

HISTORICAL REVIEW OF AGRICULTURAL EFFICIENCY STUDIES

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ABSTRACT

Traditional growth and development theories have demonstrated how efficient allocation of resources in all economies depends on economic efficiency in the agriculture sector. Historically, the agriculture sector has been supplying productive resources to other sectors in the economy as its productivity and efficiency improves over time. This report takes a comprehensive and historical look at the literature on agriculture efficiency from 1950 to 2011, while focusing on the various methodologies used and important results relevant for agricultural policy formulation. The review revealed that overtime the complexity of method used to examine agricultural efficiency has increased from simple index numbers and econometric analysis to complex non-parametric and parametric analysis. The overall results indicated that farms are generally technically and scale inefficient. Smaller farms are less efficient than big farms because large farms tend to adopt new technology faster than smaller farms due to their relative better access to credit, information, and other scarce resources. Technical efficiency is related to economic factors, environmental conditions, locations, size of local market, and agricultural policies. However, in general, the level of farm inefficiencies have been reducing as new and better farm practices have been implemented over time. Farmers' education level has positive and significant impact on farm level efficiency. Organic farmers on the average are more efficient than conventional farmers. Most importantly, different econometric specification led to different results. For policy purposes the results from the studies shed light on the importance of improvement in extension services and increased access to credit and other resources as critical components of agricultural policy options to make farms, particularly the small ones, more technically and scale efficient. The results also demonstrate the importance of implementing agricultural policies that pays attention to other farm characteristics such as location and type of farms.

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Introduction

Agricultural efficiency is a key contributor to agricultural productivity growth and efficient allocation of resources in the economy. Studies in the agricultural efficiency literature have focused on determining if farmers have been using resources more efficiently by applying best technological and managerial practices from the existing stock of knowledge (technical efficiency). Other studies have also determined if the price of a farm product is equal to the value that consumers place on the product (allocative efficiency) and or if farms are operating at the optimal size that guarantee production at the minimum average cost (scale efficient) Over the decades, the studies have used diverse methodologies to identify the nature and the dynamics of efficiency in agriculture production. The methodologies differ by concept and by approach of measurement.

The goal of this document is to present an historical review of agricultural efficiency studies from 1950 to the 2011. The entire period is divided into three sub period: studies prior to the 1990s; studies between 1990 and 2000; and studies from 2000 to 2011. There are two main purposes of this historical review. The first purpose is to identify the methodology used; the research question addressed; the shift of research focus over time; the main research findings; and policy implications thereof. The second purpose is to determine if empirical studies on agricultural efficiency have caught up with theoretical development of methodologies.

The main theoretical methodologies of efficiency analysis are econometric estimation of production relationship (Stochastic Frontier Analysis- SFA and the Regression Quintile Production Frontier Analysis); non-parametric approaches (Data Enveloping Analysis-DEA);

and a combination of both approaches. These methodologies were all developed around the same period. Prior to their popularization, index numbers approach was predominantly used in agricultural productivity and efficiency studies. However, due to their poor performances of the index number approach in the 1950s and 1960s, Aigner et al. (1977) and Meeusen and van den Broeck (1977) proposed the stochastic frontier production function approach (SFA) where a non-negative random variable (one-sided error) (μ_i) representing technical inefficiency in production is added to a symmetric error term (ν_i) in a typical production function. Around the same period Koenker and Basset (1978) developed the quintile regression which is an econometric approach which differs from the SFA by not requiring the imposition of a particular form on the distribution of the inefficiency term. The technique estimates the efficiency production frontier by a quintile regression of high percentile, which describes the production process as the obtained regression parameters display the “optimal” technique used by the most efficient farms (farms that produce on the production frontier). Efficiency estimate of all farms are derived by using the obtained coefficients and comparing each farm’s factual output with its potential output using the “optimal” technique. An appealing characteristic of the approach is that, it is robust to deviations from distributional assumptions since it imposes asymmetric distribution of the error term. However, quintile regression is not designed for investigation relationship between variables, such as investigating the determinants of technical change or technical efficiency which may be of great interest to policy makers. The choice of the upper quintile for the estimation of the production frontier is arbitral as quintiles differentiation depends on the size of the sample and the amount of information it contains about the upper tail.

The DEA approach to frontier estimation was developed after Charnes *et al.* (1978) provided measures of efficiency in production based on the works of Debreu (1951) and Farrell (1957). It was also proposed as an alternative to growth accounting approach to calculating TFP as well as an alternative to the then existing index number methodologies for measuring technical efficiency. The approach uses lineal programming technique to identify the input-output combinations that define the production frontier (technological efficiency) either overtime or across countries. When applied to time series data, efficiency is defined as the proportion of output not explained by the inputs and is measured relative to other operations in the data set. The calculated efficiency index can be used by itself for comparative purposes or as a dependent variable to examine what factors might affect technological efficiency.

The rest of the document is organized as follows. Section 1 presents the earlier efficiency studies over the decades between 1950 and 1990. The review of agricultural efficiency studies during the 1990s is presented in section 2. Section 3 presents the review of recent studies from 2000 and beyond. Section 4 provides the overall conclusion of the report.

1. Technical Efficiency Studies between the 1950s and 1980s.

1.1 Summary

The main aim of studies during these decades was to determine technical efficiency in agricultural production. Most of these studies did not investigate the extent of allocative efficiency as it required complete and quality data on input prices which in most part were

difficult to obtain. The methodology used gradually shifted from simple econometric estimation of the production function, indexing methods, and yield efficiency measures in the 1950s and 1960s to a relatively more sophisticated econometric estimation (Stochastic Frontier Analysis-SFA, and Quintile Regression Analysis) and Data Enveloping Analysis-DEA (DEA) or a combination of both, in the 1970s and 1980s. The shift was consistent with the development of theoretical methodologies for determining production efficiency in the 1970s and 1980s. Though some of the studies focused on agricultural practices in the developing world, most of the studies focused on agricultural production efficiencies in the developed world with predominant studies focusing on farms in the United States and England. The overall results indicated that farms are generally technically inefficient. The efficiency rate ranged from as low as 53% to 100%. About 60% of the technical inefficiency was due to pure technical inefficiency and about 40% due to scale inefficiency. There was a wide variation in the efficiency measures obtain by different methods. Smaller farms are less efficient than big farms because large farms tend to adopt new technology faster than smaller farms due to their relative better access to credit, information, and other scarce resources. Crops technical inefficiency is less than livestock technical inefficiency. Farm location also matters for level of efficiency. Farms located in areas with better soil and weather conditions are more efficient than those who do not. It was also found that farms in lower income countries are less efficient compared to their counterparts in middle income and developed income. Finally most farms were found to be scale inefficient either because they operated under capacity or at a higher scale than optimal due to their inability to adjust scale to changing economic circumstances. For policy purposes the results shed light on the importance

of improvement in extension services and increased access to credit and other resources as critical components of agricultural policy options to make farms more technically efficient.

1.2 Review

The seminal paper by Farrell (1957) constructed a measure of productive efficiency which accounted for all inputs and overcame index number problems. The model was applied to the agricultural production in forty-eight states of the United States for the year 1950, except for the data relating to materials which pertained to 1949. Output was measured by cash receipts from farming plus the value of home consumption. Inputs considered included land (farms less woodlands and other lands not pastured), labor (farmers, farm managers and unpaid family workers), materials (feed, livestock and seeds), and capital (farm implements and machinery).

A matrix inversion sub-routine in Electronic Delay Storage Automatic Calculator (EDSAC) was used in the estimation of efficiency. The measure was gradually developed from a simple case under condition of constant returns to scale, with two inputs and one output, to the general case of many inputs and outputs. It was then expressed using an isoquant diagram. Overall productive efficiency was divided into price efficiency (a firm's success in choosing an optimal set of inputs), and technical efficiency (a firm's success in producing maximum output from a given set of inputs).

The diagrammatic representations of the results indicated that the law of diminishing returns was clearly evident when measuring productive efficiency. The results also showed that a

process which used a great deal of land was economical in both capital and materials. The Cobb-Douglas function was attributed to be the most plausible approximation of the efficient production function. It was opined that technical efficiency was more controllable and hence more meaningful. It was also suggested to build models that considered other inputs like climate, location and fertility.

Bhatia (1967) constructed a measure of agricultural efficiency suitable for areas where livestock did not constitute an integral part of the agricultural production. The study focused on the agricultural practices in the province of Uttar Pradesh, India, using data over the period 1960-61. Agricultural efficiency was stated to be a function of various factors that included the physical (climate and soil), socio-economic (size of holding and type of farming), and technical-organizational (crop rotation, irrigation and mechanization). The author used an indexing method, classifying the efficiency index into high, medium, low and very low. This was done by first estimating yield efficiency of each crop and expressing acre-yields as a percentage of average acre-yields. Then agricultural efficiency was measured by the weighted average of all the yield efficiencies using the share of cropland devoted to each crop as the weight. A total of 11 crops, representing 86.4 percent of cropland, were selected for this study, these included rice, wheat, barley, jowar (sorghum), bajra (millet), maize, chick peas, arhar (a pulse), peas, sugar cane, and groundnut (peanut).

The results showed that the yields of rice, wheat, barley, bajra, grams, and sugar canes displayed wide disparity of efficiency within the province. In the case of rice, barley, bajra and grams, high density areas did not generally show high acre-yield, unlike wheat and sugar cane.

Finally, there was a wide disparity in spatial efficiency with more efficient regions recording up to thirty percent higher than the average yield. The low and medium efficient regions generally skirted around the continuous belts of the very low and highly efficient regions. The study suggested that the indexing method, complemented with a linear equation, can be used to calculate the rate of growth in agricultural efficiency.

Timmer (1971) developed a measure for technical efficiency relative to a probabilistic frontier production function. The study was based on forty-eight U.S. states during the period 1960 to 1967. The deterministic and probabilistic frontier Cobb-Douglas production functions were estimated using linear programming. Econometric analysis was used to compare the results. The estimated frontier production function was similar to that estimated by Griliches (1963a, 1963b, and 1964). The variables used were state-level gross agricultural output (livestock, crop, and government payments components), labor (family and hired workers), capital input (land (1964 sales values), fertilizers (nitrogen, phosphorous oxide and potassium oxide), seeds and miscellaneous (pesticides, electricity, irrigation, veterinary services and medicines).

The results from the econometric analysis showed that the ratios of marginal revenue product to marginal cost were 1.17 for labor, 1.05 for livestock, 0.29 for land, 1.62 for seed and miscellaneous, 3.76 for capital and 4.86 for fertilizer. The ratios implied that during the period 1960 to 1967 the farmers used excessive land, while the use of capital and fertilizer was low. A covariance analysis indicated that output elasticity of capital was insignificant, which was attributed to weak data quality. The elasticity of fertilizers fell sharply from 4.86 to 1.57, but remained significant in the covariance analysis. The coefficient of land increased in comparison

to the OLS estimates and other variables, the reason for which could be the restrictions imposed by the government. The labor coefficient dropped from 1.17 to 0.75, which implied that farmers were using excessive labor at the existing wage rate.

The coefficients obtained by fitting the log linear Cobb-Douglas production function using the linear programming model (frontier model), were similar to that obtained by the OLS regression when 3% of the most efficient farms-firms were excluded. The labor efficiency increased which could be due to the frontier farm-firms using less labor and more capital. About 75% of the states had efficiencies within 10% of the frontier (0.90). West Virginia, the least efficient state, was 20% away from the frontier. The most significant variable was the number of days worked off the farm, the higher the numbers of days the lower the farm efficiency. The next most significant variable was the relative number of tenants who were farm operators. The reason attributed for the high significance being the motivation for tenant farmers to work harder in order to save to buy their own farms. This study cautions that estimated efficiency may not be interpreted as applicable uniformly across a state, since aggregated data was used for each state.

Bagi (1982) estimated technical efficiency for 193 small and large farms in two counties of Western Tennessee in the year 1978. He used the maximum likelihood method to estimate a Cobb-Douglas stochastic frontier function. The variables used were the value of farm output, acreage of crop and pasture land, number of hours of human labor actually used on individual farms (family and hired), annualized flow of capital services from agricultural machinery and equipment, farm buildings and fences, value of fertilizer, lime, herbicides and other chemicals, and value of feeds and veterinary care,

The results indicated that crop farms have greater efficiency than mixed farms, while small and large crop farms have similar levels of efficiency. Mixed large farms showed higher technical efficiency compared to mixed small farms. Only small crop farms showed significant increasing returns to scale. The gap between the observed output and the frontier output represented the factors within control of the farmers. When farm size classification was based on farm sales, larger farms had higher efficiency than smaller farms. Finally, it was found that there was a potential to increase farm output between 15% and 25% by increasing technical efficiency.

