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The Effects of U.S. Meat Packing and Livestock Production Technologies on Marketing Margins and Prices

Gary W. Brester and John M. Marsh

Real livestock prices and farm-wholesale marketing margins have steadily declined over the past 20 years. Studies examining the causes of these declines have generally failed to account directly for technological change in livestock production and red meat slaughtering. We estimate reduced-form models for beef and pork farm-wholesale marketing margins and cattle and hog prices that include specific measures of technological change. Empirical results indicate cost savings generated by improved meat packing technologies have reduced real margins and positively influenced real cattle and hog prices. However, technological change embodied in cattle production weights has led to substantial declines in real slaughter cattle prices. Nonetheless, the net effect of improved meat packing technology has been to increase cattle price by $1.75/cwt and reduce the farm-wholesale beef marketing margin by 22.8 cents/lb.

Key words: livestock prices, marketing margins, technological change

Introduction

U.S. real livestock prices and farm-wholesale marketing margins have declined over the past several decades. For example, from 1970–1998, real slaughter steer and slaughter hog prices declined by 50% and 66%, respectively. Over the same period, real beef and pork farm-wholesale marketing margins declined by 57% and 65% [U.S. Department of Agriculture/Economic Research Service (USDA/ERS) 2000]. Many studies have evaluated potential reasons for these declines, including: increased meat packing concentration, declining retail demand, and increased red meat and poultry supplies (Azzam and Anderson; Brester and Marsh 1999; Martinez; Purcell; Wohlgenant 1985).

In general, increased supplies of red meat and poultry, coupled with declining consumer demand, appear to have had the largest negative effect on livestock prices. Increases in meat packer concentration have had minor effects [USDA/Grain Inspection, Packers and Stockyards Administration (GIPSA)]. Although not extensively considered to date, technological change in the beef and pork production and marketing sectors may also be a contributing factor to the decline of both livestock prices and farm-wholesale marketing margins.

Technological change in the food processing industry has increased rapidly over the past several decades. Technology development and adoption have been a product of

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changing relative prices, increasing competitive pressures from globalized markets, improving transportation and logistical infrastructures, developing information systems, and increasing consumer demands for quality-differentiated products (Antle; Brester, Schroeder, and Mintert). Theoretically, technological change in the food processing sector may lower unit production costs, and given adequate competitive pressure, may lower consumer prices, reduce marketing margins, and increase farm output prices.

Livestock production technologies have also changed over the past several decades. For example, the size of animals has increased significantly, as indicated by increasing average dressed weights. These increases have resulted from changes in genetics, animal nutrition, and health management. Increases in meat production per animal are expected to reduce livestock prices. In addition to changes in animal size, livestock production enterprises have become much larger. Changes in animal health and information technologies have allowed livestock production facilities to operate on a much larger scale. Given that such expansion could generate scale economies, one would expect livestock prices to be positively affected by these technologies.

Our objective is to estimate econometrically the long-term effects of changes in farm-level and processing-level technologies on farm-wholesale marketing margins and livestock prices in the beef and pork sectors. Intuitively, technological change would be expected to be an important factor in explaining long-term declines in livestock prices and farm-wholesale marketing margins. Surprisingly, the issue has received only cursory attention in the literature and, at best, researchers have used time trends as proxies for technological change. Of course, changes in technology are difficult to measure.

The paucity of research in this area is in stark contrast to the numerous studies focusing on meat packer concentration as an explanation for declining farm-level cattle and hog prices (for an excellent review of these studies, see Azzam and Anderson). The primary emphasis of most of these investigations has been the identification and extent of monopoly/monopsony market power within the meat packing industry. Technological change in the processing sector has also been considered by estimating cost functions using cross-sectional data (Ball and Chambers; Morrison-Paul).

We use annual time-series data and specific productivity measures to investigate the long-term effects of technological change on beef and pork farm-to-wholesale marketing margins and cattle and hog prices. A structural demand and supply model of the beef and pork processing sectors and the cattle and hog production sectors is developed. Specific measures of technological change are used in estimating reduced-form marketing margin and livestock price equations. Our results confirm that technological change in the meat packing industry has reduced farm-wholesale marketing margins and contributed to higher real livestock prices. However, the negative effects of farm-level technological change on livestock prices have dominated these positive effects, and contributed to lower real livestock prices.

Marketing Margins and Livestock Prices

In the beef and pork sectors, real farm-retail price spreads (marketing margins) have remained relatively constant since 1970. However, as shown in figures 1 and 2, farm-wholesale and wholesale-retail margins have demonstrated opposite trends. Specifically, from 1970 to 1998, real farm-wholesale margins decreased by 56.6% for beef and 64.5% for pork, while real wholesale-retail margins increased by 27% for beef and 148.9% for pork (USDA/ERS 2000).

