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Complementarity among Alternative Procurement Arrangements in the Pork Packing Industry

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Abstract

We estimate the economies of scale for a sample of pork packing plants and use these estimates together with two other performance measures (EBIT and gross margin) to examine whether the alternative procurement methods for live hogs are complementary. The results indicate that all procurement arrangements portfolios improve plant performance relative to the simple spot market purchases, but the portfolio coefficients in performance equations do not always monotonically increase with the portfolio order. However, looking at the price packers pay to procure their hogs, the results indicate that plants that use a combination of higher-order procurement arrangements on average pay lower prices relative to plants that use the spot market only. Comparing the magnitudes of the portfolio effects with the magnitudes of the individual procurement arrangement effects shows that individual practices have minimal additional impact on the procurement price, indicating that the procurement methods may be complementary.

KEYWORDS: supply-chain management, economies of scale, organization of firms

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1. Introduction

A common finding of the early empirical literature on organizations in firms (e.g., Arora and Gambardella, 1990; MacDuffie, 1995) was that organizational design practices are clustered—meaning that the adoption of one practice is correlated with the adoption of other practices; consequently, clusters of practices consistently appear together. As a result, a rich theoretical debate has arisen attempting to explain clustered organizational forms, with implications for adoption and performance. Similar theoretical perspectives developed in both organization economics and business strategy have suggested that interdependencies among practices can be crucial for determining the payoffs for individual practices (Milgrom and Roberts, 1990; Levinthal, 1997). An important line of literature has emphasized the potential for complementarity, which is defined as positive interdependencies among pairs of practices (Milgrom and Roberts, 1990; Holmstrom and Milgrom, 1994; Siggelkow, 2002).

This article presents the first empirical evidence of complementarity effects of alternative marketing arrangements used by pork packers in the procurement of live hogs on firm performance. Simultaneously with a lesser reliance on cash/spot markets, the alternative marketing arrangements such as marketing contracts, production contracts, and packer owned farms are becoming an integral part of pork packers' procurement strategies. The observation that packers use different procurement practices in clusters (portfolios) indicates that these practices may be complementary to each other in the sense that implementing one of them may increase the marginal return of the other. The principal source of complementarity is the supply chain management issues. In meat packing, high level of capacity utilization is critical for profitability. It is essential therefore for packers to be able to secure an uninterrupted flow of particular quality animals for slaughter to keep the plant running efficiently. Organizing supply through channel diversification minimizes the risk of supply interruption as the result of unpredictable events that could choke off the supply in one of the channels. Another source of complementarity comes from the fact that organizing the procurement of inputs through multiple channels mitigates the information asymmetry problems. For example, producing own hogs on packer owned farms instead of solely relying on outsider producers keeps packers better informed of competitive costs and practices. At the same time, even if own-production of hogs is relatively more efficient than relying on outside suppliers (perhaps because of noncontractible relationship-specific investments), packers would want to at least partly rely on outsiders to keep pressure on in-house management to produce efficiently. Yet another source of complementarity may be related to market power considerations. For example, procuring hogs using multiple marketing arrangements enhances packers bargaining power when negotiating with suppliers. The threat of walking away with no deal and still being able to secure enough hogs through another channel gives a packer an upper hand when negotiating purchases.

Verifying or formally testing the existence of the complementarity among alternative procurement arrangements has important policy implications. The increased use of alternative procurement arrangements raised a number of questions about their effects on economic efficiency and on the distribution of the benefits and costs of livestock and meat production and consumption between producers and consumers (see: Vukina et al. 2007). It also resulted in a series of legislative attempts to regulate the use of alternative marketing arrangements in the livestock sectors. The concerns about the effects of the so called *captive supplies* culminated in a legislation proposed as part of the 2002 Farm Bill (subsequently omitted) to ban most packer ownership of cattle. As recently as April 2005, senators Grassley and Harkin of Iowa and others introduced another bill that would make it unlawful for packers to own, feed or control livestock intended for slaughter. Testing for complementarities is important for measuring the economic effects of such regulatory proposals. If marketing arrangements are complements, a restriction that would ban or constrain the use of one marketing arrangement would have a direct welfare effect, because the practice would no longer be available. It would also have an indirect welfare effect arising from the fact that the regulated practice may be complementary to some other unregulated practice, and the efficiency of the unregulated practice may be diminished as its complementary practice use is reduced or eliminated.

In order to examine for possible complementarity among various marketing arrangements we use the performance approach that closely resembles the approach of Ichniowski, Shaw, and Prennushi (1997). The performance approach involves regressing some firm-level performance measures on observed combinations of marketing arrangements (i.e., portfolios) and a vector of exogenous control variables. We first examine whether the efficient scale of production systematically varies with the portfolio of marketing arrangements used by firms to acquire hogs. Because it measures the minimum point of a plant's average cost curve, larger efficient scale indicates a more efficient plant. We also investigate the relationship between the use of marketing arrangements and two short-run firm-level performance measures: gross margin defined as the total revenue minus the cost of live animals, and earnings before interests and taxes (EBIT). Finally, because the available data on these three measures do not allow us to examine the complementarities among individual practices directly, we also look into the relationship between the prices that packers pay to procure their hogs and their procurement portfolios.

The results indicate that all procurement arrangements portfolios improve plant performance relative to the simple spot market purchases, but the portfolio coefficients in performance equations do not always monotonically increase with the portfolio order, in violation of the complementarity assumption. However, looking at the prices packers pay to procure their hogs, the results indicate that plants that use a combination of higher-order procurement arrangements on average pay lower prices for their hogs relative to plants that use the cash/spot market only. In addition, comparing the magnitudes of the portfolio effects with the magnitudes of the individual procurement arrangement effects shows that individual practices have minimal additional impact on the procurement price, i.e., the portfolio system categorical variables capture almost the entire effect on lowering the procurement price.

