INTERREGIONAL COMPETITION IN THE U.S. SWINE-PORK INDUSTRY: AN ANALYSIS OF OKLAHOMA'S AND THE SOUTHERN STATES' EXPANSION POTENTIAL

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During the past few years, considerable interest has been expressed by swine producers, pork packers, and processors concerning the potential for expanding Oklahoma's swine-pork industry, even though the state's largest hog slaughtering facility has ceased operation. The study described herein was undertaken to satisfy these interests. The general objective was to identify the conditions necessary for and the limits to the expansion of Oklahoma's swine-pork industry. Due to the national scope of the model, similar information concerning other regions is also made available. The objective was addressed through a series of sub-objectives that dealt with the determination of expansion potential under various exogenous conditions. The characteristics of the various situations were:

1. Base situation: Oklahoma's slaughter capacity was reduced to reflect the July 1981 closing of the Wilson Foods Corporation slaughter plant in Oklahoma City. This plant accounted for an estimated 67 percent of the 1979 pork slaughter capacity in Oklahoma. Demand functions for pork were estimated using 1979 population distributions. Slaughter costs include aggregate (union and nonunion) wage rates. Transportation costs were based on 1979 fuel prices.
2. Entry of a new packer: The entry of a new packer in the Corn Belt area is imminent. Pork industry personnel and producer groups have discussed the potential entry of a new, highly capitalized pork processor entering the industry. It is anticipated that the entry of a new firm might bring about major changes in the industry. The packer is assumed to have a capacity of two million head per year and slaughter costs twenty percent below those of Iowa. The lower slaughter costs are attributed to a combination of improved technology and lower wage rates. The location of this new packer was assumed to be at Kirksville, Missouri, or Davenport, Iowa. All the costs and demand functions were as they were in the base situation.
3. Varying wage rates: Only slaughter costs differed from the base situation. Labor costs are one of the primary factors used to explain recent slaughter-plant closings. The new slaughter costs reflected (1) totally unionized wage rates or (2) totally nonunionized wage rates in all regions.

MODEL

The theory of spatial price and quantity equilibrium among separated regions has been addressed by several authors (Samuelson; Bressler and King; Hoover; Enke). Several methodologies have been used to formulate models for spatial studies. Three common mathematical programming techniques used are reactive, linear, and quadratic programs. King and Logan developed a linear programming transhipment model to determine the optimum number and size of beef slaughtering plants in California. Ladd and Lifferth used a linear program to determine number, size, and location of grain-handling facilities in Iowa. Both studies assumed inelastic supply and demand functions. Fuller et al. used a mixed-integer linear program formulation to determine optimal location and size of cotton gins in the Rio Grande Valley of Texas.

Von Oppen and Scott combined a single-equation location model and a quadratic program to simultaneously determine regionally optimal numbers and sizes of processing plants and optimal interregional trading and pricing. Reactive programming was used by Trammel and Seal, King and Ho, and Riley to study spatial problems.

Several researchers have applied the basic concepts of spatial theory and interregional supply and demand relationships to the swine-pork industry. Judge and Wallace were among the first to investigate spatial aspects of the U.S. swine-pork industry. They used linear programming to determine which shipment patterns minimize total transport costs of live hogs and pork from surplus to deficit regions. Production and slaughter costs were not considered in their study. Kelly et al. used a model similar to that of Judge and Wallace to investigate the possibility of increasing hog production in western Kansas. Again, neither production nor slaughter costs were considered, and supplies were assumed to be fixed.

Lee and Perrin, and Sprott both used linear programming transhipment models for spatial studies of

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the swine-pork industry. Sprott's model used perfectly inelastic demand functions, perfectly elastic supply functions, and estimates of regional slaughter costs. The model was solved using several sets of assumed conditions for purposes of sensitivity analysis. Lee and Perrin assumed that the supplies of hogs and demands for pork were fixed and did not include production or slaughter costs.

The integrated programming model developed for this study involved a sequential employment of reactive programming and linear programming (Meyer). To the author's knowledge, this is the first application of an integrated model of this type to a spatial problem. Reactive programming was used to calculate spatial equilibrium quantities and prices for pork in each consumption region assuming that the total available supply of pork was fixed. Linear programming was used to develop a transhipment model for solving least-cost patterns of production, live hog shipments, slaughter, and meat shipments. The transhipment routine contained stepped supply functions for live hog production assuming that the total quantity of pork demand was fixed. In essence, the total quantity of hogs produced and consumed is fixed; however, the model allowed the use of inelastic supply and demand schedules to endogenously determine quantity and prices for each of the swine-production and pork-consumption regions.

