Economic Efficiency of Ethanol Plants in the US North Central Region

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Abstract

In this study we use data envelopment analysis to decompose the overall economic

efficiency of a sample of ethanol plants into three subcomponents: technical efficiency,

allocative efficiency and a new component we call marketing efficiency. The relative

importance of these sources of efficiency is of particular interest given the recent history

of bankruptcies, plant closings and ownership change in the industry.

Results reveal that observed production units are very efficient from a technical point

of view as suggested by a standard deviation of 1% in technical efficiency. However, our

results also show that bigger plants tend to be more economically efficient than others.

The conventional methodology would have identified this difference as coming from

allocative sources, i.e. bigger plants were correct in anticipating better relative prices and

built more capacity accordingly. However introduction of a new concept we call

marketing efficiency reveals that bigger production units obtain better relative prices

(through marketing contracts) than smaller production units rather than anticipating

prices more accurately. This might be a potential reason underlying the recent wave of

mergers and acquisitions in the industry.

Key words: ethanol, data envelopment analysis, efficiency decomposition, marketing

efficiency

Introduction

In this study we decompose the overall economic efficiency of a sample of ethanol plants into three subcomponents: technical efficiency, allocative efficiency and a new component we call marketing efficiency. The relative importance of these sources of efficiency is of particular interest given the recent history of bankruptcies, plant closings and ownership change in the industry. Of particular interest in this study is the extent to which some firms achieve more efficiency than others by receiving higher prices for products and/or paying lower prices for inputs.

The economic viability of the US corn ethanol industry depends upon prices, economic efficiency of ethanol plants, and public policy support. In the last two years prices have not been very favorable for the ethanol industry (low oil prices and high corn prices) and, in addition, public policy support is being debated due to doubts about the overall effect of the industry on emissions of greenhouse gases. Therefore the ability of plants to maximize net operating revenues (NOR) with current technology (i.e. their economic efficiency) is of the upmost importance for survival in the industry. In turn the economic efficiency and survival of individual plants may affect market structure (through exit and ownership changes) and hence future performance in the industry.

To measure efficiency and understand their drivers we decompose the overall economic efficiency of a sample of ethanol plants into three subcomponents: technical efficiency, allocative efficiency and a new component we call marketing efficiency. The relative importance of these sources of efficiency is of particular interest given the recent history of bankruptcies, plant closings and ownership change in the industry. Of

particular interest in this study is the extent to which some firms achieve higher NOR than others by receiving higher prices for products and/or paying lower prices for inputs.

The ability of some plants to achieve net operating revenues (NOR) realized by others may be limited by several factors. Plant configurations or financial constraints may prevent plants from choosing the scale and input-output combinations that maximize NORs. In addition, production plans are decided based on expected prices and errors in expectations formation may affect NORs. Finally, NORs may also be affected by the ability of the managers to secure favorable prices by contracting or by transacting in the futures market. This study aims at answering the following questions: How efficient are these relatively new ethanol plants? What are the net operating revenues foregone due to potential inefficiencies? Can we identify the sources of such inefficiencies? Can we distinguish inefficiencies due to marketing methods from technical and allocative inefficiencies? How do plants' marketing strategies affect their overall performance?

The existence of technical inefficiencies (i.e. plants underperform with respect to defined "best practice frontier") implies that there is room for plants to reduce the amount of inputs used per gallon of ethanol produced improving returns over operating costs. Existence of allocative inefficiencies point towards the fact that a plant can recombine inputs and outputs (e.g. change the dry/wet byproduct proportion which in turn may imply changes in natural gas/electricity proportion) along the technological frontier in such a way that it would increase NOR. Therefore elimination of technical and allocative inefficiency implies first reaching the technological frontier and then moving along this frontier to find the NOR maximizing combination, given prices.

It is usually assumed in studies of firm performance that all plants face the same market prices. Therefore prices are usually deemed exogenous and homogeneous across plants. But in reality prices are neither homogeneous nor entirely exogenous. Prices are not homogeneous because ethanol plants are located in different parts of the country and there are spatial differences in market prices for both corn and ethanol. In addition ethanol plants' managers use a combination of spot markets and future contracts to market their ethanol and procure their corn rendering prices that are partially controlled by management.

