Title

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Publication Date

2001-02-01

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February, 2001

Working Paper No. 01-012

California Agricultural Experiment Station
Giannini Foundation for Agricultural Economics

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Catherine J. Morrison Paul*

ABSTRACT

Expanding concentration in many industries has generated concern about the extent and determinants of these market structure patterns. Understanding such trends requires information on technological characteristics underlying cost efficiency. However, market structure and power analyses are typically based on restrictive models that limit the representation of cost drivers. In this paper we model and estimate a comprehensive cost specification allowing for utilization, scale, scope, and multi-plant economies, using U.S. beef packing plant data. We find evidence that these cost economies are substantive, and in combination cause a short-fall of marginal from average cost, provide economic motivations for concentration, consolidation, and diversification, and facilitate the interpretation and use of market structure measures.

Preliminary, November 2001, SEJ10.doc

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Introduction

Many industries in the U.S. and other developed countries have experienced increased concentration and consolidation in the past few decades, stimulating concerns about market power and questions about the factors underlying such trends. Evaluation of market power often takes the form of measuring perceived output demand relationships, and imputing the implied price-marginal cost deviations. However, understanding market structure patterns in more depth requires obtaining comprehensive information about the cost structure, which is precluded by the restrictive cost assumptions of most market structure models. Since cost economies imply greater cost efficiency for larger scale or more diversified operations, this may seriously limit the insights obtainable from such models.

Cost economies – including short run (utilization), long run (scale), scope (output jointness), and multi-plant (information or risk-sharing) economies – may provide incentives for expanding throughput, size, diversification, and plant numbers. Such cost characteristics in turn imply economically valid motivations for increasing concentration. Thus, information on the existence and extent of a variety of potential cost economies is a key to the relevant construction, interpretation, and use of market structure and power measures. It provides insights about why concentration might have increased, whether these trends could be welfare enhancing rather than harmful, and what trends to expect in the future, that are crucial for guiding policy measures to monitor and control market power.

The importance of the cost structure as a potential driver of market structure patterns, and thus of a comprehensive empirical representation for its evaluation, has been recognized at least since the advent of the New Empirical Industrial Organization (NEIO) literature.[1] The literature on regulation and natural monopoly, primarily targeting public utilities, has also focused on the extent and form of cost (usually scale) economies, and how they affect appropriate policy formulation.[2] But for most industries the cost structure has received little attention in models of market structure, power, and welfare, which are often based on an assumption of constant returns to scale or a simple proportional cost-output relationship. Even when the existence of cost economies is acknowledged, consideration is typically restricted to scale economies. The cost interactions that drive economic behavior and potentially motivate firms to expand and diversify are, however, much more complex than this suggests. So recognition of a broader range of cost economies is required to facilitate analysis of cost and market structure patterns and interactions.

One industry that has generated significant concern about market power, because it (traditionally and increasingly) has experienced large firms and high concentration levels, provides a fundamental consumption commodity (food), and draws from a primary supplying sector (agriculture), is the U.S. beef packing industry. Although concentration in this industry declined after reaching very high levels in the late 1800s to mid 1900s, due to both technological changes and regulatory measures,[3] plant and firm size again increased dramatically after various structural changes in the late 1900s.

As documented in USDA/GIPSA (1996),[4] although the four largest packers accounted for only 36 percent of the market in 1980, this percentage had increased to 72 percent by 1990 and 82 percent by 1994. Concern about this trend is evident from the many studies of market structure for this industry in the past two decades.[5] Although a crucial factor underlying such patterns is the cost or technological structure, the cost side of the problem has usually been finessed in these studies, which severely limits the appropriate interpretation and use of resulting market structure and power measures.

In particular, the role of cost economies is often alluded to but not effectively addressed in the beef packing industry literature. For example, USDA/GIPSA (1996) stresses that understanding such economies is a key to assessing whether “potential efficiency gains of larger firms offset potential adverse market power effects of concentration,” and determining “the role of Federal regulation in preventing large firms from abusing potential market power, and in monitoring the industry.” Questions are posed about whether cost (scale and scope) economies result in enhanced efficiency of large or diversified operations, and so have a role in driving observed structural changes. Related queries regarding the importance of maintaining high utilization levels, given large capital stocks and rigidities, are raised. The potential that these technological cost economies may occur in combination with pecuniary economies, reflecting input (cattle) market power if large operations exhibit buying power in cattle markets, is underscored. But the lack of evidence in the existing literature about these patterns is also recognized, and lamented.

In this study we explore these technological and market characteristics and inter-relationships. We use monthly cost and revenue data from the USDA/GIPSA survey of the 43 largest U.S. beef packing plants in 1992-93, and a cost function-based model, to represent the cost structure of these plants. We incorporate profit maximization over cattle purchases, and fabricated, slaughter, hide, and byproduct production. And we take regional, firm, category (type) and monthly differences into account as fixed effects. The resulting estimates and measures facilitate the empirical identification and evaluation of cost economies associated with utilization, scale, scope and multiple plants.

Our results suggest that substantive utilization economies exist, that cause large plants in particular to value keeping throughput (and thus cattle input) at high levels. Significant scale and scope economies also prevail,[6] that provide driving forces toward large and diversified plants. And multi-plant economies are evident, although they are less substantive than those embodied in individual plants. These technological economies are slightly counteracted by pecuniary diseconomies deriving from the cattle input market, although the latter appear insignificant, and neutralized by utilization economies. Overall, these cost economies cause marginal costs to fall significantly short of average costs. Thus, measures of market power based on simple cost structure (and thus marginal cost) assumptions are at best limited in their interpretability, and at worst may be erroneous.

The Cost Structure Model and Measures

The Model

A cost function model provides a natural foundation for a detailed structural characterization of costs. Such a model may be represented in general form as $TC(\mathbf{Y},\mathbf{p},\mathbf{r},\mathbf{T}) = VC(\mathbf{Y},\mathbf{p},\mathbf{r},\mathbf{T}) + \Sigma_k r_k p_k$, where VC is variable costs, **Y** is a vector of M outputs produced, Y_m, **p** is a vector of J variable input prices, p_j, **r** is a vector of K restricted or control variables, r_k, with market prices p_k, and **T** is a vector of external shift factors.

This framework may be used to represent many aspects of the cost structure.[7] In particular, cost effects may arise from utilization changes (due to input fixities), input substitutability, scale economies (and biases), scope economies (output jointness), and other inter-dependencies such as endogenous input prices (buying power) or multi-plant economies.[8] These cost structure characteristics can be represented via first and second derivatives and elasticities of the cost function, if a flexible functional form including a full range of cross-effects is assumed, price endogeneity for netputs potentially subject to market power is recognized, and fixed effects representing firm affiliation are accommodated.

Modeling and measuring this range of output and input relationships also requires a detailed data set. For our purposes we use data from a USDA/GIPSA survey of the 43 largest U.S. beef packing plants (elaborated in USDA, 1996),[9] defined as having annual slaughter of more than 75,000 head of steers and heifers, and comprising more than 90 percent of production in this industry.[10]

These data include information on the volume and value of shipments for non-fabricated carcasses and a number of fabricated (more processed) sub-categories. These categories were aggregated, due to apparent inconsistencies across plants in the divisions among types of fabricated outputs; only byproducts and hides were separately distinguished for our output specification. The total chilled carcass weight, and the total delivered cost of the cattle, were used to represent the cattle input and price. A combined (slaughter and fabrication, and overtime and regular) measure of hours worked was used for our labor input, and a weighted average of regular and overtime wages for its price. Data on fuel and electric expenditures and quantities were aggregated to construct total energy price and implicit quantity indexes. Data on quantities and values of purchased or transferred beef products, and values of "other" purchased materials inputs (primarily packaging material), completed our variable input specification. The weekly data were aggregated to the monthly level since many values had been interpolated from monthly data, and input-output relationships may not be well represented on a weekly basis.[11]

For our empirical cost specification we thus recognize four products in the **Y** vector – slaughter and fabricated meat products (Y_S and Y_F), byproducts (Y_B) and hides (Y_H). We distinguish five variable inputs – labor (L), energy (E), and purchased beef (M_B, where M denotes "materials", and B "beef"), "other" materials (M_O), and the primary input, cattle (C). And we include one fixed input, the capital base (K), represented by the reported "replacement cost" of the plant (as discussed further below).

The **p** vector includes the prices of inputs that may be assumed to be variable, to have appropriately measured prices, and to possess competitive markets.[12] Demands for these inputs are thus represented by Shephard's lemma: $v_j=\partial VC/\partial p_j$, for j= L,E,$M_B$. The remaining three inputs are treated as **r** vector components, for various reasons.

First, M_O is reported in (nominal) dollar values rather than (real) quantities, without a well-defined price. Because the data are essentially a one-year cross-section, increases or inflation in M_O prices are not an issue, and the M_O cost share is less than 2 percent, so the representation of optimization over M_0 is not critical. Thus, M_O is included in the **r** vector as a value, but is recognized as part of variable costs.[13] Second, K does not vary for any plant during the time period of the data, and so is considered a control variable. Utilization changes therefore involve variations in the amount of output produced from the existing capital stock. Third, and most importantly for our application, the C level is included as an argument of $VC(\cdot)$ to reflect the potential for monopsony behavior in this market, so optimization takes the form of a pricing decision. This implies an endogenous input price for the cattle input, p_C

$= p_C(C)$, and thus input market buying power (the potential for p_C to be depressed by large packers), so C demand decisions involve price (pecuniary) as well as quantity components.

Also, cost effects may result from interdependencies among plants within firms – multi-plant economies – that allow plants to internalize cost savings from, say, spreading overhead labor or exploiting communications networks. They may take the form of neutral downward shifts of the whole cost function (fixed effects), or involve interactions with other arguments of the function. Dummy variables representing these interdependencies, $\mathbf{D_F}$ (where F denotes "firm" and D "dummy") are thus also considered **r** vector components.