The explicit objective of reactive programming was to maximize the net revenues to shippers of pork. In this study, pork shippers were represented by slaughter regions. In mathematical terms, this objective is stated as:

$$(1) \qquad Z = \sum_{j=1}^{m} \sum_{k=1}^{n} Q_{jk} (P_k - C_j - MT_{jk})$$

subject to

$$\sum_{j=1}^{m} Q_{j\cdot} = \sum_{k=1}^{n} Q_{\cdot k}$$

$$Q_{jk}, P_k, C_j \geq 0$$

Where

Z = total net revenues for slaughterers

Q_{jk} = quantity shipped from the jth slaughter region to the kth consumption region $j = 1, \ldots m$ and $k = 1, \ldots n$

P_k = price in the kth consumption region,

$$P_k = f(\sum_{k=1}^{m} Q_{jk})$$

C_j = cost of pork in the jth slaughter region

MT_{jk} = transport costs per unit from the jth slaughter region to the kth consumption region

$Q_{j\cdot}$ = quantity shipped from the jth slaughter region

$Q_{\cdot k}$ = quantity received in the kth consumption region

Equation 1 was maximized only when spatial equilibrium conditions were fulfilled since, under any other situation, there existed incentives for slaughterers to redirect pork shipments to higher-value markets.

The strength of reactive programming lies in the theoretical correctness of its solutions. Downward-sloping demand functions, either perfectly inelastic or upward-sloping supply functions, and constant transfer costs are used to derive the quantities supplied and demanded in all regions, quantities shipped between regions, and prices in all regions that satisfy spatial equilibrium conditions. However, only one level of a marketing system can be investigated with this algorithm. It contains no mechanism by which two slaughter regions or suppliers of pork can purchase raw product from one production region. The program views each purchase as unique and computes supply prices for each purchase as $f(Q_1)$ and $f(Q_2)$, when the actual supply price should be $f(Q_1 + Q_2)$.

Hurt rectified the "single-level" shortcoming of reactive programming by incorporating a transhipment problem into the routine assuming that raw product supplies are fixed and that marketing margins must conform to a functional form. Moreover, costs of some levels are aggregated, and thus some items of useful detail information may not be available in the output. To provide detail information concerning each level of the marketing system, a separate transhipment model including activities for live hog production, live hog shipment, slaughter, and meat shipment was used.

The objective of the transhipment routine was to minimize the total cost of pork to consumers subject to several constraints. Mathematically, this objective was:

Minimize:

$$(2) \qquad Y = \sum_{i=1}^{1} (PC_i \cdot Q_i^P) + \sum_{i=1}^{1} \sum_{j=1}^{m} (LT_{ij} \cdot Q_{ij}) + \sum_{i=1}^{1} \sum_{j=1}^{m} (SC_j \cdot Q_{ij} (1 - S_{ij})) + \sum_{j=1}^{m} \sum_{k=1}^{n} (MT_{jk} \cdot Q_{jk})$$

subject to

$$Q_i^P \geq F_i^P$$

$$\sum_{i=1}^{1} Q_{ij} (1 - S_{ij}) \leq SCAP_j$$

$$\sum_{j=1}^{m} Q_{jk} = Q_k^D$$

$$Q_i^P Q_{ij} Q_{jk} \geq O$$

Where

Y = total cost of pork in consumption regions

PC_i = cost of live hog production per unit in the ith production regions $i = 1, \ldots, l$

Q_i^P = quantity of pork produced in the ith production region

LT_{ij} = live transport costs per unit for shipments from the ith production region to the jth slaughter region $j = 1, \ldots, m$

Q_{ij} = quantity of live hogs shipped from the ith production region to the jth slaughter region

SC_j = slaughter costs in the jth slaughter region

S_{ij} = percent shrinkage of live hogs shipped from the ith production region to the jth slaughter region

F_i^P = production constraint level in the kth production region

$SCAP_j$ = slaughter capacity in the jth slaughter region

Q_k^D = demand requirement in the kth consumption region

Like reactive programming, the LP-transhipment routine has its share of weaknesses. Linear programs (of any sort) are rather difficult to use for spatial equilibrium studies in that they require the manual adjustment of quantities supplied and/or demanded and costs and/or prices. Stepped functions (Henry and Rauniker) for supply and/or demand may be included but, due to their discontinuity, exact spatial equilibrium conditions may not be met. Furthermore, solutions for least-cost flows with fixed supplies and demands in no way guarantee a spatial equilibrium solution.

