Determinants of Farm Size and Structure

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EMPIRICAL STUDIES OF SIZE AND STRUCTURE IN AGRICULTURE

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The structure of firms within an industry influences the structure of the industry and firms are influenced by that industry structure. The viability and profitability of firms are partially determined by elements associated with firm size, firm structure and the character of the industry in which they compete. The joint determination of firm structure and industry structure is important in analyzing the effects of factors that influence the evolution of firms and industry performance over time. The relevance of firm size and structure cannot be determined independently of industry structure because the causal factors are not unidirectional.

In many cases, however, the size or structure of firms at a point in time can be described or measured somewhat independently of industry dynamics. By measuring economies of size or scale for a particular industry or class of firms, a useful snapshot of the current situation can be obtained. The measurements obtained can then be used in two distinct ways. The effects that a particular measured structure may infer for the future of the firm and the industry can be analyzed. For example, if increasing returns to scale for a particular technology are discovered, then inference about firm growth and changes toward a more concentrated industry structure may be hypothesized. Alternatively, measurements of industry structure can be used as dependent variables in the analysis of factors that may influence the structure of firms and the industry. For example, measurements of firm efficiency may be obtained by cross-section analysis. These factors can then be related to other variables associated with the firm such as age, ownership pattern, or degree of diversification. Of course simultaneity problems must be addressed in such analyses.

This paper takes the snapshot and reviews previous studies that have attempted to measure economies of scale, size and scope in agriculture. The paper also considers studies of firm efficiency and firm growth or survivorship. The purpose is to investigate previous empirical work in order to discover central tendencies in the areas of size and structure in agriculture. The paper considers normative studies first and then examines positive investigations. The positive studies are broken down by functional structure used to conduct the analysis. Research investigating firm efficiency is then examined, followed by the review of studies analyzing firm viability and growth. Pecuniary economies are mentioned briefly.

Normative Studies of Size and Scale

Normative studies usually measure economies of size by either synthetic construction of optimal firm plans using budget and technology data or through the use of programming models. Sometimes size economies are inferred by simply comparing average costs of

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production for firms producing different levels of output. The classic monograph by Madden summarizes a variety of studies based on linear programming. Rather than discuss specific studies, since they are analyzed in Madden, some general conclusions will be drawn. For crop farms, the general trend is for the cost curve to decline over some range but flatten out at moderate output levels and decline little thereafter. Studies by Ihnen and Heady and Heady and Krenz found minimum average costs could be obtained at sizes of less than 500 acres. A variety of studies conducted in California, of which the ones by Carter and Dean are representative found larger farm sizes associated with minimum cost production but still found few economies for farm sizes above 700 acres.

Economies of size for beef feedlots discussed in Madden were generally found to be more significant however. In almost all studies average costs declined as size increased. The decline in costs was usually associated with the utilization of larger and more efficient equipment such as mills or feeding equipment.

The results of these early studies also found some economies of size for dairy farms but the cost curve levelled off for sizes considered very small by today's standards (<100 cows).

A more recent comprehensive study was conducted by Miller et al. using linear programming and data from the 1978 Firm Enterprise Data System (FEDS). For each of seven regions they developed representative farm models and minimized the cost of meeting certain revenue targets associated with farm size as defined by census data. In each region they considered three to four enterprises with a fixed machine component and fixed operator labor. Producers were allowed to rent land in addition to owned land. While economies of size were found in all regions the extent of these economies was limited. For example in all regions farms that were 33% of the size of the most efficient farm attained at least 90% of the resource return rate of the most efficient farms.

Moore, in response to concern about possible changes in the Federal 160 acre limitation, investigated economies of size for farms in 18 Federal irrigation districts in the Western United States. Short run average costs curves were developed using linear programming and then the long run average cost curve was obtained by tracing the envelope of these curves. All of these curves declined rapidly up the point where gross sales exceeded $100,000 and were relatively flat thereafter. The acreage needed to achieve 98% of the efficiency of the most cost effective farm sizes was relatively low ranging from 200 acres in Oklahoma to 1350 acres on a heavy soil in the Imperial Valley of California. The same economies were attained on a farm of 375 acres on a light soil in the same area. The conclusion was that few advantages were obtained by increases in farm size for farms receiving Federal water.

In an investigation of optimal feedlot configuration Weimar et al. using economic engineering techniques found substantial economies of size for beef feedlots in the corn belt. The cost savings were generally associated with feed handling and waste handling equipment. Recent changes in the tax laws favored larger feedlots (5,000-10,000 head) due to lower tax brackets, though changes in depreciation laws mitigated these effects.

Most normative studies of crop farms, both early and recent, while identifying economies of size, have given little evidence that the cost curve deviates significantly from a sagging "L" shape. This result may be influenced in part by the size measure used since these studies typically use gross revenue as an output measure and crop specific economies may be blurred in optimal enterprise choice. Studies of livestock farms have generally identified economies of size or scale with larger firms having advantages both in production and other facets of the business (Meisner and Rhodes). These conclusions are consistent with the overall growth in the size of livestock operations over time while the growth of crop farms has been less significant. In this sense the normative models of three decades past have been accurate predictors of industry dynamics. While normative studies have been immensely popular in investigating economies of size, the number of such studies reported in professional journals has declined dramatically in recent years.

