The Economic Impact of Alternative Policies on the Illinois Grain Marketing System

James M. Harris, E. Dean Baldwin, Lowell D. Hill and Tom Worley

The national grain marketing system is in a state of transition. Changes in the methods of production and harvesting grain have improved yields and shortened the time required for harvesting grain (Jones, Sharp, and Baldwin; Penn, pp. 119-129). Specialization in grain or livestock production, and increases in foreign demand have caused more grain to gravitate through the marketing channels (Penn, pp. 119-129; Stallings, Harris, Sappington). Transportation rates are increasing for all modes, rail abandonment of branch lines is being accelerated, the rural road system is in disrepair, and waterways and ports are being altered (Fedeler and Heady; Rudel and Payne). All of these changes increase the pressure on the marketing system and increase the demand for specialized marketing services.

National government policy is also in a state of flux with legislators developing food policy for consumers in competition with agricultural policy for producers. Trade policy has been reorientated by decreasing the quantities for food aid and increasing the quantities sold for "hard" currency to offset balance of payment deficits (Penn, pp. 1-29, 130-137). These and other policies pertaining to production, transportation, and grain marketing systems foster a disequilibrium within the grain marketing system requiring major adjustments in resource allocation (Heady, Faber, and Sonka; Jones, Sharp, and Baldwin; Penn).

Despite the importance of these disequilibria and adjustments, previous research has focused on the effects that policy changes have on the production sector, rather than effects on the marketing system (Heady, Faber, Sonka; Penn, pp. 1-12). Past marketing structure studies have had a descriptive focus (Baldwin and Sharp; Jones, Sharp and Baldwin;

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Clodius and Mueller). Marketing research by Heady, et al, evaluated the impact of alternative export policies and sizes of ports on flow of grain and production regions with assumed national and regional marketing structures (Fedeler and Heady). Another study by Baumel, et al, defined the optimum marketing structure for alternative rail abandonment plans for a six county region in which demand was assumed to be perfectly elastic (Baumel, Drinka, Lifferth, and Miller; Ladd and Lifferth).

To extend the above research, this paper specifies an economic and analytical framework for analysis and evaluates the impact of alternative policies on the Illinois grain marketing structure and grain flow patterns. A linear programming transportation model is employed to obtain results from alternative policies, and implications for the Illinois grain marketing system are cited.

Theoretical Considerations and the Linear Programming Model

The linear programming model was designed to analyze the impact of alternative policies on the market structure of the grain industry and the pattern of grain movements in intra- and inter-state movements.[1] Like all of its predecessors, this modified transportation linear programming model is solved within the theoretical framework of perfect markets. The objective function is defined to minimize the total cost of assembly, conditioning, storing, and transporting grain by mode between shipping and receiving points. The objective function coefficients satisfy the linear combination and divisibility assumptions. Using bushels and dollars per bushel as a base measurement permits the model to meet the requirement of divisibility. The linear assumption is satisfied because shipments will

[1]The linear programming model is mathematically specified in appendix form and is available to interested readers.

be transported to markets where net returns are highest, i.e., where market price minus transfer costs are highest (Dean, Leahy, and McKee). In addition, rail rates are fixed by regulatory bodies and vary by finite increments among regions and through time. Other marketing costs including truck and barge transportation rates may be fixed at the lowest segment on the long run average cost curves. Due to competition within the industry, inefficient firms operating on higher segments of the long run average cost curve will be eliminated in long run time periods.

Within the linear programming model, the effect of alternative policies or actions are simulated through sensitivity analysis and parametric programming on objective function and constraint coefficients. Firms, modes of transportation, drying and storage services provided by each firm, and grain flows among regions and firms are endogenously determined for each alternative policy. Because of the assumptions required for solving linear programming models, the absolute numbers of firms and bushels of grain are of less importance than comparisons of solutions under alternative conditions of cost, capacity restrictions and supply and demand conditions. Such comparisons provide two important types of information. First, the sensitive variables in the solution are identified whenever policy decisions alter the organization of the system. Second, the effect of a change in a variable on the base solution helps identify the cause and effect relationship between policy decisions, and the actions of firms in the grain industry.

