Environmentally Adjusted Measures of Gains From Trade Liberalization: The Case of U.S. Corn Production

by

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I. Introduction

The relationship between international trade and the environment has received increased attention in recent years, partly due to the stimulus of recent international negotiations on both environmental institutions and trade agreements. The Uruguay Round's (UR) provisions on agriculture represent an initial step toward liberalizing global agricultural commerce. Agricultural trade liberalization will lead to adjustments in production and consumption patterns and these changes may affect the environment. Agricultural production is dependent on the use of natural resources such as land and water and modern agricultural systems rely on a wide range of industrial inputs such as fertilizers and pesticides that can affect environmental quality.

The United States is a major agricultural producer and exporter. Historically, U.S. agriculture has been subject to heavy government intervention. 1995 farm legislation reduces this level of intervention and U.S. commitments under the UR agreement will further limit the level of agricultural support afforded through market interventions. These changes will have direct consequences for agricultural production, input use and consumption, and, therefore, for the state of the environment. Trade liberalization and increased market orientation in U.S. agriculture can be expected to give rise to efficiency gains and taxpayer savings as subsidies and market distortions are reduced along with social benefits or costs stemming from the environmental effects of the trade-induced adjustments in production and input use.

Most studies of the impact of trade liberalization focus on conventional efficiency gains without including the link between production and the environment. This study attempts to estimate more complete welfare effects of subsidy reduction including both the gains from trade and the environmental impacts.

II. Conceptual Framework

The agricultural provisions of the Uruguay Round of trade negotiation are designed to liberalize world agricultural markets by reducing trade-distorting policies including domestic subsidies. The impact of these changes is illustrated in Figure I. The excess supply schedule (ES), is derived from domestic supply and demand relationships and reflects only the costs that are internal to the agricultural sector. Another schedule (MES) is drawn to include the marginal external cost of environmental damage associated with agricultural production. The space between these curves is the value of the unpriced externality. The United States is a net agricultural exporter and the effect of U.S. agricultural support programs is indicated by the vertical line segment P^0 - P^0_w, the per-unit subsidy. The UR provisions do not call for the complete elimination of subsidies but rather their reduction to the level indicated, for example, by the vertical line segment P^1 - P^1_w. The full impact of UR trade liberalization also includes the effects on demand of reducing subsidies and other trade barriers in other countries.

The welfare effects of a unilateral reduction of the subsidy can be described as follows. First, area A+B+C represents a gain to U.S. taxpayers because of reduced expenditure for the subsidy. Area B represents an offsetting reduction in combined U.S. agricultural producers' and consumers' surplus, leaving net U.S. gains as measured by area A+C (area C represents an offsetting loss of benefits now being transferred to ROW producers and consumers, leaving a reduction in dead weight losses equal to area A). In addition to these traditional measures of gain, the U.S. gains the value of improvements in the U.S. natural environment indicated by area D.

For this study, a model of the U.S. corn sector is estimated and used to evaluate the gains from trade of reduction in subsidies. The model includes equations representing corn demand, output supply and input demand for the U.S. corn sector. The estimated equations are used to determine the U.S. excess supply curve to the world market. The parameters of the model are converted to elasticities and used in a comparative static framework to measure areas A and C in Figure I. Ideally, a measure of the value of all of the environmental impacts associated with the changes in corn production and input use would be developed to complete the analysis. Developing such a measure is extremely difficult and for this study only the most important environmental impact associated with corn production is included. In many parts of the Great Plains and Corn Belt states, nitrogen contamination of ground water has become a significant problem as excess fertilizer is leached into underground aquifers. Adjustments to corn production induced by trade liberalization will lead to changes in fertilizer use which in turn will have an effect on ground water contamination. For this study, the value of changes in the use of nitrogen as a result of trade-induced adjustments is measured using nitrogen budgets and estimates of the costs of nitrate contamination from other studies. The estimates of changes in the social costs associated with this environmental externality are a lower-bound estimate of area D in Figure I. This estimate is added to the direct welfare effects of trade liberalization.