As a follow up study to Bagi (1982), Bagi & Huang (1983) estimated technical efficiency for individual farms in two counties of Western Tennessee in the year 1978. Corrected least squares method was used to estimate coefficients of a translog frontier production function. The variables used were the value of farm output, land area operated, number of hours of human labor actually used on individual farms (family and hired), annualized flow of capital services from agricultural machinery and equipment, depreciation, repairs and maintenance, and operating expenses, value of fertilizer, lime, and other chemicals, and value of fodder, hay, feeds, veterinary care and miscellaneous livestock expenses.

The results indicated that about 53% of the gap between observed output and frontier (maximum) output in the case of crops were due to technical inefficiency. In the case of livestock it was at 75%. It was found that crop farms and mixed farms showed substantial economies of scale. The output elasticities showed that land has the highest output elasticity for crop farms at 0.4077, meaning that a one percent increase in the acres of land increased output by about 0.41 percent. Correspondingly, livestock expenses held the highest output elasticity at

0.4076. Overall, the elasticity's combined to form returns to scale of 1.1099 for crop farms and 1.1725 for mixed farms. Again, this implied that output increased by 1.1099 (1.1725) percent when all inputs for crop farms (mixed farms) increase by one percent. Most farms were found to be operating at 70% to 90% technical efficiency (63.47% of farms in the case of crop farms and 62.83% in the case of mixed farms). The average technical inefficiency observed was 22.82% for crop farms and 23.27% for mixed farms. The study recommended that improvement in extension services and farm credit may increase technical efficiency.

Russell & Young (1983) estimated technical efficiency as a measure for producers' performance. They used cross-section data on 56 North West England farms, during the period 1977 - 1978. Corrected ordinary least squares analysis was used to estimate a Cobb-Douglas frontier production function. They used the Timmer (1971) and Kopp (1981) measures of technical efficiency which applied Cobb-Douglas specification on the frontier, excluded extreme observations, and estimated an output based measure of efficiency. The variables included crop-output, livestock output, total wage bill, machinery costs (rentals, depreciation, repair, etc.), livestock and crop costs (feeding stuffs, fertilizer, seed, etc.), and value of land input.

The Timmer measure of Technical Efficiency estimated the potential extra output an individual farm could produce if it were on the frontier. This was done using the ratio of actual output to potential output, given input use on the farm. The mean efficiency level for the sample set was 0.73 with standard deviation of 0.11. The Kopp measure of technical efficiency also compared each farm to its frontier potential. It compared input use to the frontier input use, given actual output and the ratios of input usage. The mean efficiency for the Kopp measure was 0.72

with a standard deviation of 0.11. Results from the two measures indicated that there was evidence of decreasing return to scale, as depicted by slightly smaller Kopp measures. However, both measures had the same ranking of efficiency levels. Overall, 36 percent of farms were at least 75 percent efficient, 75 percent of farms were at least 64 percent efficient, and the entire sample was at least 39 percent efficient.

Bagi (1984) studied the relative efficiency of full-time and part-time farms (an individual or partnership where the operator spent less than 50 percent of working time on the farm). The study adopted the Bagi (1982) data which comprises of 193 farm families in two counties of Western Tennessee in the year 1978. The study also used the same set of variables as did Bagi (1982). The results from the estimates of the Cobb-Douglas stochastic production function indicated that full-time crop farms had an average technical efficiency of 0.7579, while part-time crop farms had an efficiency of 0.7632, which were higher than the mixed full-time farms (0.7453) and the mixed part-time farms (0.7281). Technical inefficiency accounted for 66 percent of the gap between the observed and the frontier output in the case of part-time crop farms, and 86 percent in the case of full-time crop farms. For mixed full-time farms technical inefficiency accounted for 50 percent of this gap, while for mixed part-time farms it was 70%. It was also found that there was wide variation in the technical efficiency of the individual farms within each group. 30.99% of the full-time crop farms had efficiency higher than 0.85, while only 9.09% of the part-time crop farms had similar levels of efficiency. Similarly, only 8.33% of mixed full-time farms and 14.48% of mixed part-time farms have technical efficiency above 0.85.

Dawson (1985) used different measures to study static technical efficiency in agricultural production over time. Like Russell & Young (1983), they used data on 56 farms of North West England. However, instead of using only one year data, they used a four-year data from 1974-1975 to 1977-1978. Technical efficiency was measured using two econometric methods (OLS residuals of the production function and analysis of covariance (AC)) and one linear programming (LP) method (envelopment approach). The dependent variable was total revenue in value terms. The inputs were the total wage bill, livestock and crop costs, machinery costs, general farming costs and imputed or otherwise rental value of land.

The results indicated that there was a wide variation in the efficiency measures obtained by the different methods. While OLS method estimated that, the least efficient farm was 57% as efficient as the most efficient farm, the AC and LP methods put the figures as 15% and 89%, respectively. The means (and standard deviations) of the efficiency estimates were 0.76 (0.09) for OLS, 0.50 (0.17) for AC, and 0.96 (0.02) for LP. There was a priori expectation of higher variance in bad years, as better managers used resources more efficiently, and lower variance in good years, as the quality of managers was not such an important factor. This expectation of increased overall variance was met by the efficiency estimate derived using the AC method. There was a high correlation between the OLS and LP measures, which was due to both measures being susceptible to management bias and both measures excluding time-related effects. The AC and LP measures were also highly correlated, which could be explained “if the LP frontier (was) a neutral transformation of the (average) AC regression line”. OLS and AC measures were found to have low correlations due to the management bias of the OLS measures. The lack of statistical significance of AC (which overcame management bias) correlations over

the years, indicated that the measure of relative efficiency of an individual farm may not represent its long-term or peer group's true value. It was found that there was a positive correlation (0.64) between AC measure of technical efficiency and land size. There was also a stronger positive correlation (0.81) between AC measure of technical efficiency and labor. The data showed that farms employing regular full-time workers were more efficient. The study recommended that the technical efficiency estimated over a period of years contained less errors, and increase in farm size and labor could improve technological efficiency. The study suggested that future research should address the dynamic aspect of technological efficiency.

Kawagoe & Hayami (1985) used the methodology of indexing total productivity as a ratio of total output to the aggregate of conventional input in order to make a cross-sectional comparison of agricultural production efficiency among countries at different stages of economic development. The study was based on forty-four countries and data averages between 1957 to 1962 and 1975 to 1980. Gross output net of agricultural intermediate products, such as seeds and feed represented the output variable. Five input variables, namely, labor (economically active male population in agriculture), land (hectares of agricultural land), livestock (livestock units), fertilizer (nitrogen, phosphorous oxide and potassium oxide), and machinery (tractor horsepower) were considered. Production elasticities obtained from Kawagoe and Hayami (1983); Kawagoe, Hayami, and Ruttan (1985) were used as common weights for the input aggregation for all countries.. These weights were 0.45 for labor, 0.10 for land, 0.20 for livestock, 0.15 for fertilizer, and 0.10 for machinery.

The results indicated that efficiency was lower for the low-income countries accompanied with low labor productivity. The large difference in agricultural labor productivity within developed countries was accounted for mainly by different levels of input per worker. The very low level of labor productivity in less developed countries was explained by the low level of total productivity in addition to the meager input levels. Finally, the productivity of middle-income countries rapidly improved as compared to less developed countries.

Bravo-Ureta (1986) estimated technical efficiency using the probabilistic frontier function methodology. He used data on 222 New England (U.S.) dairy farms for the year 1980. The variables used were annual milk production, number of dairy cows, annual consumption of purchased concentrate-feed, annual labor input (hired, operator, and family), and annual machinery capital services. The results showed slightly increasing returns to scale with the sum of production elasticities being equal to 1.058. Similar results were obtained from the frontier models. Technical efficiency varied from 57.69% to 100.00% with a mean of 82.17%. Further, the technical efficiency approximated normal distribution. The study concluded that farm size and technical efficiency were statistically independent. Further the study suggested that there may be limited short run effects from policies designed to reduce dairy prices. This was thought to be the result of a small impact on overall output due to producers increasing technical efficiency in response to the cost-price squeeze from lower dairy prices. The study suggested that improvements in technical efficiency were responsible for the higher levels of milk output in 1984 and 1985, as well as the production estimated for 1986.

Aly et al (1987) estimated technical inefficiency using a linear form of the ray-homothetic production function, and assessed the relationship between technical inefficiency and farm size. The scope of the study was 88 grain farms from three contiguous counties (Christian, Montgomery, and Shelby) in the south central portion of Illinois in the year 1982. They used the corrected ordinary least squares (COLS)-methodology to estimate a linear form of the production function. The ray-homothetic production function was preferred over the Cobb-Douglas production function because it allowed the attribution of the technical inefficiency to pure technical inefficiency or scale inefficiency. Technical efficiency was estimated by the ratio of actual output to potential output. The dependent variable was the gross revenue from grains, including corn, soybeans, wheat, and double crop soybeans. The input variables were land, labor, fertilizer, pesticides, seeds, equipment and buildings. Farms were classified according to tillable acres and gross revenues.

The results indicated that the farms were operating at 58% of their potential efficiency level. About 60% of the technical inefficiency was due to pure technical inefficiency and about 40% due to scale inefficiency. Smaller farms (0.55) were more inefficient than larger farms (0.60) when segregated according to land tilled. Similar results were obtained when categorized by revenues. The authors cautioned that the general economic recession during 1982 could be the reason behind the high level of inefficiency. Another reason for low level of efficiency could be that majority of the farmers were using older technologies. They then concluded that larger farms tend to adopt new technology faster than smaller farms, which could be due to better access to credit, information and other scarce resources.

Tauer & Belbase (1987) used data on 432 New York dairy farmers in the year 1984 and the COLS methodology to measure technical efficiency by estimating a log form of a Cobb-Douglas production function. The output variable was the value of production of milk, livestock, and crops, less the cost of milk marketing, government payments received, machinery work and miscellaneous income, and the net change in livestock and feed inventory. The input variables were hired labor, family labor, feed, machinery and crop, livestock, real estate and miscellaneous expenses.

The results indicated that there was slightly increasing return to scale with the output elasticity of 1.076. On an overall base the efficiency level was 69%, while the lowest was at 32%. To provide explanation for the variation, technical efficiency was regressed on dummy variables representing technology (location within the state, barn and number of cows), management (age, education, type of record keeping system, participation in dairy production evaluation programs, and number of managers), and credit constrains (debt / asset ratio). The following results explained 9% of the variation. First, mail-in record keeping system decreased the efficiency of a farm by nearly three percent, the reason for which was that many farmers did not keep on top of their mailings. Second, participation in the Dairy Herd Improvement Cooperative program did not increase efficiency of the farms. This was perhaps due to overuse of feed and other variable inputs in an effort to maximize production per cow. Third, farms in the Northwest and Central regions of New York had 3% and 4% higher technical efficiency due to better soil and weather conditions. Finally, efficiency increased with greater number of cows. An addition of 100 cows increased efficiency by 3%.

Dawson (1987) studied farm-specific technical efficiency using stochastic frontier to estimate the cost function. The study used data on 406 dairy farms in England and Wales for the year 1984 -1985. OLS was used to estimate the coefficients of the cost function, then method of moments is used to estimate the second and third moments. From this, consistent estimates of the variance of the error terms are formed. These are then used to calculate technical efficiency.

The variables under study were total cost (sum of feed, labor, machinery, notional herd replacement and rent), and quota level of milk output (sum of the wholesale, direct sales and extra quotas). The results indicated that efficiency ratings varied between 52% and 93%, with 81% of the sample being at least 75% efficient. The mean was 81% implying that output, on average, was 19% below the frontier. While, the average cost was 15% higher than the frontier. This shows that there was room for improvement in efficiency as the most efficient farm was only 93% efficient. The study recommended that if quotas were made tradable amongst the producers of milk it could lead to improvement in efficiency.

Kumbhakar et al (1989) used a sample of eighty-nine dairy farmers from five counties in Utah in 1985 to empirically examine technical, allocative, and scale inefficiencies. Econometric approach (maximum likelihood method) is used for estimation of the stochastic production frontier, in a simultaneous equation framework. Inputs were categorized into endogenous and exogenous inputs. Endogenous inputs considered were capital, and labor and exogenous inputs were years of formal education, off-farm income (measure of efforts made in off-farm activities), and two dummy variables for three farm sizes (small, medium and large). The output variable was pounds of milk produced, adjusted for waste and disease.

The results indicated that the elasticity of labor is twice that of capital. Small farms had the highest labor elasticity (0.382), implying that more management time spent on small farms would yield greater impact on output than that of larger farms. The elasticity of capital also follows the same pattern. Amongst the exogenous variables education showed a strong impact, the highest being in medium sized farms. Off-farm income showed a negative effect on farm efficiency, being the strongest for small farms. Output of small farms was 52.28% lower than that of large sized farms, while medium sized farms was 32.73% lower than that of large farms. The smaller and medium sized farms were 32.10% and 11.54% less efficient compared to larger farms.