2. Data Description

The data used in this study comes from two sources: pork packers' individual transactions (purchase) data and the profit and loss (P&L) statements data.[1] The packers' individual purchase transactions contain self-reported data on prices and quantities during the time period from October 2002 through March 2005. In this study we used only the price data. Each transaction in the data included the base price (average base price paid for the lot), price adjustment (average merit-based adjustments, such as premiums and discounts), and pricing units. For transactions in which adjustments were reported, the net prices were calculated by summing the base price and adjustment. The pricing units variable indicates whether prices were reported on the basis of live-weight or carcass weight. Some plants use both pricing units and some only use one type. For analysis purposes, we converted all live-weight prices to a carcass weight basis using the carcass weight to live-weight ratio (percentage yield) for that transaction. When live-weights or carcass weights were missing, we were unable to calculate yield; therefore, that transaction was dropped. We also pre-screened transactions based on price. Observations with a price per hundred weight (cwt) less than \$20 or greater than \$100 were dropped. This rule approximately corresponded to eliminating observations outside the upper and lower 1 percentile of the price distribution. After this additional data preparation, we had 1,677,227 transactions (lots) from 29 processing plants owned by 15 different companies.[2]

The procurement methods were classified into the following categories: auction barns, video/electronic auctions, dealers or brokers, direct trade (cash or spot market transaction between an individual buyer and seller of livestock within

[1] For details about data collection protocols and summary results, see Cates et al. (2007).
[2] For detailed description of other variables in the individual transaction data set as well as the implemented cleaning procedures see Vukina et al. (2007, Section 2).

2 weeks of kill date), procurement or marketing contract (formal agreement specifying terms for transfer of market hogs using pre-specified price or payment formula), forward contract (oral or written agreement for the future purchase of a specified quantity of livestock; contract is entered into at any time between placement of livestock on feed and 2 weeks prior to kill date), marketing agreement (long-term oral or written arrangement where a packer agrees to purchase livestock under specific terms), packer owned, other, and missing. This classification does not specifically address production contracts which were requested separately from transactions data. However, since all data were collected at the plant level and not the company level, individual plants that did not maintain their own production contracts were unable to provide the contract settlement data. In these situations, production contract hogs were included in the transactions data and are typically included in the "other" category. The pricing methods were classified as: individually negotiated pricing, public auction, sealed bid, formula pricing (using another price as the base for the purchase of livestock), internal transfer (transfer of packer-owned livestock from a finisher to the slaughter plant), and other.

In order to be able to present the results, in compliance with the confidentiality requirements, the original procurement method categories from the individual transactions data protocol were combined into broader categories. The "cash/spot" category (MA1) includes auction barns, video/electronic auctions, dealers or brokers, and direct trade. The "marketing contracts" category (MA2) includes procurement or marketing contracts, forward contracts, and marketing agreements. The "owned" category (MA3) includes packer-owned hogs, and the "other" (MA4) combines the remaining categories (other and missing).

According to the individual transactions (purchase) data, the marketing contract is the most widely used purchase method in the pork packing industry, with 58% of hogs purchased through this channel. The second most important procurement method is the owned category with a 20% share, whereas the cash/spot method is third with 11%. The predominant pricing method observed in the cash or spot markets is an individually negotiated price, marketing contracts are dominated by various types of formula pricing, and packer owned hogs are almost always priced using internal transfer pricing. In terms of portfolios of procurement methods, according to the individual transactions (purchase) data, the most frequently used portfolio is MA1–MA2, followed by MA1–MA2–MA3, and then MA2–MA3–MA4.

The earnings before interests and taxes (EBIT) and gross (meat) margin data come from the monthly P&L statements from 18 plants belonging to 6 different companies. The total cost data used to estimate the economies of scale and the efficient scale of production in the subsequent analyses of complementarity of procurement methods are from the same source. In cases where packers reported weekly P&L data, the numbers were aggregated to obtain monthly observations. All but two plants are involved in slaughter, fabrication, and processing of live hogs; the remaining two are engaged only in slaughter and fabrication. For the group of 18 plants for which P&L data are available, the marketing arrangement portfolios are used in the following order of frequency: MA1–MA2, MA1–MA2–MA3, MA2–MA3–MA4, and MA1.

3. Conceptual Framework

In a frequently cited paper, Milgrom and Roberts (1990) developed a theoretical model of the firm that allows them to explore complementarities in modern manufacturing firms. The nonconvexities (some decision variables are naturally integer valued), together with the fact that the firm's objective function itself may be nonconcave, nondifferentiable, and even discontinuous at some points, often prevent the use of differential calculus techniques to derive the comparative statics results. Instead they use purely algebraic (lattice-theoretic) methods based on the concept of supermodularity, which provides an exact formalization of the idea of groups of complementary activities. Complementarities lead to predictable relationships among activities. A decision to increase the level of one activity will raise the profitability of any contemplated increases in levels of any complementary activities. Therefore, high levels for all the elements of a group of complementary activities go together.