The latter source of price differences is of particular importance. Different marketing arrangements result in prices' variations across plants that are partly due to the relative ability of plant managers to achieve more favorable prices. Dispersion may imply that there are plants underperforming (facing prices that are less favorable) relative to other plants in the industry and hence there is opportunity for enhancement of their profitability. But to evaluate performance we need to distinguish between spatial and managerial sources of price dispersion. Plants can not be "punished" for spatial differences[1] but they can be penalized for their inability to achieve (through a mix of spot and contracts) prices at least as favorable as spot market prices observed in their own region.

In order to calculate potential improvements in NOR this study decomposes the overall economic efficiency of a sample of ethanol plants into three subcomponents: technical efficiency, allocative efficiency and a new component we call marketing efficiency. We first characterize the plants surveyed, and then conduct a measurement

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[1] Although if prices are consistently more favorable in some regions, plants could be deemed inefficient in their location decision.

and decomposition of economic efficiency of ethanol plants. We then investigate the potential link between the size of productive units and their economic performance.

Materials and Method

Data

Until recently, no publicly-available data on the economic and technical performance of the current generation of plants was available. Previous studies have calculated input requirements and byproducts' yield per gallon of ethanol produced by plants. Using engineering data McAloon et al. (2000) and Kwiatkowski et al. (2006) measured considerable improvement in plant efficiency between 2000 and 2006. Shapouri, et al. (2005) reported input requirements and cost data based on a USDA sponsored survey of plants for the year 2002. Wang et al. (2007) and Plevin et al. (2008), reported results based on spreadsheet models of the industry (GREET and BEACCON, respectively.) Pimentel et al. (2005) and Eidman (2007) reported average performances of plants although they do not clearly indicate the sources of their estimates. Finally Perrin et al. (2009) reported results on input requirements, operating costs, and operating revenues based on a survey of seven dry grind plants in the Midwest during 2006 and 2007.

With the exception of Shapouri et al. (2005) and Perrin, Fretes and Sesmero (2009) all of these studies reported values corresponding to the average plant rather than to individual plants. In addition, it is generally believed that the industry has become more efficient and technologically homogeneous since 2005. Since the data used in Shapouri et al. (2005) was collected in 2002 it may not be representative of current technologies in the industry. In contrast to Shapouri et al. (2005), Perrin et al. (2009) surveyed plants in

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operation during 2006 and 2007 and employed a much more restrictive sampling criteria (discussed below) which yielded a modern and technologically homogenous sample of plants. This sample is believed to be more representative of current technologies and is, hence, our data of choice to assess the environmental performance of plants. Based on 33 quarterly reports of input and output quantities and prices from a sample of seven ethanol plants in the Midwest we evaluate economic efficiency of each observation relative to others in the sample and decompose it in the three sources previously discussed.

We refer to each quarterly observation as a decision making unit (DMU.) DMUs are assumed to share a technology that transforms a vector of 7 inputs (corn, natural gas, electricity, labor, denaturant, chemicals, and "other processing costs") into 3 outputs (ethanol, dried distiller's grains with 10% moisture content (DDGS), and modified wet distiller's grains with 55% moisture content (MWDGS).) Results of our survey contained total expenditures in labor, denaturant, chemicals, and other processing costs and, as a result, we calculated implicit quantities for these inputs dividing total expenditures by their corresponding price indexes. Observed combinations of inputs and outputs are taken to be representative points from the feasible ethanol technology. In this study we use non parametric programming methods (Färe, et al) to infer the boundaries of the feasible technology set. We model the technology as a multiple-input multiple-output graph and all efficiency measures are defined in reference to that graph.

Ethanol Plants: Characteristics

Table 1 presents some characteristics of the seven dry grind ethanol plants surveyed. According to Table 1 the plants produced an average rate equivalent to 53.1 million

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gallons of ethanol per year, with a range from 42.5 million gallons per year to 88.1 million gallons per year. The period surveyed included the third quarter of 2006 until the fourth quarter of 2007 (six consecutive quarters). In addition plants could be differentiated by how much byproduct they sold as DDGS (10% moisture) compared to MWDGS (55% moisture.) Variation on this variable was significant, averaging 54% of byproduct sold as DDGS, but ranging from one plant that sold absolutely no byproduct as DDGS to another plant that sold nearly all byproduct (97%) as DDGS.