In spite of these weaknesses, the transhipment routine possesses several points of strength. Its treatment of successive levels of the pork marketing system allows the determination of optimal quantities for production and marketing activities. The information contained in the RANGE output of the MPSX linear programming routine (or sensitivity analysis sections of other routines) provides data concerning marginal values of these activities from which conclusions concerning expansion potential may be drawn.

In an effort to exploit the strengths and shore up the weaknesses of the two individual routines, the integrated model was developed. The separate routines were employed in a sequential manner to solve for least-cost patterns of production, slaughter, and shipments fulfilling spatial equilibrium demands.

First, reactive programming was used to solve for spatial equilibrium pork demands assuming that demand functions were of log-linear form and that supplies of pork were fixed. Second, the transhipment routine was solved to determine the least-cost patterns of production, slaughter, and shipments that satisfied the spatial equilibrium demands. The transhipment routine contained stepped supply functions for live hog production. Finally, the reactive program was resolved to verify that the meat shipments found by the transhipment routine actually fulfilled spatial equilibrium conditions in the pork market.

The integrated model utilized the basic functions of the system: retail demand and farm supply. It does not require a specific marketing margin to hold, but treats the margin as the residual of retail price over costs that can be specifically determined. This feature, in essence, agrees with a popular view first expressed by Gardner (p. 406). Lastly, the integrated model allows successive levels of the marketing system to be analyzed and provides a great deal of detail information regarding the marginal values of production, slaughter, and shipment activities and constraints. It is this information that was used to determine the expansion potential of the swine-pork industry in Oklahoma and the southern states.

DATA

The total 1979 U. S. commercial pork production in carcass weight (*Livestock and Meat Situation, USDA*) served as the base quantity from which regional production, slaughter, and consumption were derived. A map of the study regions appears in Figure 1. Twenty-eight production, slaughter, and consumption regions were identified in the continental United States. Some of the regions include more than one state. Region 3, denoted as 3-GA, includes both Georgia and South Carolina. Georgia was designated as the base point within region 3 for the origin, destination, production, slaughter, and/or consumption quantities of swine and pork; hence region 3 was identified as 3-GA.

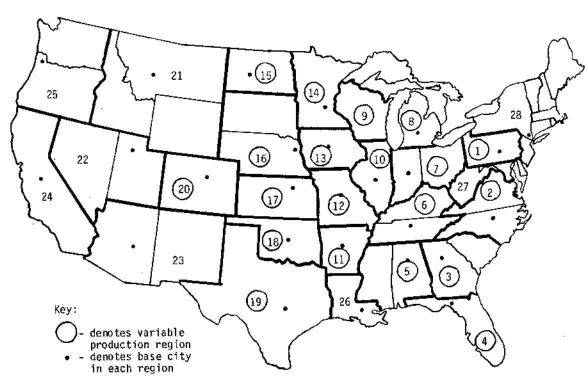

Figure 1. Regional Demarcation of the Contiguous United States.

Regional distributions of production and slaughter were computed from data from *Livestock and Meat Situation*, and the *Livestock Slaughter Annual Summary (USDA)*. Pork consumption distributions were computed using 1979 regional population estimates (U. S. Bureau of the Census), 1979 per capita pork consumption (*Livestock and Meat Situation*), and regional consumption indexes (Market Research Corporation of America). Base distributions of slaughter and consumption were then computed by multiplying the base quantity, 15.27 billion pounds of carcass pork, by the proportion of the national total represented by each of the regions for slaughter and consumption. The base quantity for live hog production was computed by multiplying 15.27 billion pounds by a conversion factor of 1.61 (weight of live hog which yields one pound of carcass pork). Regional base production quantities were then computed by multiplying each region's proportion of national total live production times the base quantity of live production.

Data showing slaughter capacities in regions are not available. Therefore, regional physical slaughter capacities were computed by multiplying the peak slaughter month for 1979 in all regions by 12. Data for 1979 were used because of the large numbers of hogs produced and of breeding herds liquidated in that year.

Regional demand functions for retail pork were assumed to be of the form

$$(3) \qquad Q_k^D = a_k P_k^b$$

Where

a_k = the scale factor for the kth consumption region

b = the own-price elasticity of demand for pork

A long-run elasticity of demand of −0.413013 estimated by George and King was assumed to apply to all regions. The 1979 national average retail price of pork (*Developments in Marketing Spreads for Food Products in 1979,* USDA) was adjusted for regional differences by using regional price indexes from George and King. Base consumption quantites were then combined with the regional retail pork prices and the estimate of the elasticity of demand to compute a_k for each consumption region. These functions were used in the reactive program.

