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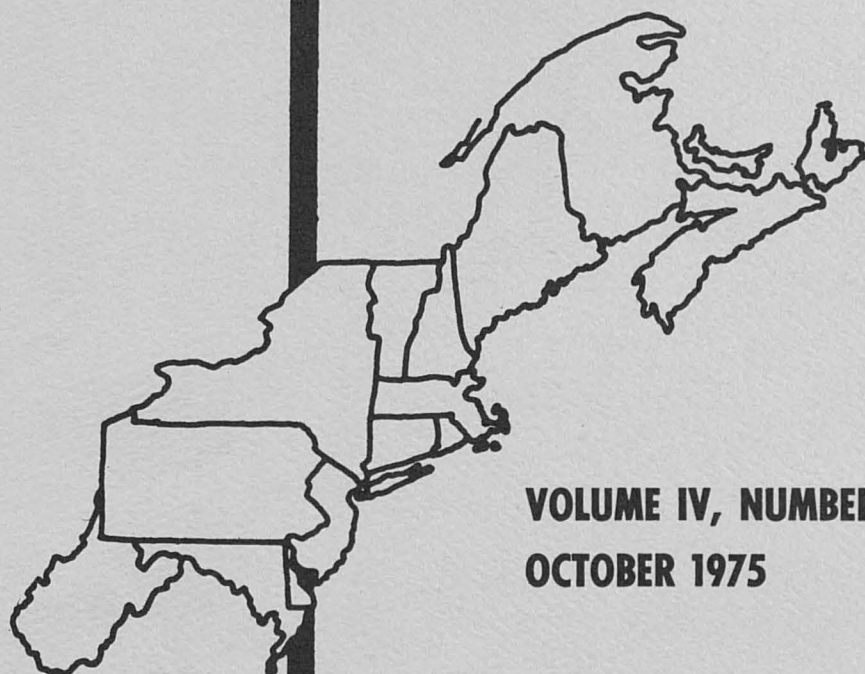
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A FRAMEWORK FOR MEASURING THE ECONOMIC IMPACT  
OF ALTERNATIVE POLLUTION CONTROL POLICIES: AN  
APPLICATION TO THE EGG PRODUCING INDUSTRY

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Present Federal legislation imposes stringent water quality standards on point source emissions from agricultural operations. In the future, individual states may propose policies which are even more restrictive. A number of studies have examined the normative responses to antipollution regulations at the individual farm level (e.g. Ashraf and Christensen [1] for the Massachusetts dairy industry; Gaede [2] for the Massachusetts egg industry). These studies assumed that individual benchmark farms would achieve compliance with pollution standards by adopting the least cost alternative disposal method. They permitted as activities in a linear programming framework only those waste disposal practices considered capable of meeting regulations.

The present study provides a linkage between the microlevel analyses described above and industry response. When all firms in an industry are simultaneously faced with a new regulation the ceteris paribus assumptions underlying the individual farm programming may be inappropriate. Aside from the difficulty of imputing values to society of cleaner water, the question of who gains and who loses in the marketplace is no longer clear. The object of this study, therefore, is to measure changes in consumer surplus and producer surplus (or economic rent) which would result from the industry wide imposition of specified restrictions. To achieve this requires a system of demand and supply functions.

The study adopts a regional framework for two reasons:

- (1) states or groups of states may decide to adopt different pollution standards; and
- (2) impacts in one region (e.g. North Atlantic) could be examined more closely.

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Additional important dimensions of farm size and type are omitted. The implicit assumption is that each region has the same size distribution and type mix. This simplification overlooks the possibility that, for example, a region with a preponderance of large, modern farms may be able to meet the regulations at a lower cost per unit output than a region of small, traditional farms. Such broad differences among regions undoubtedly exist and may be accommodated in the model by varying unit pollution charges among regions.

#### Comparison of Mainly Normative Versus Mainly Positive Approaches

To make statements about changes resulting from a shift in technology, which is what the imposition of pollution control implies, we need to know:

- (a) What is the regional supply response under the present technology?
- (b) How pervasive will the new technology be, at equilibrium, and what will be the related shift in supply functions?
- (c) What demand structure faces each region?
- (d) How are regional markets connected?

Both positive and normative methods will be required to solve these problems. The question is which parts should best be done by each method. Four techniques are available, three considered normative, one positive. They are discussed below.