Complementarity between continuous practices can be defined using the second-order cross partial derivatives. Let f be a function of practices $(x_1, x_2, \ldots, x_n)$. Practices x_i and x_j are complementary in the function f if and only if $\partial^2 f/\partial x_i \partial x_j \geq 0$ and strict inequality holds for at least one value of $(x_1, x_2, \ldots, x_n)$. In other words, complementarity exists if the implementation of one practice increases the marginal return of the other practice. In the case where the practices $(x_1, x_2, \ldots, x_n)$ are measured by the discrete measure, complementarity between two practices can be defined using the concept of the supermodularity. A function f is supermodular if, for all $x, x' \in R^n$,

$$f(x \vee x') + f(x \wedge x') \geq f(x) + f(x'), \qquad (1)$$

where $x \vee x'$ is the vector whose ith element is $max(x_i, x_i')$ and $x \wedge x'$ is the vector whose ith element is $min(x_i, x_i')$. Note that supermodularity is defined in terms of ordinal rank. Based on the definition of supermodularity, the condition for complementarity between the practices x_1 and x_2 is written as

$$f(x_1 + 1, x_2 + 1, x_3, \ldots, x_n) + f(x_1, x_2, x_3, \ldots, x_n) \geq$$
$$f(x_1 + 1, x_2, x_3, \ldots, x_n) + f(x_1, x_2 + 1, x_3, \ldots, x_n). \qquad (2)$$

In order to illustrate how testing for complementarity works, let's focus on the case of two individual practices x_1 and x_2 and define their corresponding dummy variables y_1 (y_1=1 if x_1 is adopted and 0 otherwise) and y_2 (y_2=1 if x_2 is adopted and 0 otherwise). Further assume the performance function of the firm can be written as

$$f(y_1, y_2) = \theta_{00}(1-y_1)(1-y_2) + \theta_{01}(1-y_1)y_2 + \theta_{10}y_1(1-y_2) + \theta_{11}y_1y_2. \quad (3)$$

Then, a formal statistical test for complementarity (2) is reduced to testing whether

$$\theta_{11} + \theta_{00} \geq \theta_{01} + \theta_{10}. \qquad (4)$$

In the general case of n individual practices, a formal test involves a set of inequality constraints similar to (4); see Lokshin, Carree and Belderbos (2004) for more details.

The idea of complementarity is intuitively appealing, yet formally testing whether such complementarity among practices really exists is a difficult task. The problem stems from the fact that in order to perform the formal test of complementarity as outlined above, we need to identify and estimate all the parameters in (3). This requires observing the use of all the possible portfolios of practices that can be assembled from the underlying individual practices that firms use. For example, for two practices x_1 and x_2, the firms can adopt four possible portfolios: adopt both, adopt x_1 only, adopt x_2 only, and adopt none. Only when this kind of data is available (e.g. Miravete and Pernias, 2006), one can implement the structural complementarity test. In our data, however, several possible portfolio combinations are never used. For example, no packing plant relies 100% on owned hogs to keep its lines busy, so the singleton-portfolio consisting of MA3 only is never observed. Similarly, the pair-portfolio consisting of the spot market purchases and the packer owned hogs (MA1-MA3) is also never observed, and so are few others.

Rather than testing the complementarity result formally, an alternative approach first proposed by Arora and Gambardella (1990) is to test an important implication of complementarity. The idea is very simple: if two individual practices are complements, one would expect their adoptions to be positively correlated. In practice, this corresponds to testing that the covariance between two individual practices, after controlling for firms' characteristics, is non-negative. However, as pointed out by the authors themselves, this approach requires a rather strong assumption of no unobserved firms' characteristics that can lead to the correlation among the adoption of individual practices regardless of whether complementarity exists or not. In other words, the presence of firms' unobserved heterogeneity could be responsible for the correlation among practices even though complementarity may not exist at all.[3] Given the fact that we only have limited data on packers' characteristics, this approach is not suitable for our research.

Instead, in this paper, we follow the approach of Ichniowski, Shaw and Prennushi (1997) which involves regressing some plant-level performance measures (π_i) on the observed combinations of procurement arrangements (i.e., portfolios) and a vector of exogenous control variables (X_i). A challenge in using this approach is to adequately deal with the problem of selection bias resulting from nonrandom selection of procurement arrangement portfolios. The most likely reason for nonrandom selection of procurement portfolios is that most innovative companies or plants will choose the most innovative procurement practices. Ichniowski, Shaw and Prennushi (1997) corrects for the selection bias by including firm specific fixed effects in their regressions. Due to the special features of our data set, as will be explained in detail below, we use the instrumental variable method instead.

However, the estimated coefficients associated with various procurement arrangement portfolio variables, even if they show significant positive effects on some performance measures, do not compare the effects of individual procurement arrangements with those of the portfolios, and therefore do not provide unambiguous evidence on whether the individual procurement arrangements that comprise the portfolio are complementary. Complementarity among individual marketing/procurement practices implies that the magnitude of the productivity effect of the portfolio is larger than the sum of the marginal effects from adopting each individual practice. Therefore, the procedure requires adding the individual procurement channel binary variables to the regressions containing the procurement arrangement portfolio binary variables and comparing the magnitudes of the individual channel versus the portfolio effects.

[3] This is because in many industries firms face similar production technologies, make comparable choices about organizational design, but face different costs or benefits of adoption. For example, different pork packers have similar technologies and make interdependent choices about whether to use spot markets, production contracts, marketing contracts, or some combination of the above, but they procure their inputs in different regions and they deal with a different group of farmers.

4. Economies of Scale in Pork Packing

Returns or economies to scale are most appropriately measured by the relationship between total cost and output along the expansion path where input prices are constant and costs are minimized at every level of output (Hanoch, 1975). For this study we chose the translog cost function because it allows the economies of scale to vary with the level of output. This feature enables the average cost curve to attain the classical U-shape.[4] Once the estimates of the total cost function are obtained, the economies of scale measure is obtained as unity minus the elasticity of total cost with respect to output:

$$\text{ES} \equiv 1 - \frac{\partial logC}{\partial logY} \tag{5}$$

which results in positive numbers for the increasing (positive) returns to scale and negative numbers for the decreasing (negative) returns to scale. The elasticity of total cost with respect to output, however, has to be positive because the theoretically correct cost function must be nondecreasing in output. Multiplying Eq. (5) by 100 yields estimates of economies of scale expressed in percentage terms.[5]

The limited availability of information dictates the specification of the cost function that exhibits three problems, none of which is in our opinion very severe. First, the only separate cost component that can be disentangled from the rest of the total cost is the cost of live animals. Therefore, we assume that the production of pork is a function of the number of animals slaughtered and some other generic production input that jointly represents labor, capital, energy, and other intermediary inputs used in meat packing. Therefore, we can only identify the percentage cost shares of live animals and the other generic production input in the total cost structure of packing plants.