Output supply and input demand are derived from the producer's profit maximizing behavior under the constraint imposed by the fixed inputs (not included in the production function). Producers may choose the levels of all other variable inputs. In perfect competition, producers are price-takers in both input and output markets. The profit function is assumed to be non-decreasing/increasing in output and input prices respectively, homogenous of degree one, convex, continuous and twice-differentiable. The equilibrium in input markets is obtained by equating the input demand and supply equations. Input demand is derived from the producer's maximization behavior. For input supply, the amount of the input used for a particular crop, such as corn, is assumed not to affect the entire input market. Input supply, in this case, is a function of its own price.

Duality theory can be used to develop demand and supply systems which are consistent with optimizing behavior (Diewert 1974). Flexible functional forms including the translog profit function developed by Diewert (1973, 1974); Christensen, Jorgensen and Lau; and Lau (1974, 1976) allow duality theory to be applied to production structures in more disaggregated analysis. In this study, to obtain output supply and input demand elasticicies, the normalized restricted translog profit function which was developed by Diewert (1974) and Christensen, Jorgensen and Lau (1973) is applied as follows:

$$\ln \pi^{*} = \alpha_0 + \sum_{i}^{n} \alpha_i \ln w_i + \frac{1}{2} \sum_{i}^{n} \sum_{j}^{n} \gamma_{ij} \ln w_i \ln w_j \tag{1}$$

Where π^* is restricted profit defined as total revenue less the cost of variable inputs, normalized by output price, w_i is the price of variable input x_i normalized by output price.

The translog profit function is continuous, twice differentiable, convex in price and quantity, and also positive homogeneous of degree one in price and quantity. By differentiating (1), input demand functions in terms of the share of each input are obtained. The output share (s_v) is the ratio of output supply to normalized restricted profit. However, since the sum of input (s_i) and output (s_v) shares equal one, one equation must be dropped in estimation to avoid a singular matrix. In this case s_v is dropped. Only the share functions of the variable inputs and translog profit equation are used for the econometric estimation.

$$s_i = \alpha_i + \sum_j^n \gamma_{ij} \ln w_j . \tag{2}$$

Symmetry and homogeneity are imposed while adding up is automatically satisfied since the output share (s_v) equation is dropped. The Seemingly Unrelated Regression approach is applied to find the value of the parameters. The elasticities of variable input demand and output supply are computed using the fomulae shown in Table 1.

For the demand side, it is assumed that a representative consumer receives utility from consuming a set of commodities. The consumer in this case is a user of corn as an input into livestock production and other processes. The utility function is assumed to be continuous, twice differentiable and strictly quasi-concave with first partial derivatives that are strictly positive. It is assumed that preferences are complete, reflexive, transitive, convex, monotonic and continuous. The representative consumer maximizes utility, derived from the consumption of goods subject to an income constraint. This demand function is also homogenous of degree zero in prices and income. Individual demand curves can be aggregated to market demand through the assumption that they reflect the preferences of a representative consumer. With this assumption, market demand will be consistent with the theoretical constraints of homogeneity, adding up, symmetry and negative semi-definiteness. For this study the AIDS model developed by Deaton and Muellbauer is estimated:

$$k_i = \alpha_i + \sum_j^n \gamma_{ij} \ln h_j + \beta_i \ln \frac{E}{h^*} + \varepsilon_i . \tag{3}$$

To avoid estimating a non-linear system resulting from the non-linear price index, Stone's price index is used in place of the Deaton and Muellbauer index. This approximation is referred to as the LA/AIDS model. To satisfy the theoretical demand properties, the following restrictions are applied.

$$\ln h^{*} = \sum_{i}^{n} k_i \ln h_i . \tag{4}$$

Where k_i is the expenditure share of corn, sorghum, oats, barley and soy bean; E is the total expenditure on feed grains as a group; h_j is the price of good j.

