Simulated Impact of a Regional Shift in Fed Cattle Production on the Location of Fed Cattle Slaughter

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During the past decade fed cattle slaughter has relocated to states situated in the southwest plains. Concern has developed that the economic depletion of groundwater used for irrigating feed grain could result in reduced levels of cattle feeding in that region. A reduction in cattle feeding activity could result in slaughtering plant closures and a relocation in slaughter activity to other regions. A mixed integer programming model was developed to simulate the possible effect of a declining cattle feeding industry in the southwest plains on the location of the fed cattle slaughtering and processing industry. Solution of the model indicated that the primary readjustment to lower levels of cattle feeding in the southwest plains would be in terms of plant and aggregate area volume, not plant location readjustment.

During the last two decades a number of spatial and structural changes have occurred in the cattle-beef industry. Until the 1960s the midwest had been the undisputed center of fed cattle production and slaughter. The development of extensive feed grain production in the southwest plains states during the 1960–80 period encouraged the growth of cattle feeding, shifting the production of fed cattle from the midwest to the southwest plains. New slaughtering and processing plants, utilizing innovative changes in plant specification, located near the growing supplies of fed cattle. These new plants opened with a number of competitive advantages relative to older existing facilities: (1) they were technologically modern and more efficient; (2) they often had superior locations to those of the existing plants; and (3) these new plants frequently had attractive labor contracts. These changes resulted in structural and spatial reorganization of the industry.

There is not satiating evidence that the structural and spatial reorganization of the cattle feeding and slaughtering industries is complete and the industries are prepared for a period of relative stability. A U.S. Department of Agriculture study notes a continued readjustment of plant locations in response to economic incentive from 1980 to 1981. Plants that were considered large by recent standards now appear diminutive when compared to the modern plants operating with capacities in excess of one million head per year. Plant closures and openings continue to be announced with considerable frequency. A recent study by Ball and Chambers reported the existence of increasing returns to scale in the meat products industry. The study concluded that there was potential for noncompetitive behavior and the industry was not near long-run competitive equilibrium.

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The increased use of irrigation for feed grain production in the southwest plains has been credited for creating much of the rapid growth in fed cattle production in that region during the 1970s.[1] The future viability of cattle feeding in the southwest plains is symbiotically related to feed grain production which is dependent, in part, on the future availability and cost of groundwater for irrigation.[2] Declining groundwater tables and increasing irrigation costs have created debate about the future viability of the southwest as the primary cattle feeding region in the United States.

A decline in fed cattle production potentially would have immediate and long-term effects on the structure and location of the cattle slaughtering and processing industry. In the short run, industry readjustment might be expected to result in plant closures or the bankruptcy of smaller and less efficient slaughtering firms (Williams). In the longer term, new plants would likely be located near alternative cattle supply areas. In summary, the adjustment from the present disequilibrium position (Ball and Chambers) to long-run structural and spatial equilibrium would likely be extended.

The purpose of this paper is to evaluate the effect on the location of fed cattle slaughter and processing of a reduction in fed cattle production (possibly resulting from declining groundwater availability) in the southwest plains. A mixed integer programming model is developed and solved to determine the optimal location of fed cattle slaughtering plants under various scenarios.

Groundwater Issues

Most of the groundwater irrigated area of the Texas and Oklahoma panhandles, eastern Colorado, and western Kansas are experiencing declines in groundwater levels and depletion of this resource is a growing concern (Sloggett). In addition, escalating pumping costs due to increases in the pumping lift (the height the water must be raised) and the cost of energy may render irrigation economically infeasible. Studies have indicated that economic depletion of groundwater for irrigation would likely result in shifts from the production of irrigated corn to alternative crops. Although the composition and size of the shifts is partially dependent on assumed scenarios for grain prices and energy costs some tentative conclusions may be formed on the basis of available studies.[3]

It is likely that most acreage currently producing irrigated corn and alfalfa in the high plains region would shift to dryland crops (Sloggett; Young; Young and Coomer). Likely alternative crops include dryland wheat and sorghum. Studies utilizing alternative grain price scenarios suggest that higher prices delay but do not prevent the shift from irrigated corn and alfalfa to dryland crops (Young; Young and Coomer). Higher wheat prices as a result of an expanded export market would result in increased acreage directed to wheat (and correspondingly less devoted to sorghum).