Stepped approximations of farm-supply functions for all variable production regions were computed from base production quantities, USDA estimates of swine production costs, and an estimate of the long-run elasticity of supply for hogs. The elasticity of supply was assumed to be 0.45 (Ray and Richardson) and was used for all regions. Stepped cost activities for two successive 2-percent increases in production in each region were included in the transhipment model. Details associated with production costs and the stepped supply functions appear in Meyer (pp. 74–76).

Estimates of both live hog and meat transportation costs were based on data collected from an April 1981 survey of nine livestock shippers and three refrigerated-transport companies. Ordinary least squares regressions were done on the data after it was deflated to 1979 levels. All meat transport costs were increased by 19 percent to account for the fuel surcharge used by all of the surveyed refrigerated-transport companies. This surcharge did not apply to live hog shipments.

Estimates of slaughter costs used in the study are based on a survey of pork slaughter and processing plants conducted by Food Management Incorporated for the U. S. Department of Agriculture. This report contained estimates of nonlabor costs per head and labor requirements (in hours) per head. Nonlabor costs were inflated to 1979 price levels using indices from the U. S. Department of Labor and U. S. Bureau of Labor Statistics. Labor costs in 1979 were computed by using regional aggregate wages (a weighted average of union and nonunion wages) from the American Meat Institute.

RESULTS

Base Situation

The optimal solution for the base situation revealed the sources of imports to and destinations of exports from southern states for both live hogs and pork. The base situation is based on 1979 production, slaughter, and consumption data, except that Oklahoma's slaughter capacity was reduced to reflect the closing of Wilson Foods Corporation's Oklahoma City slaughter plant. Swine and pork shipments are shown in Tables 1 and 2, respectively. Among the southern states, only 11-AR and 18-OK produced and exported hogs to other southern regions. Of the live hogs needed, 24 percent originate in states outside the slaughter region. Southern states import hogs from 7-IN, 10-IL, 11-AR, 12-MO, 17-KS, and 18-OK.

Table 1. Optimal Live Hog Shipment Patterns in the Southern States for Production, Slaughter, and Consumption Required at 1979 Levels.

Region	Intraregional Shipments	Interregional Shipment Origins						Total Live Hog Demands
		7-IN	10-IL	11-AR	12-MO	17-KS	18-OK	
				(mil. lbs.)				
2-NC	1111.4	244.2						1355.6
3-GA	769.5							769.5
4-FL	47.8							47.8
5-AL	463.7			136.8	184.9			785.4
6-TN	866.1		446.9		281.8			1594.8
11-AR	73.0							73.0
18-OK	120.4							120.4
19-TX	363.2					117.6	4.9	485.7
26-LA	43.8			11.6				55.4
Totals	3858.9	244.2	446.9	148.4	466.7	117.6	4.9	5287.6

Table 2. Optimal Pork Shipment Patterns in the Southern States for Production, Slaughter, and Consumption Required at 1979 Levels.

Region	Intraregional Shipments	Interregional Shipment Origins					Total Pork Demands
		6-TN	10-IL	12-MO	13-IA	17-KS	
				(mil. lbs.)			
2-NC	842.0						842.0
3-GA	477.9	148.8					626.7
4-FL	29.7				659.8		689.5
5-AL	487.8	66.9	51.9				606.6
6-TN	774.7						744.7
11-AR	45.3			13.3	101.2		159.8
18-OK	74.8				64.0	73.3	212.1
19-TX	301.7				677.6		979.3
26-LA	34.4			259.6			294.0
Totals	3068.3	215.7	51.9	272.9	1502.6	73.3	5184.7

Region 6-TN was the only region in the South whose pork output exceeded its own demands in the optimal solution. This excess pork was shipped to 3-GA and 5-AL. Of the pork needed in the southern states, 37 percent originated from outside the region. Two regions, 13-IA and 12-MO, were major suppliers of pork to the South, exporting 1502.6 and 272.9 million pounds, respectively, to southern states. The largest amount of the Corn Belt pork was received by 19-TX and 4-FL.

A primary concern of this study was to determine expansion potential and the conditions necessay for this potential to be realized in southern states. The optimum production levels, shadow prices, upper limits of potential expansion, and the maximum change in production costs that can occur for the expansion potential to be realized for selected production regions are shown in Table 3. The long-run expansion potential is shown for the base and postulated exogenous situations. A negative shadow price indicates that the objective function (total cost of pork) of the transhipment routine will decrease by the value of the shadow price for each additional hundredweight of hogs produced in the production region up to the upper limit. Alternatively, production costs per hundredweight can increase by an amount up to the absolute value of the shadow price, provided additional facilities are available and expansion could occur up to the upper limit. A positive shadow price indicates that production costs must decrease for expansion to occur.