The resulting cost function thus becomes $TC = VC(C,K,p_L,p_E,p_{MB},Y_F,Y_S,Y_H,Y_B,\mathbf{D_F}) + p_C(C)\, C + p_K\, K$, which embodies optimization decisions with respect to the variable inputs via Shephard's lemma. To represent the full optimization process underlying both the estimation model and the construction and evaluation of cost economy and market power measures, we must also characterize optimization decisions for the outputs, Y_m, and C. The former involves equalities of marginal revenue, MR, and cost, MC: $MR_m = p_{Ym} + \partial p_{Ym}/\partial Y_m \cdot Y_m = MC_m = \partial TC/\partial Y_m$, where $p_{Ym}(Y_m)$ reflects endogeneity of the output price, so the optimal output pricing equation becomes $p_{Ym} = -\partial p_{Ym}/\partial Y_m \cdot Y_m + \partial TC/\partial Y_m$. Similarly, optimization over C is reflected by an equality of the marginal factor cost of C, MFC, and its shadow value, Z: $MFC_C = p_C + C \cdot \partial p_C/\partial C = Z_C = -\partial VC/\partial C$ (where the input shadow value is defined as in Lau, 1978).[14] C pricing behavior is thus represented by $p_C = -C \cdot \partial p_C/\partial C - \partial VC/\partial C$. Incorporating this equation into the optimization model recognizes the variable nature of the C input, in the context of sequential optimization, by contrast to K, which is a fixed input.[15]

Cost Economy Measures

The range of cost economies we are interested in may be modeled and measured within this framework. Note first that scale economies are typically represented in a cost function model by the elasticity $\varepsilon_{TC,Y} = \partial \ln TC/\partial \ln Y = MC/AC$, for one aggregate output Y. This overall cost elasticity embodies, however, many separately identifiable cost economy components, given our detailed specification of outputs, inputs, and sequential optimization.

If $\varepsilon_{TC,Y}$ is constructed directly from the TC function as defined above, it is based on existing levels of not only outputs and all input prices, but also input levels included as arguments of the function. It is thus a "short run" (S) measure, $\varepsilon^S_{TC,Y}$. Imputing sequential input decisions requires consideration of C, K (and ultimately p_C) changes that would result from changes in the scale of operations. In particular, C demand adjusts along with output expansion, implying increases in throughput or capacity utilization of the existing plant. Since C demand is thus a function of **Y**, this can be formalized as $\varepsilon^I_{TC,Y} = \partial \ln TC/\partial \ln Y + \partial \ln TC/\partial \ln C \cdot \partial \ln C/\partial \ln Y$, where I denotes "intermediate run". If $\varepsilon^I_{TC,Y}$ is evaluated at the profit maximizing C level (or at fitted values from the optimization problem), $\partial TC/\partial C=0$ and measured $\varepsilon^S_{TC,Y}$ collapses to $\varepsilon^I_{TC,Y}$ by the envelope theorem.[16] Thus, $\varepsilon^I_{TC,Y}$ is the appropriate elasticity for evaluating cost incentives for output expansion at given capacity (K) levels.[17]

The specification of $\varepsilon^I_{TC,Y}$ as a combination of elasticities is analogous to standard models of fixed input adjustment to long run levels,[18] although a time lag is not implied. The sequential adjustment representation is motivated by market structure instead of quasi-fixity. If we also wish to capture long run behavior, we may similarly impute the steady state equilibrium K level from the equality of the market (p_K) and shadow (Z_K) value of K: $p_K = -\partial VC/\partial K = Z_K$.

The implied long run $\varepsilon_{TC,Y}$ measure incorporating optimization over both C and K thus becomes $\varepsilon^{L}_{TC,Y} = \partial \ln TC/\partial \ln Y + \partial \ln TC/\partial \ln C \cdot \partial \ln C/\partial \ln Y + \partial \ln TC/\partial \ln K \cdot \partial \ln K/\partial \ln Y$.[19]

The distinction between $\varepsilon^{I}_{TC,Y}$ and $\varepsilon^{L}_{TC,Y}$ may be used to address utilization issues.[20] Full capacity utilization implies the K-Y relationship reproduces a tangency of the short and long run cost curves, where $\varepsilon^{I}_{TC,Y} = \varepsilon^{L}_{TC,Y}$. Thus, the deviation between $\varepsilon^{I}_{TC,Y}$ and $\varepsilon^{L}_{TC,Y}$ represents capacity utilization.[21] If the plant is producing such that $\varepsilon^{I}_{TC,Y} < \varepsilon^{L}_{TC,Y}$, short run cost savings results from higher utilization (more Y and thus throughput) in the plant.

Note that unit cost savings may be achieved by expanding Y if $\varepsilon^{I}_{TC,Y} < 1$, regardless of the relationship of the intermediate to the long run cost curve. But this indicates that the plant is not producing at the minimum cost point on the intermediate run average cost curve, rather than suggesting a deviation from the tangency with the long run curve. Thus $\varepsilon^{I}_{TC,Y} = 1$ is consistent with a different version of "optimality" or cost efficiency than that implied by profit maximization. And output demand conditions and input constraints might well keep the plant from reaching this minimum average cost point. This could also be true for the long run curve.

For our multiple output cost function we must also extend the usual representation of scale economies to accommodate this dimensionality, and to recognize scope economies, as developed by Baumol, Panzar and Willig (1982). In particular, scale economy measures for each Y_m may be combined to generate the overall cost economy measure $\varepsilon_{TC,Y} = \Sigma_m \partial TC/\partial Y_m \cdot (Y_m/TC) = \Sigma_m \varepsilon_{TC,Ym}$.[22] And scope economies may be represented analogously to Fernandez-Cornejo *et al* as $SC_m = ([\Sigma_m TC(Y_m) - TC(\mathbf{Y})]/TC(\mathbf{Y}))$, where $TC(Y_m)$ is the minimum cost of producing output Y_m independently of other outputs. So SC_m is dependent on second derivatives representing output jointness, such as $\partial^2 VC/\partial Y_F \partial Y_S$. $\varepsilon_{TC,Y}$ may thus be decomposed into a measure purged of scope effects, or “net” scale economies (denoted “N”), and a separate scope economy measure: $\varepsilon_{TC,Y} = \varepsilon^{N}_{TC,Y} - SC_{FHSB}$ (for our 4-output specification).

Besides the technological economies that may be entangled in the overall cost-economy measure $\varepsilon_{TC,Y}$, and identified through computation of the various cost economy elasticities overviewed above, pecuniary (dis)economies may arise from the dependence of p_C on C demand levels. Analyzing these impacts involves recognizing the dependence of $\varepsilon_{TC,Y}$ on marginal rather than average factor cost, such that monopsony power is embodied in $\varepsilon_{TC,Y}$ as a cost diseconomy; higher output levels require greater throughput, which implies higher C price (with an upward sloping input supply function). Thus, for our total cost specification, $TC = VC(\cdot) + p_C(C)C + p_K K$, the definition of $\varepsilon^{l}_{TC,Y}$ implicitly includes the component $\partial p_C/\partial C \cdot C$ in the $\partial TC/\partial C$ derivative, and the cost economy measure will be larger (lower cost economies) if input market power exists. By contrast, if $\varepsilon^{l}_{TC,Y}$ is measured without this component ($\partial p_C/\partial C$ is set to 0), a pure technological (denoted “T”) measure purged of pecuniary diseconomies, $\varepsilon^{T}_{TC,Y}$, may be defined and used to distinguish the independent impact of input market power.[23]

In turn, cost economies from multi-plant or other interdependencies may be measured by identifying the underlying interactions affecting costs. For example, information on the association of plants within a firm may be attained by considering the dummy variable derivatives or elasticities $\partial TC/\partial D_f$ or $\varepsilon_{TC,Df} = \partial \ln TC/\partial D_f$.

Finally, in addition to identifying the cost economy components underlying $\varepsilon_{TC,Y}$, we can represent adaptations in the extent of such economies from changes in external factors or behavior. In particular, the impact of increasing C (throughput) on cost economies may be computed through the second order relationship $\varepsilon_{TCY,C} = \partial \ln \varepsilon_{TC,Y}/\partial \ln C$. Similarly, the effect of increasing Y_m (output-specific scale) may be represented by $\varepsilon_{TCY,Ym} = \partial \ln \varepsilon_{TCY}/\partial \ln Y_m$. We will call these "comparative static" elasticities.

The cost economy measures overviewed in this section provide a basis for exploring and untangling the forces causing deviations between average and marginal costs. Such information has a key role in constructing and interpreting market power measures, which are typically computed as a price/marginal cost gap. MC measures may not be relevant for this purpose if they are too simplistic – if they do not appropriately account for the interactions underlying a full cost economy characterization. And if MC<AC due to any component of cost economies, excess profitability may not be implied by a measured p_Y/MC markup, although that is its typical interpretation. Efficiencies from expanding or diversifying output *are* implied, which provides a rationale for trends toward increased concentration. And if motivated by efficiency enhancement, such market structure patterns could support gains not only to producers, but also to consumers of the final products and suppliers of the inputs. Detailed models and measures of cost economies are thus required to facilitate evaluating their role in motivating concentration patterns, and their welfare implications, to guide policy about industry concentration.

The primary insights obtainable from such measures involve the existence, extent, and range of cost economies, and their potential to support trends toward increasing concentration, consolidation, and diversification. One might also wish to consider what the cost economy estimates imply about an "optimal" scale of plant. However, taking this step is not straightforward, or perhaps very informative, if motivated from the traditional perspective of the minimum point of the average cost curve, and if a range of cost economies are evident and plant heterogeneity prevails. In particular, the definition of “optimality” in this context is not well defined. Also, output demand or technical limitations could preclude moving to production levels that might be deemed optimal in the sense of cost efficiency. And finally, with multiple input and output levels and interactions there could be many solutions, or at least adjustment paths to an optimal point.[24] Each of these difficulties deserves some further elaboration.

