# Optimal Flows of Refined Sugar In the United States

by

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**Introduction**

Recent studies on interregional trade of sweeteners within the United States are practically non-existent, except for a Ph.D. thesis that used data for the period 1955-1965 (Walters). Moreover, we know of no such study on the flows of corn sweeteners. This paper is a sub-component of a broader research project that attempts to fill this void. The project is currently in progress and has as its ultimate objective the evaluation of the wholesale pricing system for refined sugar and high fructose corn syrup (HFCS).

The objectives of this paper are (1) to determine the optimal flows of refined sugar in the United States, (2) to conduct optimal flow comparisons over a five-year period (1908 to 1984), and (3) to conduct simulation experiments on demand and supply in order to observe changes in product flows. Optimal flows of refined sugar have important implications for several participants in the sweetener industry. The implications will be discussed later.

**The Model**

The objectives were achieved by applying interregional trade theory and linear programming. According to the theory on the spatial dimension of market price, for a homogeneous product, each producer will supply his product to the market that yields the highest producer price (i.e., market price less transfer cost). Further, the optimum allocation of the entire supply of the product among the various markets is that allocation that is consistent with the lowest total transfer cost for all markets (Bressler and King, Purcell, Tomek and Robinson).

A transportation model was constructed for the analysis. The linear program involved minimizing total transfer cost subject to the constraints imposed by regional surpluses and deficits. The model follows:

$$\text{Minimize TC} = \sum_{i=1}^{n} \sum_{j=1}^{m} c_{ij}\, q_{ij}$$

for $i = 1,2,\dots,n$ and $j = 1,2,\dots,m$

$$\text{Subject to} \quad \sum_{j=1}^{m} q_{ij} = S_i$$

$$\sum_{i=1}^{n} q_{ij} = D_j \quad \text{for } j=1,2,\dots,m$$

$$\text{with} \quad \sum_{i=1}^{n} S_i = \sum_{j=1}^{m} D_j$$

and $q_{ij} \geq 0$,

where TC is total transfer cost, $c_{ij}$ is unit transfer cost from region i to region j, $q_{ij}$ is the quantity of sugar shipped from region i to region j, $s_i$ is the quantity of sugar produced by region i, and $D_j$ is the amount of sugar consumed by region j (Takayama and Judge, Hillier and Lieberman).

**The Data**

Data needed for this study included transfer cost between each supply source and every market, quantity of refined sugar supplied by each producer, quantity imported by port, and quantity demanded in each market. Surveys for transfer costs were conducted and the results were cross-checked against rates published by the Interstate Commerce Commission. These rates incorporated key variables such as distance, shipment size, economies of size, demand/supply considerations, terrain and other regional characteristics.

Quantity of refined sugar demanded by region was determined primarily from the use of USDA sources such as "Sugar Market Statistics" and "Sugar and Sweetener Outlook and Situation Report" and from U.S. Department of Commerce sources such as "Census of Manufactures," "Current Population Reports," and data on sweetener imports and exports. Refined sugar supply by region was also determined from similar USDA and U.S. Department of Commerce sources, consultants such as C. Czarnikow and Thurston Greene and Company, and other researchers (Angelo and Barry, Barry).

The analysis covered a 5-year period in order to capture changes and patterns of flows over time. The data clearly indicated that transfer cost, demand and supply did not change proportionally from one year to another for the various regions. Hence, the model was run independently for each of the five years.

**Spatial Divisions**

The application of linear programming in interregional trade analysis requires the selection of a point within each specified region to represent the geographic concentration of producers and consumers. The 48 contiguous states were divided into 23 refined sugar producing regions. Beet sugar is processed primarily in the Midwest, Northwest and West. Cane sugar, on the other hand, is refined mainly in the coastal states. Texas was subdivided into two supplying regions, Texas North (TXN) and Texas South (TXS), with beet sugar produced in the north and cane sugar produced in the south.

The 48 contiguous states were also divided into 41 consumption regions. Each state was designated as a consumption region except for the following: (1) Massachusetts, Maine, New Hampshire, Rhode Island and Vermont were grouped into one region, with Boston as the demand point; (2) New York and Connecticut were combined as one region, with Albany as the demand point; (3) Pennsylvania and New Jersey were treated as one, with Philadelphia as the consumption point; and (4) Maryland, Delaware and the District of Columbia were grouped into one, with Baltimore as the demand point.