Fed Cattle Projections for Year 2000

Projections of the possible shift in the location of fed cattle production resulting

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[1] Other reasons for the increase include the introduction of hybrid sorghum, shift in acreage from cotton to grain, economies of large scale cattle feeding, and government commodity programs (Gustafson and Van Arsdell; Hieronymus).

[2] This study addresses the problem by assuming that decreases in feed grain production necessarily imply decreases in fed cattle production in the region. Cattle feeders could circumvent the problem of feed grain availability somewhat, by decreasing the quantity of grain fed to each animal (either by reducing the size of the daily ration or shortening the feeding period) or by importing feed grain from other regions.

[3] In addition the projected yield of alternative crops also affects the results.

from declining groundwater use in the southwest plains region were not found in the literature.[4] Therefore, a scenario based on relative regional fed cattle shares prior to the 1970s was developed as one pattern of production which might result from declining groundwater use. It was assumed that fed cattle production would revert back to the same regional shares of total production, updated for increased total production levels (to support expanded consumption due to a growing population). Fed cattle production for the year 2000 was projected assuming the 1970–80 average level of fed cattle marketings as a baseline. Fed cattle production estimates for the states of Texas, Oklahoma, Colorado, and Kansas were then adjusted downward by 20 percent (the approximate increase in these four states' fed cattle production during the 1970s). Since it was assumed that cattle feeding would revert back to the upper midwest, fed cattle production in Nebraska, Iowa, Minnesota, Illinois, and Missouri was adjusted upward to account for the decreased production in the southwest plains.

The Model

The impact of a regional shift in fed cattle production from the southwest plains to the upper midwest on fed cattle slaughtering and processing plant location for simulated fed cattle supplies in the year 2000 was analyzed using a mixed integer programming model. Figure 1 illustrates a simplified version of the model in terms of a prototype network graph with two supply regions, two slaughtering plants, two processing plants, and two demand regions. The formal mathematical model is described in the Appendix to this paper.

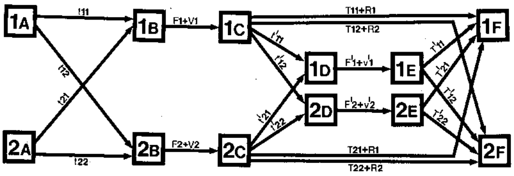

Figure 1. Network Graph of Prototype Model.

The two supply regions have available fed cattle supplies of A_1 and A_2, respectively. Each supply region may supply one or both of the two slaughtering plants. Each slaughtering plant may, in turn, supply carcasses to one or both processing plants, or ship carcasses directly to one or both of the demand regions. The arcs between nodes represent the costs of transportation, plant establishment, slaughtering, and processing.

Let iA nodes represent fed cattle supply points and jB nodes represent fed cattle slaughtering sites. The iA and jB nodes are connected by arcs representing fed cattle flows to slaughter and carry a transportation cost (t_{ij}). Level jC nodes are introduced to allow slaughtering costs. One-time fixed plant establishment costs (F_j) plus unit slaughtering costs (v_j) are carried on arcs connecting jB nodes to jC nodes. In addition, these arcs are constrained by a slaughtering plant capacity limit ($\bar{u}_j y_j$). Level kD and kE nodes represent processing plants. Level jC nodes are connected by arcs (with an associated transportation cost of t'_{jk}) to the level kD processing nodes. Level kE nodes are introduced to allow fixed (F'_k) and variable (v'_k) processing costs. These arcs are constrained by $\bar{u}'_k z_k$. Level lF nodes represent final demand sites. Arcs from jC to lF nodes represent the shipment of carcasses from slaughtering plants to final demand and carry transportation costs (T_{jl}) plus processing costs at retail (R_l). The retail processing cost is necessary to transform the carcasses to the same product value. Level lF nodes are also connected to kE

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[4] A simulation study by Ekholm *et al.* predicted a dramatic increase in fed cattle production to the year 2010, but this resulted from model parameters assigned on the basis of the rapid growth in feed grain and fed cattle production in the high plains during the 1967–75 period.

nodes. These arcs have an associated transportation cost (T'_{kl}) representing the costs of transporting processed beef to retail.

The empirical model was solved using 45 supply regions (43 sub-state and 2 aggregate regions), 52 demand regions, 50 potential slaughtering plant sites, and 50 potential processing plant sites.[5] Slaughtering and processing costs were based on economic engineering studies by Cothern *et al.* (1978a, 1978b). Transportation costs for shipping cattle and meat were developed from data provided by industry sources.