Second, we assume that firms/plants produce the homogeneous product called "pork," which is measured by the total carcass or hot weight of slaughtered animals. Because the P&L statements generally do not report carcass weight data, we calculated the average monthly, plant-level, carcass weight per incoming animal from the individual transactions data, and applied that number to the

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[4] The translog functional form provides a convenient second-order approximation to an arbitrary continuously twice-differentiable cost function (see Diewert, 1974).

[5] This approach has been prominently used in various industry studies of cost efficiency and economies of scale; see, for example, Christensen and Greene (1976) and Atkinson and Halvorsen (1984).

number of head killed as reported in the plant's P&L statements to obtain the measurement of pork output.[6]

Finally, the estimation of the standard cost functions requires having data on input prices. The price of live animals was recovered from the individual transactions data. The problem is getting the price for the generic input mentioned above. Because the labor cost appears to be the most important component in the mix of production inputs other than live animals, we used the average weekly earnings of production workers (not seasonally adjusted) for the industry "Meat Processed from Carcasses" (NAICS 311612) and "Rendering and Meat Byproduct Processing" (NAICS 311613) from the Bureau of Labor Statistics data.

The translog cost function for the two inputs case can be written as

$$\begin{aligned} logC = {} & \alpha_0 + \alpha_Y logY + \frac{1}{2}\gamma_{YY}(logY)^2 + \alpha_1 logP_1 + \alpha_2 logP_2 + \\ & \frac{1}{2}[\gamma_{11}(logP_1)^2 + \gamma_{12} logP_1 logP_2 + \gamma_{21} logP_2 logP_1 + \gamma_{22}(logP_2)^2] + \\ & \gamma_{Y1} logY logP_1 + \gamma_{Y2} logY logP_2, \end{aligned} \tag{6}$$

where $\gamma_{12} = \gamma_{21}$, C is total cost, Y is pork output, P_1 is the price of market hogs, and P_2 is the wage rate. To correspond to a well-behaved production function, a cost function must be homogenous of degree 1 in input prices, which requires imposing the following set of restrictions on the parameters:

$$\begin{aligned} \alpha_1 + \alpha_2 &= 1 \\ \gamma_{Y1} + \gamma_{Y2} &= 0 \\ \gamma_{11} + \gamma_{12} &= \gamma_{21} + \gamma_{22} = \gamma_{11} + \gamma_{12} + \gamma_{21} + \gamma_{22} = 0. \end{aligned} \tag{7}$$

The optimal procedure to estimate the above cost function and obtain the estimates of the economies of scale is to jointly estimate the cost function and the cost share equations as a multivariate regression system. The cost share equations for each factor input are easily obtainable using Shephard's lemma:

$$\begin{aligned} \frac{\partial \log C}{\partial \log P_1} &= S_1 = \alpha_1 + \gamma_{Y1} logY + \gamma_{11} logP_1 + \gamma_{12} logP_2 \\ \frac{\partial \log C}{\partial \log P_2} &= S_2 = \alpha_2 + \gamma_{Y2} logY + \gamma_{21} logP_1 + \gamma_{22} logP_2. \end{aligned} \tag{8}$$

[6] The month-by-month comparison of the number of purchased market hogs from the individual transactions data and the number of hogs killed from the P&L data indicate that the two series are reasonably close to each other. The average 30-month ratio of two numbers is between 0.9 and 1 for all but two plants.

The estimation procedure that we use involves estimating the translog cost function Eq. (6) together with one of the two share equations Eq. (8) by imposing the cross-equation restrictions on the identical parameters in the cost function and the share equation, using iterative Zellner seemingly unrelated regression (ZSUR).[7] The linear homogeneity in input prices restrictions in Eq. (7) are tested using likelihood ratio tests.

Based on the estimated parameters of the translog cost function, the economies-of-scale measure can be calculated as follows:

$$ES = 1 - (\hat{\alpha}_Y + \hat{\gamma}_{YY} \log Y + \hat{\gamma}_{Y1} \log P_1 + \hat{\gamma}_{Y2} \log P_2)\,. \qquad (9)$$

The returns to scale can be calculated for the industry as a whole by evaluating Eq. (9) at the sample means for output and input prices. Alternatively, the economies of scale can be calculated for each plant by evaluating Eq. (9) at the plant-level means for output and input prices.

The econometric model is estimated using two data sets. The large data set contains 16 plants that are involved in all three stages of production (slaughter, fabrication, and processing), and the small data set contains the remaining two plants that are involved only in the first two stages and have no further processing. The estimation results for the large group are presented in Table 1.[8] The results show that the linear homogeneity in input prices Eq. (7) is a valid restriction (i.e., we cannot reject that null hypothesis).

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[7] Barten (1969) has shown that maximum-likelihood estimates of a system of share equations with one equation deleted are invariant to which equation is deleted. Dhrymes (1970) has shown that iteration of the ZSUR procedure until convergence results in maximum-likelihood estimates.

[8] The estimation results for the small group cannot be reported because of the violation of confidentiality rules.