In 18-OK, for example, the base swine production cost was $55.53 per hundredweight. The optimal production level resulting from the integrated model was 126.9 million pounds. Region 18-OK has the potential to increase swine production from 123 million pounds to 249.9 million pounds, provided that each incremental hundredweight of swine can be produced for no more than $0.89 above the base production cost. Expansion can occur, provided production costs do not exceed $56.42 ($55.53 + 0.89) per hundredweight. If expansion occurred and production costs did not increase, then the value of the transhipment model objective function would decrease by $0.89 for each hundredweight of increased production in 18-OK up to a maximum of 249.9 million pounds. The 123-million-pounds expansion potential represents a 96.9-percent increase above the 126.9-million-pounds optimum production level. The $56.42-per-hundredweight maximum cost is 101.6 percent of the production base cost ($55.53).

In the base situation, production costs for the incremental units of production in regions 3-GA, 4-FL, and 6-TN must be below 1979 cost levels. Each of these

Table 3. Least-Cost Production Levels, Expansion Potential, and Shadow Prices of Expanded Live Hog Production in the South.

			Production Region							
Situation	Item	Units	2-NC	3-GA	4-FL	5-AL	6-TN	11-AR	18-OK	19-TX
	Production Base Cost	$/cwt.	58.14	58.14	58.14	58.14	58.14	53.96	55.53	57.99[1]
Base	Optimum Production Level	mil. lbs.	1124.5	778.5	48.4	469.2	876.3	228.9	126.9	367.5
	Shadow Price	$/cwt.	-1.79	.72	1.54	-.67	.43	-2.25	-.89	-1.10
	Upper Limit	mil. lbs.	1331.7	970.1	241.2	656.3	881.6	422.3	249.9	486.5
	Expansion Potential	mil. lbs.	207.2	191.6	192.8	187.1	5.3	193.4	123.0	119.0
	Increase in Production	pct. of '79	18.4	24.6	398.3	39.9	.6	84.5	96.9	32.4
	Max. Proportion of Base Cost	pct. of '79	103.1	98.8	97.4	101.2	99.3	104.2	101.6	102.0
New Packer Kirksville, MO	Optimum Production Level	mil. lbs.	1124.5	778.5	48.4	469.2	882.5	228.9	126.9	367.5
	Shadow Price	$/cwt.	-1.50	.76	1.57	-.63	.12	-2.21	-.29	-.48
	Upper Limit	mil. lbs.	1371.6	970.1	241.2	656.3	885.8	422.3	249.9	486.5
	Expansion Potential	mil. lbs.	247.1	191.6	192.8	187.1	3.3	193.4	123.0	119.0
	Increase in Production	pct. of '79	22.0	24.6	398.3	39.9	.4	84.5	96.9	32.4
	Max. Proportion of Base Cost	pct. of '79	102.6	98.7	97.3	101.1	99.8	104.1	100.5	100.9
Davenport, IA	Optimum Production Level	mil. lbs.	1124.5	778.5	48.4	469.2	880.7	228.9	126.9	367.5
	Shadow Price	$/cwt.	-1.50	.73	1.55	-.65	.02	-2.24	-.31	-.51
	Upper Limit	mil. lbs.	1371.6	970.1	241.2	656.3	885.4	422.3	249.9	486.5
	Expansion Potential	mil. lbs.	247.1	191.6	192.8	187.1	4.7	193.4	123.0	119.0
	Increase in Production	pct. of '79	22.0	24.6	398.3	39.9	.5	84.5	96.9	32.4
	Max. Proportion of Base Cost	pct. of '79	102.6	98.7	97.3	101.1	99.9	104.2	100.6	100.9
Wage Rates Unionized	Optimum Production Level	mil. lbs.	1124.5	778.5	48.4	469.2	876.4	228.9	126.9	367.5
	Shadow Price	$/cwt.	-1.80	.72	1.54	-.67	.58	-2.25	-.87	-1.10
	Upper Limit	mil. lbs.	1277.2	970.1	241.2	656.3	881.8	422.3	249.9	486.5
	Expansion Potential	mil. lbs.	152.7	191.6	192.8	187.1	5.4	193.4	123.0	119.0
	Increase in Production	pct. of '79	13.6	24.6	398.3	39.9	.6	84.5	96.9	32.4
	Max. Proportion of Base Cost	pct. of '79	103.1	98.8	97.4	101.2	99.0	104.2	101.6	102.0
Non-unionized	Optimum Production Level	mil. lbs.	1124.5	778.5	48.4	469.2	875.3	228.9	126.9	367.5
	Shadow Price	$/cwt.	-1.60	.72	1.54	-.67	.22	-2.25	-.56	-.76
	Upper Limit	mil. lbs.	1257.2	970.1	241.2	656.3	880.1	422.3	249.9	486.5
	Expansion Potential	mil. lbs.	132.7	191.6	192.8	187.1	4.8	193.4	123.0	119.0
	Increase in Production	pct. of '79	11.8	24.6	398.3	39.9	.5	84.5	96.9	32.4
	Max. Proportion of Base Cost	pct. of '79	102.8	98.8	97.4	101.2	99.6	104.2	101.0	101.4

