DO ECONOMIES OF SCALE EXIST IN THE PHARMACEUTICAL INDUSTRY?†

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To determine whether the pharmaceutical industry becomes more efficient as it grows larger, economies of scale were measured with a translog multi-product statistical cost function. Returns to two outputs—research and development and sales—revealed that overall firms are characterized by diseconomies of scale. But, firms of all sizes experience increasing returns as their research efforts grow larger.

An issue of concern for many years is the degree to which economies of scale are present in the pharmaceutical industry. Since the early 1990s, the health care system has been undergoing a restructuring. President Clinton, in a December 1994, letter to Congress, reaffirmed his commitment to broad health care reform (McGinley, 1995). As health care streamlines to become more cost efficient, understanding the relationship between firm size and cost effectiveness seems imperative. The purpose of this paper is to estimate pharmaceutical industry cost functions that explicitly recognize the multi-product nature of firms. Previous cost studies ignored the multi-product nature of pharmaceutical firms by focusing on a single output measure (see Simmons, S. A.; Shull, S.; and Smith, M. C. [1978]; Schwartzman [1975]; Graves and Langowitz [1992]; DiMasi et al., [1991]) or assuming that the firm can be treated as a collection of separate and independent production functions. (Studies that emphasize only research and development [R&D] or drug innovation

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activities include those by Schwartzman [1976], Grabowski [1976], Vernon and Gusen [1974], Jensen [1987], and Graves and Langowitz [1992]). Also, this research gives attention to overall scale economies as well as returns to R&D and sales.

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BACKGROUND OF THE PROBLEM AND PURPOSE OF THE STUDY

The original methodology for studying production and cost structures in the pharmaceutical industry employed the Cobb-Douglas production function. The traditional Cobb-Douglas production function takes the form:

$$Q = A L^{\alpha} K^{\beta}$$

where

Q represents output

K and L represent capital and labor, respectively

A is a constant term

α is the elasticity of output with respect to labor, and

β is the elasticity of output with respect to capital.

The sum of the elasticity coefficients, $\alpha + \beta$, decides the scale characteristics. As an example, assume labor and capital inputs are increased by an equal percentage. Three results are possible:

1. Output increases by a greater percentage than the increase in inputs. In this outcome the production process yields economies of scale, becoming more efficient as the firm becomes larger. As output volume increases, long run average costs decline. The sum of the coefficients $\alpha + \beta$ exceeds unity.
2. Input and output increase by the same percentage. With constant returns to scale general efficiency remains the same as the process grows larger. An increase in output volume results in constant long run average costs. The coefficients $\alpha + \beta$ sum to one.
3. Coefficients $\alpha + \beta$ sum to less than one. Decreasing returns to scale result when a 1 percent increase in inputs results in less than a 1 percent increase in output. As output volume increases so do long run average costs.

Recently, researchers have embraced more flexible functions, such as the translog multi-product statistical cost function, to overcome restrictions imposed by the Cobb-Douglas form. The Cobb-Douglas production form is constrained to measure increasing, decreasing, or constant returns to scale, but not a combination of these.

The translog cost function provides an appropriate functional form for answering questions about economies of scale. By not restricting scale economies, it provides the flexibility necessary to estimate "U"-shaped average cost curves, derive scale economies or diseconomies, and allow these economies to vary by size of firm. The translog multi-product cost function is expressed as:

$$\ln C = ao + \sum ai \ln Yi + \sum bi \ln Wi + 1/2 \sum \sum aij \ln Yi \ln Yj + 1/2 \sum\sum bij \ln Wi \ln Wj + \sum \sum cij \ln Yi \ln Wj \quad \ldots\ldots\ldots \text{(Equation 1)}$$

where C is total cost, the Yi represent outputs (research and development and sales) and the Wi represent input prices (cost of goods sold; employee wages; and net property, plant, and equipment). With m outputs and n inputs, the following linear restrictions on the coefficients in Equation 1 are necessary and sufficient for linear homogeneity in factor prices.

$$bj = 1;$$
$$bij = 0 \text{ for } j = 1, 2, \ldots n;$$
$$cij = 0 \text{ for } j = 1, 2, \ldots m; \text{ (Shoesmith, 1988)}$$

The determination of scale economies is straightforward. Brown et al. (1979) and Bothwell and Cooley (1982) and Cebenoyan (1988) suggest that the appropriate measure of overall scale economies (SE) is the sum of the individual output cost elasticities. This research recognizes two outputs: research and development and sales.

$$SE = (\partial \ln C / \partial \ln Yi), \quad n = 1, 2.$$

If SE is greater than one there are decreasing returns to scale; if SE equals one the industry is characterized by constant returns to scale; if SE is less than one there are increasing returns to scale (Gilligan and Smirlock, 1984).