Table 1. Translog Cost Function Parameter Estimates: 16 Hog Slaughter Plants with all 3 Production Stages

Parameter[a]	Estimate	t-Ratio
α_0	21.039	1.28
α_Y	–1.878	–1.01
γ_{YY}	0.160	1.53
α_1	1.125	2.78
α_2	–0.125	–0.31
γ_{11}	–0.050	–2.02
γ_{12}	0.050	2.02
γ_{22}	–0.050	–2.02
γ_{Y1}	–0.029	–1.28
γ_{Y2}	0.029	1.28
R^2	0.6926	

[a] Homogeneity of degree 1 in input prices imposed.

The estimated economies of scale are represented in Table 2. We partitioned the large sample of 16 plants into three groups according to size and re-estimate the econometric model for each group.[9] Each row in the table presents the results for one group. The results confirm our expectation that economies of scale diminish as plant size increases. The estimates indicate that scale economies are exhausted well within the sample output range such that the largest plants already exhibit negative economies of scale. For example, for large plants with an average capacity of producing 91 million pounds of carcass weight per month (this corresponds to a slaughter capacity of approximately 110,000 market hogs per week),[10] the economies of scale are -7.0%, which means that an increase in output of 1% will increase the total cost by 1.07%.

As plant size decreases, the negative economies of scale monotonically converge towards constant returns to scale. For example, for plants that process an average about 53 million pounds of carcass weight per month (about 65,000 hogs per week), the negative economies of scale amount to –1.2%. For the smallest plants, the economies of scale are positive. The plants that process an average about 41 million carcass pounds per month (about 50,000 hogs per week) exhibit positive returns to scale in the amount of 6.5%, which means that an increase in output of 1% would increase the total cost by 0.935%.

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[9] Results from these estimations are suppressed for confidentiality reasons.

[10] The capacities expressed in monthly carcass weights were obtained by multiplying the weekly slaughter capacities (in number of hogs) by 4.25 weeks per month and then multiplied again by the plant average monthly carcass weight per head.

Table 2. Hog Slaughter Plant Economies of Scale Measures

	Capacity[a]	Economies of Scale	Efficient Scale[b]
Large plants	91,111	−0.070	46,562
Medium plants	52,675	−0.012	46,485
Small plants	41,311	0.065	44,327

[a] Capacity is expressed as monthly carcass weight in 1,000 pounds.
[b] Efficient scale is the point of minimum average costs in 1,000 pounds.

A convenient way to summarize scale economies is to introduce the average cost curves facing various size plants. The cost curves are derived by evaluating the average cost function for a range of outputs holding the factor prices fixed at the sample means. The slope of the average cost curve is sufficient to infer the presence of economies of scale since $ES = 1 - (MC/AC)$. Declining average costs indicate increasing returns to scale, whereas rising average costs indicate decreasing economies of scale. The results indicate that different size plants operate on different segments of their average cost curves, but that their efficient scales of operations (minimum average cost) are narrowly clustered around 44 to 47 million pounds per month (see the right column in Table 2).

5. Evidence of Complementarity: Aggregated Data

In order to implement the performance approach introduced earlier, based on the estimated cost function parameters we compute the efficient scale of operations (minimum average cost) for 18 plants in the data set.[11] The efficient scale of operation may be influenced by the portfolio of marketing arrangements used to procure live hogs for two reasons. The portfolio of procurement arrangements may affect the average cost function through increased capacity utilization, through lower average factor prices (live hogs prices), or through both. The model using efficient scale is estimated using 18 observations only.

Next, we investigate the relationship between the use of marketing arrangements and two short-run firm-level performance measures: gross (meat) margin and EBIT (profit). For both of those, the portfolio of procurement arrangements may be important because, in addition to influencing the cost side, it can also potentially impact the revenue side of the meat margin or profit. The idea is that different portfolios of marketing arrangements may result in the

[11] We estimated the econometric model in the previous section 18 times, each time using the time series data from one plant. As a result, we can compute the efficient scale for each plant. Results from these estimations are suppressed for confidentiality reasons.

procurement of different average-quality live hogs, which when slaughtered and processed may yield higher quality pork that will be sold at higher market prices. These two models are estimated using the panel data with 30 monthly observations for 18 plants. The 18 plants included in this data set differ significantly according to their size. The largest plant has a maximum weekly slaughter capacity several times larger than that of the smallest plant. Thus, we standardized the gross margin and the EBIT variables based on the plant capacity.

The general form of the estimated linear regression model is:

$$\Pi_{it} = f\left(D\_portfolio_{it}, X_{it}\right), \tag{10}$$

where Π_{it} is one of the previously defined performance measures which varies only by packer *i* in the efficient scale model but varies by packer *i* and time (month) *t* in the meat margin and EBIT models, $D\_portfolio_{it}$ is the set of binary variables for each of the observed portfolios of procurement arrangements which can generally vary by plant *i* and time *t* but in our case varies only by plant, and X_{it} is vector of exogenous control variables. There are 15 possible combinations (portfolios) of procurement arrangements but only 4 are actually observed; hence, the portfolio binary variables are defined as follows:

$Portfolio\,1_i = 1$ if only cash/spot is used by the plant *i*; 0, otherwise

$Portfolio\,2_i = 1$ if only cash/spot and marketing contracts are used by the plant *i*; 0, otherwise

$Portfolio\,3_i = 1$ if cash/spot, marketing contracts, packer owned and other marketing arrangements are used by the plant *i*; 0, otherwise

$Portfolio\,4_i = 1$ if only marketing contracts, packer owned, and other marketing arrangements are used by the plant *i* ; 0, otherwise.