Marketing Regions and Data Base

The linear programming model was solved for eight separate marketing regions in Illinois (Figure 1). Each region has unique production, transportation, and marketing characteristics (Hill and Harris). Six grain elevators, three feed plants, one soybean processor, and one flour mill were selected for each marketing region. The following characteristics were used to differentiate among the respective firms: grain and processing capacity, grain and feed volumes, services offered to producers, access to transportation facilities, and cost of operation. The origin and destination of grain from each region was based on a previous study and survey of grain and processing firms. Production, harvesting, and inventory data were obtained from data published by the Illinois Cooperative Crop Reporting Service. Rail and barge transportation rates from origin to destination were derived from published sources. Truck rates were based on surveys and previous studies and were adjusted with an inflationary factor for consistency with the reported rail and barge rates.

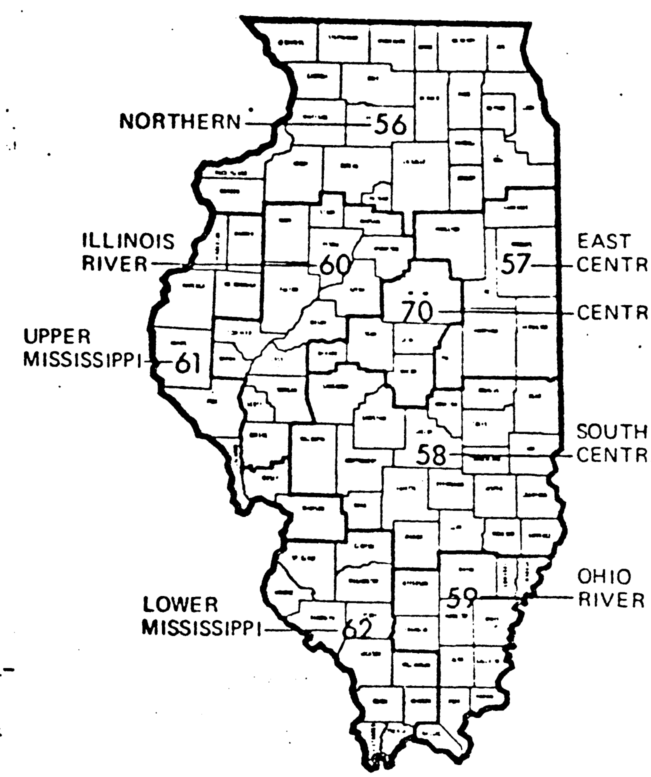

Figure 1. Grain marketing regions of Illinois.

The Effect of Policy Changes on the Grain Industry

Six policy changes were introduced into the model for the different marketing regions. These policies included rail abandonment, seasonal transportation rate increases for both rail and water, water user charges, increases in exported volumes, and production increases. Any one of these changes may represent many policy options (Hill and Harris). The effects of each of these changes are described in turn.

Rail Abandonment

Elevator type E_1, a country elevator[2] with a small annual volume, moved a small amount of grain on single-car rates in most of the solutions of the benchmark solutions for each of the eight regions. As a result of these volumes, plus location on branch rail lines, the service to these elevators is in danger of being reduced or eliminated in the plans for rail reorganization. The effect of removing rail service to this type of elevator depends on the alternative markets and transportation available in each region. In each of the eight regions, the removal of the rail option reduced the volume of grain received by the small elevators and increased the volume of the larger elevators that retained rail service.

In general, those regions of Illinois whose primary markets are close enough to be served economically by truck were relatively unaffected by loss of rail service.