Finally, plant marketing strategies are also characterized in Table 1. In purchasing input feedstock, five of the six plants purchased corn via customer contracts. Similarly, in selling ethanol, five of the six plants used third parties or agents. Byproduct marketing across plants displayed a higher degree of variance. Marketing of DDGS was split fairly evenly between spot markets and third parties/agents. An even higher variability was observed for MWDGS, where no one marketing strategy (spot market, customer contract, or third party/agent) was significantly more prevalent across plants than others.

Table 2 displays descriptive statistics of inputs used and outputs produced by the 33 DMUs in our sample. As mentioned before the basic observations in this study corresponds to a plant in a given quarter; so two quarters of the same plant are considered as two different observations as are two plants in the same quarter.

Characterization of Technology From Individual Plant Data

Plants are constrained by a technology transforming a vector of N inputs $x = (x_1, x_2,...,x_N) \in \Re_+^N$ into a vector of M outputs $u = (u_1, u_2,...,u_M) \in \Re_+^M$. Observed combinations of inputs used and outputs produced (x^j, u^j) are taken to be representative

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points from the feasible ethanol technology. In this study we use data envelopment analysis (DEA) to infer the boundaries of the feasible technology set from the observed points, following the notation in Färe, et al.

Observations from the technology consist of a sample of J DMUs producing M outputs and using N inputs. The production technology can be represented by a graph denoting the collection of all feasible input and output vectors:

$$GR = \left\{ (x,u) \in \Re_+^{N+M} : x \in L(u) \right\}$$

Where $L(u)$, is the input correspondence which is defined as the collection of all input vectors $x \in \Re_+^N$ that yield at least output vector $u \in \Re_+^M$.

The frontier of the graph GR and observed levels of inputs and outputs will serve as references for environmental efficiency assessment.

Decomposition of Economic Efficiency without Marketing Efficiency

A given DMU is deemed economically efficient whenever it chooses a feasible (subject to the graph) input-output combination that maximizes NOR given prices. In this section we proceed to calculate and decompose economic efficiency assuming that prices are exogenous and hence there is no contract management that can affect prices at which ethanol is sold and corn procured.

Assuming variable returns to scale[2] and strong disposability of inputs and outputs the graph can be denoted by:

$$GR^j(V,S) = \left\{ (x,u) : u^j \le zM, x^j \ge zN, \sum_{j=1}^{33} z^j = 1, j = 1,...,33 \right\} \tag{1}$$

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[2] In this way we minimize stronger assumptions about convexity that may result in artificially low efficiency indexes.

Where z depicts a row vector of 33 intensity variables, M is the 33x3 matrix of observed outputs, u^j is the 1x3 vector of observed outputs corresponding to the jth DMU, N is the 33x7 matrix of observed inputs, and x^j is the 1x7 vector of observed inputs corresponding to the jth DMU.

We define the set of all combinations of inputs and outputs that result in higher NOR than that actually achieved by the jth DMU as:

$$\pi_g^j\left(x^j, u^j\right) = \left\{\left(x^{j\prime}, u^{j\prime}\right) : p^j x^{j\prime} + r^j u^{j\prime} \geq p^j x^j + r^j u^j\right\} \qquad (2)$$

Where p^j is the vector of input prices paid and r^j the vector of output prices received by the jth DMU and the subscript g denotes greater than observed NOR.

We define an iso-profit line in ethanol and corn space corresponding to the jth DMU as those combinations of ethanol and corn that result in the same level of NOR given p^j and r^j. Fig. 1 depicts this set graphically in the corn and ethanol space (i.e. keeping all other inputs and outputs fixed.) The set π_g^j consists of all those points above the iso-profit line as indicated by the arrows with direction northwest.