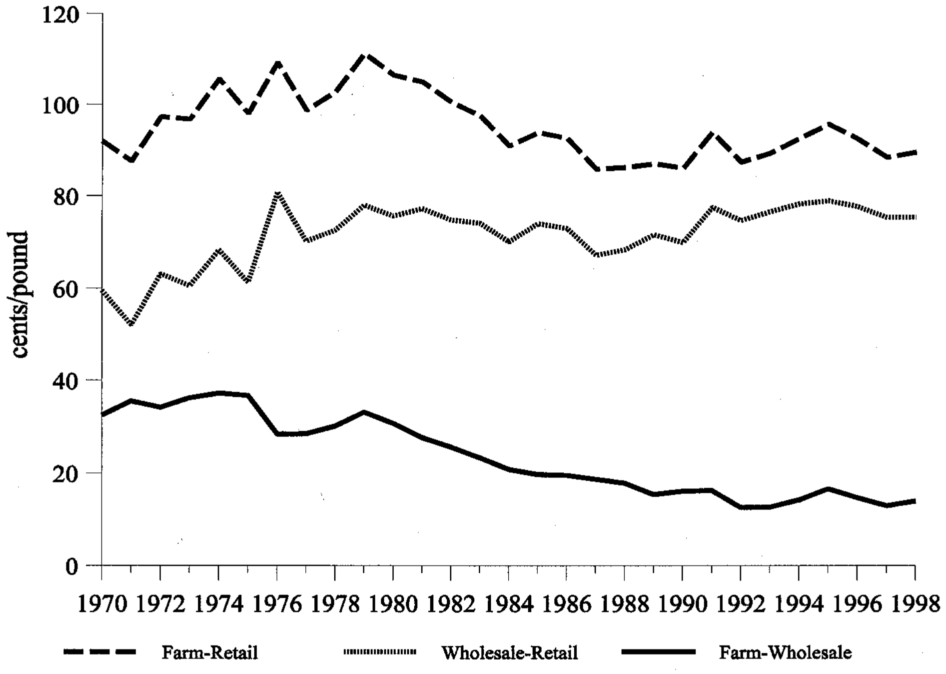

Figure 1. Real beef marketing margins, 1970–1998

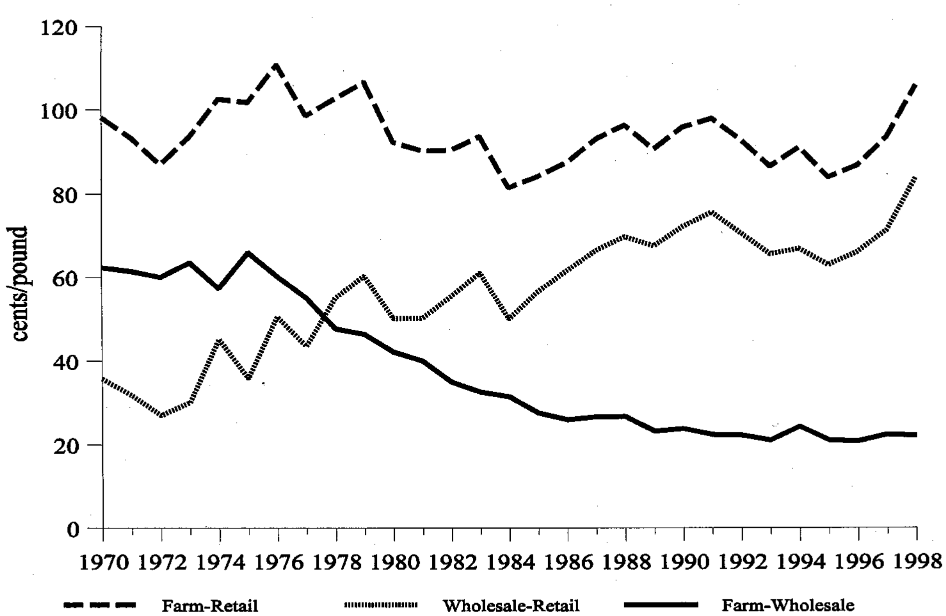

Figure 2. Real pork marketing margins, 1970–1998

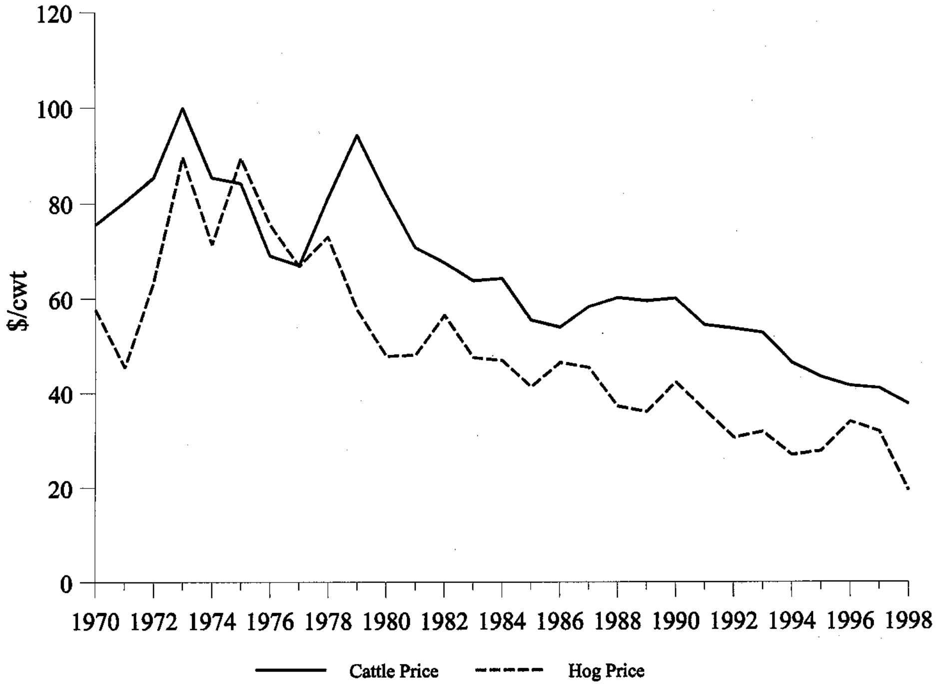

Figure 3. Real U.S. slaughter cattle and hog prices, 1970–1998

Changes in marketing margins are not necessarily indicative of farm-level price changes. Both can decline (increase) if wholesale prices decline (increase) by more than farm prices. Nonetheless, livestock producers perceive themselves to be adversely affected by widening wholesale-retail margins even though farm-wholesale margins have narrowed. In fact, real prices for slaughter cattle and hogs have declined an average of 58.3% since 1970, as shown in figure 3. Industry analysts have attributed this decline to decreased retail demand, decreased by-product values, and increased red meat and poultry supplies (USDA/ERS 2000; Purcell).