In region 59, the 29 small elevators in the benchmark solution were completely eliminated and their volume absorbed by E_3, with multiple car rates to the Southeast markets. Area 62 lost all the small elevators. In region 57, the number of small elevators was reduced from 201 to 55 as a result of a loss of rail service.

Elevators of type E_1 in region 56 actually experienced a slight increase in volume, despite the loss of rail service. The additional volume came at the expense of the E_2 elevator type. When rail service was removed from these firms, elevators of type E_1 increased their truck shipments to local millers, but the rail shipments of both firm types were taken over by larger firms, represented by E_5 and E_6.

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[2]The six elevators were numbered E_1, E_2, E_3, E_4, E_5, E_6. Size ranged from E_1, the smallest, to E_6, the largest.

Those regions with rail rates to more distant markets and with alternative modes of transport were the regions where the greatest shift among elevator types occurred following rail abandonment. Loss of rail service did not result in the development of subterminals in this model because the larger elevators were allowed to receive grain directly from farmers. Since farmers could store the grain on the farm and deliver directly to the larger elevators, the small elevators became unnecessary in the changed market channel.

Subterminal elevators can provide price protection for country elevators (paying lower prices to farmers than to elevators or refusing to accept delivery from farmers) and thereby encourage growth of the small elevators despite abandonment of branch lines. However, with adequate on-farm storage and larger farm size there is a strong incentive to by-pass smaller elevators and deliver direct to the subterminals. The effect of rail abandonment is, therefore, a function of management policies of larger elevators and the availability of alternative modes of transport.

Waterway User Charges

An increase in barge rates of 6 cents per bushel gave an additional advantage to other modes of transportation. Because published barge rates are generally below those of railroads, increases of less than 6 cents generally had no effect on the choice of transportation mode. Only regions 56, 59, 60, 61, and 62 have water routes available and only elevator types E_3 and E_6 within these regions are located on water.

In region 56, the increased cost for barge transportation resulted in the substitution of rail transportation from E_6 for barge transportation from E_3 to export. There was no effect on water shipments of corn, and the 6 cents per bushel increase in barge rates had only slight effect on volumes shipped, mode of transport, or number of firms.

In region 60, receipts and shipments were not affected by the increase in barge rates and there were no changes in numbers of firms. Region 59 was not included in this comparison since its situation was similar to region 60.

In region 61, grain moving on the Illinois River to Southern markets was shifted from water to rail, and this grain was moved through E_1 and E_2 instead of E_3. There was no effect on export destinations.

Region 62, on the lower Mississippi River, used very little water transportation, even in the benchmark solution. The higher rates shifted both wheat and corn to the railroad, and the decreased volume through E_3 was sufficient to require 29 more elevators of type E_1.

Rate increases on water movement have the effect of increasing the total cost of transportation, and falls most heavily on export markets. The resulting shift from barge to rail also gives additional advantage to land-locked elevators, such as E_1 and E_2, at the expense of river terminals such as E_3. An increase of 6 cents over published rates was insufficient to result in major changes in mode of transport.

Increased Exports

A shift in the relative importance of the export and domestic markets had the greatest effect on those elevators serving the export markets. In general, the same elevators were important in grain receipts, but the destinations of their shipments were changed from domestic to export. In some cases (for example, in region 56), elevators of type E_3 increased their volume of receipts in order to serve the expanded export market. The increased volume through elevators serving the export market reduced the volume available for some of the smaller elevators serving domestic points. For example, in region 57, the increased export demand increased the number of E_4 firms from 3 to 4, but reduced the number of E_1 elevators from 164 to 161.

Production Increase

An increase in total supply provides an opportunity for expansion by all firms. However, the expansion is not uniform among all elevator types. E_2 and E_4 experienced the greatest increase in nearly all regions. Since the increase in supply was not matched by an increase in demand, the grain was retained as inventory at those elevators nearest the production areas (i.e., the small elevators) that most economically provide storage with the greatest flexibility for future delivery. Elevators receiving grain from outside the region were more severely affected because the increased self-sufficiency within the region made their cost advantage in importing grain of less importance. Thus, in region 56, E_5 was not in the solution with the production increase, even though it received 6.9 million bushels of wheat from the Gibson City region in the base solution. In region 60, E_5 was not in the solution when production increased because the demands of the region could be met without the services of E_5.

