad \text{(A-3)}$$

The formula for the real income of the economy is given by

$$(\hat{I} - v_1\hat{p}_1 - v_4\hat{p}_4) \equiv \frac{dI}{I} - \frac{p_1D_1}{I}\frac{dp_1}{p_1} - \frac{p_4D_4}{I}\frac{dp_4}{p_4} \quad \text{(A-4)}$$

We substitute equation A-3 into A-4 to obtain

$$(\hat{I} - v_1\hat{p}_1 - v_4\hat{p}_4) = \Phi_T\hat{T} + \Phi_S\hat{S} - \frac{(PSE)}{(1 + PSE)}(\Phi_1\hat{X}_1 - v_1\hat{D}_1) + \frac{(\Phi_1 - v_1)}{(1 + PSE)}P_1^* , \quad \text{(A-5)}$$

where $\Phi_T = r_TT/I$, $\Phi_S = r_SS/I$, and $\Phi_1 = P_1X_1/I$.

The first two terms on the right-hand side of equation A-5 show the proportional increase in real income arising from changes in the stock of nonerodible and highly erodible land, respectively. The third term shows the proportional decline in real income that comes from an increase in export subsidy and deficiency payments.

Data Sources

As with any economic model, the structure and parameters of the model drive the results. For this reason, we carefully reviewed the literature to ensure that parameters were assigned that realistically reflected the economy and the structure of the model. The employment shares, λ_{ij}, expenditure shares, v_i, value-added shares, Φ_T, Φ_S, and Φ_i, and product shares, Θ_{ij}, in appendix table 1 are calculated from a social accounting matrix derived from (*9*). We calculated the land-value-added shares by assuming that 60 percent of capital value added in agriculture is the land-value-added component (*22*). Land value added is then divided into nonerodible and highly erodible land based on the proportion of total cropland which is nonerodible and highly erodible, 29.4 and 70.6 percent, respectively (*30*).

Appendix table 2 furnishes elasticity values. The cross-price, Allen elasticities of substitution for agriculture, σ^1_{ik}, $i = k$, are taken from (*2*). Own-price elasticities are calculated using the adding-up constraint ($\Sigma\sigma^1_{ik}\Theta_{kj} = 0$) (*28*). Binswanger estimates a translog cost function for U.S. agriculture using time-series data (*2*). For our purposes, Binswanger's estimates are particularly appropriate because, unlike most studies (*3, 4, 20*), the identified factors of production include both land and fertilizers. While Hertel and others (*14*) also include land and fertilizer, their aggregation scheme is quite different from the one used here. In addition, it is assumed that NEL and HEL substitute identically with other factors of production, that is, $\sigma^1_{iT} = \sigma^1_{iS}$, $\sigma^1_{KT} = \sigma^1_{KS}$, and $\sigma^1_{3T} = \sigma^1_{3S}$. We further set $\sigma^1_{TS} = \sigma^1_{ST} = 10.00$ because evidence suggests that HEL and NEL are highly substitutable for one another (*11*). The substitution parameters in the nonfarm sectors are from (*1*).

We calculated the compensated demand elasticities, e_{ij}, $i,j = 1,4$, using the elasticities form of the Slutsky equation with estimates of uncompensated demand elasticities from (5) and the expenditure shares The price elasticity of export demand, E_1, for agriculture is an intermediate-run elasticity taken from a review of the literature contained in (7)

Appendix table 1—Share parameter values

Parameter	Value	Parameter	Value
λ_{L1}	0 007	λ_{K1}	0 020
λ_{L3}	336	λ_{K3}	250
λ_{L4}	657	λ_{K4}	730
Θ_{L1}	220	Θ_{L3}	730
Θ_{K1}	280	Θ_{K3}	270
Θ_{T1}	297	Θ_{L4}	650
Θ_{S1}	123	Θ_{K4}	350
Θ_{31}	080	Φ_T	006
v_1	009	Φ_S	003
v_4	722	Φ_1	020

Appendix table 2—Elasticity values

Elasticity	Value	Elasticity	Value
σ^1_{LL}	–0 883	σ^1_{KL}	0 851
σ^1_{LK}	851	σ^1_{KK}	–2 299
σ^1_{LT}	204	σ^1_{KT}	1 215
σ^1_{LS}	204	σ^1_{KS}	1 215
σ^1_{TL}	204	σ^1_{SL}	204
σ^1_{TK}	1 215	σ^1_{SK}	1 215
σ^1_{TT}	–6 240	σ^1_{ST}	10 000
σ^1_{TS}	10 000	σ^1_{SS}	–29 200
σ^1_{3L}	–1 622		
σ^1_{3K}	– 672		
σ^1_{3T}	2 987		
σ^1_{3S}	2 987		
σ^3_{LL}	– 185	σ^4_{LL}	– 269
σ^3_{LK}	500	σ^4_{LK}	500
σ^3_{KL}	500	σ^4_{KL}	500
σ^3_{KK}	–1 351	σ^4_{KK}	– 929
e_{11}	– 164		
e_{11}	165	E_1	–2 000
e_{41}	057		
e_{44}	– 126		
η_1	376		
η_4	8 36		

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