In Fig. 1 the feasible technology set is represented by a graph displaying variable returns to scale and strong disposability of inputs and outputs as indicated by the arrows moving from the frontier ($u_{Eth} = f\left(x_c\right)$) with direction southeast. As clearly seen in Fig. 1, the set π_g^j includes combinations outside the graph and hence not attainable by DMUs in the sample. The subset of observations in π_g^j that belong to the graph and are hence attainable by DMUs is depicted by the intersection of both sets delimited by the bold lines in Fig. 1:

$$\pi_g^j\left(x_c^j, u_{Eth}^j\right) \cap GR(V,S) \tag{3}$$

The *j*th DMU could choose any alternative production plan within the area denoted by the bold lines achieving a feasible increase in NOR.
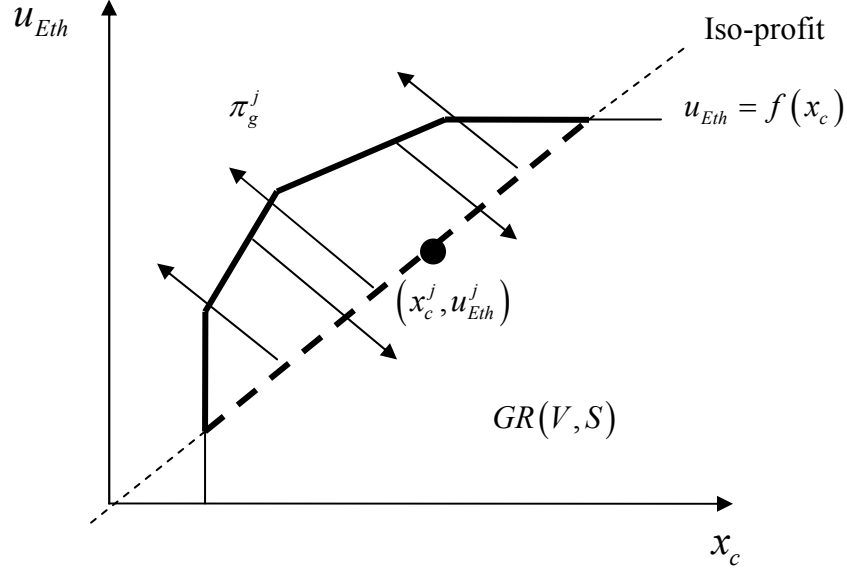
Fig. 1 – Iso-profit and Sets

We apply in this study a hyperbolic graph efficiency measure which means that the **technically** efficient projection of a given observation to the boundary of the technology set follows a hyperbolic path defined by equi-proportional reductions in inputs and increases in outputs. The value of the proportionate change necessary to reach the boundary, TE^j, is defined as the technical efficiency of plant j:

$$TE_v^j\left(x^j, u^j / V, S\right) = \min\left\{\lambda : \pi_g^j\left(\lambda x_c^j, \lambda^{-1} u_{Eth}^j\right) \cap GR(V,S) \neq \varnothing\right\} \tag{4}$$

Where λ is a scalar defining the proportionate changes and the rest is as before. We calculated the value of TE_v^j using MATLAB as indicated in the Appendix A.

Technical efficiency defined in Eq. (4) is illustrated in Fig. 2 by the distance from $\left(x_c^j, u_{Eth}^j\right)$ to point A which corresponds to the technically efficient allocation in corn and ethanol space.
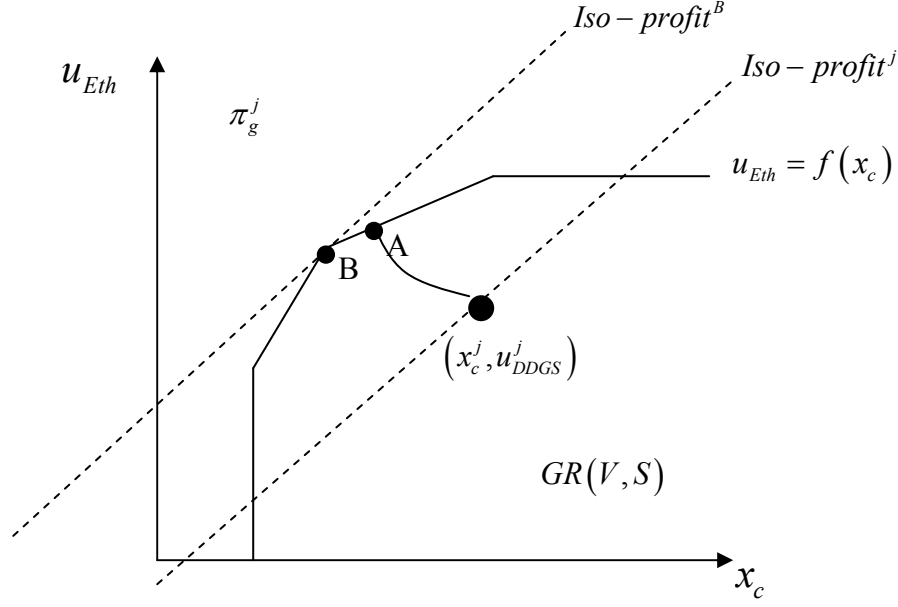
Fig. 2 - Technical Efficiency