Previous Research Regarding Technological Change

Technological change in the food processing sector has been examined in a few previous studies. Gisser used changes in concentration ratios, capital and labor inputs, and productivity to explain changes in total factor productivity in the food processing sector. Goodwin and Brester employed gradual switching regressions and an industry-level translog cost function to evaluate technological change in the food manufacturing industry. They found significant increases in labor/capital and labor/materials price ratios and changing technologies during the 1980s, and concluded technological change had allowed for greater input substitution in the food manufacturing industry.

The direct specification of technological change in the red meat processing sector has generally been considered in terms of industry-level cost functions. Ball and Chambers estimated a translog cost function for the meat products industry and included a time trend to proxy technological change. Similarly, Melton and Huffman estimated translog cost functions for the beef and pork packing industries, and also used time trends to

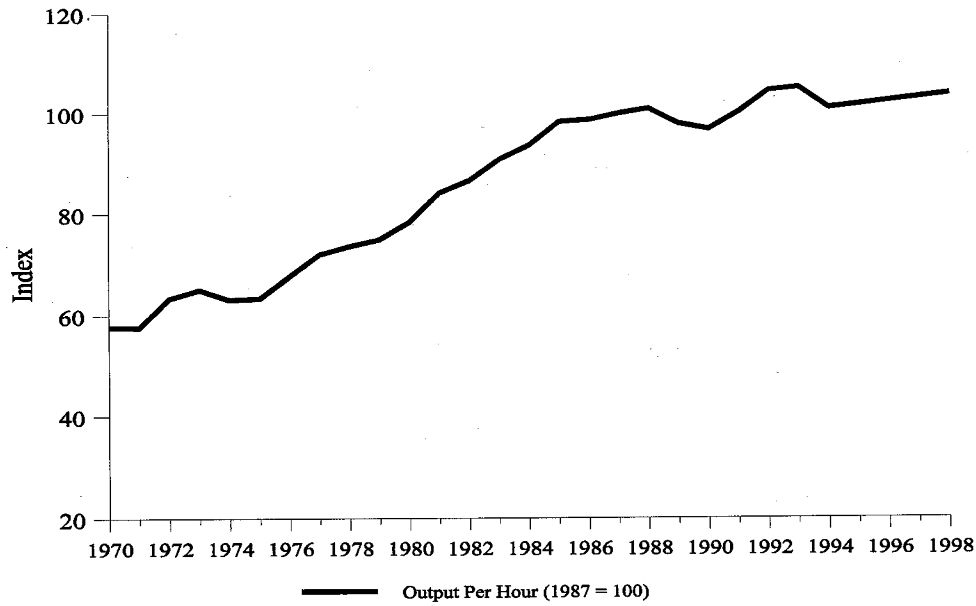

Figure 4. Index of output per employee hour in meat packing, 1970–1998

proxy technological change. Recently, Morrison-Paul used 1992–1993 revenue and cost data from a survey of the 43 largest U.S. beef packing plants to empirically estimate utilization and scope-economy cost savings in the beef processing sector. The results indicated positive effects of cost savings generated by improved meat processing technologies appeared to offset negative effects of meat processor market power on cattle prices.

Significant changes in processing technologies have occurred during the past 30 years. Figure 4 illustrates the 1970–1998 increase in meat packing technology as measured by worker output per hour (Allen). In 1970, the index of output per hour in meat packing was 57.7 (1987 = 100). By 1998, it had increased to 103.8 (U.S. Department of Labor). MacDonald et al. found that productivity and technological scale economies since the 1960s were quite extensive and have altered the structure of the meat packing industry. Thus, including measures of technological change in output supply and input demand functions in the beef and pork sectors may be important for identifying margin and price behavior.

While the above studies have considered the effects of technological change in the food/meat processing sector, little published research is available regarding the impacts of technological changes in the livestock production sector. Average dressed weights of slaughter animals have been used in a variety of studies as measures of meat supplies (e.g., Brester and Marsh 1983; Marsh 1999b). Yet, such measures have not been used to explicitly account for changes in production technologies. Marsh (2001) considered the impact of feedlot sizes and beef cow productivity on feeder cattle price determination in an effort to account for changing livestock production technologies. However, the usual approach to accounting for such changes in the livestock production sector has been to include time trends (Marsh 1999b).

Model Development: Structural Equations

Our development of a beef and pork farm-wholesale margin model begins with a general specification of structural inverse demand and supply functions at the wholesale and farm levels. Inverse demand and supply specifications are appropriate for statistical estimation of agricultural commodity models if production/processing quantities are considered predetermined (Dunn and Heien; Eales; Huang). The structural model is based on standard firm optimization behavior with respect to profit maximization.

Our model assumes completely elastic supplies of marketing services (Wohlgenant 1989). The general specification of the inverse wholesale and farm-level demand and supply structure for beef and pork is represented as follows:[1]

Wholesale Sector:

(1) $$P_w^d = f_1(Q_w^d, Q_w^{ds}, Y, MC)$$ (inverse demand),

(2) $$P_w^s = f_2(Q_w^s, P_f, LC, BP, T_{mp})$$ (inverse supply),

(3) $$P_w^d = P_w^s = P_w$$ (market-clearing price identity),

(4) $$Q_w^d = Q_w^s = Q_w$$ (market-clearing quantity identity);

Farm Sector:

(5) $$P_f^d = f_3(Q_f^d, P_w, LC, BP, T_{mp})$$ (inverse demand),

(6) $$P_f^s = f_4(Q_f^s, P_{fd}, P_{cn}, T_f, T_a)$$ (inverse supply),

(7) $$P_f^d = P_f^s = P_f$$ (market-clearing price identity),

(8) $$Q_f^d = Q_f^s = Q_f$$ (market-clearing quantity identity).