Seasonal Barge Rate Increases

To simulate a seasonal increase in barge rates, 50 and 100 percent increases in rate levels were applied from the beginning of the harvest period for corn and soybeans and extending through December. Barge rates during the remainder of the year were left unaltered. Since barge rates are usually lower than rail rates, an increase of this type represents an advantage to rail transport. And, due to the importance of water transport on longer hauls and export movements, decreases were noted in barge movements when rail rates became more competitive.

In area 60, when barge rates were increased 50 percent, grain moving down the Illinois River was shifted from water to rail transport. The increased movement required one additional E_2 elevator type and three of type E_4. Elevator type E_4 was not previously in the benchmark solution. There was no effect on grain moving to domestic destinations.

At the 100 percent rate level, shifts occurred in both export and domestic flows. The additional advantage given to land locked elevators resulted in an increase of 9 more firms of elevator type E_2.

Seasonal Rail Rate Increases

The impact of seasonal rail rates was evaluated through an increase in rates during the harvest period for corn and soybeans and extending through December. Rates were increased to levels of 10 and 30 percent above the existing level. Rates during the remainder of the year were left unchanged.

In region 57, elevator type E_1 increased in importance at the expense of elevator type E_2. The number of E_1 elevators increased from 166 to 240 at the 10 percent level and to 245 with the 30 percent increase.

Imports of grain into area 57 were similarly affected with receipts nearly equally divided among rail and truck in contrast to the benchmark solution where receipts were moved.entirely by rail.

Long distance shipments were affected very little since there were no economically viable alternatives in land-locked regions. Increased Fall rail rates in River areas also had little effect since barges were already the lower cost mode.

Summary and Implications

The benchmark solution for each region shows the least cost system of marketing, storing, and transporting grain for a specified set of rates and destinations. The six variations introduced into the model illustrate the kind of solution changes which will result from changes in supply and demand relationships, the cost of transportation, and capacity restrictions. These variations identify the interrelationships between mode of transport and size and type of firms.

The effect of removing branch line service to small elevators depended upon alternative markets for grain and transportation available. In general, areas close enough to be served economically by truck were virtually unaffected, but removal of rail access reduced the volumes of smaller elevators in favor of larger elevators with rail service.

Policy changes that increase the demand for grain at distant domestic and export points give an economic advantage to large volume firms with lower rates for these volumes. Policies that increase supplies of grain tend to increase the relative importance of storage near the point of production and increase the economic advantage of smaller firms.

Rate increases on water movements increase the total cost of transportation in areas with access to water transport and fall heaviest on export markets. The accompanying shift to rail transport favors land-locked elevators at the expense of river terminals. However, published barge rates are generally below railroad rates and increases of less than 6 cents had no effect. In more competitive situations, this differential might narrow.

Introduction of seasonal rail rates also increases the total cost of transportation and makes trucks more competitive with rail transport to intermediate points. Modal shares of movements to distant points and export were unaffected.

Even in view of the complexity of mathematical mode, none can incorporate all the quantitative and qualitative variables that influence the marketing and transportation of grain, and the set of variables selected for analysis limit the application of results. Additional analyses are required which will build on the understanding of the relationships developed from these models.