Table 3 provides the estimates of all three linear regression models using OLS where no attempt was made to correct for a possible endogeneity of procurement arrangement portfolios. Portfolio 1 (cash/spot) was left out of the regression to avoid perfect collinearity. Aside from portfolio binary variables, the only control variables included in the regressions performed with the panel data are time and time squared. Time is included to account for all possible macroeconomic influences that may be affecting the plants' performance. The efficient scale regression is performed with cross-sectional data and hence does not have time as explanatory variable. The units of the portfolio coefficients for the efficient scale regression are expressed in thousands of pounds of monthly carcass weight capacity, and those in the gross margin and EBIT regressions are in dollars per hog.

The results are relatively similar across all three performance equations. All portfolio binary variables are positive and most are significant at the 5% level. These results indicate that various combinations of procurement arrangements improve plant performance relative to the situations in which the plant uses only cash/spot markets to purchase all of its live hogs.

Table 3. Estimated Performance Effects of Different Marketing Arrangement Portfolios

Marketing Arrangement Portfolio	Efficient Scale (18 Observations)	Gross Margin/Capacity (540 Observations)	EBIT/Capacity (540 Observations)
Portfolio 2	37086.85[a] (11081.34)*	34.512 (13.95)*	1.712 (0.9583)
Portfolio 3	40202.7 (11516.07)*	100.315 (14.497)*	0.204 (0.9959)
Portfolio 4	43421.95 (12139)*	27.579 (15.281)	6.971 (1.05)*
Time		0.9862 (1.49)	0.1568 (0.1023)
Time squared		−0.0107 (0.0466)	−0.0055 (0.0032)
Constant	2536.472 (10512.69)	−1.719 (16.302)	1.032 (1.12)
Adjusted R^2	0.3922	0.1641	0.1735

[a] Standard errors are in parentheses; an asterisk indicates significance at the 0.05 level.

Because the adoption of different procurement arrangement portfolios is likely to be nonrandom, the problem of selection bias needs to be addressed. In a panel data framework, one can control for this potential source of bias with a plant-level fixed-effects specification if the plant-level procurement arrangement portfolios change over time (e.g. Ichniowski, Shaw and Prennushi, 1997). In our panel data (30 monthly observation times 18 plants), the plant-level procurement arrangement portfolios do not change over time. In this case, subtracting the plant-specific time series mean would zero out all procurement arrangement portfolio binary variables, rendering the fixed effects estimation impossible.[12] Alternatively, one can use a two-stage discrete/continuous procedure outlined in Train (1993, pp. 87-91). However, because we only have data on 18 plants,

[12] An alternative approach to deal with this issue would be to use the sales data on meat products by plant to proxy for plant fixed effects because each plant has a unique profile of meat products demanded by the market it serves. The reason this has not been done is because a meaningful aggregation of the sales data which came in thousands of different stock keeping units (SKU's) was prohibitively costly.

estimating multinomial logit in the first stage (where the LHS variable is a categorical variable for each of the existing portfolios and the RHS variables are some exogenous variables explaining the choice) turns out to be unreliable because estimates would not always converge.

Consequently, we use the simple instrumental variable estimator (two-stage least squares - 2SLS). Because we have three endogenous variables (portfolios 2, 3, and 4), we need at least three instruments. We use the size of the company as measured by the number of plants that it operates, size squared (to capture some nonlinearities), and the interaction between the size of the plant and the region where it is located. By choosing these instruments we are implicitly assuming that these variables have no direct effect on the performance of plants but only affect performance through their effect on portfolio adoption. We believe that the choice of these instruments is defensible because the size of the company, i.e. the number of plants that it owns, should not be related to the performance of the individual plants because these plants are always ran as competing profit centers. The same can be said about the region where the plant is located. Whereas the performance of the plant should not be impacted by its location, the adoption of AMAs surely is. Obviously firms operating in North Carolina will heavily rely on packer-owned sources because cash markets are rather thin. Opposite is true for traditional hog producing regions such as Iowa. Finally, the use of plant capacity is justified by referring to its long-run dimension that influences the portfolio adoption relative to the short-run dimension of the performance variables (meat margin and EBIT).[13] Another reason why these variables seem to be valid instruments is because they are all company level decisions and hence unlikely to be correlated with the error terms in the plant level performance equations.[14] The estimation results are presented in Table 4.

The coefficients associated with various binary variables are all positive and most of them are significant at the 5% level, indicating that relative to the left-out binary variable for the spot market only, all other portfolios improve the economies of scale, the normalized gross margin, and the normalized EBIT. However, the magnitudes of the coefficients do not monotonically increase as expected. In other words, the magnitude of the Portfolio 3 binary variable, which contains all procurement methods (cash, marketing contracts, and packer owned and other), is smaller than the Portfolio 2 binary variable, which includes only

[13] Notice that because the efficient scale variable is itself a long-run measure, we did not want to use plant capacity as an instrument in this regression. The reason it was interacted with the region in the aggregated data approach is because including simple regional dummies caused collinearity problems.

[14] It is interesting to note that the portfolios of marketing arrangements do not change across different plants owned by the same company. Based on this observation, we believe that the live hogs procurement strategy is determined at the company level rather than at the plant level.

two (cash and marketing contracts), signaling that including packer-owned hogs in the portfolio that already includes spot procurement and marketing contracts does not increase the performance of the plant. Interestingly, for both financial indicators (gross margin and EBIT), the magnitude of the Portfolio 4 coefficient is higher than the other two, indicating that the combination of marketing contracts and packer owned arrangements improves the performance of the plant relative to portfolios that include only spot market procurement. Therefore, based on these results, it is impossible to unambiguously conclude whether different procurement arrangements are actually complementary to each other.