Equations (1) and (2) represent inverse demand and supply relations at the wholesale-level. Equation (1) indicates that wholesale demand price (P_w^d) depends upon per capita wholesale demand for the commodity (Q_w^d), per capita wholesale demand of substitutes (Q_w^{ds}), per capita total personal consumption expenditures (Y), and processing, distribution, and marketing costs (MC). Quantity of meat substitutes and per capita expenditures represent the effect of primary demand (retail sector) on wholesale derived demand (Marsh 1988).

From equation (2), wholesale supply prices (P_w^s) depend upon per capita production of the wholesale commodity (Q_w^s), cost (price) of slaughter livestock (P_f), labor costs (wages) in food processing (LC), the value of slaughtering by-products (BP), and meat slaughtering technology (T_{mp}). The meat slaughter technology variable represents output per employee hour (productivity) in the meat packing industry. The variable shows a

[1] The framework of the market inverse demand and supply functions encompasses the conceptual arguments of derived demands, supplies, and marketing margin behavior (Tomek and Robinson). Price-dependent functional forms have been applied in various livestock-meat models (Brester and Marsh 1983; Eales; Heien; Huang; Marsh 1992; Wohlgenant 1989). Theoretical restrictions are not imposed since the structural model is not directly estimated, but is merely used to identify variables to be included in a reduced-form model.

positive trend, but its virtue in measuring technology (as opposed to the use of a linear time trend) lies in its variance. The sample (1970–1998) standard deviation as a percentage of its mean is 19.2%. Consequently, productivity may better capture cause-effect relationships between technological change in the slaughtering sector and annual changes in margins and prices than would a time-trend variable. Equations (3) and (4) are wholesale-level market-clearing identities.

Equations (5) and (6) describe inverse derived demand and primary supply functions at the farm (slaughter) level. In equation (5), the slaughter demand price (P_f^d) depends upon quantity demanded of slaughter livestock (Q_f^d), output price of the wholesale commodity (P_w), labor costs (wages) in food processing (LC), the value of slaughtering byproducts (BP), and meat packing technology represented by output per employee hour in the meat packing industry (T_{mp}). In equation (6), the slaughter supply price (P_f^s) depends upon quantity supplied of slaughter livestock (Q_f^s), the price of feeder animals (P_{fd}), the price of feed (P_{cn}), technology in the animal finishing industries (T_f or firm size), and technology in farm-level production represented by livestock weights (T_a or animal size) (Marsh 1999a).

Feeder animal prices and feed prices are important input costs—the former represent the cost of animal procurement and the latter indicate the cost of weight gain. From a derived demand perspective, feed price influences feeder animal price bids (Buccola). However, the two variables jointly influence quality and quantity of slaughter animal production which affect slaughter supply price. Equations (7) and (8) are farm-level market clearing identities.

The technology variables represent productivity measures relevant for each demand and supply function. Increasing productivity in livestock and meat production is generally the result of increasing capital-to-labor ratios, new feeding and processing methods, improved nutrition and management, and advanced genetics. It has long been recognized that technological innovation is an important determinant of livestock production (Jarvis 1969, 1974; Rosen, Murphy, and Scheinkman; Rosen).

In addition, previous researchers have noted technological improvements are manifest in larger production operations (Brester, Schroeder, and Mintert; Hurley, Kliebenstein, and Orazem). Marsh (2001) estimated reduced-form feeder cattle prices. The model included measures of feedlot size and beef cow productivity (animal weights) as proxies for technological change. Both variables were statistically significant. Technological change embodied in feedlot size positively affected feeder cattle prices, and animal weights negatively affected feeder cattle prices.

Technological change may also be influenced by relative prices. Thus, except for firm size, technology variables may not be exogenous shifters of output supplies and input demands.[2] Output per employee hour in meat packing is specific to wholesale supply and packer demand, and firm and animal size are specific to slaughter supply. For beef, firm size is measured by the percentage of cattle marketed by firms with capacities of more than 16,000 head. For pork, firm size is measured by the percentage of firms with farrowing capacities of more than 500 head. The sizes of cattle and hog production firms have increased because of technological changes manifest in capital substitution for labor and vertical coordination (Hayenga et al.).

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[2] The meat processing technology variable is defined as output per employee hour in meat packing plants. The output (quantity) component of this technology measure could be jointly dependent with the left-hand-side price variables in the margin model. Also, livestock dressed weights represented by animal size technology may be jointly dependent with slaughter prices.

Average dressed weights of slaughter cattle and hogs are also used as measures of technological change in the livestock production sector. Anderson and Trapp found declining real feed costs have contributed to increased average dressed weights of slaughter animals. However, average dressed weights have also increased because of changing genetics and nutrition/animal health management practices (Brester, Schroeder, and Mintert).

Because our model consists of derived demands and supplies, marketing costs and labor costs (MC, LC) are necessarily specified as demand and supply shifters (Tomek and Robinson). The MC variable is more comprehensive than the LC variable; the former consists of labor, processing, merchandising, and transportation costs, while the latter represents only labor costs (Harp). Consequently, MC was specified in the wholesale demand equation, while LC was specified in slaughter demand and wholesale supply equations. Excluding costs of cattle procurement, labor accounts for 40% to 50% of packer slaughtering and processing costs, depending upon plant size and production procedures (Duewer and Nelsen). Each market level is assumed to be in equilibrium over annual time periods.

Model Development: Reduced-Form Marketing Margin and Farm Price Equations

Reduced-form expressions for the farm-wholesale marketing margin equations are obtained by substituting equations (1) and (2) into equation (3), and substituting equations (5) and (6) into equation (7). The general specification of the farm-wholesale margin (M_{fw}) for beef and pork is obtained by subtracting P_f from P_w:[3]

$$(9) \qquad M_{fw} = f_5(Q_w^d, Q_w^s, Q_f^d, Q_f^s, Q_w^{ds}, Y, MC, LC, BP, T_{mp}, T_f, T_a, P_{fd}, P_{cn}).$$

The margin relationship incorporates farm-to-wholesale price linkages by including wholesale demand shifters, farm product supplies, and food marketing costs as specified in the structural model. Because no restrictions are imposed on input substitutions in meat processing, the reduced-form marketing margin model subsumes variable input proportions (Wohlgenant 1989).