The purpose of this research is to apply the translog statistical cost function to the pharmaceutical preparations industry. Attention will focus on economies of scale for two outputs, sales and R&D, along with economies of scale for the firm's overall operation.

REVIEW OF RELEVANT LITERATURE

The translog statistical cost function has been employed for measuring returns to scale for firms in various industries. One frequent application is the estimation of cost functions for multi-product banking firms. (See,

for example, Cebenoyan [1988]; Rezvanian, R., Rangan, N., and Grabowski, R. [1983]; Gilligan, T.; Smirlock, M; Marshall, W. [1984]; Kolari, J. and Zardkoohi, A. [1991], Gilligan, T. W. and Smirlock, M. [1984]; and Bentson, G.; Hanweck, G.; and Humphrey, D. [1982]).

The translog multi-product cost function has also been applied to universities by considering undergraduate and graduate instruction and research publications as outputs. Evidence of economies of scale was found along with economies of scope in the joint production of graduate and undergraduate instruction (DeGroot, McMahon and Volkwein, 1982).

An application to petroleum refining firms measured outputs as daily production of motor gasoline, distillate fuels, and other refined products. Petroleum refining is subject to classical "U"-shaped average cost (Shoesmith, 1988).

The securities industry provides another arena for application of the translog multi-product cost function. Merger activity, competition from other industries, and proposed legal changes precipitated structural changes in the industry. If economies of scale or scope exist, then firm entry may be limited to banking firms large enough to capture the available economies of scale by offering the entire range of securities services. Alternatively, if the securities industry does not exhibit scale or scope economies, smaller banking organizations may be able to operate profitably at smaller scales. Research by Goldberg et al. found an industry composed of smaller, specialized firms demonstrating economies of scale and larger, more diversified firms exhibiting diseconomies of scale (Goldberg et. al., 1991).

A recent study of retail banking by Leemputte, Burgess, and Kilgore (1993) criticizes the misuse of economies of scale research. Economies of scale has been used to justify bank mergers—a potentially dangerous notion when size alone is emphasized and not management efficiency. Their unique approach to scale economies looks not at the entire business

but at functions within the business. Within retail banking the billing and accounting function, for example, offers high returns to scale while marketing does not (Leemmputte, Burgess and Kilgore, 1993). Businesses contemplating merger activity should examine scale economies of its individual functions as well as its overall operation. Likewise, pharmaceutical firms can benefit from cognizance of overall economies as well as returns to specific outputs.

METHODS

The purpose of this research is to estimate economies of scale in the overall operation of the pharmaceutical industry. Further, function specific economies of scale will be estimated for two outputs--the research and development function and sales. The Pharmaceutical Preparations Industry, SIC 2834, makes up a subdivision of the drug industry and comprises firms primarily engaged in manufacturing, fabricating, or processing drugs in pharmaceutical preparations for human or veterinary use (U. S. Department of Commerce, 1990).

Data on individual firms within the pharmaceutical industry are found in the ***Disclosure*** (1993) data base, which provides detailed financial and textual information on public companies. Reports filed with the U. S. Securities and Exchange Commission (SEC) form the basis of the data set. Annual data for 1993 were collected for each pharmaceutical preparations firm reported in the ***Disclosure*** database. Only firms with complete data bases are used in the analysis. Variable descriptions and notations appear in Table 1.

Total cost (C)

Total cost is the sum of sales, general, and advertising expense; interest expense; and cost of goods sold.

Table 1

Variable Definitions and Notations

Notation	Definition
EXPEND	Total Cost = cost of manufacturing; sales, advertising, and general expense; and interest expense. EXPEND is the dependent variable
SALES	Annual sales (000)
RDEXP	Research and development expenditures (000)
EMPLOY	Employee wages
CGS	Cost of goods sold (000)
NPPE	Net property, plant, and equipment (000)
LNSALES	Natural log of SALES
LNRDEXP	Natural log of RDEXP
LNEMPLOY	Natural log of EMPLOY
LNCGS	Natural log of CGS
LNNETPRO	Natural log of NPPE
LNSQSALE	LNSALES * LNSALES
RDSALES	LNRDEXP * LNSALES
LNSQRDEXP	LNRDEXP * LNRDEXP
LNSQEMPL	LNEMPLOY * LNEMPLOY
EMPCGS	LNEMPLOY * LNCGS
EMPNETPR	LNEMPLOY * LNNETPRO
LNSQCGS	LNCGS * LNCGS
CGSNETPR	LNCGS * LNNETPRO
LNSQNETPR	LNNETPRO * LNNETPRO
SALENETP	LNSALES * LNNETPRO
EMPRDEXP	LNEMPLOY * LNRDEXP
RDEXPCGS	LNRDEXP * LNCGS
RDNETPRO	LNRDEXP * LNNETPRO
SALECGS	LNSALES * LNCGS
EMPSALES	LNEMPLOY * LNSALES