Two alternative plant sizes were assumed in solving the model. In the first case all slaughtering and processing plants had a maximum allowable capacity of 562,500 head per year. This annual plant output corresponds to what was generally the size of the largest existing plants during the early to mid 1970s. To account for the recent development of slaughtering and processing plants in excess of 1 million head per year capacity the model was also solved with all plants assigned a maximum annual capacity of 1,125,000 head.

Results

Table 1 shows the results of four simulations (two simulations each with a maximum allowable capacity of 562,500 and 1,125,000 head per year) and are presented on an individual plant basis. Table 2 summarizes these results on the basis of aggregated regions for the southwest plains and upper midwest. Each table compares the results from assuming no regional shift in fed cattle production to those from assuming a shift in production from the southwest plains to the upper midwest. Table 3 shows the number of plants selected for each region under the alternative scenarios.

When maximum plant capacity was restricted to 562,500 head per year the results with or without a shift in fed cattle production were quite similar. With the assumed shift in fed cattle production, plants originally selected at Friona and Dodge City left the solution while plants selected at Omaha and Dakota City entered the solution. Total output in the southwest plains fell from 11,953,163 to 10,938,339 head while it increased from 9,562,500 to 10,687,500 head in the upper midwest. The number of plants selected in the southwest plains fell by 2, from 22 to 20, while increasing from 17 to 19 in the upper midwest.

The results show more variation when maximum allowable plant capacity was increased from 562,500 to 1,125,000 head. The number of plants selected fell by nearly one-half when the allowable plant capacity was doubled. The decrease in the number of plants selected was a direct result of the utilization of available plant capacity. Total plant volume in the southwest plains fell from 13,629,048 to 10,327,054 head, while in the upper midwest plant output increased from 9,000,000 to 11,250,000 head.[6] Plants that were selected under the no shift scenario that left the solution when the regional shift was assumed included the Denver, Omaha, Oakland, Dumas, and Emporia sites. Plants entering the solution that were not selected in the no shift scenario included the Schuyler, Norfolk, Spencer, Wichita, Dubuque, and Roswell sites.

With only several exceptions, all plants selected when capacity was limited to 562,500 head per year entered the solution at the maximum allowed level. However, this was not the case with allowable capacity of 1,125,000 head per year. With no regional shift in cattle production 6 of the 22 plants selected entered with less

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[5] A detailed description of techniques used in developing regions, supplies, demands, and costs used in this study may be found in Faminow and Sarhan.

[6] The difference in total plant output for the two plant size scenarios is due to the inclusion of plants in other areas of the country. These results are not reported here but can be obtained from the authors.

TABLE 1. Results of Simulation for the Year 2000.

Plant Location	Plant Output With Annual Capacity of 562,500 Head		Plant Output With Annual Capacity of 1,125,000 Head	
	No Shift	With Shift	No Shift	With Shift
	(Number of Head)			
Greeley	562,500	562,500	1,125,000	1,125,000
Sterling	562,500	562,500	676,343	1,125,000
Fort Morgan	562,500	562,500	[a]	[a]
Denver	[a]	[a]	[a]	[a]
Denver	562,500	562,500	978,102	[a]
Schuyler	562,500	562,500	[a]	1,125,000
West Point	562,500	562,500	1,125,000	1,125,000
Omaha	[a]	562,500	[a]	[a]
Omaha	562,500	562,500	[a]	[a]
Dakota City	[a]	562,500	[a]	[a]
Omaha	562,500	562,500	[a]	[a]
Nebraska City	562,500	562,500	1,125,000	1,125,000
Norfolk	562,500	562,500	[a]	1,125,000
Omaha	562,500	562,500	1,125,000	[a]
Spencer	562,500	562,500	[a]	1,125,000
Council Bluffs	[a]	[a]	[a]	[a]
Fort Dodge	562,500	562,500	[a]	[a]
Denison	562,500	562,500	1,125,000	1,125,000
Oakland	562,500	562,500	1,125,000	[a]
Des Moines	562,500	562,500	1,125,000	1,125,000
Estherville	562,500	562,500	1,125,000	1,125,000
Portales	[a]	[a]	[a]	[a]
Clovis	[a]	[a]	[a]	[a]
Amarillo	562,500	562,500	1,125,000	1,125,000
Hereford	562,500	562,500	1,125,000	1,125,000
Hereford	562,500	562,500	[a]	[a]
Amarillo	562,500	562,500	[a]	[a]
Lubbock	562,500	562,500	1,125,000	760,063
Plainview	562,500	562,500	[a]	[a]
Friona	562,500	[a]	[a]	[a]
Dumas	562,500	562,500	1,125,000	[a]
Guymon	562,500	562,500	735,418	1,038,335
Oklahoma City	309,707[b]	250,839[b]	652,124	247,765[b]
Emporia	562,500	562,500	534,660	[a]
Liberal	[a]	[a]	[a]	[a]
Holcomb	562,500	562,500	1,125,000	1,125,000
Dodge City	562,500	562,500	1,052,401	603,813
Wichita	393,456	562,500	[a]	427,728
Lamar	562,500	562,500	1,125,000	913,108
Kansas City	562,500	562,500	1,125,000	711,242
Wichita	[a]	[a]	[a]	[a]
Arkansas City	[a]	[a]	[a]	[a]
Dodge City	562,500	[a]	[a]	[a]
Garden City	562,500	562,500	[a]	[a]
Dubuque	562,500	562,500	[a]	1,125,000
Joslin	562,500	562,500	1,125,000	1,125,000
Rock Port	562,500	562,500	[a]	[a]
St. Joseph	562,500	562,500	[a]	[a]