Equation (9) contains several variables representing similar factors in both the wholesale and farm levels of the market. Because many of these variables are highly collinear, a more parsimonious specification is required. The market-clearing quantity identities [equations (4) and (8)] allow for wholesale quantities to be represented by Q_w and farm quantities by Q_f. Assuming carcass wholesale quantities contain production information regarding live weight quantities, farm quantity (Q_f) is subsequently omitted from the specification. Because labor costs (LC) are a major component of food marketing costs (MC), LC is also omitted from the margin model.

The following reduced-form equation for beef and pork marketing margins is used for empirical estimation:

[3] We refer to these functions as reduced forms while recognizing that one or more right-hand-side variables may be endogenous. Endogeneity test results are reported in the empirical results section. Because equations (1)–(8) are not directly estimated, equation (9) does not inherit economic restrictions on the slope parameters; such would not be the case if the structural price-dependent equations were estimated and the margin relations were then solved.

$$(10) \qquad M_{fw} = f_6(Q_w,\, Q_w^{ds},\, Y,\, MC,\, BP,\, T_{mp},\, T_f,\, T_a,\, P_{fd},\, P_{cn}).$$

Because structural equations (1)–(8) include technology shifters at the meat packing and farm levels, the cost-reducing technologies are necessarily included in equation (10).

The reduced-form equations for cattle and hog farm-level prices (P_f) are obtained by returning to the structural model of the farm sector, and substituting equations (5) and (6) into equation (7):

$$(11) \qquad P_f = f_7(Q_f^d,\, Q_f^s,\, P_w,\, LC,\, BP,\, T_{mp},\, T_f,\, T_a,\, P_{fd},\, P_{cn}).$$

Using the market-clearing conditions of equation (8), equation (11) reduces to a general specification of real farm-level cattle and hog prices:

$$(12) \qquad P_f = f_8(Q_f,\, P_w,\, LC,\, BP,\, T_{mp},\, T_f,\, T_a,\, P_{fd},\, P_{cn}).$$

In summary, we will quantify the impact of technological change on farm-wholesale marketing margins by estimating equation (10) for both beef and pork. The impacts of technological change on livestock prices will be evaluated by estimating equation (12) for both slaughter cattle and hogs.

Data

The margin and slaughter price models are estimated using annual data for the 1970 to 1998 period. The data cover a period of several beef and hog cycles. All marketing margins, wholesale production and prices, cattle and hog slaughter prices, feeder cattle and pig prices, corn price, and by-product values were obtained from the *Red Meats Yearbook* (USDA/ERS) and various issues of the *Livestock, Dairy, and Poultry Situation and Outlook* (USDA/ERS). Wholesale beef and pork prices are USDA composite boxed cut-out values based upon weighted averages of the wholesale value of major, minor, and by-product items obtained from carcasses (White et al.).

Marketing cost and labor cost indexes were taken from Dunham and various issues of *Agricultural Outlook* (USDA/ERS), while the Consumer Price Index (CPI), per capita consumption expenditures, and population series were obtained from the 1999 *Economic Report of the President* (Congress of the U.S., Council of Economic Advisors). All price and value variables (including marketing and labor costs) were deflated by the CPI (1982–84 = 100), and wholesale production was divided by population.

The meat packing technology variable (index of output per employee hour in meat packing) was obtained from the U.S. Department of Labor. Firm size technology variables at the farm level (percentage of fed cattle marketed by firms greater than 16,000 head; percentage of firms with sow inventories greater than 500 head) were obtained from the Livestock Marketing Information Center (LMIC) and from *Hogs and Pigs Final Estimates* [USDA/National Agricultural Statistics Service (NASS)].

Feedlot capacities of 16,000 head-and-greater were selected over other categories because these sizes have experienced a larger growth than the 8,000 head-and-greater category. Marsh (2001) used the 32,000 head-and-greater classification for measuring the impact of technological change on feeder cattle prices. The 16,000 head-and-greater classification is more inclusive and displayed growth similar to the 32,000 head-and-greater category. Farm-level technology variables for animal size (average dressed

Table 1. Definitions of Variables for Beef and Pork Marketing Margin Model

Variables	Definition
M_b, M_p	Farm-to-wholesale margins for beef and pork, respectively (¢/lb.).
Q_b, Q_p, Q_y	Per capita commercial production of beef, pork, and poultry, respectively (lbs. of carcass weight and ready-to-cook weight).
Q_c, Q_h	Quantity of cattle and hogs commercially slaughtered, respectively (mil. head).
M_c, L_c	Index of food marketing costs and index of labor costs in food processing, respectively (1967 = 100).
B_b, B_p	Farm by-product values (hide and offal) for beef and pork, respectively (¢/lb.).
P_{wb}, P_{wp}	Boxed beef cut-out value, Choice 2-3, 600–750 lbs., and boxed pork cut-out value, no. 2, Central U.S., respectively ($/cwt).
P_c, P_h, P_{fd}, P_p	Price of Choice steers, no. 2-4, 1,100–1,300 lbs., Nebraska direct ($/cwt); Price of barrows and gilts, no. 1-3, 230–250 lbs., Iowa/So. Minnesota ($/cwt); Price of feeder steers, medium no. 1, 600–650 lbs., Oklahoma City ($/cwt); Price of 40–50 lb. feeder pigs, no. 1-2, So. Missouri ($/head).
P_{cn}	Price of no. 2 yellow corn, Central Illinois ($/bu.).
T_{mp}	Index of output per employee hour in meat packing (1987 = 100).
T_{fb}, T_{fp}	Percentage of fed cattle marketed by feedlots with capacities exceeding 16,000 head; Percentage of hog production firms with sow inventories exceeding 500 head.
T_{ab}, T_{ap}	Federally inspected average dressed weight of steers and heifers (lbs.); Federally inspected average dressed weight of hogs (lbs.).
Y	Per capita total consumption expenditures ($).

weights of cattle; average dressed weights of hogs) were obtained from the *Red Meats Yearbook* (USDA/ERS). Definitions of variables are provided in table 1, and descriptive statistics are reported in table 2.