First, one sort of optimality is already represented within our model. Our cost economy measures are implicitly evaluated at fitted profit maximizing – and in that sense optimal – values, and so take into account effective technological, output demand, and input supply conditions restricting production and profitability. If the solution to the maximization problem closely approximates a tangency between the average cost and demand curves, production could take place where cost economies are evident (MC<AC) but profits are low, similarly to a monopolistically competitive situation. Such a situation could arise if each plant perceives a downward sloping output demand curve, and yet still be consistent with effective competition and represent a (second best “optimal”) industry equilibrium.

Second, when all potential cost economies are accommodated the imputed solution could be at an infeasible production point, either due to technological or economic limitations (outside the range of observed output levels, or where total costs exceed revenues, given output demand).[25] This could imply a combination of “natural monopoly” and (effective or monopolistic) competitive forces, given prevailing demand and supply conditions; existing demand may just not support a group of plants producing at their minimum average cost point.

Finally, empirically implementing the minimum-AC version of “optimality” involves finding the minimum point of the long run (or intermediate run) average cost curve, or imputing the **Y** levels where ε_{TCY}=MC/AC=1. With multiple outputs this becomes problematic, because this one condition cannot be solved for the optimal levels of the M outputs. Although the adapted condition $1 = \varepsilon_{TCY} = (\Sigma_m \partial TC/\partial Y_m \cdot Y_m) / TC = \Sigma_m MC_m \cdot Y_m / TC = \Sigma_m \varepsilon_{TCYm}$ may be decomposed into the M conditions $\varepsilon_{TCYm} = S_m$ (where S_m is the Y_m "share"), or $MC_m=AC_m$, this ignores cross-effects. Plant heterogeneity, particularly when some plants do not produce all outputs, further convolutes the computation and interpretation of such measures. And in our primarily cross-sectional treatment dynamic behavior, or convergence toward some long run "optimal" type of plant, is not readily analyzed. Nevertheless, solving such a system of equations to reproduce one possible cost-based solution provides a potentially informative if limited base for evaluating the concentration implications of our cost economy estimates.[26]

Empirical implementation and results

The estimating model

To empirically implement our model for U.S. beef packing plants we assume VC(**Y**,**p**,**r**,**T**) can be approximated by a (flexible) generalized Leontief function, with quadratic cross-terms for variables expressed in levels. Such a function, augmented by fixed effects for regions and firms through dummy variables DUM_r and DUM_f, has the form:

1) $$VC(\mathbf{Y},\mathbf{p},\mathbf{r},\mathbf{T}) = \Sigma_i p_i \cdot C \cdot (\Sigma_r \delta_r DUM_r + \Sigma_f \delta_f DUM_f)$$
$$+ \Sigma_i\Sigma_j \alpha_{ij} p_i^{.5} p_j^{.5} + \Sigma_i\Sigma_m \delta_{im} p_i Y_m + \Sigma_i\Sigma_k \delta_{ik} p_i r_k$$
$$+ \Sigma_i p_i (\Sigma_m\Sigma_n \gamma_{mn} Y_m Y_n + \Sigma_m\Sigma_k \gamma_{mk} Y_m r_k + \Sigma_k\Sigma_l \gamma_{lk} r_k r_l) .$$

In addition to equation (1), the estimating system includes the variable input demand equations derived from Shephard's lemma, $v_j=\partial VC/\partial p_j$. To address the great variability in demand for M_B, and to allow for firms using no intermediate beef products, additional dummy variables were included in the M_B demand function to represent plants with zero and with particularly high M_B input levels. The resulting equations have the form:

$$2a)\ v_j(\mathbf{Y,p,r,DUM}) = C \cdot (\Sigma_r\delta_r\ DUM_r+\Sigma_f\delta_f\ DUM_f) + \Sigma_i\ \alpha_{ij}\ (p_i/p_j)^{.5} + \Sigma_m\ \delta_{jm}\ Y_m$$

$$+ \Sigma_k\ \delta_{jk}\ r_k + \Sigma_m\Sigma_n\ \gamma_{mn}\ Y_m\ Y_n + \Sigma_m\Sigma_k\ \gamma_{mk}\ Y_m\ r_k + \Sigma_k\Sigma_l\ \gamma_{lk}\ r_k\ r_l\ , \quad \text{for } j=E,L, \text{ and}$$

$$2b)\ M_B(\mathbf{Y,p,r,DUM}) = DUM_{MB0} \cdot \delta_{MB0}+DUM_{MBL} \cdot \delta_{MBL}$$

$$+ C \cdot (\Sigma_r\delta_r\ DUM_r+\Sigma_f\delta_f\ DUM_f) + \Sigma_i\ \alpha_{iMB}\ (p_i/p_{MB})^{.5} + \Sigma_m\ \delta_{MBm}\ Y_m$$

$$+ \Sigma_k\ \delta_{MBk}\ r_k + \Sigma_m\Sigma_n\ \gamma_{mn}\ Y_m\ Y_n + \Sigma_m\Sigma_k\ \gamma_{mk}\ Y_m\ r_k + \Sigma_k\Sigma_l\ \gamma_{lk}\ r_k\ r_l$$

for M_B, where DUM_{MB0} and DUM_{MBL} are dummy variables for M_B=0 and M_B large. Note that the dummy variables for firms and regions in (1) are incorporated in such a fashion that they retain required linear homogeneity properties, and thus appear in the input demand equations.

The pricing equation for C, as discussed above, is based on the profit maximizing equality of the marginal factor cost and shadow value of C: $p_C = -C \cdot \partial p_C/\partial C - \partial VC/\partial C$, or[27]

$$3)\ p_C = -\beta_C - \beta_{CCS2} \cdot CS + \Sigma_i p_i \cdot (\Sigma_r\ \delta_r\ DUM_r + \Sigma_f\ \delta_f\ DUM_f) + \Sigma_i\ \delta_{iC}\ p_i\ C$$

$$+ \Sigma_i p_i\ (\Sigma_m\ \gamma_{mC}\ Y_m\ C + \Sigma_l\ \gamma_{lC}\ C\ r_l)\ ,$$

given the assumed form of the (average) $p_C(C)$ equation

$$4)\ p_C = p_C(C) = \alpha_C + \beta_C \cdot C + \beta_{CNB} \cdot NB + \beta_{CP} \cdot PRC + \beta_{COT} \cdot OT + \beta_{CCS} \cdot CS$$

$$+ \beta_{CQU} \cdot QU + \beta_{CCS2} \cdot C \cdot CS + \Sigma_i\delta_M \cdot DUM_M\ ,$$ [28]

where NB is the number of cattle buyers, PRC is expenditures on cattle procurement, OT is pay for overtime workers, CS is captive supplies (percent by weight of packer fed cattle), QU is quality (percent of steers and heifers), and DUM_M are monthly dummies. Equations (4) and (5) are thus also included in the system of estimating equations.

The optimal output pricing equations are similarly based on the profit-maximizing pricing expressions $p_{Ym} = -\partial p_{Ym}/\partial Y_m \cdot Y_m + \partial TC/\partial Y_m$, from the marginal revenue and cost equalities for each output.[29] Since output market power is not expected to have significant consequences in this industry,[30] simple linear forms for the $p_{Ym}(Y_m)$ relationships were assumed: $p_{Ym} = \alpha_{Ym} + \beta_{Ym} Y_m$. These equations, with dummy variables included to represent plants with zero output values, complete the estimating system:

5) $p_{Ym} = -\lambda_{Ym} \cdot Y_m + \delta_{Ym0} DUM_{Ym0} + \Sigma_i \delta_{im} p_i + \Sigma_i p_i (\Sigma_n \gamma_{mn} Y_n + \Sigma_k \gamma_{mk} r_k)$,

where m,n =F,S,H,B; DUM_{Ym0} represents the Y_m=0 plants; $\lambda_{Ym} = \partial p_{Ym}/\partial Y_m$, and $\lambda_{YB} = 0$.[31]

Equations 1-5 thus comprise our final system of estimating equations for our beef packing plant data. Different plant "categories" were specified based on identifiable structural differences across the plants, such as plants selling only fabricated or only slaughter output, and those purchasing no (or a large amount of) intermediate beef products, M_B. Plants were also distinguished by region – the East, West, Western Corn Belt and Plains (and an "Adapted Plains", AP, category including the 13 largest slaughter/fabrication plants in the plains).[32]

Econometric concerns addressed include potential endogeneity from the joint choice of quantity and prices in markets that may be subject to market power. Three stage least squares (THSLS) methods were used to accommodate unmeasured plant-specific differences, although the findings did not differ substantively from multivariate regression estimates. We tried various specifications of the instruments, with little impact on the results, except for the $\varepsilon^L_{TC,Y}$ estimates. All other estimates proved to be very robust. The final instruments chosen were one month-lagged ratios of C, Y_S, Y_F, and M_B to total revenues, and measures of distributing, merchandising and sales expenses, total compensation of cattle buyers, cost of fringe benefits, and revenue from custom cattle slaughter. A MILLS ratio based on TOBIT estimation of the cost function was also included for completeness, but had a negligible effect on the overall estimates.

An additional econometric issue involved the measurement of capital, K, since the values for replacement capital reported by the plants in our data set have an uncertain reporting basis, and in a few cases were nonexistent. A separate regression was thus estimated to represent the effective capital base for each plant, using the data for plants that did provide replacement capital estimates. After experimental empirical investigation to fit the existing data as closely as possible, the chosen determinants of this regression were maximum slaughter and fabrication rates, the extent of fabrication, energy use, and the number of shifts. The fitted K values for all plants were then used for estimation of the full model. We found little empirical sensitivity of the model to this treatment (likely due to the limited role K plays in the estimation process, since it is essentially a control variable), except again for the long run measures, which are clearly less reliable than the remaining estimates.