"This analysis does not support the notion that large is better in terms of sales efficiency. But, it does suggest . . . research operation becomes more efficient."

Output (Sales and R&D)

Sales and research and development (R&D) expenditures comprise the outputs. A question may arise about considering R&D expenditures an output when it could be viewed as an input. If data were available on new drug innovation, then R&D could be regarded as an input that results in the output of new drugs. Without the data on new drug introductions, R&D expenditures will serve as a proxy measure of innovative output. To recognize R&D output only when a new drug is introduced, and not along the development time horizon, would needlessly exclude from the data set firms that had no new drugs in 1993. R&D expenditures overcome this bias and provide a satisfactory measure of innovative output.

Inputs (employees; cost of goods sold; and net property, plant, and equipment)

Labor, raw materials, and capital comprise the inputs into pharmaceutical production. Labor input is represented by employee wages. Cost of goods sold defines the price of raw materials, and the price of capital is captured in the depreciated value of plant, property, and equipment.

All outputs and input prices are scaled to one at their sample means to be able to interpret the regression coefficients as elasticities of the "average" pharmaceutical firm.

ESTIMATION AND RESULTS

The functional form used for tests of economies of scale will be the translog multi-product cost function. Two outputs, sales and R&D expenditures, and three inputs, employee wages; cost of goods sold; and net value of property, plant, and equipment; define the model. Total cost comes from expenses of manufacturing products, selling products, and maintaining the physical plant. Multiple regression analysis provides the multivariate technique necessary for model estimation. Table 2 displays the regression coefficients and statistics for estimates of Equation 1.

Table 2

Multi-Product Cost Function Estimation

Multiple Regression Analysis Results

Total Expenditures -- Dependent

Variable	Regression Coefficient	P-value
LNSALES	0.9106	***
LNRDEXP	0.8330	
LNEMPLOY	-0.3755	*
LNCGS	0.3779	*
LNNETPRO	-0.0025	
LNSQSALE	0.1573	***
RDSALES	-0.1993	***
LNSQRDEXP	0.0489	
LNSQEMPL	0.4471	**
EMPCGS	-0.2795	
EMPNETPR	-0.3954	
LNSQCGS	0.0775	
CGSNETPR	0.1112	
LNSQNETPR	0.0392	
SALENETP	0.0207	
EMPRDEXP	-0.1640	*
RDEXPCGS	0.0918	
RDNETPRO	0.1668	*
SALECGS	-0.1193	
EMPSALES	0.0040	

R^2: 0.988 P-value: 0.0001

P-Values: *** Significant at least at the 0.01 level

** Significant at least at the 0.05 level

* Significant at least at the 0.10 level

Note the following about the multiple regression equation:

- The coefficient of determination shows that approximately 99 percent of the variance in total cost is explained by the independent variable set.

- The complete equation is significant at least at the 0.001 level.

- The coefficients of the quadratic terms for outputs are positive and significantly different from zero for both sales and research and development expenses. Average cost per dollar of sales or average cost per dollar of research and development expenditure eventually will increase with continued expansion of those outputs.

- A t-test shows that a1a2 + a12 is positive (0.0004) and not significantly different from zero. This implies no economies of scope between sales and R&D expenditures at the sample mean.

To broaden interpretation of the cost function, scale economies were calculated for different output mixes. Table 3 displays both the individual output cost elasticities and scale economies for all firms in the sample and also for firms grouped into three expenditure categories: small firms defined as those with expenditures of less than $30,000,000 medium firms with expenditures between $30,000,000 and $150,000,000 and large firms with expenditures over $150,000,000.

Pharmaceutical firms in all size categories seem characterized by diseconomies of scale (SE > 1). But, it is noteworthy that the economies of scale improve as the firms become larger. The most severe diseconomies of scale are experienced by the smallest firms.