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Appendix

The specification of the linear programming model for a marketing region takes the following form:

(1) $$\text{Minimize } Z = \sum_s \sum_p \sum_t C.H._p\, H^t_{ps} + \sum_p C.T._{p_{fm}}\; X.T.^t_{p_{fm}}$$
$$+ \sum_o \sum_{fe} \sum_m \sum_p C.T._{pof_e m}\; X.T.^t_{pof_e m}$$
$$+ \sum_j \sum_{D_1} \sum_m \sum_p \sum_t C_{pjD_1m}\; X.A.^t_{pjD_1m}$$
$$+ \sum_{D_1} \sum_S \sum_P \sum_t C_{pfmD_1}\; X.A.^t_{pfmD.S}$$
$$+ \sum_m \sum_{f_e} \sum_{D_2} \sum_s \sum_p \sum_t C_{pfeD_2m}\; X.A.^t_{p\,fe\,D_2\,m\,s}$$
$$+ \sum_c \sum_L \sum_p \sum_t C.C._{plc}\; A.C.^t_{plc}$$
$$+ \sum_c \sum_L C.I._{LC}\; A.I._{LC} + \sum_{fb} \sum_t C.P._{fb}\; A.P.^t_{fb}$$

Subject to the constraints:

(2) $$\sum_s \sum_t H^t_{ps} + X.T.^{t=1}_{pbm} + \sum_o \sum_{fe} \sum_m X.T.^{t=1}_{p\,o\,fe\,m} + \sum_j \sum_{D_1} \sum_m \sum_t X.A.^t_{p\,j\,D_1\,m}$$
$$= \sum_t D.F.^t_p + \sum_{fe} \sum_j \sum_m \sum_t X.D.O.S.^t_{p\,fe\,j\,m} + \sum_{o_1} \sum_{fb} \sum_m \sum_t X.D.F.M.^t_{po_1fb\,m}(R_p)$$
$$+ \sum_{o_1} \sum_{fp} \sum_m \sum_t X.D.P.^t_{p\,o_1\,fp\,m} + X.T.^{t=4}_{pfm} + \sum_o \sum_{fe} \sum_m X.T.^{t=4}_{pofem}$$

(3) $$I^t_p = X.T.^t_{pfm} + \sum_o \sum_{fe} \sum_m X.T.^t_{p\,o\,fe\,m}$$

(4) $$Spj \geq \sum_j \sum_{D_1} \sum_m \sum_t X.A.^t_{p\,j\,D_1\,m}$$

(5) $$D.F.^t_p = Q.S.^{t-1}_{p\,fm} + \sum_{fe} X.A.^t_{p\,fe\,fm} - \sum_{D_1} X.A.^t_{p\,fm\,D_1}$$

(6) $$D.^t_{pj} = \sum_{fe} \sum_m X.A.^t_{p\,fe\,j\,m}$$

(7) $$D.F.M.^t = \sum_{fb} A.P.^t_{fb} = \frac{\sum_{o_1} \sum_{fb} \sum_m X.A.^t_{p\,o_1\,fb\,m}}{Rp}$$

(8) $$D.P._{p}^{t} = \sum_{o_1} \sum_{m} X.A._{p\, o_1\, fp\, m}^{t}$$

(9) $$Q.S._{p\, fe*}^{t} = Q.S._{pfe*}^{t-1} + X.A._{p\, fm\, fe*}^{t} + \sum_{j} \sum_{m} X.A._{p\, j\, fe*\, m}^{t} + \sum_{m} \sum_{fe} X.A._{p\, fe\, fe*\, m}^{t} - \sum_{D_2} \sum_{m} X.A._{p\, fe*\, D_2\, m}^{t}$$

(10) $$DCAP_{fm} \geq \sum_{p} \sum_{t} H_{p\, s_1}^{t} - \sum_{fe} \sum_{p} \sum_{t} X.A._{p\, fm\, fe\, S_1}^{t}$$

(11) $$DCAP_{fe*} \geq \sum_{p} \sum_{t} X.A._{p\, fm\, fe*\, S_1}^{t} + \sum_{fe} \sum_{p} \sum_{t} X.A._{p\, fe\, fe*\, s_1}^{t} - \sum_{fe} \sum_{p} \sum_{t} X.A._{p\, fe*\, fe\, s_1}^{t}$$