(1) Normative supply response. This requires the specification of a number of benchmark farms and the construction by means of linear programming of a stepped supply function for each farm. Using the number of farms represented by each benchmark as weights, the individual supply functions can be aggregated into a regional supply response. Under the assumption that farmers maximize profits and that aggregation bias is insignificant the normative supply function for the industry approximates the actual supply function. The problems with this approach are well summarized by Sharples [7] and have received extensive consideration in the literature, particularly the problems of aggregation bias, and of selecting the benchmark farms.

(2) Spatial equilibrium. Samuelson [6] first proposed the idea that spatial equilibrium could be viewed as a maximization problem (of the net social payoff). This idea was developed in the 1960's, principally by Takayama and Judge [8]. For given regional demand and supply functions and interregional transport costs they formulated a quadratic programming problem in which the objective function was to maximize net social payoff. In this framework quantities produced and consumed within each region are not set but are given in the solution as those values which maximize the objective function.

(3) Transportation model. A simpler variation of the spatial equilibrium approach is to set the regional consumption and production quantities. All that remains is to find the least cost pattern of shipments among regions.

(4) Econometric approach. By treating aggregate supply and demand functions for all regions as a simultaneous system, the parameters of the structural equations for each region may be estimated. Lee and Seaver [4] followed this approach, then inserted values of predetermined variables and used the resulting functions of quantity on price as a basis for the type of spatial equilibrium analysis described above. However, as will be developed below, a dynamic econometric model can do more than this; it can be used to determine equilibrium prices and quantities in each region for any exogenous variable set.

Data are available, over an extended period of time, for consumption production and price in each region. Quantities transshipped are unknown but must be estimated to calculate the changes in welfare of society. These unmeasured data make inevitable an approach which is at least partially normative. However, the normative supply response (1) is not considered further. There are thus two potential model systems, the Econometric-Spatial Equilibrium (ESE) and Econometric-Equilibrium-Transportation (EET) models.

The ESE estimates demand and supply functions (first part of 4) not equilibrium quantities. Spatial equilibrium (2) therefore maximizes, in effect, social payoffs less transport costs. It assumes transport costs are correctly measured. The key relations are the price differential restraints,  $P_j - P_i \leq T_{ij}$ , which require that the unit price difference between two regions be not greater than the unit transportation cost from surplus to deficit region. These restraints determine not only prices but also regional consumption and production.

The EET estimates equilibrium quantities and prices through a dynamic econometric model (4). It assumes equilibrium quantities are correctly measured and relative but not necessarily absolute transport costs are correct. The transportation algorithm (3) then selects the transshipment pattern which minimizes costs. Given that the data series for transport costs are less reliable than those for quantity data, the EET approach would seem more accurate, and preferred.

#### Econometric Model of the U.S. Egg Producing Industry

In the model, the United States is divided into six areas corresponding to the census regions (North Atlantic, East North Central, West North Central, South Atlantic, South Central and West). Data are available on production, consumption, farm price, per capita income and population in each region.



On the supply side of the model, neoclassical assumptions dictate that the regional supply function be found by solving the equilibrium relation which sets the price of output equal to marginal cost. The supply function is usually specified directly; the present case uses Nerlove's [5] delayed adoption ("technical rigidity") approach:

$$(1) \quad Q_{it}^{s*} = a_{i0} + a_{i1} P_{it-1} + a_{i2} S_{it-1} + a_{i3} t + u_{it}$$

where

$Q_{it}^{s*}$  is anticipated quantity of egg production, region i, year t

$P_{it-1}$  is the price received by farmers for eggs, region i, year t-1

$S_{it-1}$  is the price paid by farmers for feed, region i, year t-1

$u_{it}$  is the disturbance term assumed to have the usual spherical properties

Since feed cost represents the major proportion of total cost, it is a minor misspecification to exclude prices of other inputs. The time trend variable allows for technical advances in production.

A simplification of equation (1) is possible by making use of the fact that it is the difference between output price and input price which is important. Let  $M_{it}$ , the "profitability" in region i in year t be

$$(2) \quad M_{it} = P_{it} - S_{it} \cdot C_t$$

Data on the rate of converting feed to eggs,  $C_t$ , are available only at the national level. Because changes in  $C_t$  include most of the technical change previously expressed in the time variable, t is dropped from the supply equation, which now becomes

$$(3) \quad Q_{it}^{s*} = a_{i0} + a_{i1} M_{it-1} + u_{it}$$

Equation (3) will be found to be a very convenient form for introducing cost of production changes in the analysis of the impact of antipollution regulations. This will be developed in a later section.