Cross-section Studies of Size and Scale

The most popular alternative to normative analysis in investigating size economies is the direct estimation of size measures using cross section or time series data. Since cross-section results are the most straightforward to interpret and apply they will be discussed first.

Cost Function Studies. Given data on firm level output, inputs, and input prices, an industry cost function can be obtained by assuming a similar technology across firms. Differences in technology are controlled for through the use of other explanatory variables such as soil type in the case of crop farms or farmer education. The book by Johnston documents early empirical efforts in this area.

An example of this technique is a recent paper by Fleming and Uhm that estimates a cost curve for Saskatchewan grain farmers. Average production cost per kilogram of grain is regressed on kilograms of production, input prices, amount of livestock on the farm and other control variables. Average costs were found to fall as output initially increases and then decline much more slowly over a wide range of outputs. These results are consistent with normative studies.

Developments in duality theory led to a proliferation on articles measuring the cost structure of firms and implied size economies in the general economics literature. Many of these studies considered aggregate data and did not analyze returns to size (Berndt and Wood). Given the historical interest for size economies in agriculture a number of studies estimating cost functions using cross section data might have been expected. Such is not the case however. One example is a recent paper by Cooke and Sundquist. Using enterprise specific data they estimate cost functions for corn, soybeans, wheat and cotton. The data is taken from surveys conducted by USDA. This study assumes constant returns to size within three size categories but compares rates of cost efficiency across sizes to investigate economies of size. The study finds evidence of size economies between medium and large and between large and very large firms in corn, soybeans and cotton but mixed evidence for wheat. These size economies are not large in percentage terms, however (1%-12%) and do not imply significantly different industry structure than earlier results.

The lack of papers applying single product cost functions is a natural outcome of the application of theory to empirical data. Most agricultural firms produce several products. While the production processes for these firms may often be non-joint and allow the estimation of enterprise specific functions, the data typically available does not allocate inputs by enterprise and so multiproduct cost estimation is inevitable. Early research on multiproduct cost structures did not consider returns to size, however (R. Hall). While returns to size is an unambiguous measure in single output firms, it is not well defined for multiproduct firms (Chambers). Thus the measurement of returns to size, scale and scope for these firms lagged until the development of a theory of cost structures for these firms (Baumol, Panzar and Willig). The three measures applicable to multiproduct firms are economies of scope, product specific economies of scale, and multiproduct economies of scale which measures the effect of increased production on ray average cost.

Three recent papers apply these multiproduct techniques to the agricultural industry. A recent paper by Akridge and Hertel considers the retail fertilizer industry. They find that multiproduct scale economies exist for the average firm in a cross-section sample of Indiana and Illinois fertilizer plants. They consider six output categories: dry fertilizer, fluid fertilizer, anhydrous ammonia, chemicals, custom services and other sales. Variable inputs were aggregated into labor and energy while fixed inputs were represented by management, plant and equipment and other inputs. Due to data limitations economies of scope were computed between anhydrous ammonia and all other outputs. Economies of scope were identified, with the cost of producing anhydrous ammonia and the other five outputs being 84.8% lower in joint production. Product specific scale economies were found in anhydrous production. At average output, marginal cost was over $12.00 less than average incremental cost. Product specific economies of scale were not found for the other five outputs so that overall economies of scale were primarily due to economies of scope. Analysis of long run equilibrium conditions imply that the average plant in the sample overinvested in plant and equipment. The major limitation of the paper is the inability to compute more specific scale measures since many plants did not produce all outputs.

A paper by Moschini analyzes the structure on Ontario dairy farms using a hybrid-translog multiproduct cost function. Three output categories are considered in the analysis; namely, milk, livestock products and crops, and other products. The four inputs considered are labor, feed, intermediate inputs and capital. A service price is computed for capital. The farms are further classified by various demographic and production technique variables. The results imply increasing returns to scale for a wide range of output levels. The returns to scale become closer to one only for the largest firms in the sample. The hypothesis that milk production is non-joint with the other outputs was not rejected. Therefore average incremental cost for milk, holding other outputs constant, is a reasonable measure of economies of size. Average incremental cost for milk production is "L" shaped but implies increasing returns over a sizeable range of production with most of the firms still not capturing the significant economies of scale. The results of this study are consistent with previous studies of the dairy industry but imply increasing returns for larger firms than the studies summarized in Madden.

A recent paper by Deller, Chicoine, and Walzer considers economies of size and scope in rural low-volume roads. The paper analyzes the production of paved, bituminous and gravel/earth roads in townships in the states of Illinois, Ohio, Minnesota and Wisconsin. The inputs are labor, earth graders, trucks, and the types of materials needed for each road type. Exogenous variables considered included utilization and government road aid. Multiproduct economies of scale, which the authors call economies of size, were identified with the average measure being .466 (A positive number indicates economies of scale). These results indicate that the total cost of maintaining roads in two average size townships could be reduced by 50% with a merger of townships. Economies of scope were also evident in the sample. This implies that specialization in specific road types is probably not of value.