[1] Production cost is for the second level of the stairstepped production function. The production cost and maximum production allowed for the initial production level was $55.53/cwt. and 360.3 mil. cwt., respectively.

regions must decrease production costs if expansion is to occur. For all other regions, production costs can be greater than 1979 costs, and the expansion will still occur, provided that enough production facilities are added. Region 4-FL has the greatest expansion potential as a percentage of 1979 (398.3%), but also has the largest cost-decrease requirement (2.6%). Region 2-NC has the largest expansion potential in physical units (207.2 million pounds) and the second-largest production-cost-increase allowance (3.1%). Region 11-AR has the largest cost-increase allowance (4.2%) for additional production activities. Fulfillment of expansion potential in 19-TX would allow that region to be self-sufficient with respect to live hogs. All other potentials, when fulfilled, allowed the respective regions to displace shipments from Corn Belt producers into southern states.

Entry of a New Packer and Swine Production

The entry of a new packer at either location increased the expansion potential over the base situation in physical units for 2-NC by 19 percent (207 to 249 million pounds) and decreased the potential for 6-TN by 2 million pounds. The physical expansion potentials for all other regions remained the same. The maximum cost of production for expansion quantities in regions 2-NC, 18-OK, and 19-TX decreased by approximately one percent. These changes occurred because the respective Corn Belt regions in which the plants were located had a ready market for live hogs near the points of production. Therefore, more slaughter capacity in region 2-NC was made available, and production costs in the three regions noted could not increase as much and still be in an advantageous competitive position.

Unionized vs. Non-unionized Wages and Swine Production

Totally unionized labor in slaughter plants had very little impact on the swine expansion potential of Oklahoma and the southern states. In physical units, the expansion potential for region 2-NC decreased by 26.3 percent (54.5 million pounds), while region 6-TN showed the only increase 2 percent above the base situation.

Totally nonunion wages had a minimal effect on the expansion potential of pork production. Regions 2-NC and 6-TN showed decreases in physical quantities of 74.5 and 0.5 million pounds, respectively. The shadow price associated with 2-NC was negative, while that associated with 6-TN was positive. The effect of wage rates on expansion potential were the result of varying relative differences among regions between aggregate wages, and the nonunion and union wages.

Slaughter Industry

Just as information concerning the potential for expansion of live hog production was provided in the transhipment routine, so was similar information concerning expansion potential for slaughter. However, several differences exist in the analytical procedures used. First, the assumption that the supply of slaughter services was perfectly elastic precluded any analysis of short-run expansion potential. Second, any investment in new slaughter facilities must hold the promise of a return that is at least as large as the return from the next-best alternative for investment. Finally, since the objective of the transhipment routine was to minimize the total cost of pork to consumers, the shadow price on the slaughter capacity constraint row for any region represents the value of an additional unit of slaughter capacity in that region.

Potential returns to investment in new slaughter facilities were computed assuming that the potential new or expanding packer could (1) capture the entire value of an additional unit of slaughter capacity, (2) slaughter hogs in the additional facilities for costs that were not higher than the costs used in the study, and (3) build new capacity for $50 per head of annual capacity.[1] Table 4 shows these estimates, slaughter activity levels, and expansion limits for the given returns for all situations. The assumed locations for the new slaughter facility were Kirksville, Missouri, or Davenport, Iowa. No information appears in Table 4 concerning region 2-NC. This omission is the result of the region's having excess slaughter capacity for all situations. The marginal value of slack resources (i.e., excess slaughter facilities) is zero.

Under the base situation and the assumptions previously stated, the potential returns upon investment in slaughter capacity were the greatest in regions 11-AR and 18-OK. The return to investment in each of the regions was 16.0 and 16.4 percent, respectively. Expansion quantities for which the computed return applies are greatest for regions 19-TX, 11-AR, and 26-LA. Each of the regions has potential to expand slaughter by 290, 141, and 137 million pounds, respectively, before a change in the base solution would occur.