The empirical results

Cost economy estimates for the 40 plants in the USDA/GIPSA Cost and Revenue Survey for which we had comparable data are presented in Table 1.[33] The measures were computed for each plant and then averaged across plants overall, and for different categories and regions.[34] The discussion below primarily focuses on the average values over the entire sample, to highlight patterns.

First note that the overall cost economy estimate incorporating cattle input adjustment, $\varepsilon^{I}_{TC,Y}$, is 0.960 on average across all plants. This suggests a 4 percent cost savings on a marginal increase in overall output; growth in the scale of production given existing capacity may be accomplished with a smaller (96 percent) cost as compared to output increase. $\varepsilon^{S}_{TC,Y}$ (0.919 for the average plant) falls short of $\varepsilon^{I}_{TC,Y}$ by the marginal cost impact of cattle input adjustment, so the estimated differential of approximately 0.04 suggests that marginal increases in throughput and thus utilization levels reduce average costs by 4 percent. That is, evaluated at existing input and output levels, utilization economies support unit cost reductions from profit maximizing increases in cattle inputs in response to output demand increases.

$\varepsilon^{I}_{TC,YF}$ = 0.626 and $\varepsilon^{I}_{TC,YS}$ = 0.231 are the (average) Y_F- and Y_S-specific components of $\varepsilon_{TC,Y}$. These values depend in part on the output shares of Y_F and Y_S, but also embody information on the relative cost savings from producing each type of output. Comparing the estimates to the average output shares of 0.662 for Y_F and 0.239 for Y_S suggests that Y_F production generates greater cost economies than Y_S. The $\varepsilon^{I}_{TC,YF}$ value is significantly lower than the share, so higher Y_F levels contribute less to cost increases than to output augmentation.

ε^{L}_{TCY} , by contrast to ε^{I}_{TCY}, exceeds 1.0; long run cost economies appear to fall short of economies based on utilization of the existing plant. In fact, on average (small) diseconomies are evident, suggesting that moving toward an "optimal" plant size would cause downsizing for at least some plants. However, these estimates are the least robust of the model, due to the essentially cross-section nature of the data, and thus are not very definitive.[35]

In turn, our (average) measure of scope economies including all cross-effects, SC_{FSHB}=0.030, suggests that, on average, 3 percent of the 8 percent observed cost economies are due to scope economies.[36] The remaining scale economies account for 5 percent, as is more directly evident from the $\varepsilon^{N}_{TC,Y}$=0.949 estimate. Also, the SC_{FS} measure indicates that only

0.008 of exhibited scope economies are due to complementarities between Y_F and Y_S; the balance involves cross effects with Y_H and Y_B. Although not reported separately in the tables, these economies are almost invariably associated with Y_F rather than Y_S. The SC_{FH} and SC_{FB} elasticities are 0.010 and 0.007, respectively (on average across all plants), whereas the Y_B and Y_H cross-effects with Y_S are nearly always close to zero.[37]

We can also disentangle the pecuniary diseconomies embodied in $\varepsilon^I_{TC,Y}$, due to cattle market power, from the technological economies reflected by $\varepsilon^T_{TC,Y}$=0.947.[38] These measures indicate that cost economies net of cattle price changes exceed those including these changes by 0.013. Pecuniary diseconomies reduce cost economies by about 1.3 percent, which is consistent with measures of cattle price "markdowns" of approximately 2.2 percent.[39] Combined with our evidence on utilization economies, this implies that cost savings from the associated increased throughput outweigh any p_C increases due to greater cattle purchases.

Finally, multi-plant economies are evident from our parameter estimates associated with the D_F fixed effects, although they are typically not large or significant.[40] Since they are fixed effects, they affect the denominator of the $\varepsilon_{TC,Y}$ measures (AC), but not the numerator (MC).

The cost economy measures vary somewhat across categories and regions. In particular, plants for which Y_F=0 or Y_S=0 are by definition unable to take advantage of scope economies across these outputs, although some cost economies remain due to complementarities with Y_B and Y_H. For Y_F=0 plants such economies comprise only a tenth (0.003 rather than 0.030) of the scope economies evident on average across plants. Overall cost economies are also smaller for plants that do no fabricating, and similar to those that sell no slaughter output.

By contrast, most of the large cost economies found for plants in the plains, and in particular the largest ones (in the AP category), seem to be attributable to extensive measured scope economies (0.062 as compared to 0.030 on average). Plants that purchase or transfer a significant amount of intermediate beef products (M_B) also exhibit greater cost economies, and especially scope economies, than average. And they tend to do a considerable amount of fabrication, as compared to selling just slaughter output.

The comparative static elasticities reported in Table 2 summarize the impacts of changes in cost function arguments on the cost economy measures, and thus provide further insights about their patterns. Perhaps the most striking implication from these measures is that increases in Y_F cause $\varepsilon_{TC,Y}$ to fall, and thus cost economies to rise, for all categories and regions.[41] This supports the notion that diversifying production to include fabricated products generates cost-savings benefits, which was suggested by other measures. By contrast, increases in Y_S tend to reduce cost economies, but only by .01 percent with a 1 percent increase in Y_S on average, so the magnitude is negligible. Also, for the Plains plants, with their greater scope economies, $\varepsilon_{TCY,YS}$ is instead negative (greater cost economies arise from Y_S expansion) although the impact is small (1.2 percent instead of the 50 percent change for Y_F).

As one might expect, $\varepsilon_{TCY,C}>0$, suggesting that increases in cattle input, and therefore throughput, cause $\varepsilon_{TC,Y}$ to rise. This implies increased utilization, and thus a movement down the average cost curve, that is a motivating factor to increase C even in the face of (minor) associated p_C increases. In reverse, $\varepsilon_{TCY,K}$ is invariably negative. Increasing K when low utilization levels prevail further reduces utilization rates; $\varepsilon_{TC,Y}$ falls, or potential cost economies rise. Also, higher variable input prices – especially p_{MB} – tend to cause reductions in cost economies, possibly due to a substitution toward cattle inputs instead of intermediate beef products. It is also worth noting that the plains (particularly the large AP) plants exhibit relatively high $\varepsilon_{TCY,C}$ and $\varepsilon_{TCY,YF}$ elasticities, suggesting that cost-savings derived from utilization and diversification are even greater in these larger plants.

In sum, it appears from the cost economy measures for the beef packing plants in the USDA/GIPSA survey that larger and more diversified plants have greater potential to expand production at low costs. Also, their relatively low marginal costs seem to stem from cost economies rather than cattle input market power. Some pecuniary diseconomies – and thus market power in cattle markets – are evident, but cost economies derived from high utilization levels outweigh these diseconomies.

The wide variations across different types of plants apparent from these estimates make it conceptually as well as analytically problematic to move on to determine an "optimal" size of plant, in the sense of the minimum of the combined average cost curve (with or without K adjustment). Although it appears that plants that diversify across both outputs and inputs tend to be both larger and more profitable, this may well be due to a different technological base. Thus, imputing the optimal plant in this sense (taking all cost economies and interactions into account) is not a well-defined exercise.

However, based on the discussion in the previous section, we solved a system of $\varepsilon_{TCYm} = S_m$ (implying $MC_m=AC_m$) equations to impute one version of cost efficient (minimum AC) Y_m and C levels, which we denote $Y_{m,O}$ and C_O (where O indicates "optimal"). Resulting Y_{mO}/Y_m and C_O/C ratios, based on both existing capacity (denoted I) and with long run K adjustment incorporated (L), are reported in Table 3. These measures suggest that, given capacity and if demand conditions allowed, the average plant would need to increase Y_F, Y_S and C levels to attain full cost efficiency. But if K were divisible and adjustable, on average lower K and thus production and cattle input demand levels would be consistent with long run cost-efficient production.[42] This follows from the (usually small and not very robust) long run diseconomies evident from the $\varepsilon^L_{TC,Y}$ estimates, as contrasted to the large capacity-constrained or utilization (intermediate-run) economies suggested by the $\varepsilon^I_{TC,Y}$ estimates, especially for the large plants.

However, the high measured Y^I_{mO} and C^I_O levels seem unlikely to be feasible due to restrictions in output demand and input (and output) substitution. That is, if supported by demand, "cost efficient" Y^I_{FO}, Y^I_{SO}, and C^I_O levels would be more than 30 percent higher than observed, with the implied Y_F increases even greater than for Y_S. These large numbers suggest (on average) a fairly flat capacity-constrained unit cost curve in this range, since the average $\varepsilon^I_{TC,Y}$ measure is close to 1. By contrast, in the long run, average imputed Y^L_{FO} levels would be about 20 percent *lower* than observed Y_F, and correspondingly C^L_O<C, whereas Y^L_{SO} is even higher than Y^I_{SO}, and nearly 38 percent greater on average than Y_S.

These implications again vary significantly by type of plant. In particular, for AP plants the implied full utilization C^I_O is smaller – about 16 percent greater than C – although Y^I_{FO}/Y_F and Y^I_{SO}/Y_S are in the same range (and the shortfalls of Y^I_{HO} and Y^I_{BO} from Y_H and Y_B are greater, suggesting the perceived cost effectiveness of these jointly produced products is low). However, to attain full long run cost efficiency, it seems Plains plants would need to significantly reduce production of all outputs and use 9 percent less C input. This again supports the conclusion that utilization considerations augment C demand particularly for these large plants, given existing capacity levels and market conditions.

Concluding Remarks

Characteristics of the cost structure in the U.S. beef packing industry, and their implied impetus for observed concentration patterns, seem well portrayed by our robust cost economy measures. The estimates indicate significant utilization economies, or scale economies given an existing plant capacity, and thus substantial cost efficiency benefits of maintaining high utilization levels. These measured economies outweigh the slight evidence of pecuniary diseconomies associated with buying or market power in cattle markets. Scope economies are also prevalent, especially associated with fabricated output; in-plant processing seems considerably to contribute to cost efficiency. And larger and more diversified plants tend to exhibit even greater technological economies than smaller plants.