One additional line of work should be mentioned. Dixon, Batte and Sonka and Hornbaker, Dixon and Sonka have developed a way to estimate average production costs for multiproduct firms using cost and output data. By generalizing the Hildreth and Houck random coefficients model along a line suggested by Swamy and Tinsley they are able to estimate individual enterprise activity costs. While not explicitly recovering size and scale data the method could be used to estimate production costs for samples of differing size firms.

The cost function studies, while few in number, seem to imply increasing returns to size or scale for livestock producers at current production levels for many firms, but much less significant returns to size for crop farms. While these studies have found that firm characteristics are good independent variables in explaining differences across firms, no theory of how these characteristics affect optimal decision rules is presented.

Production Function Studies. While economies of size are typically measured using the cost function, economies of scale have traditionally been measured using the production function. A number of early studies are summarized and critiqued by Hoch. Hoch also presents the results of a study involving California dairy herds. Milk production was postulated as a function of feed, capital, cow service flow, labor and operating costs. Multicollinearity among variables led to the combining of all non-feed inputs. Analysis of covariance was used with effects for firm, year, month, breed and membership in the Dairy Herd Improvement Association (DHIA). The Cobb-Douglas functional form was used. Ignoring firm effects, returns to scale was close to one. When firm effects were included the elasticity sum fell to less than one for all market-milk samples and was greater than one for manufacturing-milk samples. The study not only implied that long run returns to scale may be decreasing due to inherently fixed factors but pointed out some of the difficulties in interpreting empirical results. The results on returns to scale for these dairy herds are very different from those found when measuring returns to size as should be expected. This difference should be kept in mind when analyzing returns to scale (size is not defined) for multiproduct firms.

Much of the impetus for more flexible functional forms was the inability of simple forms to measure variable returns to scale and variable elasticities of substitution. The paper by Zellner and Revankar addresses many of these issues. Flexible functional forms associated with the advent of duality theory also led to increased interest in returns to scale (Christensen, and Green, 1976; Christensen, Jorgensen and Lau, 1973). A somewhat unique approach is that proposed by Fare, Jansson and Lovell, who advocate the use of ray-homothetic production functions. These functions, while less flexible than true second order approximations, are parsimonious in the use of parameters and generate more plausible results than general homothetic functions. When reestimating a production function for the transportation equipment industry using Zellner and Revankar's data they find that although there is little statistical support for ray-homotheticity over homotheticity or ray homogeneity, the implied returns to scale over the output and input range are much more plausible using the ray homothetic form. Applications of this approach in agriculture have been rather few, exceptions being a recent paper by Grabowski and Sanchez on Japanese agriculture and another by Grabowski and Belbase on Nepalese agriculture. Both papers, however, used aggregate rather than cross section data and thus apply more to representative firms than actual ones. The former paper found increasing returns to scale in Japanese agriculture over the period 1874-1940.

The cost function, as discussed above, is the most common method for measuring returns to size. An alternative approach is to estimate the firm's production function and then solve for optimal input demands. From these the shape of the average cost curve can be obtained by solving first-order conditions. The direct estimation of the production function for determining size economies has certain advantages and disadvantages relative to alternative methods and has been primarily applied by Australian researchers (Anderson and Powell, 1973). The approach has several problems, however. These are discussed elsewhere (Hallam, 1988). One of the most troubling computationally is that the economies of size measure must be obtained by solving first-order conditions. An excellent recent example of this approach is Vlastuin, Lawrence, and Quiggin. They estimate a translog production function for the New South Wales Wheat/Sheep zone using cross section data. Output was estimated as a function of labor, livestock, materials, capital and land. When operator and hired labor were excluded from the right hand side the sample exhibited constant returns to scale but exhibited the standard "L" shape when they were included. To investigate economies of size the sample was divided into five size groups based on total output. Scale elasticities were slightly greater than one for each group in 1976-77 but less than one in all but one group in 1966-67. In the latter sample returns to scale increased with size classification. Cost curves were not obtained by solving first order conditions but by plotting cost as a function of output. The derived curves were rather flat as expected given nearly constant returns to scale for the case of excluded family labor. The difference in the shape of the curves would imply that size economies are primarily derived from making full use of fixed operator and family labor. This finding should be tested against U.S. data as it has important implications for public policy related to off-farm employment.

Profit Function Studies. Just as the firm's technology can be obtained from the cost function, it can also be recovered using the profit function (McFadden). For a well-defined profit maximization problem to exist, the production function must be concave and this implies decreasing returns to scale at the optimum. Thus, increasing returns to size or scale cannot be identified from a well-behaved profit function since the measure is costs divided by revenue and if costs are greater than revenue then the firm will not operate.