Allocative inefficiency increased costs, on average, by 8.89% for small farms, by 3.62% for medium farm and by 3.87% for large farm. Large farms were 13.52% more efficient (technically) than small farms. Hence, it was shown that farms could increase profits by 13.16% for small farms, 8.17% for medium farms, and 6.06% for large farms, by simply operating at optimal levels. Scale inefficiencies resulted in a loss of profits to the extent of 5.59% for large farms and 13.73% for small farms. Finally, the results suggested that there was over-production across all sized farms, simply because farms did not adjust their outputs enough to the drop in milk prices during the previous three years.

2. Technical Efficiency Studies during the 1990s.

2.1 Summary

During the 1990s studies focused on determining technical efficiency, allocative efficiency and scale efficiency among various sizes of farms and how different methodology may yield different results. As previously discussed, the development of the DEA and SFA methodologies in the 1970s led to the application of those methodologies to empirical agricultural efficiency studies. This continued in the 1990s. Most of the studies used a combination of non-parametric approaches (Data Enveloping Analysis-DEA) and parametric approaches. In terms of econometrics, the studies used more complex estimation methods that are intended to correct some of the unintended econometric errors of earlier studies. Some of the studies also focused on sensitivity analysis of different methodology.

The predominant results were that farms are not technically efficient or allocatively efficient, though the extent of farms efficiencies was higher than those of the studies in the previous decades. There were mixed results on size of farms and efficiency level, however, there were some regional differences of farm efficiency. Farmers' education level has positive and significant impact on farm level efficiency. Younger farmers are more efficient than older farmers because younger farmers adopted more efficient production methods. Finally, the level of efficiency improved overtime. It was concluded that policies that aim at improving farm technical efficiency should focus more on large-farm managers, less experienced farmers, managers of farms with multiple owners as well as farmers that are reluctant to adopt new practices

2.2. Review

Bravo-Ureta and Rieger (1990) used data on 404 dairy farms in New England and New York states for the years 1982 and 1983 to undertake sensitivity analyses of four different frontier production models of estimating technical efficiency (TE), one model based on linear programming, and three models based on the statistical production frontier.

For the linear programming approach, technical efficiency (LPROG) was calculated as the one-sided residual of a Cobb-Douglas production function. A frontier function was then estimated by minimizing the linear sum of residuals through linear programming. The second approach used corrected ordinary least squares to estimate a statistical production frontier (STATC). The third model used a statistical production frontier estimated by the maximum likelihood model, assuming a gamma distributed efficiency term (STATM). The fourth model estimated a stochastic production frontier, with a Cobb-Douglas specification, using maximum-likelihood techniques (STOCM). The fourth model had the advantage of representing noise, measurement error, and exogenous shocks through a disturbance term. Therefore, the technical efficiency measurement from this model was expected to be higher. An index of technical efficiency was computed using the ratio of actual output to optimal output (computed from the frontier function) of each farm and for each of the 4 models (total of 4 indexes per year).

The variables used were milk production per farm (Y , cwt and adjusted to a 3.5 per cent butterfat basis), full-time worker equivalents per farm (X_1 , hired, operator and family), purchased dairy concentrates (X_2 , tons per farm), veterinary and breeding fees, and other animal expenses (X_3), other feed and machinery expenses (X_4 , fertilizer, lime, seed, and spray, plus machinery repairs, gas and oil). The results indicated that although there was wide variation in the TE

estimates across the models, the estimates were highly correlated. However, the correlation within the same method between the two years was low. The parameter estimates for X_1 (full time workers) displayed the maximum similarity, across methods and time. The estimated parameters for X_2 (purchased dairy concentrates) were greater in 1982 than 1983. The estimated parameters for X_3 (animal expenses) and X_4 (machinery expenses) were greater in 1983 than 1982. The exception to this consistency was that the parameter estimates from the LPROG method for X_2 (purchased dairy concentrates) in 1982 and for X_4 (machinery expenses) in both the years.

The correlation of efficiency with farm size and of efficiency vis-à-vis ratio of returns to variable costs (ROVC), were similar across the models. The correlation between efficiency and farm size was positive but weak. The correlation between efficiency and ROVC was positive and strong. The mean technical efficiency for the LPROG model was 74.5% in 1982 and 73% in 1983, 68.2% in 1982 and 68.8% in 1983 for the STATC, 49.2% in 1982 and 45.9 in 1983 for the STATM model, and 82.4% in 1982 and 85.3% in 1983 for the STOCM model.

Weersink et al (1990) estimated technical efficiency and disaggregated it into purely technical (PE), congestion efficiency (CE) and scale efficiencies (SE). They used data on 105 Ontario dairy farms for the year 1987 and the non-parametric programming (deterministic) and econometric approaches to compute technical efficiency (TE). Overall technical efficiency (TE) was measured as the ratio of actual to potential (efficient) output. Pure technical efficiency (PE) was then calculated in a similar manner, through linear programming, using a transformed set that incorporates non-constant returns in technology. Scale efficiency (SE) was calculated as the overall technical efficiency (TE) over pure technical efficiency (PE). A value of one implied

constant returns of technology in the observed input and output data, whereas a values less than one implied non-constant returns of technology. Congestion Efficiency relied on the assumption of weak disposability, which implied that a negative marginal product of an input was possible (output falls when an input was increased). Therefore, congestion efficiency represented overutilization of inputs. This efficiency value was calculated using a new pure technical efficiency (PE*), which was calculated in the same manner as PE except it used a transformation set that incorporated weak disposability of inputs and non-constant returns to scale. After PE* was calculated, the effect of congestion on efficiency (CE) was given as PE over PE*. If CE was less than one, congestion was present for an individual farm. Therefore, if PE and PE* were equal (i.e. strong and weak disposability assumptions are equal) then overutilization of inputs was not present.

The results indicated that technical efficiency varied between 65% to 100%, with about 43% of the farms being technically efficient. For the balance farms, the major sources of inefficiency were technical allocation and non-optimal scale of production. Congestion was a minor source of inefficiency. Although there were more farms (57) displaying pure technical efficiency than scale efficient farms (43), the average level of pure technical efficiency (95%) was lower than the average level of scale efficiency (97%). The farms that were purely technical but not scale efficient were operating under increasing returns to scale. Most farms that were scale inefficient were also technically inefficient. The results suggested that although some small farms were combining resources properly the farm size needed to be increased. Farms with average herd size of 51 displayed decreasing returns to scale, while 44 farms showed constant returns to scale and 24 farms exhibited increasing returns to scale. Farms with fewer than 30

cows did not suffer from a decrease in relative output from operating at the point of decreasing returns to scale. The farms that experienced decreasing returns to scale were those with large herds and mid-sized herds. Most of the farms that displayed increasing returns to scale were not the smallest, but in the middle 30-49 herd size range.

The regression results of factors affecting overall technical efficiency levels indicated that herd size, milk yield and butterfat content of milk had a positive impact on efficiency, while proportion of total feed purchased and overcapitalization had a negative influence on efficiency. The efficiency increase from herd size was at a decreasing rate, and maximized at a herd size of 102 cows. The number of years in dairy farming had a negative effect on farm efficiency, which was explained as perhaps due to beginning farmers being more knowledgeable about recent technological advances. Increase in butterfat showed the largest relative impact on efficiency. The coefficient of feed purchased suggested that feed grown on the farm may be produced cheaper and be of higher quality than purchased feed. The negative correlation of debt to asset ratio and value of buildings per cow variables may have indicated that to some extent dairy farmers may be operating at less than full capacity, which resulted in a loss of scale economies. The strong relationship between debt and total assets implied overcapitalization. Dairy farms in South Central and Eastern regions of Ontario were found to have a positive impact on technical efficiency. Sole proprietorships and partnerships were found to be more efficient than corporations. Different milking systems employed did not influence farm efficiency. Farms with stable cleaners and liquid manure systems were slightly more efficient than farms manually cleaning barns. Manure pack systems were found to be less efficient than a manual system, which may be due to the diseases associated with the manure pack system.

Bravo-Ureta and Rieger (1991) followed Kopp & Diewert's (1982) to construct a stochastic efficiency model, which was used to decompose and analyze technical, economic, and allocative efficiency. The study focused on a sample of 511 New England and Rhode Island's dairy farms in the year 1984. Technical and economic efficient input vectors were found by computing a cost function, based on the Cobb-Douglas production function, and applying Shephard's lemma. Multiplying these vectors by the input price vector resulted in the cost of the technically efficient (X_tP) and economically efficient (X_eP) input combinations. These were then used to form indexes of technical efficiency (TE) and economic efficiency (EE) calculated as the cost of technical efficiency (X_tP) or economic efficiency (X_eP) over the cost of the firm's actual operating input combinations (X_aP). Allocative efficiency (AE) was then computed as economic efficiency (EE) over technical efficiency (TE).

The results indicated that average economic efficiency was 70%, technical efficiency was 83% and allocative efficiency was 84.6%. The most economically inefficient farms could save \$ 1.44 per hundredweight (100 lb) if they became technically efficient and \$3.60 if they became economically efficient. The corresponding figures for the highest economically efficient farms were \$ 0.87 and \$ 0.96 per hundredweight. Finally, farm size, education, extension and experience did not have a marked impact on efficiency.

Dawson and Woodford (1991) estimated farm-specific technical efficiency among 306 dairy farms in the post quota regime in England and Wales over the period 1984–1985 to 1986–1987. They used the same panel data set as Dawson (1990). One stochastic frontier production function for the 3 years was econometrical estimated by the maximum likelihood method. Farm-

specific technical efficiencies were calculated for each farm over time. The results indicated that, firstly, herd replacements had the highest elasticity followed by concentrates. Secondly, the estimated efficiencies of the farms ranged from 99% to 50%. 42% of the farms were 90% or more efficient; 75% of the farms were at least 80% efficient, while 87% of the farms were at least 75% efficient. The mean efficiency was 86% and the median was 88%. The overall average efficiency was 85%. The significance of the coefficient of skewness implied that the distribution of efficiency ratings was negatively skewed. The results were comparable to Dawson (1990). The study further concluded that dairy farmers operating under the quota policy constraint do not see the necessity for increasing technical efficiency. Thus, substantial inefficiencies on about 10% of farms were likely to persist as long as quotas remained.

Kumbhakar et al (1991) used data on dairy farms in the U.S. in the year 1985 to study the profitability of dairy farms in relation to returns to scale (RTS) and relative economic efficiency. The focus was on technical and allocative inefficiency. The single-method maximum likelihood estimation technique was used in the estimation of the stochastic production frontier and calculating the measures of technical efficiency. The variables considered were milk production per farm (hundredweight and adjusted to a 3.5% butterfat basis), cattle (the number of dairy cows per farm), labor (hired and family), capital stock (the actual number of dairy machinery hours, and included tractor hours exclusively for dairy purposes plus hours of operation of various other feed equipments adjusted for their capacity by the number of horsepower of each individual machine), farm size (small if the number of cows did not exceed 100, medium if the number of cows was between 101 and 500, and large if the number exceeded 500), regional dummies (control variables – region 1 included eastern U.S. states, region 2 included central and

midwestern states, region 3 included southwestern states, and region 4 included the western states), and education dummies (level 1 representing schooling up to high school, level 2 above high school, and level 3 into college).

The results indicated that the inputs elasticities were lower for large farms. The number of cows had the highest elasticity followed by capital and labor (except in Model 3). It was found that medium and large farms were more efficient. There was no evidence of increasing return to scale. Model 1 showed, education levels 1 and 2 increased technical efficiency and reduced the demand for each input by 7.5% and 0.6%, respectively. The effect of education level 1 was stronger than that of level 2. The mean technical inefficiency values of large, medium, and small farms were -.226, -.292, and -.332, respectively. The technical inefficiency increased cost, on the average, of these farms by 20.43%, 26.4%, and 30%, respectively. In the case of model 2, average values of technical inefficiency for large, medium, and small farms were .259, .305, and .356, respectively. Here the use of inputs was higher by 24.23%, 29.56%, and 33.29% for large, medium, and small farms. Compared to model 1 these estimates were about 3% to 4% higher.

For allocative inefficiency the increase in costs for farmers at the 3 levels of education were 9.7%, 8.1%, and 7.4%, respectively. It was found that large farms were relatively more efficient both technically and allocatively. In conclusion it is emphasized that (a) levels of education had a substantial impact on technical inefficiency, (b) large farms were more efficient both technically and allocatively, (c) RTS of the large-sized farms were lower, and (d) given the output price, large farms were overall more efficient.

Neff et al (1991) used a sample of 170 central Illinois grain farms to study farm level efficiency over a six-year period that range from 1982 to 1987. The study employed econometric methods and the ray-homothetic approach. The variables incorporated were gross accrual farm receipts, accrual fertilizers, pesticides, seed, capital (power and equipment), buildings (drying, storage, building repair and depreciation), labor (hired and unpaid), and land expenditures (interest charge times a total land value and reflects the net rents).