(12) $$X.T._{p\, fm}^{t=1} \leq I.S._{fm} \geq \sum_{p} Q.S._{p\, fm}^{t}$$

(13) $$\sum_{o} \sum_{m} \sum_{p} X.T._{Pofem}^{t=1} \leq I.S._{fe} \geq \sum_{p} Q.S._{p\, fe}^{t}$$

(14) $$TCAP \geq \sum_{o_1} \sum_{D_2} \sum_{m} \sum_{p} \sum_{t} X.A._{p\, o_1\, D_2\, m}^{t}$$

(15) $$\sum_{fe} TCAP_{fe} \leq TCAP$$

(16) $$\sum_{fe} TCAP_{fe\, m} \leq TCAP_{m}$$

Where:

i — is the region for which the model is being solved

Z — is the total cost of marketing and transporting grain in region i

S — is the moisture levels of grain (s_1 = wet, S_2 = dry)

p — is the grain types (p = corn, wheat and soybeans)

t — is the time period (t = 1,2,3,4)

m — is the transportation mode (m = truck, rail, and water)

L — is the location of grain conditioning (L =E_1 -E_6, fm)

C — is the type of grain conditioning capacity (C = drying or storage capacity)

fm — is an average farm type for region i

fe — is the elevator types (fe = E_1, E_2. E_3, E_4, E_5, and E_6)

fp — is a grain processor (fp = wheat miller or soybean processor)

f_b — is a feed mill type (f_b = f_1, f_2, and f_3)

j is an origin or destination, including export points

O is a set or origins in region i (O = fm_1 fe's)

D is a set of destinations in region i (D = fm, fe's)

D_1 is a set of destinations in region i (D_1 = fe's, f_b's and fp's)

D_2 is a set of destinations (D_2 = fe's in region i, f_b's in region i, fm in region i, fp's in region i, and region j)

O_1 is a set of origins (= fm in region i, fe's in region i, and region j)

$C.H.p$ is the cost of harvesting a unit of product p

H^t_{ps} is the quantity of product p harvested at moisture level S in period t

$C.T._{pfm}$ is the cost of transferring a unit of product p from inventory to farm storage

$X.T.^t_{pfm}$ is the quantity of product p transferred from inventory to farm storage in period t

$C.T._{p\ o\ fe\ m}$ is the cost of transferring a unit of product p from inventory at origin O to elevator storage by mode m

$X.T.^t_{p\ o\ fe\ m}$ is the quantity of product p transferred from inventory at O to elevator storage by mode m in period t

$C_{p\ j\ D_1\ m}$ is the cost of transporting a unit of product p from region j to destination D_1 by mode m

$X.A.^t_{p\ j\ D_1\ m}$ is the quantity of product p shipped from region j to destination D_1 by mode m in period t

C_{pfmD_1} is the cost of transporting a unit of product p from farm type fm to destination D_1

$X.A.^t_{p\ fm\ D_1\ S}$ is the quantity of product p shipped from farm type fm to destination D_1 at moisture level S in period t

$C_{p\ fe\ D_2\ m}$ is the cost of transporting a unit of product p from elevator type fe to destination D_2 by mode m

$X.A.^t_{p\ fe\ D_2 m\ s}$ is the quantity of product p shipped from elevator type fe to destination D_2 by mode m at moisture level S in period t

$C.C._{pLc}$ is the cost of conditioning a unit of product p at location L at conditioning method C

$A.C.^t_{pLc}$ is the quantity of product p conditioned at location L by conditioning method C in period t

$C.I._{Lc}$ is the cost of investing in a unit of conditioning capacity C at location L

$A.I._{LC}$ is the quantity of conditioning capacity units C invested in at location L

$C.P._{fb}$ is the cost of manufacturing a ton of feed at feed mill type fb

$A.P._{fb}^{t}$ is the tons of feed manufactured by feed mill type fb in period t

$D.F._{p}^{t}$ is the on farm demand for product p in period t

$X.D.O.S._{p\ fe\ j\ m}^{t}$ is the quantity of p shipped by elevator type fe to meet out of state demand in region j, including export, by mode m in period t

$X.D.F.M._{p\ O_1\ fb\ m}^{t}$ is the quantity of product p shipped from origin O, to feed mill type fb by mode m in period t

Rp is the bushels of product p required to manufacture a ton of feed in all feed mill types f_f.