A recent innovative paper by Squires estimates economies of scope, overall and product specific economies of scale, and measures of capacity utilization for the New England otter trawl industry. The paper extends a model of partial equilibrium due to Brown and Christensen to multiproduct firms in a profit function framework. The model estimates variable input demands as functions of quasi-fixed factors but also endogenously determines the levels of those quasi-fixed factors. For the multiproduct firm increasing ray returns to scale may be compatible with profit maximization since some other division of outputs between smaller firms may be more cost effective. Thus the profit function can be used in this case to measure ray returns to scale. Economies of scope can be determined by testing for the subadditivity of costs. While economies of scope due to allocable fixed factors will vanish in the long run they can be observed in the short run. Product specific economies of scale can be estimated by examining incremental marginal costs.

The paper by Squires uses panel data from 1980 and 1981 to estimate a profit function for otter trawl vessels. Economies of scope between different types of fish output are not found. Decreasing product specific returns to scale are found in roundfish and flatfish with increasing returns in the "all others" category. Overall ray returns to size is found to be decreasing. While the results of the paper are not of specific interest to agricultural researchers, the technique is interesting and should be considered. In particular the technique is important in the case where some factors are fixed in the short run and where multiproduct returns to size and scale are important.

Aggregate Studies of Size and Scale

While the most natural way to measure economies of size and scale is to use cross section data on individual firms, the use of aggregate time series data to represent either an aggregate technology or a representative firm has also been used extensively in the literature. Aggregate time series studies usually assume some type of technological progress in the underlying technology. The scale or size measure calculated in such studies will represent short run returns to scale or size since the observations are from points on a short run production, cost or profit function. Measures of returns to scale will summarize general tendencies of the industry while measured returns to size are probably not meaningful since they come from points on different short run cost curves. Technical change will also influence measures of scale economies since changes in productivity may be difficult to separate from movements along a non-homothetic production function (Diamond et al.). Thus in measuring and comparing factor productivity the effects of returns to scale and non-neutral technical change must be considered. These drawbacks from using aggregate data have not dissuaded many researchers (e.g. Berndt and Khaled), however. A number of recent papers investigating returns to size or scale using aggregate data are considered here.

A recent paper by Chan and Mountain investigates returns to scale in Canadian agriculture using annual data from 1952-1977. They found that the hypothesis of a Hicks neutral technology with no technological change could not be rejected by the data. They did, however, find increasing returns to scale over the sample period. Their "naive" estimates of factor productivity were consequently revised downwards due to the identified increasing returns to scale.

Ray estimated a two output cost function for U.S. agriculture using annual data from 1939-77. He used a translog form that allowed for a non-homothetic technology with Hicks-neutral technical change. He found overall scale economies indicating diminishing returns but that returns to scale have increased over time. Family labor was not considered as an input in the study and its exclusion may have biased the results.

Ball and Chambers applied a non-homothetic, non-neutral translog cost function to the U.S. meat products industry using annual data from 1954-76. A single output aggregate was used along with data on four input categories i.e., capital equipment, capital structures, labor, energy, and intermediate materials. The results show that over the latter years of the sample the industry was characterized by increasing returns to scale. The results also indicate negative technical progress over the same period. While these results might be confounding, the existence of increasing returns has important policy implications as the industry continues to become more concentrated.

Weaver estimated returns to size for North and South Dakota producers using data from 1950-70. He estimates a multiproduct translog profit function allowing for non-homotheticity and biased technical change. While he finds decreasing returns to size over the sample period, this is not surprising since as discussed earlier returns to size is just costs divided by revenue and this will be less than one for the rational firm. The estimated cost revenue ratios range from .59 to .74 over the sample period.

There have been a variety of profit function studies (eg. Antle) that have investigated the non-homotheticity of aggregate technology but these studies have generally not considered size economies and so are not mentioned here.

In general the results of aggregate studies are mixed. Most have identified non-homothetic technologies but both increasing and decreasing returns to size and scale have been recognized. Aggregate studies on specific crop production have not been undertaken so no direct comparison to normative and cross-section results is possible. Most aggregate studies have been undertaken for a purpose other than the estimation of size economies and so less emphasis has been placed on the accurate measurement of such economies. This should be a caution to the prospective user of such research.

In summarizing studies relating to economies of size and scale, two general conclusions can be drawn. There do not seem to be significant economies of scale in the production of individual crops, at least at average firm size. The cost curve does fall, but remains rather flat over acreages compatible with the "average" family farm. Cost curves for livestock producers fall more sharply and over a larger range of output sizes. The lack of data on input allocations by multiproduct firms has hampered the estimation of size economies, especially in the case where production may be non-joint (Just et al.) The overriding impression from analyzing these studies is either that not enough work has been done on documenting the presence of size economies using actual data or such analysis is not relevant enough for general interest and analysis. Indeed, many studies (eg. Hall and LeVeen) were undertaken with specific policy implications in mind.