The results indicated that the total efficiency ratio of the farms varied between 0.51 in 1984 to 0.60 in 1985. The total inefficiency comprised of 70% pure technical and 30% scale inefficiency in each of the years. It was determined that output could be increased by about 35% with the same level of input. The increase in size of farms was accompanied by rise in efficiency up to a certain size after which the efficiency maximized. The pure technical inefficiency decreased, while scale inefficiency increased. There was evidence of decreasing returns to scale. Farm efficiency appeared to be dependent on time; hence it was suggested to be cautious in making policy decisions based on one year's data.

Kalaitzandonakes et al (1992) used a latent variable model and data on 50 grain farms in North Central Missouri during the period 1985 to 1989 to measure farm efficiency levels. The output variables used were the physical units and monetary value of crops (corn, soybeans, wheat and milo). Inputs included land, labor, chemicals, fertilizer, seed, machinery and energy, and buildings.

The results of the deterministic model indicated that, the average technical efficiency was 57%. Firms with gross annual revenues over \$300,000 were 33% more technically efficient than

firms with gross revenues less than \$100,000. Firms with tillable land over 1000 acres were 10% more technically efficient than firms with less than 1000 acres of tillable land. The results from the stochastic frontier model indicated that the overall average technical efficiency was 85 %, which was almost 30% higher than that estimated through the deterministic frontier. It is believed that a considerable portion of technical inefficiency measured by the deterministic frontier appeared to be statistical noise. The correlation between farm size and technical efficiency was found to be similar to the deterministic frontier. The results of the non-parametric model returned a much higher overall efficiency of 94%. Moreover, the average technical efficiency of farms with gross revenues over \$300,000 was similar to that of farms with gross revenues under \$100,000. The result from the latent variable model indicated that the degree of specialization and farm size appeared to be positively related to the levels of technical efficiency.

Haag et al (1992) studied agricultural efficiency with the objective to estimate relative technical efficiency of observed agricultural production levels in counties with similar soil types, using DEA (additive) methodology. The study is based on 41 counties in the Blackland Prairie of Texas. The year of study is not mentioned but the data appears to be drawn from 1987 census. The outputs considered were market value of crops and livestock sold. The inputs included were harvested cropland, cropland used for grazing, land fit for grazing and farm production expenses (total investment in livestock, fertilizer, fuel and power, feed, equipment, labor, seed, and other farm related costs).

The results indicated that 10 counties were efficient with efficiency rating of 1. Out of the 10, 3 counties were robustly efficient (most often in the facets of inefficient counties). It is

recommended that to improve the production and consumption levels, the less efficient counties should study the practices of the counties having superior efficiency. The authors stated that DEA analysis determined where the inefficiencies were occurring but not necessarily why they are occurring and allocative efficiency needed to be incorporated into the DEA model. Further, they highlighted that future research should consider soil quality and check sensitivity of error classifications within the data.

Cloutier and Rowley (1993) estimated the relative productive efficiency of the individual farms using the scalar measure provided by Data Envelopment analysis (DEA) and data on 187 dairy farms in Quebec for the years 1988 and 1989. Three measures of output were chosen, total quantity of milk (litres) produced during the year, revenue from the sale of milk, and other revenue accruing to individual farms. The inputs considered were herd size, labor (family and hired), cultivated land (including rented areas), animal feed and a composite of other inputs.

The results indicated that the number of fully efficient farms increased in 1989 (40), as compared to 1988 (28), with the improvement in average (1989: 0.913, 1988: 0.883) and minimum efficiencies (1989:0.683, 1988: 0.662). The most efficient farms were about 50% more efficient than the least farms and about 10-12% more efficient than overall average. There was clustering of efficiency by herd size. The authors hinted that the substantial changes in the efficiency estimates between the two years casted some doubt on the DEA method or on the choices of variables.

Ivaldi et al (1994) measured time-varying technical efficiency by estimating a stochastic frontier production function using panel data on 81 French grain producing farms between 1982

and 1986. Indexing (Törnqvist's) was used to aggregate the outputs and inputs. The results indicated that the levels of inefficiency were quite high. It was also noted that there was a decreasing trend in efficiency accompanied by an increase in the utilization of materials. Hence, the authors concluded that the decrease in productive efficiency was in part due to a drop in efficiency of the usage of materials. Also, the stochastic frontier was considerably different from the traditional average production function. Technical efficiency of farmers was found to vary with time. Finally, only the quantity of materials and the individual-varying coefficient of time exhibited correlation.

Carter and Zhang (1994) studied agricultural production efficiency in nine centrally planned economies (CPE) over two time periods, 1965-1977 and 1978-1989. The nine CPE nations were Bulgaria, the former Czechoslovakia, the former East Germany, Hungary, Poland, Romania, the former Yugoslavia, the former Soviet Union (FSU), and the Peoples' Republic of China (PRC). They used econometric method to estimate a Cobb-Douglas production function and used the residual to represent production efficiency. The results indicated that the efficiency improved in the period 1965-1977 by 2.14% per year (Czechoslovakia, Hungary, Romania, Yugoslavia, and the PRC at higher than 2.50%, while FSU, East Germany, Bulgaria, and Poland were less than 2%). It was found that during the period 1978-1989 the efficiency rate fell to 1.29% (except for PRC and East Germany all countries had lower growth rates and Romania, Yugoslavia and Bulgaria had the lowest growth rates of below 0.5%). Most of the CPEs experienced much slower growth in labor and land productivity in the second period. This slower growth may have been due to rising real input prices and elimination of government subsidy.

Efficiency gains in terms of labor and land productivity in Czechoslovakia, East Germany, Hungary and Poland were much larger than in PRC. Bulgaria, Czechoslovakia, East Germany, Hungary, and the FSU, which are dominated by state farms, still achieved equal or higher gains in efficiency as compared to private farm dominated countries (RC, Poland and Yugoslavia). This indicates that privatization is not a necessary condition to achieve efficiency gain. It was concluded that the reduction in growth of agricultural production in the CEE and the FSU in the 1980's was as a result of slower growth of inputs, in particular fertilizer.

Kumbhakar and Heshmati (1995) studied estimated technical inefficiency and analyzed the distribution pattern of the inefficiency for Swedish dairy farms during the period from 1976 to 1988. The output variable used was aggregate measure of milk, beef, pork, lamb, wool, poultry, and other dairy products. The inputs consisted of fodder, material, land, labor, capital, insurance, net interest rate costs, age of the farmer, and time. In addition farm size (small, medium and large) and region (southern, central and northern) was controlled for by dummy variables.

The results indicated that the marginal product of each input is positive and decreasing (except for concentrate fodder). Returns to scale were found to be inversely related to farm size and less than unity, increasing from 0.76 in 1976 to 0.82 in 1988. Therefore, they were increasing over time. The mean persistent technical efficiency of all farms in the data set was 90.90%, with 1.3% of the farms having efficiency less than 70%. The average residual farm and time specific efficiency was 93.25%, with most farms (34.7%) in the 97% to 100% efficiency

range. The average technical efficiency is 84.74%, with most farms being in the 82% to 91% efficiency bucket.

Overall technical change during the period 1976 to 1988 was -0.82. According to the authors, the result is due to stricter regulations (animal health control, minimum space requirement per animal, ban on growth hormones, minimum grazing time per cow, pesticide control, herbicide control), a fall in the number of milking cows, and lack of competition. The small and medium sized farms are 28.3% and 13% less productive respectively as compared to large farms. Farms in the Southern and Central regions are more productive than the Northern region by 7.2% and 6.4% respectively.

Hallam and Machado (1996) investigated farm-level technical efficiency using data on 85 northwest Portuguese dairy farms for the year 1989 to 1992. The panel data estimation technique was used to estimate a frontier production functions which identified the effect of farm-specific variables such as size, specialization, and location on production efficiency. The translog frontier production function was estimated using four econometric methods – Within estimator, the Balestra-Nerlove generalized least squares or the variance components estimator, the Hausman-Taylor (H-T) estimator (Hausman & Taylor, 1981) and the Battese-Coelli (B-C) maximum likelihood estimator (Battese & Coelli, 1988).

The variables under study were gross production of the farm, feed (purchased and self-produced), other intermediate consumption (seed, fertilizer, energy, etc.), capital (including land and land improvement, buildings, plant, machinery, equipment and circulating capital), labor (quantity used on the farm), and the number of milk cows. To determine the correlation between

technical efficiency and factors of production the variables considered were: farm size, dummy variable (to differentiate specialized from mixed farms), feed per cow, land per cow, stock of machinery and equipment per cow, ratio of family labor to total labor, dummy variable (to investigate whether family-owned and operated farms were more efficient than those which used hired labor in greater proportions), location dummies (to test whether inland and central region milk farms were less productive than those located in the coastal region), altitude dummy variable, dummy variable for farms located in ‘handicapped’ zones, dummy variable for rented farms (to investigate whether tenants show significant differences in efficiency from owner-operators).

The results indicated that the average technical efficiency was around 70 per cent. The average efficiency measures varied between 56% (in the case of the “within” model) to 88% (in the case of B-C). Maximum efficiency was 100% in the “within”, GLS and H-T models and 97% in the B-C case. The minimum efficiency levels were 31% for “within”, 53% for GLS, 45% for H-T and 68% for B-C. The farm rankings produced by the different methods also differed. The study recommended that the H-T estimator may be the most conservative method and the GLS estimator was recommended as the simplest method. The significant results of OLS regression of H-T estimates indicated that the larger farms were more efficient than smaller farms, while economies of scale were unimportant. Mixed farms appeared to be more efficient than specialized ones. Farms located in the interior region appeared to be less efficient than those in the coastal zone. The central region appeared to be more efficient than those in the coastal region.

Piesse et al (1996) studied agricultural efficiency in the former homelands of KaNgwane, Lebowa, and Venda in South Africa over the 1990 to 1992 period. The paper sought to estimate total efficiency and separate scale efficiency from the technical efficiency, as well as to measure the impacts of the 1992 drought. Inputs per unit of output are minimized using linear programming to determine the frontier. The authors followed Farrell (1957) in measuring technical efficiency, which is portrayed by an isoquant using the minimum inputs to produce a unit of output.

The results indicated that in KaNgwane, the average level of total efficiency was 35.8% compared to the best practice farms, which was lower than Lebowa (at 42.7%) or Venda (at 47.6%). KaNgwane, the most advanced and commercialized region, exhibited greater variation in input levels than the other two regions. The small farms in KaNgwane were scale inefficient with the lowest average scale efficiency of 48.7%. Venda had the least variation in farm size, with a mean scale efficiency of 69.8%, which compensated for the comparatively low level of technical efficiency (67.1%). Thirdly, in the case of all the three regions, at least 40% of the farms were technically efficient, with only a little over 7% of farms large enough to be scale efficient in KaNgwane and Lebowa, whereas 23.3% of were scale efficient in Venda. Efficient farms in all the regions had a wide variation in terms of the size, yield, labor, seeds and fertilizers.

Inter-spatial efficiencies were estimated by pooling the data and it was seen that more farms lie on the separate regional frontiers than on the combined frontier. The pooled efficiency results showed that small farms in Venda (with average of 1.15 hectares), were too small to be viable. Finally, the decline in efficiencies in 1992 (drought year) was 91% for KaNgwane, 63%

for Lebowa, and 55% for Venda. It was also seen that hybrid seeds had higher average yields but greater variance with respect to weather. The authors suggested that the designers of Farmer Support Program should take into account that the farmers who adopted more modern technology were more susceptible during periods of drought and needed to be provided with drought relief.

Wang et al (1996) examined production efficiency of farm households that faced different market constraints in Chinese agriculture. The study used econometric and indexing methods (Divisia index for the prices of outputs and variable inputs). The estimation process used in the study incorporated market distortions, while retaining the advantages of stochastic frontier properties in efficiency analysis. China's Rural Household Survey data for 1991 was used. A behavioral profit function was used to estimate farmers' shadow prices. A stochastic frontier profit function, using the shadow prices, was estimated and the efficiency index was then estimated. The efficiency index was related to farm households' demographic variables to identify the variables that influenced the farm households' efficiency. The variables used were crops and livestock as output, chemical fertilizer and other purchased materials (including fuel, seeds, plastic sheets, pesticides, etc.) as variable inputs, and labor (no hired labor was recorded), land and capital as fixed inputs.

The results indicated that farm-specific price efficiency for crops was 0.84 with 99% of the individual values less than 1, and that for livestock was 0.86 with 96% of the individual values less than 1. This implied that the prices received by farmers for their products of crops and livestock were less than the observed market price due to the prevalence of market

distortions. In the case of the inputs, the average of the farmers' shadow price (1.16) of using chemical fertilizer was higher than the observed market price, with 53% of the individual values greater than 1.