Observing the cost elasticities for research and sales, it is interesting that all firms, despite size, experience economies of scale in research, with the largest firms displaying the most advantageous economies of scale. Note

how the cost elasticity on research decreases as firm size increases (from 0.98 for the smallest category of firms to 0.026 for the largest expense category). Thus, it appears large firms experience more efficient research operations as compared to small firms.

For all size categories the cost elasticity for sales is above one. Average costs rise as sales volume increases.

Table 3

Estimates of Cost Elasticities and Economies of Scales

Firm Size	Average Expenditure	Number of Firms	MC Sales	MC R&D	Scale Economies
Total Sample	$632,140	149	1.1789	0.2519	1.4308
< $30,000	$9,015	46	1.69	0.98	2.67
$30K $150,000	$40,400	33	1.56	-0.3212	1.2388
>$150,000	$1,580,000	34	1.23	0.026	1.256

DISCUSSION

Any thoughts of regulation of firm size should be reconsidered based on these results. Evidence suggests that pharmaceutical production is not Cobb-Douglas in nature and that studies that have imposed this assumption may contain questionable results. This analysis does not support the notion that large is better in terms of sales efficiency. But, it does suggest that firm size expansion results in declines in per unit research costs; that is, the

research operation becomes more efficient. The relationship between firm size and research efficiency deserves attention. Because of rising R&D costs and their effect on profitability, more pharmaceutical companies will be forced to merge in the 1990s (*R & D Magazine*, 1991). As pointed out in a study by DiMasi et al. (1991), within the past few years there have been several major mergers and acquisitions in the pharmaceutical industry including SmithKline—Beecham, Bristol Myers—Squibb, Eastman Kodak—Sterling Drug, Merrell Dow—Marion Labs, and American Home Products—Robins. The present study suggests that as firm size increases, research and development activity becomes more efficient. It would be interesting to look at R&D and innovation activity in these firms before and after the mergers to see if they do, in fact, experience lower average costs.

Prior studies of pharmaceutical firms have not conclusively accepted or rejected the hypothesis that innovative output increases with firm size. Comanor (1965) examined the relationship between the number of new chemical entities introduced to firm sales. Economies of scale existed for small firms while large firms displayed diseconomies of scale. Grabowski (1976) found that research output initially increased with firm size but decreased with respect to size for larger firms. Vernon and Gusen (1974) found the number of new chemical entities introduced increased with firm size, giving larger firms an advantage over smaller ones. Schwartzman (1976) also concluded that large firms display economies of scale in research and development. Jensen (1987) found a positive relationship between R&D expenditures and the number of new chemical entities introduced. But, Jensen concluded that for most firms the elasticity of new chemical entity introduction with respect to R&D expenditures is not significantly different from one, which implies constant returns to scale. Thus, volume of R&D expenditures leads to neither efficiency nor inefficiency in terms of innovation.

More recently a study of the pharmaceutical industry by Graves and Langowitz (1992) employed a unique measure of innovation. After

classifying innovations according to type and significance, they measured the relationship between innovations and R&D expenditures. Their results show decreasing returns to scale for all firm sizes. Small firms have higher innovative productivity as compared to larger firms.

"As firm size increases, research and development activity becomes more efficient."

So this research adds to the equivocal findings regarding the connection between firm size and R&D efficiency. The relationship between firm size and sales efficiency is clarified. Perhaps another research step would apply the method explained by Leemputte et al. (1993). They find that simply being bigger often does not result in lower costs. Their approach examines separate banking functions and measures returns to scale for each function. Scale matters in some functions within a given business, but not in other functions. An application of this method to the pharmaceutical industry could shed light on the question of whether firm size should be regulated. Instead of saying that a larger firm size is inherently good or bad, look at the returns to various functions (e.g., marketing, development, production) to determine whether firm size and average costs are related.

Future research might investigate the relationships across firm size, returns to scale for R&D activities, and costs of new drug introductions. A question of concern to all consumers, as well as the federal government, is: If increasing firm size translates into lower production costs, can and will the consumer benefit from lower drug prices? Development of the national health plan necessitates investigation of this question. Consumers, whether the U. S. Government or individuals, should pay a smaller average price per drug if economies of scale exist in R&D.

CONCLUSIONS

As plans for a national health care plan evolve, production characteristics of the pharmaceutical industry must be considered. Based on this research we cannot say that bigger is better for pharmaceutical firms. If we look at the overall operation of the firm, increasing firm size does not lead to lower average cost. But, for those firms trying to improve research efficiency, bigger is better; this research discloses economies of scale in research. The final decision of which health care policies are applicable to take advantage of these characteristics is left to those with a decision-making role.

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