Now, proceeding as did Nerlove [5] and assuming that institutional and technical rigidities limit the adjustment between two years according to the relation

$$(4) \quad Q_{it}^s = Q_{it-1}^s + \alpha (Q_{it}^{s*} - Q_{it-1}^s); \quad 0 < \alpha < 1$$

where  $Q_{it}^s$  is the actual output of eggs in region i, year t. Rearranging (4) and substituting it into (3) we get

$$(5) \quad Q_{it}^S = \beta_{i0} + \beta_{i1} M_{it-1} + \beta_{i2} Q_{it-1}^S + u_{it}$$

where  $\beta_{i0} = \alpha a_{i0}$ ,  $\beta_{i1} = \alpha a_{i1}$ ,  $\beta_{i2} = 1 - \alpha$  and multiplication of  $u_{it}$  by a scalar leaves its spherical properties unchanged.

On the demand side, theory indicates that per capita consumption of a commodity is a function of its own price, those of substitutes and complements, income, and change in taste. The current model is simplified by assuming that the cross price elasticity between eggs and possible substitutes and complements is zero. Changes in taste over time are included by means of a trend variable, which does not therefore permit temporal reverses in preferences.

Demand functions are of the form

$$(6) \quad Q_{it}^D = \beta_{i0} + \gamma_{i1} P_{it} + \beta_{i3} Y_{it} + \beta_{i4} t + \beta_{i5} N_{it} + v_{it} \quad (i = 7, \dots, 12),$$

where  $Q_{it}^D$  is quantity of eggs consumed, region  $i$ , year  $t$

$N_{it}$  is civilian resident population, region  $i$ , year  $t$

$Y_{it}$  is total income per capita, region  $i$ , year  $t$

$v_{it}$  is the disturbance term, assumed to have spherical properties.

A number of identities are required to close the system. Total quantity consumed in year  $t$  equals total quantity produced in year  $t$  less other disappearances. Changes in year end inventory over time are insignificant and other disappearances are accounted for almost completely by eggs used for hatching.

$$(7) \quad \sum_{i=1}^6 Q_{it}^S = \sum_{i=7}^{12} Q_{it}^D + H_t,$$

where  $H_t$  is the total quantity of eggs for hatching and non-civilian consumption in the United States for year  $t$ .

If the system is to be used for forecasting, an additional function must be present to explain  $H_t$  or it should be removed from the system. For example,

$$(8) \quad H_t = d_0 + d_{it} \sum_{i=1}^6 Q_{it}^S$$

Substitution of (8) into (7) removes  $H_t$  from the system and makes total quantity consumed functionally related with quantity supplied. Since no forecasting is planned, the implications of particular forms of (8) are not pursued further.

Consumption in each of the six regions depends on the shipments among them. Shipments will be made from one region to another as long as the price



differential is greater than the transport cost per unit. Thus provided a region is not in production-consumption balance with itself, and hence "isolated", the system will need five transportation identities. For example these might be

$$(9) \quad T_{1j} F_t = P_{jt} - P_{1t}; \quad j = 2, 3, \dots, 6,$$

where  $T_{1j}$  is the transport cost from region 1 to region  $j$  in the base year (1969),  $F_t$  is the index of freight rates in year  $t$  (1969 = 1.00). All other  $T_{ij}$ 's can be written as linear combinations of the five transport identities in (9).

#### Estimation Problems and the Model

The model to be estimated consists of the twelve structural equations, (5) and (6), and the six identities, (7) and (9). Any structural equation, e.g. the  $m^{\text{th}}$  can be written as

$$y_m = Y_m \gamma_m + X_m \beta_m + u_m = Z_m \delta_m + u_m$$

where  $y_m$  is a  $T \times 1$  vector of observations on the jointly dependent variable to be explained.

$Y_m$  is the  $n \times k_m$  matrix of explanatory dependent variables and

$\gamma_m$  is the corresponding  $k_m \times 1$  coefficient vector

$X_m$  is the  $n \times l_m$  matrix of explanatory dependent variables and

$\beta_m$  is the corresponding  $l_m \times 1$  coefficient vector, finally

$u_m$  is the  $n \times 1$  vector of structural disturbances. Also

$$Z_m = [Y_m \ X_m], \quad \delta_m = \begin{bmatrix} \gamma_m \\ \beta_m \end{bmatrix}.$$

The 12 structural equations may be written compactly as

$$y = Z\delta + u$$

where



$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_{12} \end{bmatrix}, Z = \begin{bmatrix} x_1 & 0 & \dots & 0 \\ 0 & x_2 & \dots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \vdots & x_6 \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \dots & z_{12} \end{bmatrix}, \delta = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_6 \\ \delta_7 \\ \vdots \\ \delta_{12} \end{bmatrix}, u = \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_{12} \end{bmatrix},$$

The first particularization is that the supply equations,  $m = 1, \dots, 6$ , contain no explanatory dependent variables.