It was found that the level of education was positively related to allocative efficiency. The estimates of households' labor/land ratio displayed a mixed effect on allocation performance. The estimated coefficients of technical efficiency variables exhibited that larger farms were comparatively technically efficient (0.83) and the small farms were technically inefficient (-0.57). The level of efficiency among households varied between 0.06 and 0.93. Finally, the household's educational level, family size and per capita net income were positively correlated to its efficiency. The households located in mountain areas and those with family members employed in the government or state industries were comparatively inefficient. The authors recommended that the effects of price distortions must be adjusted for in the studies of farm behavior. Some China specific policy recommendations were made such as removing market distortions (including government's monopolistic power), improving land rental market, and facilitating the farmers' accessibility to education.

Sharma et al (1997) assessed technical efficiency of 60 swine farms in Hawaii during 1994 using a stochastic frontier production function and DEA. The variables used were weighted average of the pigs produced (output), feed (swine concentrates and other grain based feeds, excluding garbage), labor (family and hired), other variable inputs (representing the total of all variable expenses except feed and hired labor), and capital (fixed cash costs and depreciation expenses on capital, including pig housing, machinery, and other equipment).

The results of the parametric estimations indicated that the estimated average technical efficiency was 0.749, implying substantial inefficiency. The DEA models (constant returns to scale, CRS, and variable returns to scale, VRS) indicated that the average technical efficiencies were 0.726 and 0.644, respectively. In the VRS model, 17 farms were fully efficient, while in the CRS model, 10 farms were fully efficient. The efficiency measures estimated under the VRS DEA model were equal to or greater than those estimated under the CRS DEA model. The mean scale efficiency was 0.892. 10 farms exhibited CRS, 19 increasing returns to scale, and 24 decreasing returns to scale. Within the scale inefficient farms, most of the large farms (> 75 sows) exhibited decreasing returns to scale while most of the small farms (< 25 sows) exhibited increasing returns to scale.

The DEA efficiency estimates exhibited a considerably higher variability than the stochastic efficiency measures. The correlation coefficients between the estimates from the two approaches were positive and highly significant. The stronger correlation was with the CRS DEA model. In terms of farm size, the average frontier outputs from the two methods were similar, except for farms with 25–75 sows, where the DEA frontier outputs were considerably more than the stochastic frontier output. The stochastic estimates indicated that large farmers could, on average, increase their output by 24%, medium farmers by 40%, and small farmers by 30%, by producing at their frontier outputs. The counterpart values for the VRS DEA frontier were 16% (small farmers), 82% (medium farmers), and 34% (large farmers) increases in output by producing at the frontier. While producing at the CRS DEA frontier would increase output by 25% (small), 97% (medium), and 54% (large). If all producers operated at full efficiency, there

was scope for increasing industry's production by 28–43%, which would be sufficient to replace the imports from the U.S.

Featherstone et al (1997) studied agricultural efficiency using a sample of 195 Kansas farmers. Each farm's performance was compared to the production or cost frontier. The study used the linear programming technique to estimate efficiency. Further, econometric method (Tobit model) was used to examine the relationship between the efficiency measures and farm characteristics (the age of the operator, the number of beef cows on the farm, tenancy position, leverage, and the percentage of gross farm income from beef cow production). Six inputs were considered - feed, labor, capital, utilities and fuel, veterinary expenses, and miscellaneous costs. The output was accrual value added gross income.

The results indicated that the overall efficiency ranged from 0.31 to 1.00, with the average at 0.60. About 75% of the farms were between 50% and 80% efficient. Technical efficiency varied between 0.37 and 1.00, with an average of 0.78. It was found that 49 farms were technically efficient. Allocative efficiency varied between 0.47 and 1.00, with an average of 0.81. Over 60% of the farms had allocative efficiency measures greater than 80%, as compared to 48% of the farms in the case of technical efficiency. Scale efficiency varied between 0.53 and 1.00, with an average of 0.95. About 84% of the farms were over 90% scale efficient. About 68% of the farms indicated decreasing returns to scale.

The results of Tobit model showed that younger farmers were more efficient, which could be due to younger farmers adopting more efficient production methods. Diversified farms were more technically efficient. Larger beef cow herds were more technically efficient than

smaller beef cow herds. In general, large farms were more efficient. The tenure and leverage variables were not significant. Feed cost was the most important factor affecting technical efficiency. Allocative inefficiency was not correlated with the independent variables. However, it was found that allocative efficiency was affected by labor, capital, utilities and fuel, veterinary services, and miscellaneous costs. Scale inefficiency was negatively associated with size and specialization. Though, capital was the only variable that affected scale efficiency. Feed, labor, and capital costs impacted overall efficiency, with feed and capital being more important. Finally, the net income per cow was positively correlated with overall efficiency (0.95), technical efficiency (0.70), allocative efficiency (0.37), and scale efficiency (0.18). The authors concluded that producers should focus more on reducing input use per unit of output instead of adjusting the size of the cow herd.

Heshmati (1998) used a sample of 1425 Swedish dairy farms observed during 1976 to 1988, and econometric method to estimate technical efficiency. The output was total income from production of milk, beef, pork, lamb, wool, poultry and other dairy products. The inputs considered were fodder (concentrate and grass), material (items purchased and used only in the production of dairy products, including mineral fodder, purchased coarse, purchase of animals used in the production of dairy, and other expenses), land (farming and pasture), labor (family and hired), and capital (capital equipment including depreciation, maintenance, insurance and net interest rate costs). The age of the farmer and time were incorporated as explanatory variables. Dummy variables representing size of animal stock, size of operation, and location were added to the model.

The results indicated that elasticity of concentrated fodder (EC) increased over time. The standard deviation of EC was about 31%, implying that there was large variation in concentrated fodder usage. Farms with large stocks of animal used on the average 47% more concentrate fodder. The elasticity with respect to grass, declined over time, implying that the farms shifted from the use of grass to concentrates. Elasticities with respect to both labor, and capital increased over time. This may be due to labor becoming expensive and the production process becoming more capital intensive. The Southern region used less labor and capital. Large farms with large stock of animal were more labor and capital intensive. The elasticity of material declined over time with low variations across regions and farm sizes. There was higher variation across stock of animals because farms with large animal stock applied mechanized equipment which resulted in lower material use per herd. The elasticities with respect to farm land declined over time, which could be due to increased yield per hectare of land and the usage of industrial byproducts as concentrated fodder. The elasticities with respect to pasture land also declined over time. Age was positively related to output, with declining elasticity over time. The elasticity of output with respect to time (exogenous technical progress) declined till 1984 thereafter increased from 1985 to 1988 at a low rate.

The average technical efficiency was 94.5% ranging from 68% to 100%. The technical efficiency was more for the farms with small animal stock, suggesting that small farms run by family labor are more efficient. The percentage of farms operating below 80% level of efficiency ranged from 0.3% to 1.5%. Only 0.7% of the farms were operating at below 80% level of efficiency. The maximum value of technical efficiency over the period was about 94%, with 16.4% of the farms being fully efficient. With the percentage of fully efficient farms increasing

after 1984. There was variation in the profile of the fully efficient farms with respect to animal stocks in that there were fewer fully efficient farms with 31 or more cows, and with smaller farm size.

Amara et al (1999) estimated technical efficiency of potato farmers and investigated the relationship between technical efficiency and the adoption of conservation technologies. The scope of the study was 82 potato farms in 4 regions of Quebec (Portneuf, Catherine-de-la-Jacques-Cartier, Lanaudière, Ile d'Orleans and Nicolet-Yamaska), with surveys conducted during the spring of 1995 and the winter of 1996. The output variable was per hectare actual yield of potato in 1994 and was measured as the ratio of total quantity of potatoes produced to total potato area farmed. The input categories were fertilizer, labor, capital (total per hectare machine, insecticide, and fungicide).

The results indicated that the average technical efficiency was 80.27%, with a minimum of 19.31%. Insecticides and fungicides had a negative impact on the frontier potato yield if they were applied more than eight times and four times, respectively. It was found that 6% of farmers were below the 50% efficiency level, and 19% were in the 50–70% efficiency level. However, 75% of farmers were at an efficiency level over 70%, with 50% of the farmers being more than 90% efficient. The results of the regression to investigate the relationship between technical efficiency and adoption of conservation technologies were significant. These results indicated that the single-owner farmers took greater care to use production inputs efficiently, with cost concerns outweighing the concerns for larger volumes of output. Farming background was a positive determinant of a farmer's technical efficiency. Large farmers could encounter more

problems in applying farm inputs at the right time. The farmer's adoption of conservation practices increased efficiency.

The results of environment orientation showed that about 67% of the efficient farms and 34% of the non-frontier farms were willing to invest in innovations that could decrease soil erosion. Furthermore, 57% of efficient farms and 46% of non-frontier farms were willing to pay more for innovations that conserved groundwater quality. These results suggested that frontier farms and non-frontier farms shared a common concern for their long-term survival as production units through the conservation of groundwater and soil quality. The study recommended that policies that aimed to improve farm technical efficiency should be focused more towards large-farm managers, less experienced farmers, managers of farms with multiple owners as well as farmers that are reluctant to adopt conservation practices.

Thiele and Brodersen (1999) used the DEA methodology and data on 386 farms from West Germany and 214 farms from East Germany during the period 1995 – 1996 to 1996 – 1997 to study agricultural efficiency. Production efficiency was broken up into technical and scale effects. The output variables were returns from crop, livestock and miscellaneous production. The input variables were labor, land, capital, variable inputs (seeds, fertilizers, chemicals, and feedstuff) and miscellaneous (energy, water, fuel, etc.).

The results indicated that West Germany farms were more efficient than East German farms, exhibiting higher scale efficiency and lower variance of scale efficiency. The average overall efficiency for West Germany farms was 0.86, with 15% of farms being more than .96 efficient and 27% of farms below the efficiency level of 0.80. The average overall efficiency for

East German farms was 0.79, with 19% of farms more than .96 efficient and 48% of farms below the efficiency level of 0.80. Furthermore, 45% of West German farms exhibited technical efficiency level of 0.96 or more with 2% below a technical efficiency of 0.80. Whereas 44% of East German farms exhibited technical efficiency level of 0.96 or more and 14% below technical efficiency of 0.80. It was also found that 38% of West German farms exhibited scale efficiency level of 0.96 or more and 12% below scale efficiency of 0.80 whereas 38% of East German farms had technical efficiency level of 0.96 or more and 23% below technical efficiency of 0.80.

3. Agricultural Efficiency Studies during the 2000s.

3.1 Summary

Studies during the 2000s focused primarily on using different methodologies to determine agricultural efficiency of various form of agricultural production (organic vs. conventional farms) while determining the effect of government policies on agricultural efficiency. The studies also investigated the relative contributions of inputs growth, management practices, and other factors to agricultural efficiency. A few studies compared efficiency level of different sized of farms. The dominant methodologies used were the DEA and the SFA. Most studies used econometric estimation technique and analyzed the impact of various estimation techniques, functional form, and sample size on technical efficiency estimates.

The main results can be summarized as follows: Organic farmers on the average were more efficient than conventional farmers; technical efficiency is related to economic factors, environmental conditions, locations, size of local market, and agricultural policies; farm size

matters for technical efficiency; different results for different econometric specifications; non-parametric deterministic models showed higher mean technical efficiency than parametric stochastic models; government supports has mixed effect on farm level efficiency; and efficiency improved over time; Family operated farms exhibited higher efficiency than farms with a greater share of hired labor, while the level of debt was positively related to technical efficiency: It was found that to improve sustainable efficiency, the strategy to maximize output given the input level was better than the strategy to minimize the input level given output; and Education level appeared to have little significant or consistent impact, but age was negatively correlated with efficiency for both specifications.

3.2 Review

Giannakas et al (2000) investigated the relative contributions of input growth, technological change and technical efficiency in olive oil production growth using a panel data set of 125 Greek olive farms (in the regions Peloponissos, Crete, Sterea Ellada and Aegean Islands), during the period 1987 to 1993. The study estimated a stochastic production frontier function (flexible modified translog functional form with a single time trend) with the Box-Cox transformation of the independent variables in stochastic decomposition analysis. The output variable was annual olive oil production. The aggregate inputs were total labor, fertilizers, other cost expenses, capital, and land.

The results indicated that land contributed the most to olive production, which was followed by labor, other capital inputs and fertilizers. There was diminishing returns to scale,

which declined over time (1987 - 0.930, 1993 - 0.872). Technical efficiency was low over the study period, dropping from 73.75% in 1987 to 68.98% in 1989, and stabilizing thereafter. The low efficiency levels were attributed to the small size, extensive fragmentation, and extensive protectionism of the Greek olive growing holdings. Thirdly, the average annual rate of technological progress was 0.92%. The rate of technical change was 0.6% per year during 1987 to 1990 and 1.24% per year during 1990 to 1993. The neutral technical change exhibited a moderate rise while the non-neutral or biased technical change was negative and dropping.