Figures 1 and 2 illustrate the spatial divisions and indicate the specific supply and demand points for refined sugar. In cases of dispersed production within a multi-plant state, the most representative plant location or equidistant supply point was chosen. For consumption designations, population concentration centers and major industrial users' locations figured prominently in the demand point selections.

**Scenarios**

Optimal refined sugar flows were generated under three relevant scenarios. Scenario 1 involved the conventional or strict application of the transportation model. In other words, it entailed employing the least transportation cost for each possible route and the conventional demand and supply con-

**Figure 1**

Regional Demarcation and Refined Sugar Supply Points

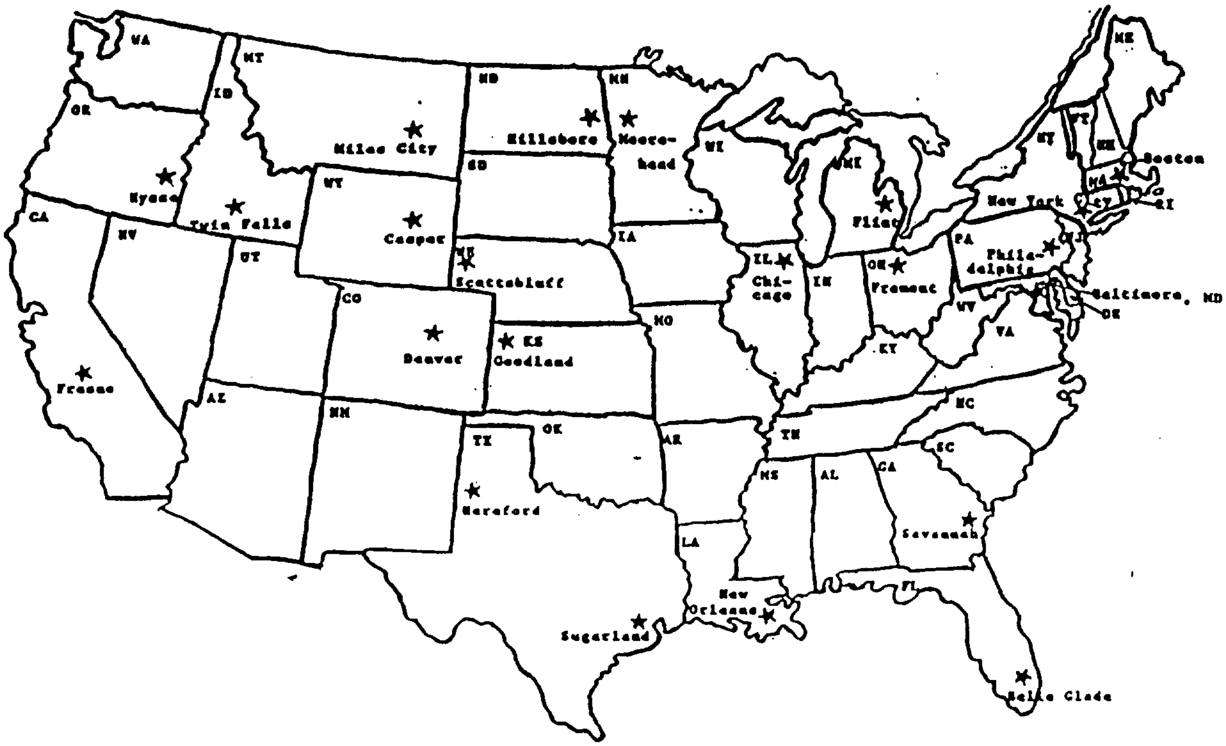
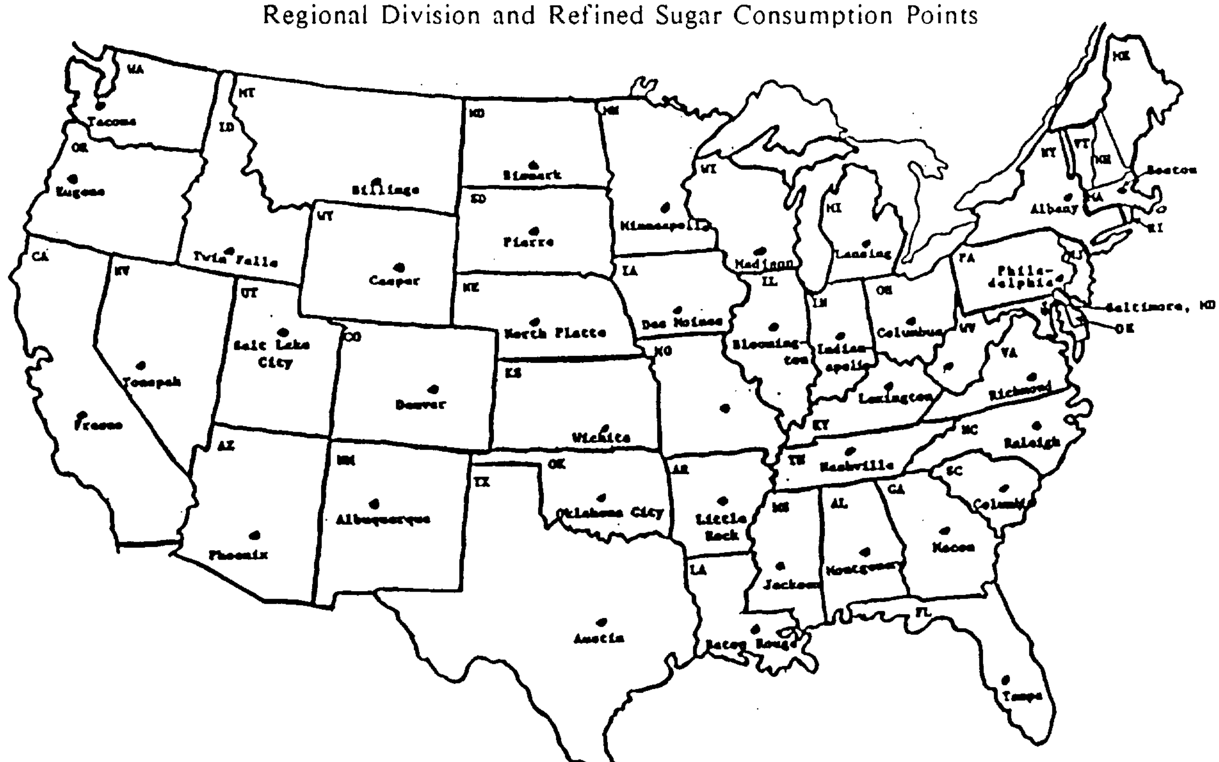