Taken as two groups, the supply side and demand side form a recursive system. Total demand is derived from total supply through the identity (7). Individual prices and quantities demanded in each region are simultaneously determined but constrained by total demand. There is thus a causal relationship without feedback from prices ( $t-1$ ) to quantities supplied ( $t$ ) to quantities demanded ( $t$ ) and prices ( $t$ ).

The stochastic specifications imposed are that the disturbances of the structural equations have zero mean, are serially independent and are homoscedastic in the sense used by Zellner and Theil [10]. That is, their variances and contemporaneous covariances are finite and constant through time. Additionally, assuming that none of the disturbance terms in the supply equations is correlated with the disturbance term in a demand equation, we have a fully block recursive system, whose variance-covariance matrix may be written as

$$\Sigma = \begin{bmatrix} \Sigma_1 & 0 \\ 0 & \Sigma_2 \end{bmatrix} \otimes I, \Sigma_1 = \begin{bmatrix} \sigma_{11} & \dots & \sigma_{16} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \sigma_{61} & \dots & \sigma_{66} \end{bmatrix}, \Sigma_2 = \begin{bmatrix} \sigma_{77} & \dots & \sigma_{7,12} \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \vdots & & \vdots \\ \sigma_{12,7} & \dots & \sigma_{12,12} \end{bmatrix}.$$

where  $I$  is an  $n \times n$  identity matrix and we assume that  $\Sigma$  is nonsingular.<sup>1/</sup>

<sup>1/</sup> This might appear to be a problem since each identity in the system will produce a row and column of zeros. These identities could be eliminated by substitution of variables but as Zellner and Theil [10] point out (footnote 9) this complicates computation and is unnecessary.

These stochastic specifications enable an important simplification to be made for now each block of structural equations can be estimated separately. Ordinary least squares (OLS) applied to the supply equations would give consistent estimators. However, these functions are an example of Zellner's [9] "seemingly unrelated regressions." As he showed, a gain in efficiency generally occurs if all coefficients are estimated simultaneously by Aitken's generalized least squares.

The demand functions must be estimated simultaneously to get consistent estimators since prices and quantities are determined together, linked through identity (9). Two stage least squares (2SLS) will give consistent estimators and is widely used. A gain in efficiency can be achieved by use of Three Stage Least squares (3SLS). An improvement in degrees of freedom and some suppression of multicollinearity will occur if supply equations are estimated separately from the block of demand equations. If the methods described above are used, simultaneous equations bias is eliminated.

#### Equilibrium Quantities and Alternative Cost Assumptions

The question to be answered can be phrased as: "What is the total effect of a change in 'profitability' on equilibrium quantities supplied and consumed?" This change is the result of additional costs per unit of output incurred in meeting antipollution regulations. Clearly, the structural form of the system will not answer the above question since profitability,  $M_{it}$ , occurs only in the supply equations. We must calculate the reduced form coefficients to determine the impact and long-run multipliers required. This could have been done by direct estimation of a reduced form system. The argument for not doing so is that the calculated reduced form incorporates more information and is, at least asymptotically, more efficient.

In standard matrix notation, the model of the system is

$$(10) Y\Gamma + XB = U$$

where Y is the n X 18 matrix of jointly dependent variables

$\Gamma$  is the 18 X 18 matrix of the coefficients of the jointly dependent variables,

X is the nX 32 matrix of predetermined variables

B is the 32 X 18 matrix of coefficients on the predetermined variables

U is the n X 18 matrix of disturbance terms

n is the number of observations

Rearrangement of (10) and postmultiplication by  $\Gamma^{-1}$  gives

$$Y = X\Pi + U\Gamma^{-1}$$

when  $\Pi$  is the 32 X 18 matrix of reduced form coefficients.



Using the structural methods of estimation outlined in the previous section an estimate of the reduced form coefficient matrix can be calculated:

$$\hat{\Pi} = -\hat{B}\hat{\Gamma}^{-1}$$

The coefficients which comprise  $\hat{\Gamma}$ ,  $\hat{B}$  and  $\hat{\Pi}$  are illustrated in figures 1 and 2.