Entry of a New Packer and the Slaughter Industry

The entry of a new packer at either location causes potential returns on new slaughter investment to decrease markedly in all regions except 11-AR, 18-OK, and 19-TX. This is caused by low-cost slaughter being available near the point of production for many hogs that were shipped to southern states. Neither 11-AR, 18-OK, nor 19-TX receive live hogs from the Corn Belt area. The location of the new plant at Kirksville, Missouri, decreases the expansion quantities to which possible returns apply in all regions except 18-OK when compared to the base situation. Expansion quantities decreased in regions 11-AR, 19-TX, and 26-LA in the solution in which the new plant was located in Davenport, Iowa. Returns to additional slaughter facilities will decrease less if the new packer locates in Davenport, Iowa, for 3-GA, 4-FL,and 6-TN than if the packer

[1] The estimate of investment ($50) was deduced from general knowledge of the entry of a new packer. This packer has mentioned a $100-million investment in a plant with a 2-million-head-per-year capacity.

Table 4. Least-Cost Quantities of Hogs Slaughtered, Expansion Potential, and Return to Investment of Added Slaughter Capabilities.

Situation	Item	Units	Production Region							
			3-GA	4-FL	5-AL	6-TN	11-AR	18-OK	19-TX	26-LA
Base	Quantity Slaughtered	mil. cwt.	769.5	47.8	785.4	1594.7	73.0	120.4	485.7	55.4
	Upper Limit	mil. cwt.	853.0	152.0	868.9	1678.2	214.3	125.4	775.3	192.2
	Expansion Potential	mil. cwt.	83.5	104.2	83.5	83.5	141.3	5.0	289.6	136.8
	Proportion of Existing Capacity	pct.	10.8	218.0	10.6	5.2	193.5	4.1	59.6	246.9
	Return to Investment	pct.	9.4	10.0	5.9	7.82	16.0	16.4	5.4	6.1
New Plant Kirksville, MO	Quantity Slaughtered	mil. cwt.	769.5	47.8	785.4	1594.7	73.0	120.4	485.7	55.4
	Upper Limit	mil. cwt.	838.7	117.0	854.6	1663.9	142.0	125.4	554.9	124.6
	Expansion Potential	mil. cwt.	69.2	69.2	69.2	69.2	69.0	5.0	69.2	69.2
	Proportion of Existing Capacity	pct.	8.9	144.7	8.8	4.3	94.5	4.1	14.2	124.9
	Return to Investment	pct.	6.4	7.0	3.1	4.8	13.2	16.3	5.5	3.4
Davenport, IA	Quantity Slaughtered	mil. cwt.	769.5	47.8	785.4	1594.7	73.0	120.4	485.7	55.4
	Upper Limit	mil. cwt.	853.0	152.0	868.9	1678.2	180.8	125.4	590.2	159.8
	Expansion Potential	mil. cwt.	83.5	104.2	83.5	83.5	107.8	5.0	104.5	104.4
	Proportion of Existing Capacity	pct.	10.8	218.0	10.6	5.2	147.6	4.1	21.5	188.4
	Return to Investment	pct.	6.5	7.2	3.1	4.9	13.2	16.3	5.4	3.4
Wage Rates Unionized	Quantity Slaughtered	mil. cwt.	769.5	47.8	785.4	1594.7	73.0	120.4	485.7	55.4
	Upper Limit	mil. cwt.	853.0	152.0	868.9	1678.2	214.3	125.4	775.3	192.2
	Expansion Potential	mil. cwt.	83.5	104.2	83.5	83.5	141.3	5.0	289.6	136.8
	Proportion of Existing Capcity	pct.	10.8	218.0	10.6	5.2	193.5	4.1	59.6	246.9
	Return to Investment	pct.	9.6	10.2	6.0	8.0	15.6	15.3	4.3	5.7
Non-unionized	Quantity Slaughtered	mil. cwt.	769.5	47.8	785.4	1594.7	73.0	120.4	485.7	55.4
	Upper Limit	mil. cwt.	831.5	152.0	847.4	1656.7	214.3	125.4	775.3	117.4
	Expansion Potential	mil. cwt.	62.0	104.2	62.0	62.0	141.3	5.0	289.6	62.0
	Proportion of Existing Capacity	pct.	8.0	218.0	7.8	3.8	193.5	4.1	59.6	111.9
	Return to Investment	pct.	6.3	6.8	2.7	4.7	14.4	17.5	6.6	4.5

locates in Kirksville, Missouri. In no case is expansion potential for pork slaughter increased or returns to investment increased for the southern region by entry of a new firm at either location. Locating the new plant at Davenport, Iowa, would be less detrimental to the southern region.