**Figure 2**

Regional Division and Refined Sugar Consumption Points



straints. It is not necessarily the case that a producing region will supply itself first, since (1) the transfer cost of moving refined sugar internally from production point to consumption point may be higher than the cost of moving it to a neighboring region's consumption point, and (2) the minimization of total transfer cost may require flow patterns that may appear questionable from eyeballing. Hence, scenario 2 was developed.

Scenario 2 differed from scenario 1 only in that each producing region was assumed to supply itself first, and subsequently exported its surplus, if any, to deficit regions or accumulated stocks. Scenario 2 required adjustments in both the demand and supply constraints for refined sugar producing regions. Scenario 2's results were expected to differ from scenario 1's because of demand and supply constraint modifications, which resulted in a modified version of the conventional model.

Finally, scenario 3 depicts a likely situation, the assumption that the demand for refined sugar would decline and the U.S. government would intervene to protect domestic sugar processors and growers from price decline. More specifically, the overall demand for refined sugar would decline by 5 percent and by the same percentage in all consuming regions. Scenario 3 assumed further that the 5 percent decline would not affect adversely domestic cane growers, millers and beet processors, since the nature of the intervention would be the lowering of the sugar import quota by the equivalent of the drop in demand. This type of intervention, however, would have an adverse impact on cane sugar refining states that obtained the bulk of their raw sugar input from foreign countries. The reduction in raw sugar imports would lead to further modifications of the supply constraints of the original transportation model. Hence, a modified model would be required for this final scenario. Scenario 3's model was, then, executed under two conditions: (1) by using the conventional approach employed by scenario 1, and (2) by using the modified version of the conventional model employed by scenario 2. Scenario 3 was executed for 1984 only, the latest year for which complete data were available.

**Results**

*Scenario 1*

Table 1 presents the optimal source(s) of supply of refined sugar for each consumption region for 1980, 1982 and 1984. For a consumption region that received sugar from two or more supply sources during a given year, the corresponding relative shares are indicated below each source. Total share is equal to 1.

A consumption region with a single supply source should have obtained 100 percent of its sugar from that producing region. For example, in 1980, Alabama should have obtained 100 percent of its sugar from Louisiana--similarly for 1982 and 1984.

A consumption region with two or more supply sources should have received sugar from the sources specified and according to the relative shares of total sugar needs given. During 1980, for example, Florida should have provided 78 percent of its sugar requirements and imported 22 percent from Louisiana. Illinois should have been supplied by an even greater number of sources, with some changes in sources from one year to another.