The overriding evidence of cost economies, and resulting cost-saving values of increased throughput and processing, is quite consistent across plants with varying structures. However, regional variation does exist, with (large) Plains plants exhibiting the greatest utilization and scope economies. Moreover, these factors cause them to require especially large quantities of cattle input for profitable operation, augmenting their demand for cattle even with some market pressure on cattle prices.

The estimates not only provide evidence on the significance and balance of cost economies, but also suggest that such cost characteristics have an important role in understanding market structure patterns. The existence, extent and range of cost efficiencies likely underlie the trend toward large and more diversified plants, and thus increasing concentration and consolidation, in the U.S. beef packing industry. Technological conditions not only appear to be a primary driving force for observed market structure patterns, but also cause these patterns to be consistent with greater cost efficiency than would be possible with greater perceived competitiveness (in the form of lower concentration levels).

Structural change dynamics, and thus adjustment in the industry toward an "optimal" size of plant, are not well defined with a comprehensive web of cost economies, plant heterogeneity, and industry output demand and input supply limitations, especially in an essentially cross-section context. However, we have shown that our cost economy measures provide implications about these forces. These results for 1992-93 are also consistent with the inference that cost economies motivated observed further concentration increases in this industry in the later 1990s.

Our findings indicate the key role of cost economies in driving market structure patterns, and thus the importance of cost structure information for appropriate construction and interpretation of market power indicators, and ultimately the relevant use of these measures to guide policy regarding concentration issues. Modeling and measuring cost structure and economies thus seems central to understanding market structure patterns and trends, which have often involved increasing concentration and consolidation, also for other industries in our modern economy.

References

Azzam, A.M., and D.G. Anderson. *Assessing Competition in Meatpacking: Economic History, Theory and Evidence*. USDA/GIPSA report GIPSA-RR-96-6. 1996.

Azzam, A.M., and E. Pagoulatos "Testing Oligopolistic and Oligopsonistic Behavior: An Application to the U.S. Meat-Packing Industry." *Journal of Agricultural Economics.* 41, September 1990: 362-70.

Azzam, A.M., and J.R. Schroeter. "The Tradeoff Between Oligopsony Power and Cost Efficiency in Horizontal Consolidation: An Example from Beef Packing." *American Journal of Agricultural Economics.* 77, November 1995: 825-36.

Ball, V.E., and R.G. Chambers. "An Economic Analysis of Technology in the Meat Products Industry." *American Journal of Agricultural Economics*. 64, Nov. 1982:699-709.

Baumol, W.J., J.C. Panzar, and R.D. Willig. *Contestable Markets and the Theory of Industry Structure.* New York: Harcourt Brace Jovanovich. 1982.

Berndt, Ernst R., and Melvyn Fuss. "Productivity Measurement Using Capital Asset Valuation to Adjust for Variations in Utilization." *Journal of Econometrics*, 33(1/2) October/November 1986:7-30.

Berndt, E. R., and M. Fuss. "Economic Capacity Utilization and Productivity Measurement for Multiproduct Firms with Multiple Fixed Inputs." manuscript. January 1989.

Berndt, Ernst R., Melvyn Fuss and Leonard Waverman. *Empirical Analysis of Dynamic Adjustment Models of the Demand for Energy in U.S. Manufacturing Industries 1947-74*, Research Report, Palo Alto, California, Electric Power Research Institute, November 1980.

Berndt, E.R., and Catherine J. Morrison. "Short Run Labor Productivity in a Dynamic Model." *Journal of Econometrics*. 16, August 1981:339-365.

Bresnahan, T.F. "Empirical Studies of Industries with Market Power." *Handbook of Industrial Organization*. (R. Schmalensee and R. Willig, eds). Amsterdam: Elsevier Science Publishers. 1989.

Fernandez-Cornejo, C.M. Gempesaw II, J.G. Elterich, and S.E. Stefanou. "Dynamic Measures of Scope and Scale Economies: An Application to German Agriculture." *American Journal of Agricultural Economics*. 74, May 1992:329-342.

Hayashi, P., Goo, J.Y. and Chamberlain, Wm. C. "Vertical Economies: The Case of the U.S. Electric Utility Industry, 1983-87." *Southern Economic Journal*, 63(3), 1995:710-25.

Hulten, Charles. "Short Run and Long Run Cost Functions and the Measurement of Efficiency Change." *Journal of Econometrics*, 33(1/2), October/November 1986:31-50.

Hunt, L.C. and E. Lynk, "Privatization and Efficiency in the U.K. Water Industry: An Empirical Analysis." *Oxford Bulletin of Economics and Statistics*, 57(3), 1995.

Lau, L. J. "Applications of Profit Functions." in *Production Economics: A Dual Approach to Theory and Applications*. (M. Fuss and D. McFadden, eds.), North Holland Pub. Co., 1978.

Morrison, C.J. "Primal and Dual Measures of Economic Capacity Utilization: An Application to Productivity Measurement in the US Automobile Industry." *Journal of Business and Economic Statistics.* 3, October 1985:312-324.

Morrison, C.J. "Productivity Measurement with Nonstatic Expectations and Varying Capacity Utilization: An Integrated Approach." *Journal of Econometrics*, 33(1/2), October/November 1986:51-74.

Paul, C.J. Morrison. "Cost Structure and the Measurement of Economic Performance." Kluwer Academic Press. 1999a.

Paul, C.J. Morrison. "Scale Economy Measures and Subequilibrium Impacts." *Journal of Productivity Analysis*. 11, February 1999b:55-66.

Paul, C.J. Morrison. *Cost Economies and Market Power in U.S. Meatpacking,* Giannini Foundation Monograph #44, May 2000.

Paul, C.J. Morrison. "Market and Cost Structure in the U.S. Beef Packing Industry: A Plant-Level Analysis." *American Journal of Agricultural Economics*, 83(1) Feb. 2001a:64-76.

Paul, C.J. Morrison. "Cost Economies and Market Power: The Case of the U.S. Meatpacking Industry." *Review of Economics and Statistics*, 83(3), August 2001b:531-540.

Schmalensee, Richard. "Economies of Scale and Barriers to Entry." *Journal of Political Economy*, 89(6), December, 1981:1228-38.

Schmalensee, Richard. "A Note on Economies of Scale and Natural Monopoly in the Distribution of Public Utility Services." *Bell Journal of Economics*, 9(1), Spr. 1978:270-76.

Schroeter, J.R. "Estimating the Degree of Market Power in the Beef Packing Industry." *Review of Economics and Statistics.* 70, February 1988:158-62.

Shin, R.T. and J.S. Ying. "Unnatural Monopolies in Local Telephone." *Rand Journal of Economics*, 23(2), 1992:171-183.

USDA/GIPSA. *Concentration in the Red Meat Packing Industry*, report, February 1996.

Footnotes

[1] This literature is often attributed to the work of Bresnahan [1989].
[2] Standard industries targeted in this literature include electricity, water, and telecommunications, as in, for example, Schmalensee (1978, 1981), Hayashi, Goo and Chamberlain (1997), Hunt and Lynk (1995), and Shin and Ying (1992).
[3] The literature on this industry, as summarized by Azzam and Anderson (1996), suggests that the primary cause of reduced concentration was technological changes such as refrigerated transportation units. It was also affected, however, by regulations such as the Packers and Stockyards Act of 1921.
[4] GIPSA is the Grain Inspection, Packers and Stockyards Administration of the USDA.
[5] The large literature in this area is excellently summarized and referenced in Azzam and Anderson (1996). Representative papers include, for example, Ball and Chambers (1982), for a treatment of aggregate cost structure, and Schroeter (1988), Azzam and Pagoulatos (1990), and Azzam and Schroeter (1995) for market structure issues.
[6] Note that long run scale economies are not well represented using these cross-section data. Paul (2001b), however, found evidence from more aggregated time series data that is consistent with the overall cost economy indicators in this study, and support the existence of significant scale and size economies. Also, note that scope economies from joint production are particularly evident when byproduct and hide outputs are recognized, especially for larger plants.
[7] See, for example, the detailed development of these types of measures, and the many references to the underlying literature, contained in Paul (1999a).
[8] Technical change is also important to incorporate in a time series context, although the essentially cross-section nature of the data used precludes consideration of such structural changes.
[9] For three of the 43 plants there were clear outliers in many of the input-output and other ratios constructed to evaluate the consistency of the data, so the data seemed inappropriately reported and these plants were omitted from the final analysis. However, the data for the other 40 plants was sufficiently consistent to warrant including them for estimation.
[10] Summary statistics for these data are provided in Appendix A, and more detail on the data and the survey used are available in USDA (1996), and Paul (2000).
[11] For example, it permits a more appropriate linkage between shipments and production (particularly for fabrication, which is often stored longer than carcasses), and reduces problems associated with differences between hours paid and worked, since the aggregation limits the discrepancies.
[12] It is sometimes argued that not only cattle but also labor inputs are subject to monopsony power, or that not only capital but also labor inputs should be considered fixed inputs due to labor unions. However, preliminary empirical investigation did not uncover evidence of such imperfections in the labor market, possibly due to the very low cost share of labor, or perhaps to the differing prices and marginal products of labor in production of fabricated as compared to slaughter output. Thus, we maintain the assumption that the labor market is sufficiently competitive for labor demand to be represented by Shephard's lemma.
[13] Purchased hides are included in this measure, since it was not possible to appropriately aggregate them into the M_B measure. Note also that, as an alternative specification, M_O was included as part of M_B to generate a measure of "all materials inputs except cattle." This adaptation hardly affected the main estimated results, so our distinction between them is primarily due to its conceptual justification.
[14] For the development of this idea for a fixed input with a competitive market, see Morrison (1985).
[15] These equations representing the cost and profit structure are more fully defined and summarized in Appendix B, as are the associated cost economy and market power measures outlined below.
[16] See Paul (1999b) for further elaboration of this notion.
[17] These two approaches to imputing scale elasticities with sequential adjustment are empirically analogous, as discussed in the context of short versus long run elasticities in Paul (1999b). If profit maximizing optimization is closely approximated, short and "intermediate" run elasticities

are very similar for any particular data point. With cross-section data and a complex multi-output and –input analytical model, however, there is likely to be an empirical distinction between the "S" and "I" elasticities, particularly for average measures across plants of various sizes.