Studies of Firm Efficiency

Studies of firm efficiency can be divided into two major types: those that estimate average functions and test for optimizing behavior and economic efficiency, and those that estimate frontier functions and compare firms to the frontier. The first type is represented by the work of Lau and Yotopoulos and their colleagues and has primarily been applied in developing countries while the second approach follows early work of Farrell and later extensions to the stochastic case by Aigner, Schmidt and others.

Relative Efficiency Models. The relative efficiency approach proposes estimation of a profit function for a cross section of firms with a dummy variable to represent differences in firm efficiency due to technical or pricing inefficiency in maximizing profits. Most studies have used the Cobb-Douglas normalized profit function. The original study by Lau and Yotopolous (1971) found that small farms in India were more efficient than large farms. The approach has also been used to investigate efficiency differences due to other factors with mixed results (Yotopoulos and Lau, 1979). A more recent paper by Kahn and Maki considered the effects of farm size on efficiency for farms in two regions of Pakistan. They found that larger farms were more economically efficient than smaller farms and that the sample farms exhibited increasing returns to scale. Both large and small firms were found to maximize profits given the output and input prices. In analyzing the findings, the authors attempt to explain reasons for the differences. Possible candidates are information availability, tenancy, and subsidized input purchases. Such an attempt to identify factors correlated with efficiency differences is important for policy analysis and will be considered in more detail later.

Trosper considered relative ranching efficiency between Indian and non-Indian ranchers in the Northern Great Plains using the Lau and Yotopolous method. He found that both groups profit maximize to the same degree but that per acre output for the Indians was lower due to less capital per acre.

Of more direct relevance, Garcia et al. (1982) applied the Lau and Yotopoulos method to a sample of Illinois cash grain farms. Variable inputs were categorized as hired labor and cash expenditure items (fertilizer, seed etc.). Fixed inputs used were family labor, land, and non-land capital. Other farm specific variables were also used to control for differences across firms. The hypothesis of equal economic efficiency across firms with more and less than 700 acres was not rejected at the 5% level. The firms did not display equal relative pricing efficiency for hired labor. Constant returns to scale were not rejected for the entire sample. One interesting explanation for the findings of the study is that all farms in the sample participated in the Illinois Farm Business Farm Management

Association and thus management differences between the two samples may have been minimized.

No general implications can be drawn from these efficiency studies. The testing of such efficiency hypotheses across various regions and firm types would seem a useful endeavor.

Frontier Functions. In estimating production and cost functions, researchers typically assume that the error terms are symmetrically distributed with a zero mean. This implies that some firms' production will lie above the estimated surface while others will lie below it. An alternative formulation (Farrell) postulates that firms have different levels of economic efficiency and that the actual production function should be a frontier function such that no observations lie above it. Such production frontiers can either be deterministic (Aigner and Chu) or stochastic (Aigner, Lovell, and Schmidt). Deterministic frontiers can either be parametric or non-parametric. Parametric deterministic frontiers are typically derived using linear or quadratic programming to minimize the difference between each firm's production and the frontier subject to the constraint of a one-sided error. Stochastic frontiers allow deviations from the frontier to be either from inefficiency (a one-sided error deviation) or random factors (two-way deviations). They are usually estimated using maximum likelihood methods where the error term is composed of two parts. Frontier cost functions can also be estimated (Schmidt and Lovell; Kopp and Diewert) and used to estimate technical and allocative efficiency and also returns to size.

A comparison of deterministic and stochastic specifications using data from Swedish dairy plants is made in the paper by van den Broek, Forsund, Hjalmarsson and Meeusen. Parameters of the deterministic model are obtained by solving a linear programming problem while parameters of the stochastic model are obtained from maximum likelihood estimates both with an exponential efficiency distribution and with a composed error term. The maximum likelihood estimates are similar to the linear programming estimates but differ from those in the composed error model. The composed error model, in general, behaved more like an average rather than a frontier estimator. The elasticity of scale function for the composed error model implied higher optimal scale than the linear programming or one sided maximum likelihood models. The general conclusion is that the results obtained are somewhat method dependent and so caution in interpreting the results of different studies should be made.

Before discussing specific applications to agriculture, two additional papers should be mentioned. Page estimates deterministic translog production frontiers for Indian manufacturing firms. The paper is interesting in the use of a flexible functional form and also in attempting to explain the effects on non-measured inputs on technical efficiency. After computing measures of technical efficiency for four industries (shoes, printing, soap and tools), the author develops a regression model to explain differences between firms based on factors such as literacy, labor force experience, capacity utilization, firm age and firm size. In all but the tool industry, firm size is not highly correlated with efficiency. The approach adopted in this study could be of general use in identifying factors correlated with agricultural efficiency.

Pitt and Lee apply the stochastic method of Aigner et al. to time series cross-section data on the Indonesian weaving industry. With this approach individual firm efficiency is not estimable, but mean efficiency can be recovered. Alternative specifications of the error term over time are considered. In order to investigate individual firm effects, separate firm intercepts obtained from the analysis of covariance are regressed on three firm characteristics. The results indicate that larger firms are more efficient than smaller firms and younger firms are more efficient than older firms. Where pooled data is available the methods proposed allow estimation of efficiency factors using the stochastic frontier method.