Table 1 also allows for a view of changes of optimal flow paths over time. Take any consumption region, changes in flows and relative shares over time can be observed. For example, Iowa should have received its sugar requirements from Colorado in 1980; from Idaho and Nebraska (84 percent and 16 percent, respectively), in 1982; and from Nebraska, in 1984. Similarly, Alabama should have consistently obtained its sugar from Louisiana over this period. Sugar stocks for the period should have been held in California and Idaho, because these regions (1) produced substantially more than they consumed, (2) the transfer cost structure dictated this, and (3) holding stocks in these regions was essential in order to achieve cost minimization for the entire distribution system.

Table 1. Optimal Flows of Regined Sugar and Relative Shares

| Consumption Region | Supply Sources | | | |
|---|---|---|---|---|
| | Scenario 1 | | | Scenario 3 |
| | 1980 | 1982 | 1984 | 1984 |
| Alabama | LA | LA | LA | LA |
| Arizona | CA | CA | CA | CA |
| Arkansas | LA | TXS | TXs | TXS |
| California | CA | CA | CA | CA |
| Colorado | CO | CO | CO | CO |
| Florida | FL LA<br>(.78)(.22) | FL GA<br>(.82)(.18) | FL GA<br>(.27)(.73) | FL GA<br>(.29)(.71) |
| Georgia | GA LA<br>(.15)(.85) | GA | GA LA<br>(.60)(.40) | GA |
| Idaho | ID | ID | ID | ID |
| Illinois | IL NE ND<br>(.39)(.32)(.29) | MN NE ND<br>(.54)(.09)(.37) | MN NE ND<br>(.55)(.09)(.36) | LA MI MN ND<br>(.14)(.03)(.54)(.29) |
| Indiana | IL LA<br>(.22)(.78) | IL LA<br>(.16)(.84) | IL LA<br>(.03)(.97) | IL LA<br>(.26)(.74) |
| Iowa | CO | ID NE<br>(.84)(.16) | NE | MN NE<br>(.30)(.70) |
| Kansas | ID | ID | ID | KS WY<br>(.38)(.62) |
| Kentucky | LA | LA | LA MI<br>(.98)(.02) | LA |
| Louisiana | LA | LA | LA | LA |
| Maryland | MD | MD | MD | MD |
| Massachus. | MA | MA | MA | MA |
| Michigan | MA MI WY<br>(.16)(.76)(.08) | MI WY<br>(.94)(.06) | MI | MI |
| Minnesota | MT ND<br>(.36)(.64) | MN | MN ND<br>(.16)(.84) | ND |
| Mississippi | LA | LA | LA | LA |
| Missouri | CO WY<br>(.33)(.67) | CO NE WY<br>(.48)(.04)(.48) | CO NE WY<br>(.42)(.04)(.54) | NE WY<br>(.65)(.35) |
| Montana | MT | MT | MT | MT |
| Nebraska | MT | MT | MT | MT |
| Nevada | ID | ID | ID | ID |
| New Mexico | CA | CA | ND | ND |
| New York | NY | NY | NY | NY |
| N. Carolina | GA | GA MD<br>(.87)(.13) | GA MD<br>(.81)(.19) | GA MD<br>(.51)(.49) |
| N. Dakota | WY | ND | MT | MT |

Table 1 (continued)

| Consumption Region | Supply Sources | | | |
|---|---|---|---|---|
| | Scenario 1 | | | Scenario 3 |
| | 1980 | 1982 | 1984 | 1984 |
| Ohio | LA NY OH<br>(.36)(.52)(.12) | LA MD MT NY<br>(.60)(.10)(.19)(.11) | LA MT OH OK<br>(.66)(.02)(.16)(.16) | LA MD OH<br>(.74)(.09)(.17) |
| Oklahoma | CO KS<br>(.41)(.59) | CO KS TXS<br>(.02)(.49)(.49) | CO KS TXS<br>(.30)(.35)(.35) | TXS |
| Oregon | ID OR<br>(.80)(.20) | ID OR<br>(.80)(.46) | ID | ID OR<br>(.62)(.38) |
| Pennsylv. | MA NY PA<br>(.07)(.07)(.86) | MA NY PA<br>(.13)(.62)(.25) | MD MA NY PA<br>(.13)(.01)(.85)(.01) | MD MA NY PA<br>(.04)(.02)(.93)(.01) |
| S. Carolina | GA | GA | GA | GA |
| S. Dakota | MT | MT | MT | MT |
| Tennessee | LA | LA | LA | LA |
| Texas | LA TXN TXS<br>(.04)(.12)(.84) | TXN TXS<br>(.17)(.83) | TXN TXS<br>(.27)(.73) | LA TXN TXS<br>(.03)(.28)(.69) |
| Utah | ID | ID | ID | ID |
| Virginia | MD | MD | MD | MD |
| Washington | OR | OR | ID OR<br>(.45)(.55) | OR |
| W. Virginia | NY | NY | MI | MI |
| Wisconsin | MN | MN | WY | MN |
| Wyoming | WY | WY | WY | WY |
| Stocks | CA ID<br>(.84)(.16) | CA ID<br>(.72)(.28) | CA ID<br>(.73)(.27) | CA CO ID MT<br>(.60)(.08)(.29)(.03) |