Average annual output growth rate during the period 1987 to 1993 was 6.88%, which was due to a 5.09% increase in the use of inputs (which contributed 74% of total output growth) over that time period. On average, fertilizers contributed the highest amount to total input growth (about 28%). The growth in land area and other capital inputs also had a substantial effect. The contribution of land appeared to decline over time because of acreage limitations. The increase in labor explained about 12% of total olive oil production growth. Total Factor Productivity (TFP) contributed only 1.92% towards the olive oil output growth, of which technical change contributed 13.4% to TFP.

Wilson et al (2001) used a stochastic frontier production function to examine the influence of management on the technical efficiency of wheat farms in eastern England based on the surveys during 1993 to 1997. Quality adjusted grain produced was the output variable. Inputs were seed, fertilize, cost of crop protection materials, labor and machinery data. The variables studied as influencing technical efficiency were area of each farm, years of managerial

experience, educational dummy variable, a set of business objective dummy variables, and a linear time trend (1 = 1993 to 5 = 1997).

The results indicated that technical efficiencies varied between 49.51% and 98.01%, with an overall average of 87.01% and standard deviation of 10.52%. More than 74% of the farms were operating at greater than or equal to the 85% level of efficiency. The significant results from the regression showed that farmers who ranked profit maximization and maintaining the environment highly were 2 % more efficient than those who did not. Farmers who were classified as information seekers were more efficient. It was found that the technical inefficiency increased as farm size decreased.

Tzouvelekas et al (2001) used a stochastic production frontier model to examine the technical efficiency of organic olive-growing farms in Greece and compare them with neighboring conventional farms. They used data on 84 organic and 87 conventional, olive-growing farms in four counties of Greece, during the period 1995 to 1996. The output variable was the organic or conventional olive-oil production and the aggregate inputs were total land devoted to olive-tree cultivation, total labor, total amount of chemical or organic fertilizers, pesticides, biological weed and pest control, and other expenses (including fuel, electricity, depreciation, fixed and current assets interest, and other miscellaneous expenses). The results indicated that land, labor and fertilizers / pesticides showed higher elasticity values in organic farming. In the case of fertilizers/pesticides the average production elasticity was almost six times more in organic farms, implying that they were considerably more important in organic farms as compared to conventional farms. Labor was also more important in organic olive

farming with a mean elasticity of 0.415 than in conventional farming which had a mean elasticity of 0.187. The average returns to scale were reducing in conventional farms at 0.718 and close to one in organic farms at 1.118.

The average output oriented technical efficiency score was 69.13% for organic farms and 58.72% for conventional farms. The technical efficiency levels varied from 28.47% (22.71%) to 94.21% (99.89%) for the organic (conventional) farms. The average input-oriented technical efficiency over the farms was 54.30% and 73.12% for the conventional and organic farms, respectively. This input-oriented technical efficiency varied from 29.16% (19.11%) to 95.13% (96.41%) in organic (conventional) farms. The above results implied that on the average, organic farms operated closer to their production frontier.

Large organic (conventional) farms were in a position to reduce their actual costs by 23.7% (44.7%), medium sized farms by 26.5% (47.5%) and small farms by 29.4% (49.6%) if they could operate at 100% technical efficiency levels. It was noted the larger farms (both conventional and organic) exhibited lower technical inefficiency than smaller farms. Traditional, family-farming practices in olive growing were less efficient than farms operating with more hired labor. Favorable environmental conditions affected farm's technical efficiency levels positively.

Giannakas et al (2001) analyzed factors influencing efficiency and examined the relative contribution of resources use and total factor productivity. The study focused on 100 wheat farms in Saskatchewan during the period 1987 to 1995. Econometric estimation (maximum likelihood) was used to stochastically decompose a flexible translog functional form that

represented an underlying production technology. The dependent variable was annual wheat production and the input variables were farm land devoted to wheat cultivation, labor, chemical fertilizer and pesticides, and other capital expenses. Additionally, three soil-type dummies (black, brown and dark brown), shares of leased and share-cropped land, and the shares of government income and crop insurance income to total farm income are included in the study.

The evidence from elasticity estimates showed that land and other capital expenses contributed the highest to wheat production (0.437 and 0.323 respectively), while labor and chemical inputs contributed less (0.214 and 0.097 respectively). The production elasticities were stable for land and labor inputs, while that for other capital expenses dropped from 0.352 in 1987 to 0.294 in 1995. The elasticity of chemical inputs rose from 0.089 in 1987 to 0.134 in 1995, implying an increased importance of fertilizer and pesticides for wheat production over time. The farms showed increasing returns to scale, with an estimated elasticity of scale of 1.071. Estimates of the rate of technical change showed technological progress at an average annual rate of 1.20%. Technological change was biased towards *using* land and chemical inputs. Whereas technological change was biased towards *saving* with labor and *neutral* with regards to capital inputs.

Mean output-oriented technical efficiency was 76.9%. The mean difference between the lower and the upper efficiency intervals was 7.6% during the study period, with the highest being in 1987 at 11.3% and the lowest in 1991 at 5.4%. The average technical efficiency among farms ranged between 65.3% and 92.0%, with 87% of the farms achieving technical efficiency between 70% and 90%. Technical efficiency improved at an annual average rate of 0.67% during the

study period and varied from a minimum of 66.4% in 1988 to a maximum of 83.8% in 1991. Exogenous shocks (weather) may have caused this variation. For example, the drought in 1988 may have caused the reduction in technical efficiency and the significant productivity losses during the year. Technical efficiency ranged between 38.2% and 92.8% in 1987, improving to between 58.7% and 91.5% in 1995.

A positive correlation was found between participation in Top Management Workshops (TMW) and farmer performance. Government and crop insurance income were related with low efficiency scores. The authors cautioned that the reason for this correlation could be adverse weather. The proportion of leased land was inversely related to technical efficiency, implying that there may be agency problems in the relationship between landowners and farmers due to information asymmetries and/or misaligned incentives. Family operated farms exhibited higher efficiency than farms with a greater share of hired labor, while the level of debt was positively related to technical efficiency. The farm size was found to not be significant and specialized farms were more efficient. The use of seed, chemical inputs, and machinery capital exhibited a positive relationship with technical efficiency.

The average total production growth rate from 1987 to 1995 was 2.28% per year, comprising of 1.85% increase in TFP and 0.37% increase in input usage. Technological change explained on average two thirds of the growth in TFP. Increased use of labor was the main contributor to input growth (0.31% of total output growth), while land had a small and negative contribution to production growth (-0.17%). Future research was suggested in the analysis of

multi-output technologies, the inclusion of human capital variables such as producer education and farming experience, and inter-sector or inter-country comparisons.

Lansink et al (2002) used the DEA methodology to study agricultural efficiency with respect to organic and conventional livestock farming in Finland for the period 1994 to 1997. The output considered was a quantity index, obtained by dividing the output value by price. The inputs considered were land, capital, energy, labor, seeds, fertilizers, planting materials, and purchased feed.

The empirical analysis revealed that, technical efficiency under constant returns to scale (CRS) was 0.91 for organic farms compared to 0.67 for conventional farms. Similar results were obtained in the case of variable returns to scale (VRS). The scale efficiency was 0.95 for organic farms and 0.92 for conventional farms. The average productivity of conventional farms was close to 1.0, whereas organic farm productivity was 0.72 in the case of CRS and 0.77 in the case of VRS. The efficiency of organic crop farms was higher but input productivity was lower than the conventional farms. Productivity of capital was particularly low on organic crop farms, while overall efficiency of organic livestock farms was considerably higher on all inputs except land and capital. The organic farms were more efficient in the use of their own technology but used a less productive technology. The low productivity in the organic farms was made up for by higher efficiency. The study recommended future research on the differences in TFP between organic and conventional farms.

de Koeijer et al (2002) examined the relationship between technical efficiency and sustainable production behavior using the data enveloping analysis and data on sugar beet

producing farmland in Netherlands during the 1994 to 1997 period. The quantity of sugar per hectare was used as as output, and nitrogen fertilizers and herbicides as inputs. Profit efficiency (PE) was estimated as returns over operating costs per hectare. Environmental efficiency (EE) was assessed by the environmental impact of nitrogen surplus, and for herbicides – leaching into groundwater, effects on aquatic organisms and effects on soil organisms. Sustainable efficiency (SE) combined EE and PE.

The results showed that the technical efficiency under constant returns to scale (TE_{CRS}) was lower than the input-saving technical efficiency (TE_{VRS}^i) and the output-increasing technical efficiency (TE_{VRS}^o) with varying returns to scale. The average TE_{VRS}^o was higher than TE_{VRS}^i , which could be due to the average variation in input use being higher than the variation in yield between farms within a year. Generally, the rank correlations for TE_{CRS} and TE_{VRS}^i during the 1994-1997 period were higher than those for TE_{VRS}^o , which could be due to the level of input varying less than the yield level between the years. The technical efficiencies were found to be related to the economic and environmental efficiency and to the sustainable efficiency. The average technical efficiency (with CRS) of 50%, implied that there was substantial scope for improving sustainability even without any improvement of technology and without conflicts between economic and environmental goals. It was found that to improve sustainable efficiency, the strategy to maximize output given the input level was better than the strategy to minimize the input level given output. Also, the farmer's management style influenced efficiency.

Iráizoz et al (2003) studied the determinants of technical efficiency of tomato and asparagus (horticulture) production in Spain using parametric and non-parametric methods. The

output variable used was sales of asparagus and gross tomato production. The inputs were hours of labor and cultivation costs, capital, and land.

The regression results indicated that, in the case of asparagus, all the inputs (except inventory) were statistically significant, with labor and land having the highest elasticity. This was consistent with the fact that asparagus production in the region was labor-intensive. In the case of tomato production all the inputs were significant, again with land and labor showing the highest elasticity. The overall mean of technical efficiency was 0.80 for asparagus production (standard deviation of 0.13), and 0.89 for tomato production (standard deviation of 0.07). These results imply that the same output could be maintained by reducing the inputs by about 15% through technical efficiency improvements.

The results of the non-parametric approach indicated that asparagus production showed an average efficiency level of 0.75. The variable returns to scale showed slightly higher pure technical efficiency implying that scale efficiency could be close to 1.0. Tomato production exhibited average efficiency of 0.81, and pure technical efficiency of 0.89. The average scale efficiency of asparagus and tomato production were 0.94 and 0.91 respectively. The correlations of efficiencies between the two approaches were similar. In the case of asparagus, 75% of the farms identified to be the top 25% best-practice farms by parametric TE, also appeared in the top 25% in the global TE. Similar results were obtained for the least efficient 25%.

The results of regression to understand the relationship between technical efficiency and relevant variables indicated that farm size appeared to be positively related to technical efficiency in the case of tomato production, while in the case of asparagus the relationship was

inconclusive. The output per unit of land was positively correlated with technical efficiency in the case of asparagus, but was non-significant in the case of tomatoes. Cultivation cost per hectare of land was negatively related with technical efficiency, in the case of both asparagus and tomato production, implying that higher cultivation costs did not result in better efficiency. The study recommended that in order to meet market competition, especially in the light of reforms of common agriculture program and WTO negotiations, the producers needed to reduce their production costs by improving technical efficiency. Another suggestion made by the study was that access to extension services and education for farmers needed to be improved to enhance the capacity of the farmers to apply available technology more efficiently.

Paul et al (2004) compared the performance (scale economies-SEC), scale efficiency (SEF) and technical efficiency(TE)) of smaller farms with larger farms in the rapidly changing agricultural environment. The study focused on the corn-belt farms in the Heartland and Northern Crescent states of the U.S. during the period 1996 to 2001. Non-parametric method (deterministic data envelopment analysis (DEA)) and econometric method (maximum likelihood estimate of stochastic production frontier model (SPF)) were used.

The scale economies (SEC) measures for both the DEA and stochastic production frontier (SPF) models were generally greater for the smaller-farm cohorts. The estimated SEC for the SPF model was larger than those for the DEA model, with a stronger tendency towards lower economies for the bigger cohorts. The marginal cost was lower for each output for smaller farms, except off-farm income for RES farms. The scale efficiency (SEF) measures for the DEA model exhibited that farms in the RES cohorts had more potential to reduce costs by moving to a scale

efficient point than that implied by the scale economies (SEC) estimates. For other cohorts slightly lower input savings per unit of output were observed from the SEF than the SEC measures. The SPF model provided even stronger similar results. The SEC estimates suggested that performance differences across cohorts arose from changes in netput (output and input) composition that accompanied growth. Expanding the scale of operations, without changing the production practices, did not save inputs.

The DEA estimates indicated a drop in scale economies (SEC) over time, while the SPF model estimated more or less constant levels. Both the methods showed potential economies of scale to fall during 1997 to 1999 and then rise thereafter. The spatial (regional) dimension displayed small variation in scale effects. The DEA model also estimated higher technical inefficiency than the SPF model and more variation across farm-types. Estimated efficiency levels for the very large (VLG) cohorts were higher than the smaller cohorts. Both models reported the lowest efficiency levels to be from farms in the SM combined cohort, followed by RES. Over time the SPF technical efficiency (TE) estimates showed consistently increasing efficiency levels, while the DEA model the TE increased in 1998, and then fell below 1996 levels during the period 1999 to 2000. However, regional TE variation was low; Northern farms were reported to be slightly less efficient in the DEA model, while in the SPF model the reverse was true.