Empirical Results for the Farm-Wholesale Marketing Margins

Equation (10) represents the margin relationships to be estimated for beef and pork. Hausman specification tests were conducted on the own-quantity, feeder price, and meat packing and animal size technology regressors. The Hausman tests for the margin equations were conducted by regressing suspected endogenous variables on instruments consisting of the exogenous variables in the entire system of equations and the four-firm concentration ratios for beef and pork slaughtering. Following Pindyck and Rubinfeld (pp. 353–54), the estimated residuals were then entered into the ordinary least squares (OLS) margin equations. Individual t-values, as well as F-values on joint residual regressors, indicated the null hypothesis of no simultaneity could not be rejected at the $\alpha = 0.05$ level of significance for any of these variables in either of the two margin equations.

Table 2. Descriptive Statistics (real 1982–84 dollars)

Symbol	Variable Name	Unit	Mean	Std. Dev.
M_b	farm-to-wholesale beef margin	cents	23.59	8.52
M_p	farm-to-wholesale pork margin	cents	37.65	16.33
Q_b	per capita beef production	pounds	9.89	0.72
Q_p	per capita pork production	pounds	6.43	0.49
Q_y	per capita poultry production	pounds	6.15	2.19
Q_c	cattle slaughter	mil. head	35.96	2.56
Q_h	hog slaughter	mil. head	86.63	7.64
M_c	food marketing costs	1967 = 100	318.50	22.17
L_c	food processing labor costs	1967 = 100	327.94	17.97
B_b	farm by-product beef value	cents	16.86	4.16
B_p	farm by-product pork value	cents	6.15	3.11
P_{wb}	boxed beef cut-out value	dollars	105.87	28.77
P_{wp}	boxed pork cut-out value	dollars	64.31	21.80
P_c	price of Choice steers	dollars	65.20	37.69
P_h	price of barrows and gilts	dollars	49.18	19.42
P_{fd}	price of feeder steers	dollars	70.50	18.22
P_p	price of feeder pigs	dollars	41.87	18.16
P_{cn}	price of corn	dollars	2.92	1.29
T_{mp}	meat packing technology	1987 = 100	86.45	16.66
T_{fb}	cattle production technology	percent	0.48	0.10
T_{fp}	hog production technology	percent	0.52	0.20
T_{ab}	cattle size technology	pounds	688.86	39.76
T_{ap}	hog size technology	pounds	175.66	6.49
Y	per capita consumption expenditures	dollars	10,471.17	1,454.82

Augmented Dickey-Fuller (ADF) unit root tests indicated the null hypothesis of nonstationarity could not be rejected for many of the model variables. Johnston and DiNardo (pp. 259–69) show that a multiple-regression equation involving nonstationary variables can be estimated in data-level form if the function is cointegrated. Cointegration is indicated in both margin equations because the ADF test rejected the null hypothesis of unit roots in the equation residuals. Thus, the empirical model is estimated with the data in levels.[4] Variables are assumed to enter the equations multiplicatively. Therefore, each equation is estimated using log transformations of the variables.

Error terms between the beef and pork margin equations are hypothesized to be contemporaneously correlated since the two products are substitutes and the beef and pork packing industries share similar technologies. The beef and pork farm-wholesale marketing margin equations could also share a common misspecification (Johnston and

[4] DeJong et al. and Gujarati suggest the power of unit root and cointegration tests are relatively weak for small samples. Gujarati (pp. 728–29) also indicates an error correction model may be more appropriate for cointegrated equations, but the results remain tenuous for small samples.

DiNardo). Therefore, both reduced-form equations are estimated as a system using iterative seemingly unrelated regressions (ITSUR) of the EViews 3.1 software program.

Table 3 presents the ITSUR parameter estimates for the margin equations. The regression fits were high, with an adjusted R^2 ($\bar{R}^2$) of 0.967 for beef and 0.975 for pork, and corresponding standard errors of regression (SE) of 0.068 and 0.067 (less than 2.4% of the mean log margins). The margin equations were initially corrected for first-order autoregressive errors [AR(1)] using a nonlinear generalized least squares (GLS) estimator. However, the AR(1) structure was significant only in the beef margin equation. The correlation coefficient between the equation errors was -0.24.

The analysis of farm-wholesale margins focuses on the effects of technological change. Most other variables (beef production, marketing costs, corn price, feeder cattle price, by-product values, poultry production, and consumer expenditures) are statistically significant at the $\alpha = 0.05$ level in the beef marketing margin model. However, in the pork marketing margin equation, most of the estimated coefficients are insignificant.

The marginal impacts of meat packing technology (T_{mp}) are negative and statistically significant at the $\alpha = 0.05$ level in both margin equations. These effects are theoretically consistent in that, given wages, increases in output per employee hour effectively reduce packer unit labor costs. The cost savings result in reduced farm-wholesale margins as packers are able to pay higher prices for slaughter cattle. Furthermore, the coefficients indicate the technology effects are relatively elastic: a 1% increase in meat packer productivity reduces beef margins by 1.85% and pork margins by 1.43%.