*Scenario 2*

Table 2 gives the optimal allocations of refined sugar for scenario 2. Louisiana produced enough sugar during 1980-1984 to satisfy all its annual sugar requirements and had enough left to ship to Alabama, Mississippi, Tennessee and other regions. On the other hand, Illinois, a producing state, did not produce enough sugar to fulfill its consumption needs. Hence, Illinois should have imported the balance of its sugar from other producing states. In the case of a non-sugar producing region that consumes the product, for example North Carolina, this region should have imported its sugar from Maryland and New York in 1980 and from Georgia and Maryland in 1982 and 1984.

Like Table 1, Table 2 reveals all optimal routes for sugar flows and relative shares for a five-year period. Sugar stocks for 1980 should have been held in California, Idaho and Minnesota; and stocks for 1982 and 1984 should have remained in California and Idaho for similar reasons given under scenario 1. In order to compare results for scenarios 1 and 2, corresponding columns in Tables 1 and 2 should be observed.

*Scenario 3*

The optimal flows of refined sugar associated with this scenario are given by the last columns of Tables 1 and 2 in order to save space and provide for convenient comparisons. The results indicate the effect of this scenario on the optimal allocation of sugar. Compared to 1984 results for scenarios 1 and 2, scenario 3's results indicate some alternate optimal paths. The policy intervention assumed by scenario 3 resulted in reduced sugar stocks held in California and Idaho and led to a shift of stocks to Colorado and Montana. Again, the policy precipitated modifications in both demand and supply constraints, with disproportionate changes in certain supply constraints. That is the reason for the additional stock locations.

**Conclusions and Implications**

Generating optimal allocation of refined sugar under alternative scenarios offers the reader a basis for comparing results in order to discover stability and instability in supply sources for given consumption regions. Some indication of sensitivity of flows to the alternative scenarios could be deduced.

Assuming competitive market conditions, the optimal results are expected to be insignificantly different from actual flows. The results would be useful in several ways. At the minimum, one learns what the optimal flows should have been for the period covered in the study. These flows may be used by several participants in the sugar industry in their internal analysis and planning.

The results lay the foundation on which to generate additional research findings--i.e., to develop equilibrium cost matrices, to determine costs of choosing non-optimal routes, to determine routes that are likely to become active in response to small changes in transfer costs, and to conduct margin studies (see Bressler and King).

The results have implications for several actors in the sugar industry. Sugar users, especially industrial users, may want to analyze their past procurement practices in order to determine whether or not they are procuring their sugar requirements in accordance with the optimal routes. If they are not, future procurement planning could utilize the results as a relevant source of information.

Sugar refiners and sugar beet processors could also use the results as a norm for evaluating their distribution system. If their distribution network does not correspond to the optimal paths, they could use these optimal results as a likely indicator of future sugar flows. They could identify current markets that are likely to be lost and prepare to adjust their marketing strategy to offset the disadvantage they may face with respect to transfer cost. Scenario 3 depicts a potential problem situation that could adversely affect most cane refiners and some major sugar users.