The technical and environmental change (TEC) measures indicated that there was some temporal variation between the technical efficiency patterns estimated by the DEA and SPF models. This may be due to differing decompositions of shifts in the function as against

movements toward the frontier. While both models exhibited a shift out in the frontier in 1997 and back in 1998, the DEA model indicated more outward shifts whereas the SPF model implied contractions. This results in an overall technological regression for the SPF model if these shifts were interpreted as technical change instead of unmeasured technical and environmental factors. The TEC patterns for the second half of the time period showed increasing estimated technical efficiency for the SPF model, whereas for the DEA model it was declining.

The regression estimates indicated that the scale effects patterns were quite consistent in both the DEA and SPF cohort. Generally, scale economies (SEC) in the larger cohorts were low, especially in the SPF specification. Over time the DEA measures indicated reducing scale economies (SEC) and the SPF measure increasing SEC, especially from 1999 to 2001. Small regional differences in scale effects appeared in the SPF specification, with less SEC in the North. The DEA estimates confirmed small increases in TE over time. In case of the SPF model, this increase was larger. The DEA estimates suggested that Northern farms had lower TE, whereas the SPF estimates were reverse. Education appeared to have little significant or consistent impact, but age was negatively correlated with efficiency for both specifications. Age appeared to be related with greater, potentially exploitable, SEC in the case of SPF model, but greater scale efficiency (SEF) according to the DEA estimates. Finally, larger share of GM corn production appeared to have lower SEC in the SPF specification but not in the DEA model. More GM soybeans appeared to be associated with lower TE. The study recommended that increasing the ability of small family farms to expand and diversify was critical to improve their competitiveness, and long term viability, in the new U.S. agricultural environment.

Tipi and Rehber (2006) estimated technical efficiency and total factor productivity (TFP) for farms in the South Marmara region of Turkey in the period 1993-2002 using DEA and the DEA-based Malmquist TFP index. The output was defined as the gross value of agricultural production of two categories of items, crops and livestock. The input variables were land (sum of area of arable land, permanent crops and permanent pastures), fertilizers (sum of nitrogen, phosphorous and potash content of various fertilizers consumed), tractors (sum of four-wheel tractors in use), and labor (population which lives in rural areas and is engaged with agricultural activities).

The results suggested that technical efficiency was affected by a number of factors that were not related to the technological choices made by the farmers. The main elements that explained technical efficiency variation was environmental conditions, location, transportation network, farm size distribution, and the size of local economies. Furthermore, institutional factors such as extension and agricultural policies also influenced efficiency. It was also found that there was a large variation in the efficiencies exhibited by the studied provinces. The component estimates of TFP, efficiency change, and technical change revealed that efficiency was the main contributor to TFP. The study suggested that the principal difficulty in the 10-year period was the slow or negative rate of increase in technical change and that research extension played a crucial role. This implies that there was a strong need for sustained improvements in technology, with a more active role for the public sector in research and extension activities in collaboration with farmers to raise the technology level significantly.

Bravo-Ureta et al. (2007) undertook a meta-regression analysis of 167 frontier studies of TE in the agricultural sector. The issues examined were: (1) whether parametric deterministic or parametric stochastic frontiers resulted in different TE estimates than non-parametric studies, (2) whether functional form had a significant impact on TE, (3) whether panel data frontier models produced the same mean TE compared to cross-sectional data frontier models, (4) whether TE from studies using a primal approach were similar to those using a dual approach, (5) whether model dimensionality (sample size and the number of variables) had a significant impact on TE; (6) whether TE varied with the type of output being studied, (7) whether geographical location generated a significant variation on mean TE, and (8) whether the income level of the country under study had any impact on TE estimates. The studies analyzed were published between January 1979 and June 2005. Econometric methods (two-limit, doubly censored, Tobit procedure, and OLS) were applied to understand the cause of the differences in the mean TE indices reported in the literature.

The results from the compilation of previous studies indicate that: (1) a comparison of the average mean technical efficiency (AMTE) between the parametric and non-parametric estimates for the parametric approach was lower (76.3%) than those estimated by non-parametric approach (78.3%). However, the differences were not statistically significant, which could be explained by the fact that non-parametric studies generally presented many TE indexes equal to 100%. (2) In the deterministic models Cobb-Douglas function yields AMTE (72.6%) higher than the translog function (68.1%). In the stochastic model the opposite held true but the differences were not statistically significant (translog functional form – 79.7%, Cobb-Douglas – 76.3%). (3) In the deterministic study the primal models yielded higher AMTE (75.5%) as compared to dual

models (67.7%), while in the stochastic studies it is reversed with dual models yielding 79.0% and primal models 77%. (4) In deterministic studies that use panel data show a higher AMTE (77.5%) than those using cross sectional data (72.8%).

(5) In the geographical categorization, studies combining deterministic and stochastic, showed that Western Europe and Oceania had the highest AMTE (82%) while Eastern Europe had the lowest (70%). (6) The higher income countries show the highest AMTE (78.8%), followed by lower middle income countries (75.7%), lower income countries (74.1%) and upper middle income countries (68.3%), when the deterministic and stochastic studies are combined. The only difference that was statistically significant was that between higher income countries and lower income countries in the stochastic studies. (7) In the product type categorization, other animals showed the highest AMTE (84.5%), followed by Dairy and Cattle (80.6%), while Rice was at the bottom of the list (72.4%).

The results from the regression indicated that (1) parametric stochastic models showed lower mean technical efficiencies (MTE's) compared to non-parametric deterministic models. This is because the non-parametric deterministic studies yield more TE indexes equal to 100%. (2) A more flexible functional form, like the translog yields a higher MTE. (3) Cross sectional data shows lower MTE estimates than panel data based models. (4) The frontier models for grain crops show lower levels of MTE than those for Dairy and Cattle, Other Crops or Whole Farm.

Odeck (2007) estimated technical efficiency and productivity growth, using stochastic frontier analysis (SFA) and data envelopment analysis (DEA) using data set on 19 specialized grain farm producers, in the lowland areas of eastern Norway, for the period 1987 to 1997. The

Malmquist indexing approach was used for both the DEA and SFA methodologies to estimate productivity growth. The variables used in the study were crops yield as an output (aggregate of barley, wheat, oats and oilseeds, e.g., rye and peas), and labor, capital, agricultural area, seeds and fertilizers as inputs.

The results indicated that in the case of both DEA and SFA the average producers experienced increasing returns to scale. Inefficiency continued to exist in the Norwegian grain production. The DEA efficiency scores were more than the SFA estimates. There was similarity with regard to potentials for efficiency improvements. However, the magnitudes depended on the model applied and by segmentation of the data set. Productivity improved on average between 30% and 38% during the study period. It was found that 14 producers experience progress when SFA was applied against 13 when DEA was applied. The components of the Malmquist index indicated that in the case of the technical change (TC) index, 16 and 8 producers experienced progress when SFA and DEA were applied, respectively. In the case of efficiency change (EC) index the results were almost the opposite, 9 and 14 experienced progresses when SFA and DEA were applied, respectively. Greater variation was observed on a year-by-year basis. In the initial period of 1987/88 and in the next two years following, there was progress in efficiency. Thereafter, there was decline in the two succeeding years from 1990/91, which was followed by progress apart from one decline in 1993/94. These progressions and declines were similar for both SFA and DEA except in the last period of 1996/97, whence there was a slow down for SFA and a decline for DEA. The study suggested that perhaps productivity and efficiency decreased during the recession periods.

Barnes (2008) used stochastic production frontier approach to study technical efficiency of Scottish agriculture by focusing on the cereals, dairy, sheep, and beef sectors of Scotland over the period 1989 to 2004. He used the sum of revenues for each agricultural enterprise type including subsidies and grants as output and non-organic fertilizers, livestock feed, crop protection and seed, hired, regular and family and managerial labor, running costs, maintenance and depreciation, along with an interest charge (3%) on capital stock, rent and other land charges, and a linear time trend as inputs. The variables for inefficiency effects model were dummy variable 1 (non-less favored area (LFA) and LFA or Mixed LFA), dummy variable 2 (non-environmentally sensitive area (ESA) and ESA or Mixed ESA), dummy variable 3 (owner-occupied and tenanted), utilized agricultural area, livestock units, ratio of short and long-term debt to net worth.

The results indicated that mean efficiencies varied from 0.71 for cereals to 0.82 for sheep. The technical change varied from 0.2% for sheep farms to 6.3% for beef farms over the study period. The elasticities showed that the largest effect on production within the cereal sector appeared to be land and capital costs, followed closely by fertilizers. For dairy and sheep farming the most important factor was feed cost, followed by capital cost. Large effects were recorded for the four inputs in the beef sector, with feed costs having the maximum effect. Beef farms revealed increasing returns to scale of 1.012. Sheep farms exhibited decreasing returns to scale of 0.875. The returns to scale for cereals were 1.054 and that for dairy 0.927.

LFA had negative effect on efficiency while ESA status had a stronger effect on the efficiency of cereal farms than those with LFA designation. Owner-occupied farms had higher

efficiencies than tenanted. Farmers with a higher debt ratio were more technically efficient. The average farms were lagging behind the frontier by 0.7% per annum for dairy, 0.1% per annum for cereals and sheep, and 0.2% per annum for beef. Dairy farms exhibited falling mean technical efficiency from 0.80 in 1989 to 0.68 in 2004. Mean technical efficiency for Sheep farms fell from 0.92 to 0.68 over the same period. Cereal farms showed an erratic trend, with efficiencies which between 0.70 and 0.77. The beef mean technical efficiency improved from 0.70 to 0.85.

Guzman and Arcas (2008) analyzed efficiency of agricultural cooperatives by comparing the predictions of the Data Envelopment Analysis (DEA) technique to the traditional economic and financial ratio analysis. The mathematical models of Charnes et al (1978) and Banker et al(1984) (BCC) were applied to 247 observations of Spanish fresh fruits and vegetables cooperatives, over the period 2001 to 2003. Model 1 was based on operating income, including costs of materials consumed, labor, depreciation and other operating expenses and revenue (Output: revenues; Inputs: cost of materials consumed, staff costs, depreciation, other operating expenses). Model 2 (Output: revenues; Inputs: staff costs, fixed assets) was based on the basic variables of a production function, including fixed material assets, staff costs, and revenues.

The results indicated that in Model 1, 27% of farms were technically efficient and 22% were totally efficient. The average efficiency scores were above 0.90. The scale efficiency was 0.97, implying that the majority of the cooperatives were operating at their optimum scale of operations. In the case of Model 2, there was a decrease in the levels of performance in the model for variable returns to scale. If the cooperatives' size was ignored, the efficiency levels in the model of constant returns to scale rose to nearly 80%. There was an increase in scale

inefficiency relative to Model 1 (in the output-oriented models), although it was less pronounced than the performance in the input-oriented case (model 2).

The results of the factor analysis showed that the ratios used when integrated into a single factor explained 54.2% of the total variance. The results of an econometric analysis (Tobit regression) showed a positive relationship in the standardized coefficients corresponding to the scores of the factor, implying that the efficiency estimated by DEA technique was an appropriate complement to the economic analysis of agricultural cooperatives. It meant that the turnover to net assets ratios, the labor force productivity and the effective use of fixed assets could be adequately represented by efficiency estimates based on DEA models.

Serra et al (2008) analyzed the impact of government payments on production inefficiencies in Kansas during the years 1998 to 2001. The study adopted econometric (maximum likelihood) estimation of stochastic frontier additive model and indexing method (Paasche price index for aggregation of crops). The output variable used was the aggregate of the production of wheat, corn, grain sorghum and soybeans. The inputs were pesticides and insecticides, fertilizers and seeds, labor, capital (machinery and other equipment). As the Kansas database did not capture farm-level production flexibility contract (PFC) payments it was estimated using the acreage of the program crops and the base yield for each crop using farm-level data.

The results indicated that the average technical inefficiency is 0.30 and depended on input use. Technical inefficiencies had a positive correlation with the variance of output and a negative relationship with production mean. The fixed government transfer every year provided

fewer incentives to farmers to efficiently work the land, as compared to farmers who were dependent on market prices as their single income source.

Hassine-Belghith (2009) examined agricultural efficiency to understand whether agriculture production for export helps to improve agricultural efficiency and quality, using data on nine South Mediterranean countries (SMC), namely, Algeria, Tunisia, Morocco, Lebanon, Turkey, Jordan, Syria, Egypt and Israel, and five European Union (EU) countries, namely, France, Spain, Italy, Greece and Portugal, during the period 1990 to 2005. Econometric approach (maximum likelihood) was used to estimate a stochastic production frontier based on a Cobb-Douglas production function.