Table 4. Instrumental Variables (2SLS) Estimates of Performance Equations

Marketing Arrangement Portfolio	Efficient Scale (18 Observations)	Gross Margin/Capacity (540 Observations)	EBIT/Capacity (540 Observations)
Portfolio 2	43622.34[a] (22727.91)	217.544 (36.612)*	10.584 (1.828)*
Portfolio 3	40911.03 (19833.6)*	154.614 (31.95)*	5.035 (1.595)*
Portfolio 4	31749.24 (23130.3)	314.837 (37.261)*	16.908 (1.86)*
Time		0.9862 (2.325)	0.1568 (0.1161)
Time squared		−0.01067 (0.0728)	−0.0055 (0.0036)
Constant	1017.42 (20047.32)	−156.194 (35.548)*	−6.402 (1.775)*
R-squared	0.0858	0.1238	0.1864

[a] Standard errors are in parentheses; an asterisk indicates significance at the 0.05 level.

As mentioned before, to examine whether the complementarity among procurement arrangements exists requires adding the individual binary variables for each individual practice to the regressions in Tables 3-4 to compare the magnitudes of individual practice versus portfolio effects. Unfortunately, this procedure is not feasible with aggregated monthly performance measures because portfolio dummy variables are functions of the individual practice dummies and hence including both portfolio as well as individual practice dummies result in perfect collinearity. Therefore, this type of analysis can only be carried out using some disaggregated performance measure like the purchase price in individual transactions. Such a model is estimated next.

6. Evidence of Complementarity: Individual Transactions Data

The rationale behind using the input price as a plant-level performance measure is that certain favorable combinations of marketing arrangements may actually result in a lower price paid to procure market hogs. Once the procurement strategy (portfolio) is in place, plants do not change it very often. Therefore the portfolio indicators in our model do not change during the sample period. However, different hogs are purchased through different channels, so each lot is associated with a particular marketing channel through which it was procured. Overall, the price of a lot of hogs is determined by the portfolio of procurement arrangements that a firm has in place, as well as by the individual practice through which the particular lot was purchased. To capture both effects, we estimate the following linear regression model:

$$P\_carcass_{ij} = f\left(D\_ma_j, D\_portfolio_i, X_{ij}\right), \tag{11}$$

where $P\_carcass_{ij}$ is the carcass prices (in \$/cwt) paid by the packer i for transaction j. $D\_ma_j = \left(d\_ma1_j, d\_ma2_j, d\_ma3_j, d\_ma4_j\right)$ is a vector of binary variables for alternative marketing arrangement categories defined as follows:

$d\_ma1_j = 1$ if procurement method for the jth transaction is cash/spot sales (MA1); 0, otherwise

$d\_ma2_j = 1$ if procurement method for the jth transaction is marketing contract (MA2); 0, otherwise

$d\_ma3_j = 1$ if procurement method for the jth transaction is packer owned (MA3); 0, otherwise

$d\_ma4_j = 1$ if procurement method for the jth transaction is other (MA4); 0, otherwise.

$D\_portfolio_i$ is the set of binary variables for each of the observed portfolios of procurement arrangements used by the plant i during the data period. There are 15 possible combinations but only 5 are actually observed; hence, the portfolio binary variables are defined as follows:

$pfbin1_i = 1$ if only cash/spot is used by the plant i; 0, otherwise

$pfbin2_i = 1$ if only marketing contracts is used by the plant i; 0, otherwise

$pfbin3_i = 1$ if only cash/spot and marketing contracts are used by the plant i; 0, otherwise

$pfbin4_i = 1$ if cash/spot, marketing contracts, packer owned and other marketing arrangements are used by the plant *i*; 0, otherwise

$pfbin5_i = 1$ if only marketing contracts, packer owned, and other marketing arrangements are used by the plant *i* ; 0, otherwise.

The exogenous variables X_{ij} included in the regression are regional binary variables, two animal characteristics variables: the loin-eye depth and the live weight of market hogs per head (in pounds), and time and time squared variables. Quadratic time trend is included in the regression to pick up all possible macro-economic influences (e.g., inflation) that may be affecting the hog price.

The left panel of Table 5 summarizes the ordinary least squares (OLS) regression results. Because of the additional elimination of outliers and missing values of some explanatory variables, an additional 154,469 observations were excluded, so the final sample size used in this regression is 1,522,758. We omitted the binary variable for cash/spot sales (*d_ma1*) and the binary variable for the cash/spot-only portfolio (*pfbin1*).

All the estimates for individual coefficients are significant at the 1% significance level, which is not surprising given the sample size. The signs of the coefficients on the procurement method variables are consistent with the previous findings. On average, the price of marketing contract purchases (MA2) is higher than cash/spot purchases (MA1) by \$0.75/cwt, while the packer owned price (MA3) is about \$0.88/cwt lower than the cash/spot price. The actual means of the data are \$59.40/cwt for cash/spot, \$62.79/cwt for marketing contracts, and \$54.66/cwt for packer owned. The sign of the regional variable *R1* shows that the East region has a lower average price than the rest of the country by \$10.50/cwt. The sign of the loin-eye depth variable is positive and significant. Thicker loin-eye depth indicates higher quality hogs, and higher quality hogs are sold at higher prices. The sign of live weight per head variable is negative and statistically significant. The magnitudes of both coefficients are small and thus have little influence on the purchase price.

Same as before, in estimating the effect of various factors on the behavior of hog price, it is necessary to avoid any possible selection bias coming from nonrandom selection of procurement portfolios. Therefore, we use 2SLS. Because we have four endogenous variables (portfolios 2, 3, 4, and 5) we need at least four instruments. We use the size of the company, the plant capacity, and its location. To capture possible nonlinearities, we also use the size squared, the capacity squared, and the interaction of size and capacity. Size of the company is measured by the number of plants that it operates, capacity is the plant's maximum slaughter capacity per week for market hogs (not the actual slaughter volume), and location was introduced via the binary variable for the East region. The results are presented in the right panel of Table 5.