[18] See, for example, Berndt, Fuss and Waverman (1980) and Berndt and Morrison (1981).

[19] In the context of our cross-section analysis, however, our imputation of the long run is not as justifiable as it would be with time series data, and more appropriate data on capital stocks and prices. Unobserved variation in economic conditions for a particular plant makes it problematic directly to compare plants, and thus to impute optimal capital levels across heterogeneous plants. Also, our data include information on replacement capital, but the numbers reported have an uncertain reporting basis and in a few cases were not provided at all. Therefore the K level used for empirical implementation was based on estimated values. Finally, the user cost p_K is typically assumed to be the investment price p_I multiplied by $r+\delta$, (where r is the rate of return to investment, and δ is the percentage depreciation rate). Since a deflator is essentially irrelevant for a cross-section, so $p_I=1$, p_K becomes a constant ($r+\delta=0.185$). These limitations in the K treatment suggest that the long run measures are not as well-defined as other indicators from this essentially cross-section analysis.

[20] See Berndt and Fuss (1986), Hulten (1986), and Morrison (1986) for further details about how capacity utilization may be defined and interpreted in this context.

[21] For a more complete discussion of how the K and Y elasticities interact to provide implications about utilization, see Morrison (1985).

[22] Note also that the adaptations to define the $\varepsilon^I_{TC,Y}$ and $\varepsilon^L_{TC,Y}$ measures pertain to each of the $\varepsilon_{TC,Ym} = \partial TC/\partial Y_m \cdot (Y_m/TC)$ expressions.

[23] The distinction between $\varepsilon^I_{TC,Y}$ and $\varepsilon^T_{TC,Y}$ is closely related to a measure of the "markdown" of input price from its marginal value, or the C price ratio $Prat_C = p_C/Z_C = AFC/MFC = (Z_C-\partial p_C/\partial C\cdot C)/Z_C$, (since $\varepsilon^T_{TC,Y}/\varepsilon_{TC,Y} = MC^T/MC = MCrat = (MC-[C\cdot \partial p_C/\partial C\cdot \partial C/\partial Y])/MC$, where MC^T is the purely technological marginal cost measure and MC is the full marginal cost including the p_C change). Thus, for the primary cost-output elasticity $\varepsilon^I_{TC,Y}$, $\varepsilon^T_{TC,Y} = MCrat\cdot \varepsilon^I_{TC,Y} \approx (1/Prat_C)\cdot \varepsilon^I_{TC,Y}$.

[24] See Berndt and Fuss (1989) for further discussion of these problems.

[25] Note that a measure implying the "optimal" output from a plant is significantly greater than observed does not necessarily imply that the existing plant is too large. This could result, for example, if large pieces of equipment are more cost-efficient to operate even at a point where cost economies prevail.

[26] For this exercise the role of scope economies must be dealt with carefully; if the share were written in terms of $TC(Y_m)/TC$ the shares would not sum to one due to these economies. Also, this procedure does not allow us to establish one optimal plant type in terms of output composition, since for firms that produce no Y_m the "share" will equal zero. Thus, this may be thought of as technological optimization given output composition choices, rather than establishing one optimal type of plant.

[27] This is developed in greater depth in Paul (2000).

[28] The arguments of this function represent characteristics of the sales market rather than directly being input supply determinants. Thus its interpretation should be in the context of a sales price relationship, capturing plants' potential to affect p_C given other aspects of the market.

[29] The "wedge" between the observed average price and marginal revenue may have various forms for a particular plant depending on the market structure assumed. Writing the profit maximizing equation in this manner implicitly assumes no interactions among plants, so the plant is an effective monopolist for the region. A similar statement may also be made about the "monopsony" assumption for the C market. However, as discussed further in Paul (2001a), the implied inverse demand elasticity from the specification used here, $1/\eta = \partial p_Y/\partial Y(Y/p_Y)$, may be written as θ/η, where θ is the conjectural elasticity, in an oligopoly (oligopsony) framework. Thus, testing whether $\partial p_Y/\partial Y(Y/p_Y) = 0$ (competitiveness) is consistent with testing whether $\theta/\eta=0$, especially if θ and η are not separately well identified. Although this assertion seems to bypass market structure issues, it turns out empirically, as found by Paul (2001a), that recognizing

the oligopoly (oligopsony) distinction makes little different to resulting measures of market structure and power.

[30] The big packers face equally large wholesalers or retail operations, so the market power emphasis in this industry is typically for the input (cattle) market.

[31] Including market power in the byproducts market caused volatility in the results, likely since the plants treat and report this output somewhat differently, so λ_{YB} is set to 0 for the final specification.

[32] See Paul (2000) for more detail about data patterns and market structure.

[33] See USDA/GIPSA (1996) for a summary of the survey and resulting research reports. The parameter estimates underlying the elasticity measures are presented in Paul (2000).

[34] The categories are distinguished by output and input composition – production processes with large or zero amounts of M_B inputs, and only Y_F or Y_S outputs. For the regions, the East is left out since there are insufficient data points to ensure confidentiality.

[35] Variations in the K and p_K data cause substantive variations in the estimated ε^L_{TCY}, to the point where in some specifications scale economies appeared to persist on average in the long run, even though other measures are negligibly affected by specification changes. This may suggest that deviations from $\varepsilon^L_{TC,Y}$=1 are not well identified, or even that they are on average insignificant.

[36] The appropriate comparison to this sub-measure is $\varepsilon^S_{TC,Y}$ since it is evaluated at given C levels.

[37] SCP_{BH}=.004 accounts for most of the remainder.

[38] This measure is directly comparable to ε^I_{TCY} in the sense that the computations used accommodate full adjustment of cattle inputs to output changes.

[39] That is, $\varepsilon^T_{TC,Y}$ /$\varepsilon^I_{TC,Y}$ = MCrat, the marginal cost ratio approximating the markdown, is 0.978.

[40] These estimates are not presented due to confidentiality limitations, although they are mentioned since the potential to estimate such effects may be important for many applications.

[41] Since these measures are computed in elasticity form, and thus in terms of percentage changes, $\varepsilon_{TCY,YF}$ = -.240 for the average plant is, for example, interpreted as causing a .24 percent drop in $\varepsilon_{TC,Y}$ for a 1 percent increase in Y_F.

[42] It should be recognized also that these levels may be overstated due to imputation outside the range of production points in the data. Optimal Y_B and Y_H, as well as variable input levels (especially E and M_B) fell short of observed levels, suggesting that substitutability reflected in the output and input interaction terms is greater than is feasible when extrapolating outside the data range. More jointness or complementarity of both outputs and inputs might be expected in this industry than is reflected by these simulations.

Table 1: Cost Economy Measures, categories and regions

CATEGORY

total	Mean	St. Dev.
$\varepsilon^{I}_{TC,Y}$	**0.960**	0.057
$\varepsilon^{I}_{TC,YF}$	**0.626**	0.334
$\varepsilon^{I}_{TC,YS}$	**0.231**	0.335
$\varepsilon^{S}_{TC,Y}$	**0.919**	0.149
$\varepsilon^{L}_{TC,Y}$	**1.022**	0.076
SC_{FSBH}	**0.030**	0.027
SC_{FS}	**0.008**	0.009
$\varepsilon^{N}_{TC,Y}$	**0.949**	0.147
$\varepsilon^{T}_{TC,Y}$	**0.947**	0.060

$M_B = 0$	Mean	St. Dev.
$\varepsilon^{I}_{TC,Y}$	**0.963**	0.049
$\varepsilon^{I}_{TC,YF}$	**0.527**	0.419
$\varepsilon^{I}_{TC,YS}$	**0.331**	0.410
$\varepsilon^{S}_{TC,Y}$	**0.899**	0.108
$\varepsilon^{L}_{TC,Y}$	**1.002**	0.055
SC_{FSBH}	**0.017**	0.020
SC_{FS}	**0.001**	0.002
$\varepsilon^{N}_{TC,Y}$	**0.917**	0.103
$\varepsilon^{T}_{TC,Y}$	**0.952**	0.055

M_B *large*	Mean	St. Dev.
$\varepsilon^{I}_{TC,Y}$	**0.944**	0.034
$\varepsilon^{I}_{TC,YF}$	**0.806**	0.061
$\varepsilon^{I}_{TC,YS}$	**0.037**	0.019
$\varepsilon^{S}_{TC,Y}$	**0.868**	0.074
$\varepsilon^{L}_{TC,Y}$	**1.088**	0.113
SC_{FSBH}	**0.047**	0.025
SC_{FS}	**0.014**	0.008
$\varepsilon^{N}_{TC,Y}$	**0.915**	0.059
$\varepsilon^{T}_{TC,Y}$	**0.922**	0.040

$Y_F = 0$	Mean	St. Dev.
$\varepsilon^{I}_{TC,Y}$	**0.973**	0.054
$\varepsilon^{I}_{TC,YF}$	**0.000**	0.000
$\varepsilon^{I}_{TC,YS}$	**0.861**	0.063
$\varepsilon^{S}_{TC,Y}$	**0.946**	0.080
$\varepsilon^{L}_{TC,Y}$	**0.982**	0.056
SC_{FSBH}	**0.003**	0.002
SC_{FS}	**0.000**	0.000
$\varepsilon^{N}_{TC,Y}$	**0.950**	0.081
$\varepsilon^{T}_{TC,Y}$	**0.972**	0.056

$Y_S = 0$	Mean	St. Dev.
$\varepsilon^{I}_{TC,Y}$	**0.973**	0.015
$\varepsilon^{I}_{TC,YF}$	**0.891**	0.018
$\varepsilon^{I}_{TC,YS}$	**0.000**	0.000
$\varepsilon^{S}_{TC,Y}$	**0.899**	0.064
$\varepsilon^{L}_{TC,Y}$	**1.022**	0.046
SC_{FSBH}	**0.013**	0.011
SC_{FS}	**0.000**	0.000
$\varepsilon^{N}_{TC,Y}$	**0.912**	0.059
$\varepsilon^{T}_{TC,Y}$	**0.959**	0.014

Table 1, contd.