Since expenditure shares of the equations sum to unity, this implies a zero sum of the error terms across equations at each observation, and this causes the covariance matrix to be singular and not diagonal. To avoid this problem, one equation must be dropped. The error terms are also assumed independently and identically normally distributed with mean zero and nonsingular covariance matrices. For the system of simultaneous equations Zellner's method of Seemingly Unrelated Regression (SUR) is applied. Compensated (η_{ij*}) and uncompensated (η_{ij}) price elasticities of LA/AIDS model and expenditure (ϵ_i) are calculated as shown in Table 1.

Once this system is estimated, the elasticities can be used in a comparative static framework to assess the impact of trade liberalization on production, input demand, excess supply and the areas A and C in Figure 1. The environmental impact shown as area D in Figure 1 is approximated by linking changes in the use of the fertilizer input due to trade liberalization to nitrate contamination of groundwater and using estimates of the value of this environmental impact to adjust the welfare effects derived from the comparative static system.

Nitrate concentrations in groundwater are influenced by the amount of nitrogen fertilizer applied, rainfall and soil characteristics. These factors are very site-specific. For this study, a measure of the relationship between aggregate fertilizer applications and the general state of underground water in the United States is needed. A model of this relationship requires a great deal of information, some of which is not available. As an initial approximation, information from Nebraska will be used to identify this relationship and it will be assumed that the results are sufficiently representative to be incorporated into the aggregate model as an estimate of area D in Figure 1. More specifically, ordinary least squares regression is applied to cross-sectional data on observed levels of dissolved nitrogen in groundwater and corresponding fertilizer applications within Nebraska. The estimated coefficient provides a link between adjustments in fertilizer use and the amount of nitrogen found in ground water.

The amount of nitrogen contamination must be converted into a monetary value. For environmental amenities for which a market does not exist, this value may not be easy to obtain. For this study, estimates of expenditures on averting nitrate contamination used to estimate a willingness to pay for an improvement in groundwater quality (Sukharomana). This value is multiplied by the change in the amount of nitrogen found in the ground water as producers adjust their fertilizer applications in response to price changes brought about by trade liberalization.

III. Empirical Results

Data required for the SUR estimation of the translog profit function of corn in the US are corn prices, cost shares of variable inputs and output value. All data are obtained from Agricultural Statistics and Economic Indicators-Costs of Production, 1975-1993. The dependent variables are the shares of variable inputs. The producer prices are obtained form adding deficiency payment rates to the market prices. For the demand side, the data requirements for SUR estimation of the LA/AIDS model of demand for corn in the United States are prices and cost shares of the main feed ingredients. The independent variables are assumed to be exogenous allowing the system to be estimated with SUR. All data are obtained from Agricultural Statistics 1963-1994. The dependent variables are shares of total livestock feed of the main ingredients including corn, sorghum, oats, barley and soybeans.

Before estimating the series, it is necessary to test the data for stationarity of the time-series. This is done by applying unit root tests to all the data series, all of which are non-stationary except wages. Non-stationarity of the data series requires either that the Error Correction Model or first differencing be employed. For this study, the equations are estimated in first differences. Durbin-Watson statistics for the equations in the system are all close to 2.0 suggesting that auto-correlation is not a problem.

SUR parameter estimates for the translog restricted profit function and input demands are reported in Table 2 and the corresponding elasticities are shown in Table 3. The system R^2 is 0.9976. Symmetry and homogeneity are tested with log-likelihood ratio test which shows that these restrictions cannot be rejected. The restricted parameter estimates of the LA/AIDS model and their associated standard errors are reported in Table 4. The barley equation is dropped and homogeneity is imposed by dividing all the other commodity prices by the barley price. As with the translog restricted profit function and input demands, the LA/AIDS model is estimated in first differences. The system R^2 is 0.9673. The homogeneity and symmetry restrictions are tested with a log-likelihood ratio test which suggests that they cannot be rejected at the 0.005 level of significance. The uncompensated and compensated price and expenditure elasticites are reported in Table 5. All own-price demand elasticities are negative. Base on the estimates for compensated elasticities, corn is a substitute for sorghum, oats and soybean while corn and barley and sorghum and oats are complements. All of the other cross price elasticities indicate that the commodities are subsitutes. by subtracting total supply from the total demand. To estimate the excess supply elasticity, the average value of demand, supply and excess supply are required.