[a] No plants were selected at this site.

[b] In the plant selected at this location a slaughter facility was selected and the processing facility was not selected.

TABLE 2. Summarized Simulation Results by Aggregate Region.

Region	Plant Output With Annual Capacity of 562,500 Head		Plant Output With Annual Capacity of 1,125,000 Head	
	No Shift	With Shift	No Shift	With Shift
	(Number of Head)			
Southwest Plains[a]	11,953,163	10,938,339	13,629,048	10,327,054
Upper Midwest[b]	9,562,500	10,687,500	9,000,000	11,250,000

[a] Eastern Colorado, Texas panhandle, Oklahoma, and Kansas.
[b] Nebraska, Iowa, Minnesota, Missouri, and Illinois.

than full capacity (the Dodge City plant entered near capacity). With the assumed regional shift 7 of the 22 selected palnts entered below capacity, all located in the southwest plains region.

Summary and Conclusions

This study considered the effect of shifts in fed cattle production from the southwest plains to the upper midwest on the location and volume of fed cattle slaughtering and processing. Fed cattle supply was projected to the year 2000 assuming the 1970–80 average levels of regional fed cattle supply as a baseline under two alternative scenarios: (1) no shift in the regional pattern of fed cattle production and (2) a shift from the southwest plains to the upper midwest. A mixed integer programming model was used to simulate the plant selection process.

The results of the study indicated increases in both the number of plants and volume of production in the upper midwest at the expense of the southwest plains. However, increases in production were relatively larger than the increases in the number of plants. Given the size of the shift in fed cattle production, the shift in plants and beef production was rather modest. This was due to two factors. First, plant cost functions used in mixed integer linear programming models (such as the one used here) are expressed in terms of a fixed (all or nothing) plant establishment cost plus a constant marginal cost. Therefore, average total cost is a declining function of plant output and it generally pays to utilize all available plant capacity, at least up to the point where the increase in the cost of shipping livestock at the margin is not greater than the cost reduction of an additional unit of output. Second, the population estimates for the year 2000 used to project regional demand contained a relative shift in population (and hence beef demand) to the western part of the country. The economies in plants located in the upper midwest resulting from increased fed cattle supplies (and hence decreased unit plant costs) were offset somewhat by increased demand in the western states where the southwest plains states have a spatial advantage (in terms of beef shipping costs) vis-à-vis the upper midwest.

In summary, it appears that although a shift in fed cattle production (possibly re-

TABLE 3. Number of Plants Selected by Region.