Different techniques as applied agriculture are illustrated by considering some recent papers investigating technical efficiency. The paper by Hall and LeVeen on farm size in California uses the non-parametric approach as developed by Farrell and extended by Seitz to investigate efficiency for small fruit and vegetable farms. While farms of all sizes were close to the efficiency locus, small farms were relatively farther from it. A statistical test rejected the hypothesis that large and small farms had equal efficiency. The study also found that pricing efficiency was more important than technical efficiency for the firms in the sample.

An early application of the stochastic technique to U.S. farms is the paper by Bagi that investigates the relationship between size and efficiency for a sample of a Tennessee farms. The study uses a Cobb-Douglas production function with a composed error term. The symmetric disturbance is normal and the one-sided disturbance is a truncated normal. The sample of 193 farms was divided into crop and mixed crop and livestock farms and further divided into small and large classes. Size divisions were made both on acreage and sales. Average technical efficiency was larger for crop farms than mixed farms. Small and large crop farms had similar levels of technical efficiency while large mixed farms had superior technical efficiency. Results between the different definitions of size were not significant. Overall levels of efficiency showed possible gains in output of from 15%-25% given current input levels.

In a related study, Bagi and Huang, using a decomposition technique due to Jondrow et al., investigated individual firm technical efficiency using the same data set and a translog production function. The translog function fit the data better than a Cobb-Douglas. Results indicate that the one-sided error dominated the symmetric error for mixed farms but that the errors were of about equal size for crop farms. Technical inefficiency was between 22% and 24% for both types of farms. There was wide variation in the level of technical efficiency for farms within the sample.

Bravo-Ureta investigates technical efficiency for a group of New England dairy farms using the deterministic approach of Aigner and Chu as modified by Timmer. The data is from a cross-section of 222 New England dairy herds in 1980. The Cobb-Douglas production function is used for estimation. Using the approach suggested by Timmer, sample observations were deleted from the programming model until the estimates stabilized. This resulted in deletion of 4% of the observations. Average efficiency in sample was 82% Returns to size for the sample was slightly larger than one. While data allowing estimation of factors correlated with efficiency was not available, a simple test of independence showed no relationship between firm size and efficiency.

Data from the Illinois Farm Business Farm Management Association records is the basis for two recent studies applying different methods of analysis. The first study by Aly et al. uses corrected least squares (Greene, 1980b) to estimate a deterministic statistical frontier. Rather than positing a two-part composed error, a single sided error is used. The method estimates the production function and shifts the constant term up until no residual is positive and a least one is zero. While all error is attributed to technical efficiency, the method has some advantages over the stochastic frontier approach. The technology can usually be specified more flexibly and multiple outputs can be handled more easily. The study uses a ray-homothetic production function to represent technology. This allows returns to scale to vary with output and input levels. A cross-section of data on grain farms from 1982 was used for the analysis. Gross revenue was used as an output measure. The average technical efficiency was 58%. Of the total efficiency loss about 60% was due to technical inefficiency and 40% due to scale inefficiency. Differences in efficiency were compared for different farm sizes. Larger farms tended to be more technically efficient than smaller firms when size was measured both in terms of acreage and sales classes. The most striking result of the paper is not the differences in efficiency between classes as the overall level of inefficiency of all farms.

A study by Byrnes, Fare, Grosskopf and Kraft extends the non-parametric approach of Farrell to the case of non-constant returns to scale without strong disposability of inputs. In this way technical inefficiency can be divided into scale, congestion and pure technical components. The sample consisted of 107 cash grain farms in Illinois. Multiple outputs were explicitly accounted for by specifying a multiproduct production possibility set. Efficiency for the average farm in the sample was only 4% below maximum efficiency. The largest loss in efficiency was due to scale inefficiency. Pure technical efficiency was very high with some inefficiency due to congestion of inputs. Given the results on scale inefficiency, the sample was grouped based on size. Using 700 acres as dividing line between large and small farms, smaller farms were more efficient overall. For smaller farms, congestion was the major source of efficiency while scale inefficiencies were the major problem for larger farms. Most large farms were producing in a region of decreasing returns to scale. Statistical tests of the differences between technical efficiencies showed that the differences were not significantly different.

A final paper should be mentioned though it deals with Australian dairy farms. Battese and Coelli extend the results of Jondrow et al. to panel data sets in order to estimate individual firm efficiency levels using the stochastic frontier approach. While the approach requires specific distributional assumptions it allows for the prediction of individual firm effects. Schmidt (1985) has pointed out, however, that estimates of the one-sided errors developed in this way are not consistent in the usual manner.

The results of these frontier function studies of efficiency provide little clear guidance about firm size and firm efficiency. Smaller firms were found to be less, equally and more efficient than larger firms. This type of work applied to cross section data on many firms and across many regions would provide more definitive conclusions and policy recommendations.

Models of Firm Growth and Survival

An alternative way to analyze industry structure and tendencies for change is to track the rates of growth, contraction, and demise of firms. If particular sizes or types of firms stand the test of time and grow and/or prosper, this provides information on the future structure of the industry and the viability of other types of firms.