$X.D.P._{p\ O_1\ fp\ m}^{t}$ is the quantity of product p shipped from origin O_1 to grain processor f_p by mode m in period t

I_{p}^{t} is the total inventory of product p in period t

Spj is the quantity of product p available for shipment to region i from region j

$Q.S._{pfm}^{t-1}$ is the quantity of product p stored in preceeding period at farm fm

$Q.S._{pfm}^{t}$ is the quantity of product p stored in period t at farm fm

D_{pj}^{t} is the demand for product p in region j in period t

$D.F.M.^{t}$ is the total demand for feed in tons in region i in period t

$X.A._{p\ O_1\ fb\ m}^{t}$ is the quantity of product p shipped from origin O_1 to feed mill type fb by mode m in period t

$D.P._{p}^{t}$ is the grain processor demand for product p in period t

$Q.S._{p\ fe*}^{t}$ is the quantity of product p stored at elevator type fe* at the end of period t

$DCAP_{fm}$ is the drying capacity at farm Fm

$DCAP_{fe*}$ is the drying capacity at elevator type fe* (fe* is the elevator type whose drying capacity is being calculated, fe is the remaining elevator types excluding fe*)

$I.S._{fm}$ is the quantity of storage investment by farm fm

TCAP is the total annual quantity of transport modes m in region i

$TCAP_{fe}$ is the total quantity of transportation modes m by elevator type fe in region i

$TCAP_{fe\ m}$ is the quantity of transportation mode m available to elevator type fe

$TCAP_{m}$ is the quantity of transportation mode m available in region i

Equation (1) is the objective function which minimizes the total cost of assembly, conditioning, storing and transporting the total grain supply for region i.

Equation (2) states that for each grain, the total supply must equal the total demand. The total supply of grain is harvested grain ($\sum_{s} \sum_{t} H^{t}_{ps}$), beginning inventory transfers to farms, ($X.T.^{t=1}_{pfm}$), beginning inventory transfers to elevator types, ($\sum_{o} \sum_{fe} \sum_{m} X.T.^{t=1}_{p\ o\ fe\ m}$), and grain receipts from out of state origins, ($\sum_{j} \sum_{D_1} \sum_{m} \sum_{t} X.A.^{t}_{p\ j\ D_1\ m}$). Total grain demand consists of on farm demand, ($\sum_{t} D.F.^{t}_{p}$), grain demand at out of state destinations, ($\sum_{fe} \sum_{j} \sum_{m} \sum_{t} X.D.O.S.^{t}_{p\ fe\ j\ m}$), feed mill demand in region i [$\sum_{O_1} \sum_{fb} \sum_{m} \sum_{t} X.D.F.M.^{t}_{p\ o_1\ fb\ m}$ (Rp)], grain processor demand in region i, ($\sum_{O_1} \sum_{fp} \sum_{m} \sum_{t} X.D.P.^{t}_{p\ o_1 fp\ m}$), ending farm inventory, ($X.T.^{t=4}_{pfm}$), and ending elevator inventories, ($\sum_{o} \sum_{fe} \sum_{m} X.T.^{t=4}_{p\ o\ fe\ m}$).

Equation (3) equates the exogenously set beginning and ending inventories, (I^{t}_{p}), with the inventory transfers of grain.