Unionized vs. Non-unionized Wages and the Slaughter Industry

Unionized wages caused possible returns on investment to increase in regions 3-GA, 4-FL, 5-AL, and 6-TN and decrease in the remaining regions. Expansion quantities were unchanged from the base situation for this solution. The differing effects of unionized wages resulted from the relative differences in wage rates among regions cited earlier.

Non-unionized wages in the slaughter sector caused potential returns to increase approximately 1 percent in regions 18-OK and 19-TX but decrease from 1.5 to 3.2 percent in all other regions. Expansion quantities for regions 3-GA, 5-AL, 6-TN, and 26-LA were smaller than in that of the base situation.

Imputed Costs of Hogs and Pork

The construction of the transhipment model in linear programming format yields information concerning the imputed costs of hogs and pork at various levels of the marketing system. These imputed costs appear as the shadow prices for transfer rows between sectors and for the demand-requirement rows. The latter are of major interest. The shadow prices for demand-requirement rows (equality constraints) represent the imputed cost of one pound of carcass pork as it reaches a consumption region. This point in the marketing system may be interpreted as the arrival of pork at a retail grocer or meat market.

The only costs not included in these imputed cost figures involve final processing, packaging, merchandising, and so forth. The U.S. Department of Agriculture estimates such costs annually. The retail cost component of the farm-retail price spread for pork in 1979 was estimated to be 35.2 cents per pound. Assuming that this cost component is equal for all regions, the total imputed costs of producing, slaughtering, shipping, and retailing pork in each region can be computed by adding 35.2 cents to the shadow price of the region's demand-requirement row. The imputed costs appear in Table 5.

Table 5 also shows the spatial equilibrium demand prices for pork in all regions. These prices are computed by the reactive program and appear in its output. Note that the total imputed cost of pork is approximately equal to the spatial equilibrium price for all regions. This occurrence was in no way foreseen or planned; however, it leads to two conclusions. First, the model is accurate in that these findings seem to be logical. Second, the assumption that the swine-pork industry is highly competitive is confirmed because, in the long-run, marginal cost, average cost, and price are equal in a perfectly competitive system.

CONCLUSIONS

The integrated mathematical programming model developed for this study is useful, easy to understand,

Table 5. Imputed Wholesale and Retail Costs and Spatial Equilibrium Prices of Pork for the Base Situation for Southern States.

Region	Demand Requirement Shadow Price	Total Imputed Cost of Retail Pork	Spatial Equilibrium Pork Price
		($/cwt.)	
2-NC	106.38	141.58	142.80
3-GA	106.62	141.82	143.08
4-FL	106.90	142.10	143.33
5-AL	106.52	142.72	142.96
6-TN	106.10	144.30	142.55
11-AR	106.11	141.81	142.56
18-OK	106.08	141.28	142.53
19-TX	106.78	141.98	143.22
26-LA	106.84	142.04	143.29

and flexible. The iterative process consisting of reactive and linear program routines allowed stair-stepped supply and inelastic demand functions to be included in the spatial study. It also allowed successive levels of the marketing system to be examined and provided information from which inferences concerning industry expansion potential, possible payoffs from investments, and product reorganization can be made.

The integrated mathematical programming model developed for this study offers a new and relatively simple approach for studying spatial problems. The model should be useful to other researchers who study spatial problems. The results of the study should also be useful to researchers, extension personnel, policy makers, swine producers and slaughterers, and those interested in entering or financing businesses associated with the swine-pork industry in Oklahoma and the South. The upper production cost constraints and quantities for increased swine production were specified for each region within the South. The study reports an estimated upper limit to possible slaughter expansion in each region and potential return on investment.

The greatest opportunities for increased swine production exist in 2-NC, 11-AR, 18-OK, and 19-TX. Expansion in the other regions will occur only as their relative production costs decrease. Research, extension, and industry personnel should be aware of these findings. The entry of a new packer in the Corn Belt area does not have major effects on upper limits of expansion potential; however, it does decrease the value of increased hog production in the South. In no case does unionized labor improve the competition of southern producers; however, nonunionized labor improves the competitive position of 6-TN.

In the base situation, the potential for increased slaughter capacity is greatest in 19-TX, 11-AR, 26-LA,and 4-FL. The upper limit for expansion potential in the pork industry was 289.6, 141.3, 136.8, and 104.2 million pounds, respectively. This represents an increase ranging from almost 50 to 250 percent of estimated existing physical capacity.

Under both sets of postulated exogenous situations, the potential for increased slaughter capacity is greatest in 19-TX, 11-AR, 26-LA, and 4-FL.

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