Table 5. Estimated Price Effects of MA Portfolios and Individual MAs: Pork Packer's Transactions (Purchase) Data, October 2002-March 2005

	OLS Regression		Instrumental variable (2SLS)	
Variable	**Parameter**	**t-value**	**Parameter**	**t-value**
Intercept	53.518	437.35	58.030	402.92
D_ma2	0.746	32.81	1.928	35.79
D_ma3	−0.875	−29.54	−0.167	−5.06
D_ma4	1.561	33.96	3.925	16.51
R1[a]	−10.486	−399.83	−10.710	−296.50
pfbin2	4.341	28.72	−29.705	−77.69
pfbin3	0.734	12.55	−5.939	−30.06
pfbin4	−1.750	−31.65	−7.888	−62.07
pfbin5	13.899	209.66	5.933	17.54
Loin-eye depth (mm)	0.013	8.41	0.000	0.01
Live weight/head (lb)	−0.047	−103.55	−0.039	−67.42
Time	0.055	528.25	0.055	492.39
Time squared	-2.123	-191.63	−2.140	−177.23
Adjusted R^2	0.670		0.651	

[a] Regional dummy variable R1=1 if region is East; R1=0, otherwise.

Accounting for the endogeneity of portfolio choices produced a couple of interesting results. First, two coefficient estimates on the portfolio binary variables changed signs, such that now three out of four portfolio binary variables are negative. The signs on *pfbin2* (marketing contracts), *pfbin3* (cash/spot and marketing contracts), and *pfbin4* (cash/spot, marketing contracts, and packer owned) are negative, meaning that all alternative marketing arrangements reduce the transaction price for live hogs relative to cash/spot procurement only. The only qualitatively different result is *pfbin5* (marketing contracts, packer owned, and other), which is positive. This result is difficult to interpret because this portfolio includes the category "other," whose content is unknown. Another feature of this portfolio is that it does not include cash/spot market purchases. However, this may not be a decisive factor because *pfbin2* does not include cash/spot purchases either, yet it is still associated with a lower transaction price relative to cash market purchases. The results show that packers that use of a combination of marketing arrangements, on average, pay lower prices for their hogs relative to plants that use the cash/spot market only.

The second interesting result comes from comparing the magnitudes of the portfolio effects with the magnitudes of the individual channel effects. Take, for example, *pfbin3* (cash/spot and marketing contracts) and compare it with *d_ma2* (marketing contracts). The magnitude of the negative price effect of the portfolio ($58.03 – $5.94 = $52.09/cwt) is larger (i.e., the price is lower) than the sum of the individual channel effects ($58.03 + $1.93 = $59.96/cwt). Furthermore, comparing the magnitude of the *pfbin4* (cash/spot, marketing contracts, and packer owned) with the sum of *d_ma2* (marketing contracts) and *d_ma3* (packer owned), the effect of the portfolio ($58.03 – $7.89 = $50.14/cwt) is larger (price is lower) then the sum of individual effects ($58.03 + $1.93 – $0.17 = $59.79/cwt). The results appear to indicate that individual procurement practices have minimal additional effect on the transaction price (i.e., the portfolio system binary variables capture almost the entire effect on lowering the transaction price). These results are supportive of the claim that the various procurement arrangements may be complementary to each other.

7. Conclusions

Based on the observation that majority of pork packers procure their live hogs by using different portfolios of procurement arrangements, we started this investigation with a notion that procurement methods may be complementary to each other in the sense that implementing one practice may increase the marginal return of the other practice. The main sources of complementarity are the supply chain management issues, the mitigations of the information asymmetry problems, and market power considerations. In order to carry out the test we rely on several plant-level performance measures.

Virtually all existing literature in this area reveals the fact that the main issue is always how to disentangle complementarity from extraneous unobserved (by the econometrician) firm or plant level factors driving correlated adoption across distinct choices for reasons that might not be related to complementarity. Even in the most sophisticated approaches can be criticized with rather standard arguments. This is also the reason why most authors looking for complementarities among practices are always very cautious in the interpretation of their empirical results, and so are we.

Using the efficient scale measure we tried to establish the long-run relationship between plant-level efficiency and the utilization of alternative marketing arrangements used by pork packers in procurement of live hogs. The observed patterns of procurement portfolio choices by packers indicate that certain combinations of marketing arrangements may reduce cost or increase economies of scale. In particular, relative to the use of spot market procurements alone, all other marketing arrangement portfolios increase the efficient scale of production. Similar results were obtained using two short-term plant-level performance measures: gross (meat) margin and EBIT. These results indicate that various combinations of procurement arrangements improve short-term plant performance relative to the situations in which the plant uses only cash/spot markets to purchase all of its live hogs.

Since the complementarities among individual marketing arrangements could not be ascertained with the data structures afforded by these three measures, we also look at plant-level live hogs purchase prices to see whether various portfolios of marketing arrangements allow plants to procure their hogs at lower prices. The detected differences in carcass prices that packers pay for their hogs are significant, some of which can be explained by factors such as region, quality, or plant size. However, even after controlling for those factors, the remaining differences need to be explained by organizational issues related to supply chain management. Results seem to indicate that plants that use a portfolio of procurement methods on average pay lower prices for their hogs relative to plants that use the cash/spot market only. The second interesting result comes from comparing the magnitudes of the portfolio effects with the magnitudes of the individual channel effects. The results indicate that individual procurement channel have minimal additional effect on the transaction price (i.e., the portfolio system binary variables capture almost the entire effect on lowering the transaction price), signaling the possible presence of complementarities among procurement methods in the pork packing industry.

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