REGION

	Mean	St. Dev.		Mean	St. Dev.
West			*Plains*		
$\varepsilon^{I}_{TC,Y}$	**0.950**	0.046	$\varepsilon^{I}_{TC,Y}$	**0.955**	0.067
$\varepsilon^{I}_{TC,YF}$	**0.562**	0.289	$\varepsilon^{I}_{TC,YF}$	**0.730**	0.253
$\varepsilon^{I}_{TC,YS}$	**0.286**	0.262	$\varepsilon^{I}_{TC,YS}$	**0.125**	0.264
$\varepsilon^{S}_{TC,Y}$	**1.000**	0.151	$\varepsilon^{S}_{TC,Y}$	**0.888**	0.176
$\varepsilon^{L}_{TC,Y}$	**0.976**	0.059	$\varepsilon^{L}_{TC,Y}$	**1.050**	0.081
SC_{FSBH}	**0.017**	0.009	SC_{FSBH}	**0.045**	0.028
SC_{FS}	**0.008**	0.007	SC_{FS}	**0.010**	0.010
$\varepsilon^{N}_{TC,Y}$	**1.017**	0.151	$\varepsilon^{N}_{TC,Y}$	**0.933**	0.175
$\varepsilon^{T}_{TC,Y}$	**0.946**	0.042	$\varepsilon^{T}_{TC,Y}$	**0.934**	0.072

WCB			*"Adapted" Plains*		
$\varepsilon^{I}_{TC,Y}$	**0.968**	0.040	$\varepsilon^{I}_{TC,Y}$	**0.936**	0.072
$\varepsilon^{I}_{TC,YF}$	**0.474**	0.405	$\varepsilon^{I}_{TC,YF}$	**0.803**	0.055
$\varepsilon^{I}_{TC,YS}$	**0.390**	0.400	$\varepsilon^{I}_{TC,YS}$	**0.035**	0.017
$\varepsilon^{S}_{TC,Y}$	**0.929**	0.068	$\varepsilon^{S}_{TC,Y}$	**0.862**	0.194
$\varepsilon^{L}_{TC,Y}$	**0.991**	0.047	$\varepsilon^{L}_{TC,Y}$	**1.062**	0.093
SC_{FSBH}	**0.013**	0.014	SC_{FSBH}	**0.062**	0.020
SC_{FS}	**0.004**	0.006	SC_{FS}	**0.015**	0.009
$\varepsilon^{N}_{TC,Y}$	**0.941**	0.065	$\varepsilon^{N}_{TC,Y}$	**0.924**	0.197
$\varepsilon^{T}_{TC,Y}$	**0.961**	0.041	$\varepsilon^{T}_{TC,Y}$	**0.909**	0.073

Table 2: Comparative Static Cost Economy Elasticities, categories and regions

	Mean	St. Dev.
total		
$\varepsilon_{TCY,C}$	**0.252**	0.242
$\varepsilon_{TCY,YF}$	**-0.240**	0.243
$\varepsilon_{TCY,YS}$	**0.014**	0.053
$\varepsilon_{TCY,pL}$	**0.032**	0.034
$\varepsilon_{TCY,pE}$	**0.051**	0.033
$\varepsilon_{TCY,pMB}$	**0.824**	0.109
$\varepsilon_{TCY,K}$	**-0.021**	0.037
$M_B = 0$		
$\varepsilon_{TCY,C}$	**0.154**	0.192
$\varepsilon_{TCY,YF}$	**-0.131**	0.170
$\varepsilon_{TCY,YS}$	**0.038**	0.061
$\varepsilon_{TCY,pL}$	**0.040**	0.026
$\varepsilon_{TCY,pE}$	**0.060**	0.027
$\varepsilon_{TCY,pMB}$	**0.882**	0.083
$\varepsilon_{TCY,K}$	**-0.008**	0.010
M_B *large*		
$\varepsilon_{TCY,C}$	**0.340**	0.163
$\varepsilon_{TCY,YF}$	**-0.463**	0.207
$\varepsilon_{TCY,YS}$	**-0.011**	0.007
$\varepsilon_{TCY,pL}$	**-0.006**	0.025
$\varepsilon_{TCY,pE}$	**0.013**	0.028
$\varepsilon_{TCY,pMB}$	**0.682**	0.077
$\varepsilon_{TCY,K}$	**-0.062**	0.082
$Y_F = 0$		
$\varepsilon_{TCY,C}$	**0.028**	0.081
$\varepsilon_{TCY,YF}$	**0.000**	0.000
$\varepsilon_{TCY,YS}$	**0.104**	0.051
$\varepsilon_{TCY,pL}$	**0.060**	0.025
$\varepsilon_{TCY,pE}$	**0.080**	0.022
$\varepsilon_{TCY,pMB}$	**0.839**	0.052
$\varepsilon_{TCY,K}$	**-0.003**	0.004
$Y_S = 0$		
$\varepsilon_{TCY,C}$	**0.162**	0.141
$\varepsilon_{TCY,YF}$	**-0.154**	0.157
$\varepsilon_{TCY,YS}$	**0.000**	0.000
$\varepsilon_{TCY,pL}$	**0.039**	0.009
$\varepsilon_{TCY,pE}$	**0.065**	0.019
$\varepsilon_{TCY,pMB}$	**0.909**	0.041
$\varepsilon_{TCY,K}$	**-0.013**	0.010

	Mean	St. Dev.
West		
$\varepsilon_{TCY,C}$	**0.169**	0.178
$\varepsilon_{TCY,YF}$	**-0.139**	0.129
$\varepsilon_{TCY,YS}$	**0.009**	0.061
$\varepsilon_{TCY,pL}$	**0.023**	0.022
$\varepsilon_{TCY,pE}$	**0.047**	0.019
$\varepsilon_{TCY,pMB}$	**0.740**	0.101
$\varepsilon_{TCY,K}$	**-0.010**	0.009
WCB		
$\varepsilon_{TCY,C}$	**0.098**	0.116
$\varepsilon_{TCY,YF}$	**-0.100**	0.139
$\varepsilon_{TCY,YS}$	**0.042**	0.061
$\varepsilon_{TCY,pL}$	**0.036**	0.029
$\varepsilon_{TCY,pE}$	**0.056**	0.030
$\varepsilon_{TCY,pMB}$	**0.785**	0.106
$\varepsilon_{TCY,K}$	**-0.008**	0.008
Plains		
$\varepsilon_{TCY,C}$	**0.377**	0.250
$\varepsilon_{TCY,YF}$	**-0.363**	0.258
$\varepsilon_{TCY,YS}$	**-0.003**	0.035
$\varepsilon_{TCY,pL}$	**0.029**	0.038
$\varepsilon_{TCY,pE}$	**0.046**	0.036
$\varepsilon_{TCY,pMB}$	**0.868**	0.095
$\varepsilon_{TCY,K}$	**-0.028**	0.047
"Adapted" Plains		
$\varepsilon_{TCY,C}$	**0.500**	0.206
$\varepsilon_{TCY,YF}$	**-0.502**	0.200
$\varepsilon_{TCY,YS}$	**-0.012**	0.011
$\varepsilon_{TCY,pL}$	**0.014**	0.037
$\varepsilon_{TCY,pE}$	**0.030**	0.033
$\varepsilon_{TCY,pMB}$	**0.861**	0.094
$\varepsilon_{TCY,K}$	**-0.038**	0.056

Table 3: cost-"optimal" Y_m and C ratios, categories and regions

CATEGORY

	Mean		Mean		Mean		Mean		Mean
total		*M_B =0*		*M_B large*		*Y_F =0*		*Y_S =0*	
Y^{I}_{FO}/Y_F	**1.340**	Y^{I}_{FO}/Y_F	**1.406**	Y^{I}_{FO}/Y_F	**0.901**	Y^{I}_{FO}/Y_F	**0.000**	Y^{I}_{FO}/Y_F	**1.202**
Y^{I}_{SO}/Y_S	**1.297**	Y^{I}_{SO}/Y_S	**1.287**	Y^{I}_{SO}/Y_S	**0.733**	Y^{I}_{SO}/Y_S	**1.141**	Y^{I}_{SO}/Y_S	**0.000**
Y^{I}_{BO}/Y_B	**0.666**	Y^{I}_{BO}/Y_B	**0.688**	Y^{I}_{BO}/Y_B	**0.528**	Y^{I}_{BO}/Y_B	**1.092**	Y^{I}_{BO}/Y_B	**0.583**
Y^{I}_{HO}/Y_H	**0.936**	Y^{I}_{HO}/Y_H	**0.932**	Y^{I}_{HO}/Y_H	**0.620**	Y^{I}_{HO}/Y_H	**1.080**	Y^{I}_{HO}/Y_H	**0.908**
C^{I}_{O}/C	**1.361**	C^{I}_{O}/C	**1.377**	C^{I}_{O}/C	**1.157**	C^{I}_{O}/C	**1.320**	C^{I}_{O}/C	**1.310**
Y^{L}_{FO}/Y_F	**0.803**	Y^{L}_{FO}/Y_F	**0.612**	Y^{L}_{FO}/Y_F	**0.730**	Y^{L}_{FO}/Y_F	**0.000**	Y^{L}_{FO}/Y_F	**0.775**
Y^{L}_{SO}/Y_S	**1.377**	Y^{L}_{SO}/Y_S	**1.716**	Y^{L}_{SO}/Y_S	**0.630**	Y^{L}_{SO}/Y_S	**1.605**	Y^{L}_{SO}/Y_S	**0.000**
Y^{L}_{BO}/Y_B	**0.859**	Y^{L}_{BO}/Y_B	**0.903**	Y^{L}_{BO}/Y_B	**0.748**	Y^{L}_{BO}/Y_B	**1.852**	Y^{L}_{BO}/Y_B	**0.563**
Y^{L}_{HO}/Y_H	**0.851**	Y^{L}_{HO}/Y_H	**0.932**	Y^{L}_{HO}/Y_H	**0.862**	Y^{L}_{HO}/Y_H	**2.366**	Y^{L}_{HO}/Y_H	**0.574**
C^{L}_{O}/C	**0.996**	C^{L}_{O}/C	**1.161**	C^{L}_{O}/C	**0.765**	C^{L}_{O}/C	**1.772**	C^{L}_{O}/C	**1.038**