Coefficient estimates on livestock production technologies are represented by firm size (T_{fb}) and animal size (T_{ab}). The estimate for firm (feedlot) size in the beef margin equation is positive and significantly different from zero at the $\alpha = 0.05$ level. Firm size was expected to decrease margins if larger feedlots were able to reduce feeder-to-packer transaction costs and market price and quantity risks (Hayenga et al.; Nelson and Hahn; Schroeder et al.). However, the estimated positive effect may indicate larger feedlots are able to capture scale economies and offer cattle to processors at lower prices due to cost savings.

Alternatively, feedlots market cattle both "on the average" and through value-based contractual arrangements. In general, higher quality animals tend to be sold on value-based contracts, with remaining animals sold in the open market at average (identical) prices in any given week. If larger feedlots tend to market a higher proportion of cattle on a value basis, then the average price of cattle may have declined in concert with increases in feedlot size. Thus, increases in feedlot size may have contributed to wider farm-wholesale marketing margins. Whether or not value-based marketing is feedlot size-neutral is an interesting topic for future research.

The coefficient estimate for animal size in the beef margin equation is positive (2.81) and significantly different from zero at the $\alpha = 0.05$ level (table 3). Increases in animal size may increase processing and handling costs, and thus increase margins. Beef animal size (dressed weights) increased by 18.2% from 1970 to 1998. Based on the estimated coefficient and mean of the farm-wholesale marketing margin, change in technology increased the margin by 12.1 cents/lb. or 51.1%. Firm and animal size variables are not statistically significant in the pork margin equation from table 3.

The elastic coefficients for meat packer technology in both margin equations imply relatively large impacts. For example, between 1970 and 1998, meat packing technology (as measured by an index of output per employee hour) increased by 79.9%. Based on the estimated coefficients and mean values of the margins, this technological change

Table 3. Iterative Seemingly Unrelated Regression (ITSUR) Results for the Beef and Pork Double-Log Marketing Margin Model

Margin Equations (10)	Regressors/Statistics
Beef Farm-Wholesale (M_b) =	$1.04 - 1.61Q_b + 1.91M_c - 0.48P_{cn} - 0.91P_{fd} + 0.84B_b$
	(0.14) (-3.61) (5.33) (-5.76) (-5.73) (7.85)
	$+ 0.06Q_p - 0.87Q_y - 1.27Y - 1.85T_{mp} + 0.43T_{fb} + 2.81T_{ab}$
	(0.29) (-4.21) (-2.94) (-6.80) (2.06) (3.09)
	$\bar{R}^2 = 0.967$ SE = 0.068 LM = 3.082
Pork Farm-Wholesale (M_p) =	$2.56 + 0.04Q_p + 1.01M_c - 0.03P_{cn} - 0.03P_p + 0.16B_p$
	(0.15) (0.07) (1.13) (-0.28) (-0.21) (1.27)
	$+ 0.40Q_b + 0.01Q_y + 0.31Y - 1.43T_{mp} - 0.11T_{fp} - 0.49T_{ap}$
	(0.92) (0.01) (0.85) (-4.33) (-0.22) (-0.18)
	$\bar{R}^2 = 0.975$ SE = 0.067 LM = 3.540

Notes: Numbers in parentheses below each estimated parameter represent asymptotic t-ratios. $\bar{R}^2$ is the adjusted R^2, SE is the standard error of regression, and LM is the log mean of the dependent variable. The means of the real margin variables are: $M_b = 23.59$ cents/lb., and $M_p = 37.65$ cents/lb. The critical t-values for the $\alpha = 0.05$ and $\alpha = 0.10$ significance levels are 2.042 and 1.697, respectively (32 degrees of freedom). Degrees of freedom for the system are calculated as $MT - K$, where M = number of equations (2), T = number of sample observations (29), and K = number of parameters estimated in the system (25). In this case, MT is reduced by one observation because of an AR(1) error structure in the beef margin equation (Greene, pp. 617–20).

was responsible for reductions in real beef and pork marketing margins of 34.9 cents/lb. (147.8%) and 42.6 cents/lb. (114.3%), respectively.

These results suggest enough competition remains in the packing industry to cause margins to decline in response to cost savings generated by technological changes (Anderson et al.). That is, over the long run, technological cost savings have been bid into the value of live animals and wholesale products. Our findings are consistent with the long-standing existence of excess capacity in the beef packing sector which has probably led to aggressive pricing of inputs and outputs among large packers (Azzam and Anderson).

The composite effects of farm-level and meat packing technological changes indicate the latter has dominated. Specifically, based on the 1970–1998 sample period, our estimates of the effects of meat packing technological change show a net reduction in the beef farm-wholesale margin of 22.8 cents/lb. This estimate is consistent with the overall decline in the marketing margin.

Empirical Results for the Slaughter Price Equations

Information regarding the effects of technological change on marketing margins may not be as important to livestock producers as associated impacts on farm-level prices. Simply because real farm-wholesale marketing margins narrow over time does not necessarily imply positive impacts on farm-level prices. Equation (12) represents the slaughter price relationships to be estimated for farm-level cattle and hog prices.