Region[a]	Number of Plants Selected: Maximum Annual Capacity of 562,500 Head		Number of Plants Selected: Maximum Annual Capacity of 1,125,000 Head	
	No Shift	With Shift	No Shift	With Shift
	(Number of plants)			
Southwest Plains	22	20	14	12
Upper Midwest	17	19	8	10

[a] See Footnotes to Table 2.

sulting from declining groundwater use) will hurt the fed cattle slaughtering and processing industry in the southwest plains, the impact is not as great as might be feared. The primary readjustment in the model was in terms of volume (individual plant and aggregate volume) not plant closures. It appears, based on the results presented above, that the future viability of large-scale slaughtering and processing plants is dependent upon trends in fed cattle production. Significant declines in fed cattle production in the southwest due to the possible economic depletion of groundwater could affect the long-term viability of existing large-scale plants (over 1 million head per year capacity). However, the results also indicate that the readjustment would not likely result in a large reduction in the number of major plants operating in the region.

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Appendix

Constants indicate the costs, plant capacities, regional supplies, and regional demands in the model. Let: F_j = the annual fixed cost of establishing a fed cattle slaughtering plant at site j; F'_k = the annual fixed cost of establishing a fed beef carcass processing plant at site k; v_j = the unit cost of slaughtering fed cattle in a plant located at site j; v'_k = the unit cost of processing fed beef carcasses in a plant located at site k; t_{ij} = the unit cost of transporting fed cattle from supply region i to a slaughtering plant located at site j; t'_{jk} = the unit cost of transporting fed beef carcasses from a slaughtering plant located at site j to a processing plant located at site k; T_{jl} = the unit cost of transporting fed beef carcasses from a slaughtering plant located at site *j* to final demand region *l* plus the unit cost of processing fed beef carcasses at demand region *l*; T'_{kl} = the unit cost of transporting processed fed beef from a processing plant located at site *k* to final demand region *l*; $\bar{u}_j$ = the annual slaughtering plant capacity for a slaughtering plant located at site *j*; $\bar{u}'_k$ = the annual processing plant capacity for a processing plant located at site *k*; A_i = the supply of fed cattle in supply region *i*; and D_l = the demand for fed beef in final demand region *l*.

Given the above fixed and known coefficients the following decision variables are defined: x_{ij} = units of fed cattle transported from supply region *i* to slaughtering plant located at site *j*; c_{jk} = units of fed beef carcasses transported from a slaughtering plant located at site *j* to a processing plant located at site *k*; cr_{jl} = units of fed beef carcasses transported from a slaughtering plant located at site *j* to final demand region *l*; b_{kl} = units of processed fed beef carcasses transported from processing plant located at site *k* to final demand region *l*; S_j = units of fed cattle slaughtered in a slaughtering plant located at site *j*; P_k = units of fed beef carcasses processed in a processing plant located at site *k*; y_j = a binary variable for selecting or not selecting a slaughtering plant at site *j*; and z_k = a binary variable for selecting or not selecting a processing plant at site *k*.

The mathematical model is defined so as to minimize aggregate industry costs of fed cattle transportation, slaughtering and processing, and beef transportation subject to plant capacity, product flow, fed cattle supply, and fed beef demand constraints. Formally, the problem may be stated as follows. Minimize:

$$\begin{aligned}\sum_i \sum_j t_{ij}x_{ij} + \sum_j \sum_k t'_{jk}c_{jk} + \sum_j \sum_l T_{jl}cr_{jl} \\ + \sum_k \sum_l T'_{kl}b_{kl} + \sum_j (F_jy_j + v_jS_j) \\ + \sum_k (F'_kz_k + v'_kP_k).\end{aligned} \qquad (1)$$

Subject to:

$$S_j \leq \bar{u}_jy_j \qquad \text{(for all j)}, \qquad (2)$$

$$P_k \leq \bar{u}'_kz_k \qquad \text{(for all k)}, \qquad (3)$$

$$\sum_l cr_{jl} + \sum_k c_{jk} = S_j \qquad \text{(for all j)}, \qquad (4)$$

$$\sum_l b_{kl} = P_k \qquad \text{(for all k)}, \qquad (5)$$

$$\sum_i x_{ij} = S_j \qquad \text{(for all j)}, \qquad (6)$$

$$\sum_j c_{jk} = P_k \qquad \text{(for all k)}, \qquad (7)$$

$$\sum_j x_{ij} \leq A_i \qquad \text{(for all i)}, \qquad (8)$$

$$\sum_j cr_{jl} + \sum_k b_{kl} \geq D_l \qquad \text{(for all l), and} \qquad (9)$$

$$S_j, P_k, y_j, z_k, cr_{jl}, c_{jk}, b_{kl}, x_{ij} \geq 0. \qquad (10)$$