REGION

West		*WCB*		*Plains*		*"Adapted" Plains*	
Y^{I}_{FO}/Y_F	**1.579**	Y^{I}_{FO}/Y_F	**1.141**	Y^{I}_{FO}/Y_F	**1.331**	Y^{I}_{FO}/Y_F	**1.398**
Y^{I}_{SO}/Y_S	**2.317**	Y^{I}_{SO}/Y_S	**1.210**	Y^{I}_{SO}/Y_S	**1.101**	Y^{I}_{SO}/Y_S	**1.276**
Y^{I}_{BO}/Y_B	**1.289**	Y^{I}_{BO}/Y_B	**0.844**	Y^{I}_{BO}/Y_B	**0.559**	Y^{I}_{BO}/Y_B	**0.539**
Y^{I}_{HO}/Y_H	**1.599**	Y^{I}_{HO}/Y_H	**1.113**	Y^{I}_{HO}/Y_H	**0.823**	Y^{I}_{HO}/Y_H	**0.833**
C^{I}_{O}/C	**0.778**	C^{I}_{O}/C	**1.250**	C^{I}_{O}/C	**1.165**	C^{I}_{O}/C	**1.155**
Y^{L}_{FO}/Y_F	**1.018**	Y^{L}_{FO}/Y_F	**0.813**	Y^{L}_{FO}/Y_F	**0.793**	Y^{L}_{FO}/Y_F	**0.811**
Y^{L}_{SO}/Y_S	**1.647**	Y^{L}_{SO}/Y_S	**1.688**	Y^{L}_{SO}/Y_S	**1.038**	Y^{L}_{SO}/Y_S	**0.758**
Y^{L}_{BO}/Y_B	**0.911**	Y^{L}_{BO}/Y_B	**0.997**	Y^{L}_{BO}/Y_B	**0.839**	Y^{L}_{BO}/Y_B	**0.846**
Y^{L}_{HO}/Y_H	**1.145**	Y^{L}_{HO}/Y_H	**1.395**	Y^{L}_{HO}/Y_H	**0.737**	Y^{L}_{HO}/Y_H	**0.688**
C^{L}_{O}/C	**0.872**	C^{L}_{O}/C	**1.273**	C^{L}_{O}/C	**0.931**	C^{L}_{O}/C	**0.910**

Appendix A: summary statistics and regions

VALUES

	Mean	St. Dev.	Min.	Max.
total				
$p_F Y_F$	**55.383**	38.345	8.282	174.46
$p_L Y_L$	**1.996**	1.542	0.126	7.0397
$p_E Y_E$	**0.193**	0.136	0.016	0.6062
$p_M Y_M$	**51.439**	35.177	7.231	159.66
K	**48.427**	31.730	4.092	128.24

OUTPUT and INPUT LEVELS

	Mean	St. Dev	Min.	Max.
total				
Y_F	**44.618**	39.540	0.000	171.865
Y_S	**9.253**	9.724	0.000	48.272
Y_H	**3.137**	2.615	0.373	17.445
L	**1.840**	1.415	0.138	6.540
E	**0.176**	0.126	0.014	0.606
C	**38.934**	25.005	5.542	110.000
M_B	**4.314**	10.537	0.000	56.487
M_O	**0.788**	0.641	0.011	2.890

Regions:

West – AZ, CA, UT, WA

Western Corn Belt (WCB) – IL, WI, IA MN, MI

Plains – CO, NE, TX, KS

“Adapted” Plains – 13 largest slaughter/fabrication plants in the Plains

Appendix B: Summary of constructed measures

The shadow value of input C is $\mathbf{Z_C = -\partial VC/\partial C}$ (and would equal p_C in equilibrium with perfect competition in the cattle markets).

The marginal cost of output Y_m is $\mathbf{MC_m = \partial VC/\partial Y_m}$.

The marginal revenue of this output is $\mathbf{MR_m = p_{Ym}(Y_m) + Y_m\, \partial p_{Ym}/\partial Y_m}$, so

$$\mathbf{p_{Ym} = -\partial p_{Ym}/\partial Y_m \bullet Y_m + MC_m}$$ is the optimal Y_m pricing equation.

The marginal factor cost for **C**, $\mathbf{MFC = p_C + C\, \partial p_C/\partial C}$, will equal $\mathbf{Z_C}$ in equilibrium, so

$$\mathbf{p_C = C\, \partial p_C/\partial C - \partial VC/\partial C}$$ is the optimal C pricing equation.

The general cost-side measure of cost economies (for one output) is $\varepsilon_{\mathbf{TC,Y}}=\partial \mathbf{ln\ TC}/\partial \mathbf{ln\ Y}$, where $\mathbf{TC=VC(\bullet)+p_C(C)C+p_K K}$, includes all cost changes with output expansion, such as scale and scope economies, and input price changes with C adjustment

Thus, in the "short run," defined as implied cost changes evaluated at the existing C level, t

this measure is $\varepsilon^{\mathbf{S}}_{\mathbf{TC,Y}}=\partial \mathbf{VC}/\partial \mathbf{Y(Y/TC)}$;

When the possibility of increasing throughput and thus raising utilization is recognized,

$\varepsilon^{\mathbf{I}}_{\mathbf{TC,Y}}=[\partial \mathbf{TC}/\partial \mathbf{Y}+\partial \mathbf{TC}/\partial \mathbf{C}\ \partial \mathbf{C}/\partial \mathbf{Y}](\mathbf{Y/TC})$; and

When K adjustment is included to recognize the possibility of "long run" behavior,

$\varepsilon^{\mathbf{L}}_{\mathbf{TC,Y}}=[\partial \mathbf{TC}/\partial \mathbf{Y}+\partial \mathbf{TC}/\partial \mathbf{C}\ \partial \mathbf{C}/\partial \mathbf{Y} + \partial \mathbf{TC}/\partial \mathbf{K}\ \partial \mathbf{K}/\partial \mathbf{Y}](\mathbf{Y/TC})$.

These measures are defined for each output, Y_m, where m=F,S,B,H

Total cost economies for changes in all outputs are thus defined as

$\varepsilon_{\mathbf{TC,Y}} = \Sigma_{\mathbf{m}} \mathbf{Y_m TC_m(Y)/TC(Y)} = \Sigma_{\mathbf{m}}\ \partial \mathbf{TC}/\partial \mathbf{Y_m}\ (\mathbf{Y_m/TC}) = \Sigma_{\mathbf{m}}\ \varepsilon_{\mathbf{TC,Ym}}$,

(where $TC_m=\partial TC/\partial Y_m$).

And scope economies are defined as

$\mathbf{SC=([\Sigma_m\ TC(Y_m)]-TC(Y)/TC(Y)) = -\Sigma_i p_i\ \Sigma_m \Sigma_n\ \gamma_{mn}\ Y_m\ Y_n/TC}$.

Thus cost economies "net" of scope economies are $\varepsilon^{\mathbf{N}}_{\mathbf{TC,Y}} = \varepsilon_{\mathbf{TC,Y}} + \mathbf{SC_{FSHB}}$.

And for pure technological measure without pecuniary diseconomies, $\varepsilon^{\mathbf{T}}_{\mathbf{TC,Y}}$, $\partial p_C/\partial C=0$.

Comp Stats elasticities are 2nd order elasticities identifying determinants of $\varepsilon_{TC,Y}$, such as

$\varepsilon_{\mathbf{TCY,Ym}} = \partial \mathbf{ln}\ \varepsilon_{\mathbf{TCY}}/\partial \mathbf{ln\ Y_m}$

$\varepsilon_{\mathbf{TCY,i}} = \partial \mathbf{ln}\ \varepsilon_{\mathbf{TCY}}/\partial \mathbf{ln\ p_I}$

$\varepsilon_{\mathbf{TCY,K}} = \partial \mathbf{ln}\ \varepsilon_{\mathbf{TCY}}/\partial \mathbf{ln\ K}$

$\varepsilon_{\mathbf{TCY,Df}} = \partial \mathbf{ln}\ \varepsilon_{\mathbf{TCY}}/\partial \mathbf{ln\ DUM_f}$

"Optimal" or cost efficient Y_m and C levels were computed by solving a system of $\varepsilon_{TCYm} = S_m$ (implying $MC_m=AC_m$) equations for the implied minimum AC levels, denoted $Y_{m,O}$ and C_O (where O indicates "optimal"), to compute the implied Y_{mO}/Y_m and C_O/C ratios.