A popular technique used to analyze firm growth is the finite Markov chain. A finite Markov chain is one in which a population at time t has a distribution S^t over the discrete states, $S_1, S_2, \ldots S_n$, and in which the probability P_{ij} of moving from state S_i to state S_j depends only on the state S_i and not on prior states. In firm growth analysis, the states are various size categories of firms. Using historical data, transition matrices can be estimated and then used to project future size distributions. If the transition probabilities are not constant, then alternative methods for estimation must be employed.

Studies by Padberg, Hallberg, and Stanton and Kettunen are early examples of application of the technique to agriculture. Several recent studies have employed Markov chains to project farm size changes. Ethridge, Roy and Myers investigated structural changes in the Texas cotton ginning industry using both stationary and non-stationary transition probabilities. They consider five size and four activity groups. Activity groups are new entrant, dead, inactive and active. In the non-stationary analysis wages, electricity costs, lagged capacity utilization, lagged local production, and technological change variables were used as explanatory factors. All but capacity utilization and lagged production were significant. Projections to the year 1999 indicated a movement away from smaller firms and toward larger firms with a decline in the total number of firms. Changes in technology accelerated this trend.

Garcia, Offutt, and Sonka applied the Markov chain technique to a sample of 161 Illinois cash grain farms for which data was available from 1976-85. They used both output (gross value) and acreage measures of size and found some differences in results. Transition matrices estimated using the output variable showed little change in size while those estimated using acreage showed some growth towards larger and smaller firms. They tested for stability and found that transitions were stationary over a ten-year period. They then used the estimated probabilities to project the size distribution for 1990 and 2000. While the estimates based on gross product showed little change in farm structure, that based on acreage implied fewer middle sized farms and a slight tendency for a bimodal distribution. The authors then used discriminant analysis to explain whether firms grew or shrunk over their sample period. The general conclusion was that farm growth is fairly unpredictable.

Two early studies using aggregate U.S. data were carried out by Daly et al. and Lin et al. (1980) using upper triangular transition matrices. Recently Edwards, Smith, and Patterson analyzed changes in farm size and numbers using data from the 1974 and 1978

Census of Agriculture. They use acreage as a measure of size. They found that the percentage of mid-size farms decreased over the period but that long run projections show no major shift to a bimodal distribution. They also conclude that the future will be more like the present than the present is like the past. The Office of Technology Assessment (U.S. Congress) used Markov chains to project U.S. farm sizes over the remainder of the century. They used the deflated gross value of farm income as a measure of size. They suggest a rather dramatic decline in mid-sized farms. Both of these studies must be viewed with some caution, however, since constant transition probabilities were used.

These Markov chain studies are important in that they provide a way to characterize past growth and project future change. The results are not strong enough to justify the assumption of a bi-modal distribution although many reasonable scenarios are compatible with such a distribution. The development of better such projection models with non-stationary probabilities explained by economic factors could provide useful characterizations of the future.

An alternative method of analyzing firm growth and survival is through simulation. By simulating the growth and survival of hypothetical firms over time, information on success probabilities and factors related to success can be obtained. Two studies in this regard will be mentioned. Patrick and Eisgruber develop a farm simulator for an Indiana crop and livestock farm based on 1964 data. The model includes consumption and multiple goals for the farm family. They project the model out for 20 years under a variety of alternative managerial and economic environment scenarios. Managerial ability was found to be the major determinant of firm growth. Interest rates were important in explaining firm growth and survivability. The availability of long-term credit was also important in determining firm growth.

A more recent paper by Richardson and Condra uses a dynamic Monte-Carlo simulation-programming model to analyze the projected survival and success of four alternative farm sizes in the El Paso Valley. While the model by Patrick and Eisgruber simulated alternative environments it did not consider the environments to be random. The Richardson and Condra paper postulated probability distributions for a variety of economic factors and then used Monte-Carlo techniques to compute a cumulative probability of success/failure for the farm classes. Alternative managerial strategies were not explicitly considered as in Patrick and Eisgruber. The results indicate that initial equity is an important factor in explaining success. Furthermore, straight cash lease farms had little chance of success. Another interesting result is that for a 50-50 chance of success the farms needed at least 100% equity in 640 acres of farmland. The rather negative conclusions of this study for smaller farms should be validated with other data sets and techniques.

There has been recent renewed interest by the economics profession in various forms of Gibrat's law (Evans, 1987a,1987b; B. Hall). Gibrat's law postulates that the growth rate of firms is determined by random factors independent of firm size. The basic equation used to test Gibrat's law is

$$\ln S_{it} = \alpha + \beta \ln S_{it-1} + e_{it}$$

where S_{it} is the size of the i^{th} firm in the t^{th} period. Gibrat's law predicts that $\beta = 1$.