Table 2. Optimal Flows of Regined Sugar and Relative Shares

| Consumption Region | Supply Sources | | | |
|---|---|---|---|---|
| | Scenario 2 | | | Scenario 3 |
| | 1980 | 1982 | 1984 | 1984 |
| Alabama | LA | LA | LA | LA |
| Arizona | CA | CA | CA | CA |
| Arkansas | LA | TXS | LA TXS<br>(.30)(.70) | LA TXS<br>(.78)(.22) |
| California | CA | CA | CA | CA |
| Colorado | CO | CO | CO | CO |
| Florida | FL LA<br>(.78)(.22) | FL GA<br>(.81)(.19) | FL GA LA<br>(.27)(.37)(.36) | FL GA<br>(.29)(.71) |
| Georgia | GA | GA | GA | GA |
| Idaho | ID | ID | ID | ID |
| Illinois | ID IL NE ND<br>(.27)(.13)(.20)(.40) | ID NE ND IL<br>(.13)(.21)(.33)(.33) | IL MN MT ND<br>(.01)(.37)(.10)(.52) | IL LA MN ND<br>(.01)(.12)(.34)(.53) |
| Indiana | LA | LA | LA | LA |
| Iowa | CO NE<br>(.99)(.01) | ID | ID NE<br>(.05)(.95) | MN NE<br>(.55)(.45) |
| Kansas | ID KS<br>(.38)(.62) | ID | ID KS<br>(.62)(.38) | KS WY<br>(.38)(.62) |
| Kentucky | LA | LA | LA | LA |
| Louisiana | LA | LA | LA | LA |
| Maryland | MD | MD | MD | MD |
| Massachus. | MA | MA | MA | MA |
| Michigan | MI MN<br>(.75)(.25) | MI WY MT<br>(.06)(.01)(.93) | MI | MI |
| Minnesota | MN | MN | MN | MN |
| Mississippi | LA | LA | LA | LA |
| Missouri | CO WY<br>(.20)(.80) | CO TXN WY<br>(.23)(.06)(.71) | CO NE TXN WY<br>(.31)(.10)(.07)(.52) | CO NE TXN WY<br>(.15)(.40)(.10)(.35) |
| Montana | MT | MT | MT | MT |
| Nebraska | NE | NE | NE | NE |
| Nevada | ID | ID | ID | ID |
| New Mexico | CA | CA | CA | ND |
| New York | NY | NY | NY | NY |
| N. Carolina | MD NY<br>(.10)(.90) | GA MD<br>(.86)(.14) | GA MD<br>(.82)(.18) | GA MD<br>(.52)(.48) |
| N. Dakota | ND | ND | ND | ND |

Table 2 (continued)

| Consumption Region | Supply Sources: Scenario 2, 1980 | Scenario 2, 1982 | Scenario 2, 1984 | Scenario 3, 1984 |
|---|---|---|---|---|
| Ohio | LA NY OH (.37)(.09)(.54) | LA MT NY OH (.50)(.36)(.13)(.01) | LA MT OH OR (.60)(.11)(.16)(.13) | LA MD OH (.74)(.09)(.17) |
| Oklahoma | CO | CO TXS (.74)(.26) | CO TXS (.64)(.36) | TXS |
| Oregon | OR | OR | OR | OR |
| Pennsylv. | MA NY PA (.13)(.01)(.86) | MA NY PA (.14)(.62)(.24) | MD MA NY PA (.13)(.01)(.85)(.01) | MD MA NY PA (.04)(.02)(.93)(.01) |
| S. Carolina | GA LA (.81)(.19) | GA | GA | GA |
| S. Dakota | MT | MN | MT | MT |
| Tennessee | LA | LA | LA | LA |
| Texas | LA TXN TXS (.09)(.13)(.78) | TXN TXS (.14)(.86) | TXN TXS (.20)(.80) | TXN TXS (.20)(.80) |
| Utah | ID | ID | ID | ID |
| Virginia | MD | MD | MD | MD |
| Washington | ID OR (.48)(.52) | OR | ID | ID OR (.40)(.60) |
| W. Virginia | NY | NY | MI | MI |
| Wisconsin | MN | MN | MN | MN |
| Wyoming | WY | WY | WY | WY |
| Stock | CA ID MN (.83)(.15)(.02) | CA ID (.73)(.27) | CA ID (.71)(.29) | CA CO ID MT (.56)(.06)(.28)(.10) |

Sugar beet and sugar cane growers might use the results to determine the specific locations for holding stocks and the associated relative shares. This information could indicate the anticipated private sector demand for their product. Areas with large stocks are likely to reduce the quantity of raw sugar used in the refining process.

Consumers may derive some benefits from the results. If real world flows approximate optimal flows, then society benefits from the lower total cost of product distribution. If not, then society pays a higher price than is necessary--an inefficient use of resources.

Finally, the transportation model used in this study, along with the available data, could be used to generate results based on a number of additional likely scenarios such as plant closings, construction of new plants, or government intervention of some form. Several simulations could be executed. The authors' current research will produce additional results in the near future.

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