The outputs comprised of fruits (apricots, dates, figs, olives, peaches and nectarines, pears, apples, plums, grapes), shell-fruits (almonds, peanuts, hazelnuts, pistachios), citrus fruits (lemons, oranges, tangerines, grapefruits, other citrus fruits), vegetables (artichokes, carrots, cucumbers and pickles, strawberries, watermelons and melons, peppers, potatoes, tomatoes), cereals (rice, wheat, maize, barley) and pulses (beans, peas, chick-peas, lentils, vetches). The input variables were cropland, irrigation water, fertilizers, labor and machines. The variables representing country characteristics were agricultural land, irrigated agricultural area, water resources and agricultural capital equipment (number of wheeled and crawler tractors), environmental variables (average precipitations, agricultural area incurring severe and very severe degradation and land fragmentation evaluated by the share of land area with plots under five hectare), and human capacities (the Human Development Index).

The results indicated that input elasticity were positive, with water and cropland exhibiting the largest elasticity. Water was the most critical production factor, which is consistent with the fact that Mediterranean crops were highly water intensive. Fertilizers had a limited effect on South Mediterranean Countries (SMC) production, which may be due to fertilizer being used as a complementary factor to less expensive organic manure. The SMC crops appeared to be labor intensive while EU products were capital intensive. Precipitation and water availability had a positive impact on the efficiency of inputs, while land degradation and land fragmentation had a negative influence. The positive impact of precipitation on efficiency in SMC could be due to the fact that a relatively important part of the crops grown in the regions were produced in rain fed areas. Land fragmentation indicated that an important number of small farms with limited financial resources, low skills and inefficient traditional production methods existed.

It was found that the same level of production could be achieved from 33% less input use through improvements in technical efficiency. For the SMC region the average efficiency score is about 0.656. Exported products were more efficient, perhaps due to exposure to the international competitiveness or the self-selection of the most productive crops to the export market. Although, EU countries showed slightly better efficiency in the exporting sector and SMC producers appeared to be more efficient in domestic oriented sectors. This was probably due to the fact that most non-exported commodities in the EU panel were produced in Greece and Portugal, which had relatively low efficiency levels.

Performance persisted over time because the coefficients on lagged efficiency and lagged quality were positive and highly significant in the efficiency equation and the past quality was statistically significant in the quality equation. Export experience seemed to contribute to production efficiency in the EU panel, which could be because international competition enhanced the producers' incentives to export higher quality goods. The effect of exporting was greater for shell fruits, cereals and pulses. Significant impact of quality was there on the production efficiency of vegetables, fruits and citrus products, which could be due to the agricultural strategy promoting those commodities, whereas pulses and cereals were mostly planted in rain fed areas and using traditional farming methods.

Land degradation and farm fragmentation were negatively related with performance. Capital equipment and wider irrigated areas appeared to be positively correlated to performance. Human Development Index (HDI) was positively correlated with production efficiency and quality levels. It was higher for the SMC implying that improvements in worker skills and abilities may significantly enhance performance in these countries.

The authors found strong evidence of self-selection effects, as lagged efficiency and lagged quality significantly affect the probability of exporting. Production efficiency was higher in the EU, where countries such as France, Italy and Spain, exhibited higher technical efficiency and high quality levels in the cereals and pulses sectors. In the SMC, Turkey displayed relatively high efficiency and quality scores in all sectors. Countries such as Tunisia, Syria, Jordan, Lebanon and Morocco, exhibited moderate efficiency levels and showed quality advantage in fruits and vegetables. The study suggested that the liberalization process should be carried out

along with restructuring policies so that vulnerable countries survive the transition toward more liberal trade.

Mayen et al (2010) examined productivity and technical efficiency of organic and conventional dairy farms in the 24 major states of the United States.¹ The variables included milking cows, feed, labor, capital, other costs, farm characteristics, and operator characteristics. The results from the econometric analysis indicated that in the case of conventional production, the input elasticities for cows, feed, and other costs were positive and statistically significant, with cows having the largest marginal effect on milk production, followed by feed and other costs. In the case of organic production the elasticity was negative and statistically significant, implying lower productivity in organic production. The input elasticity of cows was lower in organic production, and the input elasticity of capital higher in organic production. Increasing all inputs by 1% would translate to a 1.33% increase in milk output on an organic farm, and a 1.21% increase in milk output on conventional farms.

The technology used by farms in the Southeast was more productive compared to the Upper Midwest. Farms with cows of higher weight produced more milk. The farms that were prone to rent more of their land for either crop production or pasture were less productive. Farms that raised more of their own feed seemed to be less productive. Operator age was associated with lower productivity. As herd size increased, statistical variance decreased while inefficiency

¹ The 24 major dairy states were Illinois, Indiana, Iowa, Missouri, Ohio (Corn belt region), Michigan, Minnesota, Wisconsin (Upper Midwest region), Maine, New York, Pennsylvania, Vermont (East region), California, Idaho, Oregon, Washington (West region), Arizona, New Mexico, Texas (Southwest region), Florida, Georgia, Kentucky, Tennessee, and Virginia (Southeast region).

variance increased. Furthermore, the organic dairy technology was approximately 13% less productive. Mean technical efficiency was 81.73% on organic farms and 83.60% on conventional farms. On correction of self-selection and assumption of a homogeneous technology, the technical efficiency of organic farms was 78.11%, which was 5% lower than conventional farms. If we ignore the self-selection, the organic productivity was 16% less productive than the conventional frontier, compared to 13% difference in the case of propensity score matching (PSM) to control for selection. If we assume same technology across farms, the average technical efficiency was 11% lower on organic farms than on conventional farms.

Zhu and Lansink (2010) studied the effect of common agricultural policy (CAP) reforms, in particular subsidies on technical efficiency of crop farms on agricultural efficiency of specialized cereals, oilseeds and protein crop (COP crops) farms in Germany, the Netherlands and Sweden during the period 1995 to 2004. Econometric method was used to estimate a stochastic frontier function (SFA). Törnqvist index was used to estimate price indexes of the composite inputs and outputs. The variables included in the study were cereals, root crops (sugar beets and potatoes), other crops and other products (non-crop) as output; seeds, chemicals (fertilizers and pesticides) and other direct items as variable input; and capital, labor and land as factor inputs.

The results indicated that the mean technical efficiency was 64% in Germany, 76% in the Netherlands and 71% in Sweden. The mean annual changes in technical efficiency were 0.1%, 0.4% and 2.3%, respectively. Furthermore, the share of crop subsidies in total subsidies had a negative impact on technical efficiency in Germany, a positive impact in Sweden, and was

insignificant in the Netherlands. The share of total subsidies in total farm revenues had negative effect on technical efficiency in all the three countries.

The multiple output production elasticity for each input was positive, except labor in Germany, which was non-significant. Crop farms in the Netherlands and Sweden showed increasing returns to scale (RTS), while farms in Germany exhibited decreasing returns to scale, which was in keeping with its negative production elasticity for labor. The high RTS in the Netherlands was attributed to the smaller size of Dutch farms. The annual mean technical change during the study period was 1.6% for Germany, 2.6% for the Netherlands and 1.6% for Sweden. Technical change was positive and decreasing in Germany and nearly constant at a fairly high level in the Netherlands. In Sweden, technical change was increasing. Fifthly, the positive (negative) change in technical efficiency was mainly due to farm size (degree of specialization) in Germany, and the degree of specialization (degree of subsidy dependence) in the Netherlands and Sweden.

Samarajeewa et al (2011) studied the causes of variation in efficiency for Alberta beef producers, and compare results from different density functions for a pooled cross-sectional data of 333 Albertan cow-calf farms during the period from 1995 to 2002. The variables used were the real value of weaned calves as output, labor, capital (depreciation and machinery / equipment / building lease payments on assets allocated to the cow-calf enterprise), winter feed (including fed grain, hay and silage) and pasture (animal unit months (AUM) per cow), veterinary (real veterinary, medicine and breeding expenses) and utilities (real value of total expenditures on fuel, machinery / corral / building repairs, utilities and miscellaneous expenses, custom work and

specialized labor, operating interest paid, taxes, water, license and insurance payments) as inputs. Additionally dummy variables were for time effects on cow–calf output, attributable to other factors of production. The variables used for inefficiency effects model were herd size, government support, three location variables, three biological efficiency variables, share of family labor, bedding costs and marketing costs.

The results indicated that the mean technical efficiency was 83.3% (ranged from 16.3% to 98.3%), allocative efficiency 78%, and economic efficiencies 67% (ranged from 0.84% to 98%). About 65% of sample farms attained technical efficiency levels above the average, while 58% attained economic and allocative efficiencies above the average. It was found that biological efficiency (increased conception, calving and weaning rates), larger herd size, higher share of family labor, and greater expense for bedding material reduced inefficiency. Government support had a significant positive association with technical, allocative and economic inefficiencies, implying that production efficiency of operations that received government support was lower than those which did not receive any government support. Herd size had a negative effect on technical, allocative and economic inefficiencies, which could be related to the benefits from economies of size. The Aspen Parkland and Boreal Transition region had a positive and significant correlation with technical and economic inefficiency, implying that geographic location was an important characteristic that could account for factors (e.g. soil fertility, differences in weather) not included in the production function. It was found that high correlation among density functions implied that ordinal rankings of technical efficiency measures for the sample farms were not sensitive to density function.

4. Summary and Concluding Comments

The study of agricultural efficiency is important to all economies, developed and developing. Traditional growth and development theories have demonstrated how efficient allocation of resources in all countries depends on economic efficiency in the agriculture sector. Historically, the agriculture sector has been supplying productive resources to other sectors in the economy as its productivity and efficiency improves over time. This report takes a comprehensive look at the literature on agriculture efficiency while focusing on the various methodologies used and important results relevant for agricultural policy formulation. The report is divided into three main parts. Part 1 consists of the review of studies conducted from the 1950s to the 1980s, part 2 followed with studies in the 1990s and part 3 finished with studies from 2000 and beyond. The division is necessary for a clear identification of the evolution of the purpose of the studies, methodologies used, and results and their implications.

Prior to the 1990s, the main objective of agricultural efficiency studies was to determine technical efficiency in agricultural production. Most of the studies did not investigate the extent of allocative efficiency as it required complete and quality data on input prices which in most part were difficult to obtain. During the 1990s, most studies focused on determining technical efficiency, allocative efficiency and scale efficiency among various sizes of farms and how different methodology may yield different results. During the 2000s agricultural efficiency studies focused primarily on using different methodologies to determine agricultural efficiency of various form of agricultural production (organic vs. conventional farms) while determining the effect of government policies on agricultural efficiency. The studies also investigated the

relative contributions of inputs growth, management practices, and other factors to agricultural efficiency.

Methodologies used overtime changed according to the level of simplicity of the objectives of the studies. Studies that were conducted prior to the development of the DEA (Data Enveloping Analysis-DEA which use lineal programming technique) and the stochastic frontier analysis (SFA) predominantly used index numbers, and simple econometric techniques to determine agricultural efficiency. By the mid 1970 till the end of the eighties most studies started using the DEA and SFA techniques in a relatively simpler manner. During the 1990s most of the studies used a combination of non-parametric approaches (Data Enveloping Analysis-DEA) and parametric approaches. In terms of econometrics, the studies used more complex estimation methods that are intended to correct some of the unintended econometric errors of earlier studies. Some of the studies also focused on sensitivity analysis of different methodology. During the 2000s, a more complex use of the DEA and the SFA emerged. Most studies used econometric estimation technique and analyzed the impact of various estimation techniques, functional form, and sample size on technical efficiency estimates.

The overall results indicated that farms are generally technically and scale inefficient. Smaller farms are less efficient than big farms because large farms tend to adopt new technology faster than smaller farms due to their relative better access to credit, information, and other scarce resources. Farm location, age of farmers and different crops or types of farms also matter for level of efficiency. Technical efficiency is related to economic factors, environmental conditions, locations, size of local market, and agricultural policies. Farms located in areas with better soil and weather conditions are more efficient than those who do not. It was also found

that farms in lower income countries are less efficient compared to their counterparts in middle income and developed income. However, in general, the level of farm inefficiencies have been reducing as new and better farm practices have been implemented over time. Farmers' education level has positive and significant impact on farm level efficiency. Organic farmers on the average are more efficient than conventional farmers. Most importantly, different econometric specification led to different results.

For policy purposes the results from the studies reviewed here shed light on the importance of improvement in extension services and increased access to credit and other resources as critical components of agricultural policy options to make farms, particularly the small ones, more technically and scale efficient. The results also demonstrate the importance of implementing agricultural policies that pays attention to other farm characteristics such as location and type of farms in order to avoid unintended negative impact of policies on farm level efficiency. It is also important that agricultural efficiency studies use the right model specification to yield the true efficiency parameters for policy purposes.

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