Equation (4) states that the exogenous supply of grain from each of the out of state origins, (S_{pj}), must be greater than or equal to the total quantity of grain moved by all modes into region i, ($\sum_{j} \sum_{D_1} \sum_{m} \sum_{t} X.A.^{t}_{p\ j\ D_1 m}$).

Demand for grain by farms is exogenously set for each period. In equation (5), farm demand in period t, ($D.F.^{t}_{p}$), must equal the quantity of grain stored on farms in period t-1, ($Q.S.^{t-1}_{pfm}$), plus farm grain receipts from elevators in period t, ($\sum_{fe} X.A.^{t}_{p\ fe\ fm}$), minus the shipments of grain from farms in period t, ($\sum_{D_1} X.A.^{t}_{p\ fm\ O_1}$), minus the quantity of grain in farm storage in period t, ($Q.S.^{t}_{pfm}$).

Equation (6) equates exogenously set grain demand at out of state destination, (D^t_{pj}), with shipments to these points, ($\sum_{fe}\sum_{m} X.A.^t_{p\ fe\ j\ m}$). Equation (8) equates the grain processor demands in region i, ($D.P.^t_p$), with shipments to processors, ($\sum_{O_1}\sum_{m} X.A.^t_{p\ o_1\ fp\ m}$).

The exogenously set feed demand, ($D.F.M.^t$), in equation (7) must equal the quantity of feed manufactured by all feed mill types, ($\sum_{ff} A.P.^t_{fb}$). The quantity of feed processed by all feed mills must also equal the quantity of each grain shipped to the feed mills, ($\sum_{o_1}\sum_{fb}\sum_{m} X.A.^t_{p\ o_1\ fb\ m}$), divided by the bushels of each grain required to produce each ton of feed, (Rp).

Equation (9) states that the quantity of grain stored in each elevator type in any period, ($Q.S.^t_{p\ fe*}$), must equal that elevator's grain supply minus its grain uses.

For farms, equation (10), the quantity of wet grain requiring drying is the harvested supply of wet grain ($\sum_{p}\sum_{t} H^t_{ps_1}$), minus the shipments of wet grain to the elevator types, ($\sum_{fe}\sum_{p}\sum_{t} X.A.^t_{p\ fm\ fe\ s_1}$). For each elevator, equation (11), the wet grain to be dried is the wet grain received from farms, ($\sum_{p}\sum_{t} X.A.^t_{p\ fm\ fe*\ S_1}$), plus wet grain received from other elevators, ($\sum_{fe}\sum_{p}\sum_{t} X.A.^t_{p\ fe\ fe*\ s_1}$), minus the wet grain shipped to other elevators, ($\sum_{fe}\sum_{p}\sum_{t} X.A.^t_{p\ fe*\ fe\ S_1}$).

Equations (12) and (13) constrain investment in storage capacity at each location. In equation (12), investment in farm storage, ($I.S._{fm}$) must be greater than or equal to the beginning inventory transfer of grain to farms ($\sum_{p} X.T.^{t=1}_{pfm}$). Farm storage capacity must also be greater than or equal to macimum storage requirements for all grain in one period, ($\sum_{p} Q.S.^t_{pfm}$). In a like manner, equation (13) consists of storage capacities for elevators.

Equations (14), (15), and (16) pertain to transportation capacity. These constraints allow the transportation capacity in region i to be exogenously constrained by mode. Equation (14) states that annual transportation capacity, (TCAP), must be greater than or equal to all shipping and receiving activities, $(\sum_{O_1} \sum_{D_2} \sum_{m} \sum_{p} \sum_{t} X.A.^{t}_{p\ O_1\ D_2 m})$. Equation (15) insures that the transportation capacity used by the elevator types, $(\sum_{fe} TCAP_{fe})$, is less than or equal to the total available capacity. Equation (16) limits the use of each mode of transportation, $(\sum_{fe} TCAP_{fe\ m})$, to being less than or equal to the available capacity of each mode, $(TCAP_{m})$.