Table 4. Iterative Three-Stage Least Squares (IT3SLS) Regression Results for the Double-Log Cattle and Hog Slaughter Price Equations

Slaughter Equations (12)		Regressors/Statistics
Cattle Slaughter Price (P_c)	=	$5.41 - 0.27Q_c + 0.08B_b - 0.25L_c + 0.86P_{wb} + 0.02P_{fd}$
		(2.44) (-2.72) (2.78) (-2.17) (14.21) (0.43)
		$+ 0.01P_{cn} + 0.17T_{mp} - 0.04T_{fb} - 0.60T_{ab}$
		(0.59) (3.50) (-0.76) (-2.43)
		$\bar{R}^2 = 0.996$ SE = 0.016 LM = 4.139
Hog Slaughter Price (P_h)	=	$3.92 - 0.21Q_h + 0.05B_p - 0.20L_c + 0.35P_{wp} + 0.39P_p$
		(0.95) (-2.94) (1.12) (-1.33) (3.50) (6.56)
		$+ 0.19P_{cn} + 0.34T_{mp} - 0.08T_{fp} - 0.52T_{ap}$
		(6.87) (3.69) (-1.11) (-0.91)
		$\bar{R}^2 = 0.995$ SE = 0.027 LM = 3.821

Notes: Numbers in parentheses below each estimated parameter represent asymptotic t-ratios. $\bar{R}^2$ is the adjusted R^2, SE is the standard error of regression, and LM is the log mean of the dependent variable. The means of the slaughter prices are: $P_c = 65.20$ \$/cwt, and $P_h = 49.18$ \$/cwt. The critical t-values for the $\alpha = 0.05$ and $\alpha = 0.10$ significance levels are 2.042 and 1.697, respectively (34 degrees of freedom). Degrees of freedom for the system are calculated as $MT - K$, where M = number of equations (2), T = number of sample observations (29), and K = number of parameters estimated in the system (22). In this case, MT is reduced by two observations due to AR(1) error structures in the cattle and hog slaughter price equations (Greene, pp. 617–20).

Hausman specification tests were conducted on slaughter quantity, wholesale price, feeder price, and meat packing and animal size technology variables included on the right-hand side of the slaughter price models. The test procedures for these equations were identical to those conducted on the margin equations. The null hypothesis of no simultaneity was rejected at the $\alpha = 0.10$ level for all variables except meat packer technology. Consequently, the slaughter price model was estimated using iterative three-stage least squares (IT3SLS) with each equation initially corrected for AR(1) errors using the EViews 3.1 nonlinear IT3SLS estimator. The specification was estimated using log transformations of all variables.

Table 4 presents IT3SLS regression results for cattle and hog slaughter prices. The equations closely fit the data with respective $\bar{R}^2$ statistics of 0.996 and 0.995, and SEs of 0.016 and 0.027. The correlation coefficient between the equation errors was 0.47. Own-slaughter quantities are significant and negative in both equations, a result consistent with downward-sloping demand functions. By-product values are positive and significant in the beef price equation, but are not significant in the pork price equation. Labor costs are negative and significant in the beef price equation, but are not significant in the pork price equation. As expected, boxed beef and pork cut-out values are significant, with price transmission elasticities (between the wholesale and farm levels) of 0.86 for beef and 0.35 for pork. The feeder cattle and corn price coefficients are not significant in the beef price equation; however, the feeder pig price coefficient and the price of corn are positive and significant in the pork price equation.

The coefficients of meat packing technology (T_{mp}) are statistically significant at the $\alpha = 0.05$ level, indicating technological change (as measured by output per employee hour) positively affects both slaughter prices. For example, a 1% increase in meat packing productivity increases slaughter cattle price by 0.17% and slaughter hog price by 0.34%. These results are consistent with our finding that packer technology reduces farm-wholesale margins (table 3). It appears at least some of the cost savings generated by increased meat packing technology are bid into cattle and hog prices.

As noted earlier, output per hour in meat packing increased by 79.9% between 1970 and 1998. Using the estimated coefficients, ceteris paribus, this increase in technology translates into real price increases of 13.6% for cattle and 27.2% for hogs, or $8.87/cwt for slaughter steers and $13.38/cwt for slaughter hogs [based on real (1982–84 = 100) mean values over the period].

The firm size technology variable is not significantly different from zero in either farm price equation. The animal size technology variable, however, is significant ($\alpha = 0.05$) and negative in the beef equation (coefficient of –0.60), but is not significant in the pork equation. Thus, changing farm-level technology manifested in increasing dressed cattle weights (i.e., the result of changes in animal genetics, health, and nutrition management) is a significant contributor to the decline in real slaughter cattle price. For example, from 1970 to 1998, the 18.2% increase in average dressed weights of steers and heifers translated into a 10.9% decrease in slaughter cattle price, or $7.12/cwt using the real mean price for the period. Thus, based on the sample data, meat packing technological change offset the negative effects of farm-level technological change and increased cattle price by $1.75/cwt. This result is consistent with a decline in the farm-wholesale beef marketing margin.

Conclusions

U.S. real cattle and hog prices have declined 50% and 66%, respectively, since 1970. Concurrently, real beef and pork farm-wholesale marketing margins declined by 57% and 65%. Many factors have contributed to these declines, including increases in meat supplies, decreases in real by-product values, and declines in consumer demand. In addition, significant technological changes have occurred throughout these sectors. Most econometric studies, however, have not considered the effects of technological change on red meat marketing margins or livestock prices.

The long-term effects of technological change were estimated in this analysis by using productivity measures which are conceptually better proxies for technology-related shifts in output supplies and input demands than the use of time trends. The results are important to producers because technological changes may generate processing cost savings. If the meat processing sector is competitive, cost savings should result in higher cattle and hog prices.

Our econometric results indicate meat packing technology, ceteris paribus, has contributed to reductions in the real farm-wholesale beef and pork marketing margins, but has positively influenced real slaughter cattle and hog prices. Thus, it appears enough competition existed during the sample period to bid technological cost savings into livestock prices. Conversely, changes in farm-level technology have contributed to declines in real farm prices, especially in the beef sector.

Successful firms in a competitive commodity production sector rely heavily upon the adoption of low-cost strategies. Livestock and meat producers adopt technologies which lower unit production costs. Increased profitability invites entry and, unless commensurate demand increases occur, causes real livestock prices to decline. Potentially, the introduction of biotechnological and informational technologies into the livestock production sector could further expand animal size without commensurate reductions in end-product quality. Thus, the adoption of technologies which enhance productivity may continue to exert downward pressure on real livestock prices.

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