Before equilibrium values of egg prices and quantities can be determined, the dynamic aspects of the model must be worked through. Both the  $Q_{it-1}^s$  and  $M_{it-1}$  are treated as lagged endogenous variables (the latter since it is dependent on  $P_{it-1}$ ) and they influence the values of  $Q_{it}^s$  and  $P_{it}$  at equilibrium). Using the partitioning of  $\hat{\Pi}$  shown in figure 2 we have the relevant reduced form equations as<sup>2/</sup>

$$\begin{bmatrix} Q_{1t}^s \\ \vdots \\ Q_{6t}^s \\ P_{1t} \\ \vdots \\ P_{6t} \end{bmatrix} = \begin{bmatrix} R_1 \end{bmatrix} \begin{bmatrix} Q_{1t-1}^s \\ \vdots \\ Q_{6t-1}^s \\ P_{1t-1} \\ \vdots \\ P_{6t-1} \end{bmatrix} + \begin{bmatrix} R_2^* \end{bmatrix} \begin{bmatrix} S_{1t-1} C_{t-1} \\ \vdots \\ S_{6t-1} C_{t-1} \\ 1 \\ Y_1 \\ \vdots \\ T_{16} \cdot F \end{bmatrix}$$

$$\text{or } y_t = R_1 y_{t-1} + R_2^* z_t$$

The impact multipliers, which are the reduced form coefficients are of interest themselves since they can be used to indicate the paths of the endogenous variables towards equilibrium. These dynamic aspects are not pursued here; only the questions of stability of the system and values of the variables at equilibrium are of interest. It can be shown (see, for example, [3]) that provided  $\lim_{t \rightarrow \infty} R_1^t = 0$  or equivalently that each characteristic root

of  $R_1$  is less than 1 in absolute value then the system is stable and an equilibrium multiplier matrix,  $D$ , exists where

$$D = (I - R_1)^{-1} R_2^*$$

and in equilibrium

$$\bar{y} = D\bar{z}$$

The column vector  $\bar{z}$  consists of values of the 26 exogenous variables for which the equilibrium is sought. This when premultiplied by  $D$  gives the desired prices and quantity supplied in each region. Quantity demanded is obtained directly using the remaining submatrix of  $\hat{\Pi}$

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<sup>2/</sup>  $R_2^* = [r \ R_2]$ , a 26x12 matrix, where  $r$  is the last six columns of  $R_1$  with the signs changed.



[illegible]

Figure 2

$$\begin{array}{cccccccc}
& Q_1^s & \dots & Q_6^s & P_1 & \dots & P_6 & Q_1^D & \dots & Q_6^D \\
Q_{1t-1}^s & \hat{\Pi}_{1,1} & \dots & & \cdot & \dots & \hat{\Pi}_{1,12} & \hat{\Pi}_{1,13} & \dots & \hat{\Pi}_{1,18} \\
\vdots & \vdots & & & & & \vdots & \vdots & & \vdots \\
Q_{6t-1}^s & \cdot & & & & & \cdot & \cdot & & \cdot \\
M_{1t-1} & \cdot & & & & & \cdot & \cdot & & \cdot \\
\vdots & \vdots & & & & & \vdots & \vdots & & \vdots \\
M_{6t-1} & \hat{\Pi}_{12,1} & \dots & & \cdot & \dots & \hat{\Pi}_{12,12} & \hat{\Pi}_{12,13} & \dots & \hat{\Pi}_{12,18} \\
1 & \hat{\Pi}_{13,1} & \dots & & \cdot & \dots & \hat{\Pi}_{13,12} & \hat{\Pi}_{13,13} & \dots & \hat{\Pi}_{13,18} \\
\hat{\Pi} = -B\hat{\Gamma}^{-1} = Y_1 & & & & & & \cdot & \cdot & & \cdot \\
\vdots & \vdots & & & & & \vdots & \vdots & & \vdots \\
Y_6 & \cdot & & & & & \cdot & \cdot & & \cdot \\
t & \cdot & & & & & \cdot & \cdot & & \cdot \\
N_1 & \cdot & & & & & \cdot & \cdot & & \cdot \\
\vdots & \vdots & & & & & \vdots & \vdots & & \vdots \\
N_6 & \cdot & & & & & \cdot & \cdot & & \cdot \\
H & \cdot & & & & & \cdot & \cdot & & \cdot \\
T_{12} \cdot F & \cdot & & & & & \cdot & \cdot & & \cdot \\
\vdots & \vdots & & & & & \vdots & \vdots & & \vdots \\
T_{16} \cdot F & \hat{\Pi}_{32,1} & \dots & & \cdot & \dots & \hat{\Pi}_{32,12} & \hat{\Pi}_{32,13} & \dots & \hat{\Pi}_{32,18}
\end{array}$$