The average amount of nitrogen dissolved in groundwater in 1995 and 1996 in wells used for public water supply in Nebraska counties was used as a measure of the environmental impact of corn production. The amount of nitrogen fertilizer sold in Nebraska counties is used as a measure of nitrogen applications. Dissolved nitrogen in the groundwater and nitrogen applications are both expressed in logarithms to obtain a direct estimate of the elasticity. Although the R^2 is only 0.03, the estimated elasticity of 0.16 is significant at the 0.05 level. According to these results, a one percent change in fertilizer use in Nebraska will lead to a 0.16 percent change in the parts per million of dissolved nitrogen in the groundwater. In other studies, it has been estimated that households in major producing states such as Nebraska spend about $10 a month to prevent nitrate contamination in their water (Sukharomana). This figure can be used to develop an estimate of expenditures on nitrate contamination in the main corn producing states. It is assumed that the relationship between these expenditures and reductions in the number of parts per million of nitrates in groundwater is linear so that a one percent reduction in parts per million will lead to a one percent reduction in expenditures.

IV. Results and Conclusions

The model is used to simulate the evolution of U.S. and world corn markets to the year 2000. Baseline projections are compared with projections based on the assumption that subsidies are reduced 20 percent in line with the Uruguay Round. In fact, the main subsidy to corn, the deficiency payment was completely eliminated in the 1995 Farm Bill. The results reported in Table 6 focus on the impact of partial reduction of these subsidies but can be extended to cover the case of complete elimination. The results reported are the changes in welfare and environmental costs as represented in Figure I.

According to this analysis, U.S. welfare increases by $296 million due to the direct impact of subsidy reduction on the gains from trade. Government expenditures are reduced by $701 million of which $405 million is transferred from U.S. producers and consumers. The net change includes the recovery of the dead weight loss and of the subsidy transfer to foreigners. The adjustment in production leads to less fertilizer use and a reduction in nitrate contamination of groundwater estimated to be worth $24 million. These results indicate that the environment impact of trade liberalization is small as compared to the efficiency gains from the subsidy reduction. It should be recalled, however, that these results are lower-bound estimates because other environmental impacts, such as those associated with pesticide use, have not been included in the analysis. At the same time, the estimates of the effect of adjustments in corn production on nitrate contamination of groundwater is over-stated because corn production is not the only source of nitrate contamination. Although further research is needed to refine these results, they are not inconsistent with other studies that show relatively small environmental impacts related to agricultural production adjustments induced by trade liberalization (Anderson).

The results reported are preliminary and highly dependent on assumptions and the validity of the estimated model. An important insight gained from conducting this study is that modeling the links between markets and the environment at a policy-relevant level of aggregation is extremely difficult. Important elements have not been included in the present study due to lack of data and serious aggregation problems. Much more research is needed on the link between aggregate market adjustments and broad environmental impacts both domestically and internationally.

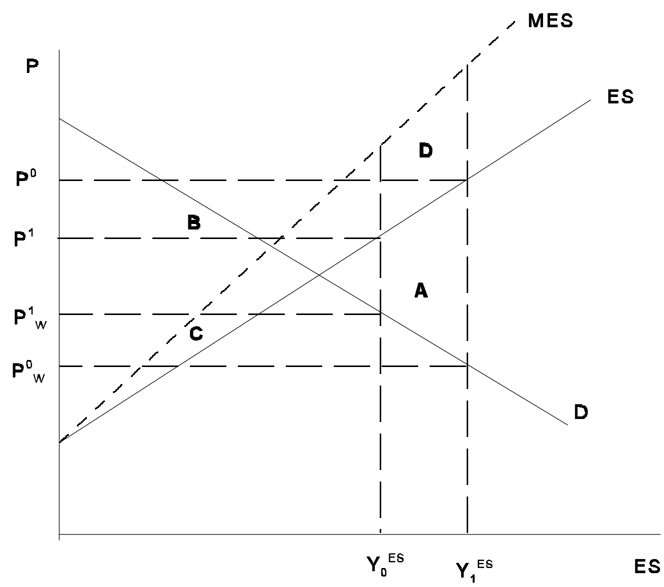

Figure I. Welfare Effect due to Change in Subsidy

Table 1. Elasticity Formulae Calculated from Translog Profit Function and LA/AIDS Model