Evans (1987a) found this law of proportional growth to hold for large firms while Hall found that smaller firms had higher and more variable growth rates. A recent paper by Shapiro, Bollman, and Ehrensaft tests this relationship for Canadian farms between 1966 and 1981. They use acres, gross sales and capital value as alternative measures of size. They found that small farms grow faster than large farms and thus reject Gibrat's law using any of the three measures. They also found that the variance of the growth rate was inversely related to farm size so that larger firms had more stable growth. Factors contributing to the faster growth of smaller firms could be investigated.

Some authors have developed analytical and econometric models to explain changes in size and structure of firms over time. Sumner and Leiby in a series of papers analyze the effects of human capital (managerial ability), size and certain control variables on the growth of firms in a sample of Southern dairies. They use number of cows as a measure of firm size. They find that size increases with operator age for low ages but decreases with over twenty years of experience. Herd size also increases with experience for lower and middle experience levels. Schooling had a positive effect on size. There was a strong positive relationship between a variable representing improved management practices and firm growth. The results of this study, while supporting the hypothesis of management effects on size, also point out the need for analysis of the lifecycle of the firm, especially the sole proprietor firm.

Kislev and Peterson argue that changes in farm size can be explained by changes in the machine-labor ratio. They postulate a model in which input prices, nonfarm income, and technology explain farm size. They use acres as a measure of farm size. They develop an equilibrium model of the agricultural sector based on a two-level production function (mechanical and biological), a demand for food equation, a land rental price equation, and a fixed supply of labor per farm. By combining empirical analysis with previous estimates they attempt to validate their model. They find that relative factor price changes explain 99% of the change in both the machine labor ratio and farm size over the 1930-70 period. They further predict that with increases in the price of capital that the trend to larger farms may decline.

These later studies point out an important area of empirical research. Rather than attempting just to measure size or scale economies, they attempt to explain the factors that lead to changes in firm structure and develop structural models that can be tested and validated using actual observations on firms. While the underlying models in the papers are not fully developed or estimated they point a useful direction for future research. Measurement in conjunction with theory and underlying economic structure may be of more value than measurement alone.

Pecuniary Economies and Firm Size

In addition to economies related to size and scale, firms may attain economies in the purchase of inputs or sale of outputs. Such economies may result from technological economies due to large transactions in the marketing process, price discrimination, transactions costs, timing of input purchases, vertical integration and spatially separated markets. Two recent studies have investigated such pecuniary economies. Tew et al. consider sales by a large Georgia agricultural supply firm. They regress the price of the product sold on the quantity sold, and a series of control (dummy) variables. They find that for seven of the inputs that lower prices are implied by larger quantities. For the other eight inputs the relationship was not statistically significant. When the implied price discounts were substituted into production budgets the effect on variable costs was negligible however.

Smith et al. investigated pecuniary economies for a sample of cotton farms in the Texas Southern High Plains. They use the composite firm approach (budgets from actual farm records) in comparing costs for firms ranging from 50 to 5,570 acres. Their sample includes 98 farms stratified by size for the 1980 crop year. Agribusiness firms surveyed indicated a preference for uniform pricing of products in order to maintain good customer relations and few price discounts were discovered. The study also found few economies due to optimal timing of input purchases. The authors did find, however, economies due to vertical integration either through cooperatives or direct ownership. Producers cited lack of volume discounts as a reason for participating in vertical integration. The study did find significant pecuniary economies associated with cotton marketing. The cotton price received by the largest firms was 7% higher than that received by the smallest producers. These economies could not be traced to specific marketing strategies.

Both of these studies provide evidence of some pecuniary economies. The existence of such phenomenon for agricultural firms in general should be verified or refuted. Given that few economies of size seem to exist for crop farms, explanations for the gradual growth in size may rely on such external economies.

Summary and Conclusions

This paper has reviewed empirical studies which investigate economies of size, scale and scope in agriculture. The paper also discusses the related issues of firm efficiency, firm growth and firm survival. The general conclusion is that while some economies of size or scale may exist for livestock farms, that significant economies, at least as conventionally defined, do not exist for most crop production activities. While differences in efficiency and growth paths differ among firms, few of these seem to be directly related to economies of size and scale. Nevertheless, the structure of agriculture is changing rapidly. The factors that are bringing about these changes are myriad but a clear theory of how they influence firm size and structure is not yet present.

The lack of definitive statements about actual technical economies affects the researchers ability to use empirical findings as a springboard for new theoretical forays.

The three areas for further research mentioned by this author in another paper still seem relevant after this extensive journey through the literature. There have been few studies of multiproduct agricultural firms using cross-section data and positive methods. The methods are straightforward and a compilation of results similar to those summarized by Madden for normative studies would be useful. A need exists for better models and empirical analysis that explains the growth and contraction of individual firms over time. The estimation of frontier functions and subsequent analysis of the results would provide much better data on the effects of firm efficiency for the structure of an industry.

The research agenda for the future should include not only descriptive or predictive analysis, but improved models that explain behavior and ability to follow decision rules. The differences in firm efficiency may be more a reflection of commitment to perceived goals than the result of any underlying differences in technology or economic environment.

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