$$\text{or } \hat{\Pi} = \begin{bmatrix} & R_1 & & & \\ & & & & R_3 \\ \cdot & 12 & \times & 12 & \cdot \\ & R_2 & & & \\ & & & & 32 \times 6 \\ 20 & \times & 12 & & \cdot \end{bmatrix}$$

$$\begin{bmatrix} Q_1^D \\ \vdots \\ Q_6^D \end{bmatrix} = \begin{bmatrix} R_3 \end{bmatrix} \bar{z}.$$

The quantities just calculated are now introduced into a standard transportation model using the  $T_{ij}$ 's as transport costs. Optimization gives the transshipment pattern which results in least cost. Total transfer cost for the shipment quantities  $X_{ij}$  for all  $i$  and  $j$  depends on the value assumed for the freight rate index,  $F$ , in the formula

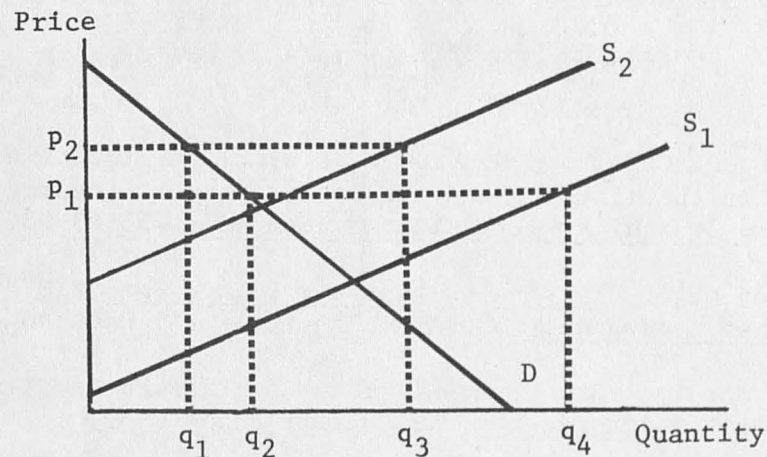
$$\sum_i \sum_j T_{ij} F X_{ij} \quad \text{for } X_{ij} \geq 0.$$

The second stage of the study is to establish a range of cost increases per dozen eggs which might result from the imposition of antipollution regulations. This could be entirely arbitrary and simply test the sensitivity of the equilibrium solution to increases in cost, while awaiting definitive estimates for each region. More usefully, the normative representative farm studies which are available at least for New England [2] could be used to center the range of cost increases.

The increases, however calculated, are used to adjust the values of the  $S_{it-1}$   $C_{t-1}$  on which the equilibrium is based. Of course such cost charges result from neither feed cost charges nor conversion efficiency differences. However, the procedure is entirely legitimate since the essential impact is on the change in profitability when all other factors except pollution control costs are held constant. The new equilibrium quantities are inserted into a transportation model as before.

### Welfare Implications

We can examine each region in turn and determine the gain or loss in total surplus, the sum of consumer surplus and producer surplus.





For this typical region we calculate consumer surplus (CS) and producer surplus or economic rent (PS) as follows. The subscript indicates values either (1) before or (2) after the supply shift.

$$CS_1 = \int_0^{q_2} D(q) dq - p_1 q_2$$

$$PS_1 = p_1 q_4 - \int_0^{q_4} S_1(q) dq$$

$$CS_2 = \int_0^{q_1} D(q) dq - p_2 q_1$$

$$PS_2 = p_2 q_3 - \int_0^{q_3} S_2(q) dq$$

The summation of change in total surplus over all regions is not the total gain or loss to society. The change in total transportation cost ( $\Delta \sum_i \sum_j T_{ij} FX_{ij}$ ) must also be deducted from the change in total surplus.

This will be the net gain or loss to society. If a loss should result decisionmakers may treat it as the cost of removing a particular kind of agricultural pollution from waterways and streams. But whatever the outcome it should permit more reasoned public debate on the information needed to estimate the costs and benefits of pollution control.

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