Elasticities calculated from translog profit function:

a. Own-price elasticity of demand for input:

$$\eta_{ii} = -s_i^* - 1 - \frac{\gamma_{ii}}{s_i^*}.$$

b. Cross-price elasticity of demand for input i[th] with respect to input j[th] :

$$\eta_{ij} = -s_j^* - \frac{\gamma_{ij}}{s_i^*} \quad , where \quad i \neq j.$$

c. Elasticity of demand for inputs with respect to output price:

$$\eta_{iy} = \sum_{i}^{n} s_i^* + 1 + \sum_{j=1}^{n} \frac{\gamma_{ij}}{s_i^*}.$$

d. Output supply elasticity with respect to its own price:

$$E_{vi} = -s_i^* - \frac{\sum_{j=1}^{n} \gamma_{ji}}{1 + \sum_{j=1}^{n} s_j^*}.$$

e. Output supply elasticity with respect to its own price:

$$E_{vv} = \sum_{i=1}^{n} s_i^* - \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij}}{1 + \sum_{j=1}^{n} s_j^*}.$$

Elasticities calculated from LA/AIDS:

a. Uncompensated price elasticity:

$$\eta_{ij} = -\delta_{ij} + \frac{\gamma_{ij}}{k_i} - \beta_i \frac{k_j}{k_i}.$$

b. Compensated price elasticity:

$$\eta_{ij}^* = -\delta_{ij} + \frac{\gamma_{ij}}{k_i} - k_j.$$

where: δ=1 for i=j and δ=0, otherwise.

c. Expenditure Elasticity:

$$\varepsilon_i = 1 + \frac{\beta_i}{k_i}.$$

s_i^* is the simple average of s_i

Table 2. SUR Parameter Estimates of Translog Profit Function of US Corn Production (Asymptotic Standard Errors are in Parentheses)

Parameters	Estimates	Parameters	Estimates
α_n	-0.027026 (0.12790)	γ_{chen}	0.017809 (0.017921)
α_{ch}	0.35470** (0.24872)	γ_{cho}	0.044544** (0.031498)
α_{en}	0.49794* (0.11923)	γ_{enen}	0.054485* (0.015052)
α_o	-0.34980 (0.21679)	γ_{eno}	0.042909* (0.018355)
γ_{nn}	0.10100* (0.018510)	γ_{oo}	0.053792** (0.033669)
γ_{nch}	-0.03072** (0.019248)		
γ_{nen}	-0.055377* (0.014421)		
γ_{no}	-0.014028 (0.01815)		
γ_{chch}	0.015937 (0.03521)		

Note: * indicate significance at 0.05 level.
** indicate significance at 0.10 level.

Table 3. SUR Estimates of Price Elasticities of Demand for Variable Inputs and Supply Elasticity.
(Asymptotic Standard Errors are in Parentheses)

	Price Elasticities of Demand		Supply Elasticities
δ_{nn}	-2.0429*	ε	0.35048*
	(0.17133)		(0.07657)
δ_{chch}	-1.2537*	ω_n	-0.12879*
	(0.25306)		(0.01529)
δ_{enen}	-1.7061*	ω_{ch}	-0.17406*
	(0.17069)		(0.01928)
δ_{oo}	-1.4898*	ω_{en}	-0.10018*
	(0.2017)		(0.01398)
δ_{nch}	0.14517	ω_o	-0.25109*
	(0.17816)		(0.03477)
δ_{nen}	0.42438*		
	(0.13348)		
δ_{no}	-0.29676**		
	(0.17045)		
δ_{chen}	-0.21615**		
	(0.12878)		
δ_{cho}	-0.48700*		
	(0.22634)		
δ_{eno}	-0.16740		
	(0.20816)		
σ_{nc}	0.83524*		
	(0.21298)		
σ_{chc}	1.7296*		
	(0.24981)		
σ_{enc}	1.0768*		
	(0.28603)		
σ_{oc}	1.8535*		
	(0.23471)		

Note: * indicates significance at 0.05 level.
** indicate significance at 0.10 level.

Table 4. SUR Parameter Estimates of LA/AIDS model-US Feed Commodities (Asymptotic Standard Errors are in Parentheses)

Parameters	Estimates	Parameters	Estimates
α_c	-0.11628 (0.40810)	γ_{sb}	0.015161* (0.005198)
α_s	-0.76510* (0.24627)	γ_{ssb}	0.007423** (0.004563)
α_o	-2.45760* (0.47923)	γ_{oo}	0.05834* (0.02101)
α_{sb}	4.59470* (0.41715)	γ_{ob}	0.007423** (0.004563)
γ_{cc}	0.11679* (0.060086)	γ_{osb}	0.012649* (0.006712)
γ_{cs}	-0.030482 (0.041083)	γ_{sbsb}	0.016834* (0.005091)
γ_{co}	-0.035872* (0.019607)	β_c	0.057925* (0.02568)
γ_{cb}	-0.025218* (0.010885)	β_s	0.054308* (0.016279)
γ_{csb}	-0.030362* (0.011267)	β_o	0.16822* (0.031882)
γ_{ss}	0.006724 (0.038576)	β_{sb}	-0.30249* (0.027881)
γ_{so}	-0.006564 (0.015117)		

Note: * indicates significance at 0.05 level.
** indicates significance at 0.10 level.

Table 5. SUR Estimated Uncompensated, Compensated price Elasticities (Asymptotic Standard Errors are in Parentheses)

	Uncompensated Price Elasticities	Compensated Price Elasticities
η_{cc}	-0.87558*	-0.17716*
	(0.11205)	(0.09381)
η_{ss}	-0.96236*	-0.83492**
	(0.52564)	(0.55746)
η_{oo}	-0.23727	-0.006377
	(0.32539)	(0.33526)
η_{bb}	-1.31960*	-1.3882*
	(0.08292)	(0.24689)
η_{sbsb}	-0.60892*	-0.72138*
	(0.01361)	(0.026789)
η_{cs}	-0.05421	0.025543
	(0.06306)	(0.064142)
η_{co}	-0.06167*	0.00666
	(0.02963)	(0.030612)
η_{cb}	-0.042416*	-0.005712
	(0.016144)	(0.016995)
η_{csb}	-0.064591*	0.14264
	(0.013607)	(0.017591)
η_{so}	-0.13629	-0.027086
	(0.20096)	(0.20671)
η_{sb}	0.24096*	0.24096*
	(0.071078)	(0.07108)
η_{ssb}	-0.039628	0.29153*
	(0.058279)	(0.062395)
η_{ob}	0.15211*	0.15211*
	(0.07282)	(0.07282)
η_{osb}	-0.30830*	0.39189*
	(0.11927)	(0.10711)

Note: * indicates significance at 0.05 level.

** indicates significance at 0.10 level.

Table 6. Simulation Results of Reduction in Domestic Corn Subsidy

	Welfare Effect of 20 % domestic expenditure subsidy reduction
Change in U.S. excess supply (mil. bushels)	103
Change in U.S. surplus, $ mil. (area B in Fig.I)	405
Change in foreign surplus, $ mil. (area C in Fig.I)	253
Deadweight loss recovered, $ mil. (areaA in Fig.I)	43
Net gains from subsidy reduction, $ mil. (area A+C)	296
Change in Environment, $ mil. (area D)	24
Total Welfare Effect, $ mil. $ (A+C+D)	320

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