Note however that point A does not correspond to the maximum feasible NOR level since it does not coincide with the point of tangency between the isoprofit and the graph (point B.) The allocation that achieves the maximum level of NOR subject to the graph is called the **overall** economic efficient allocation.

Technically, we define this maximum feasible level of NOR as:

$$\overline{\pi^j} = \max_{x,u}\left\{ \pi^j = p^j x + r^j u \quad s.t. \ (x,u) \in GR(V,S) \right\} \tag{5}$$

Where $\overline{\pi^j}$ denotes maximum NOR attainable by j subject to the graph and observed prices, x is the vector of inputs, and u is the vector of outputs and the rest is as defined before. Maximum profits have been calculated using MATLAB.

Overall economic efficiency under variable returns to scale, E_v^j , is measured by the

hyperbolic distance between a given observation j and the isoprofit line corresponding to

$\overline{\pi^j}$. The hyperbolic distance is computed through calculation of the reduction of

observed inputs and equiproportional expansion of observed byproducts such that the

isoprofit corresponding to $\overline{\pi^j}$ is reached. This is illustrated by Fig. 3 where overall

environmental efficiency is the distance between $\left(x_c^j, u_{Eth}^j\right)$ and point C.
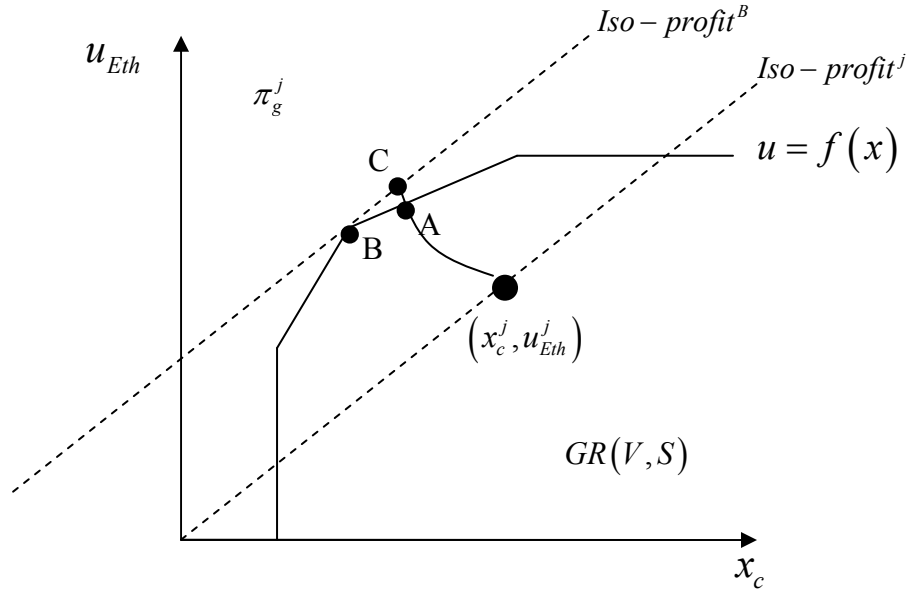
Fig. 3 - Decomposition of Overall Economic Efficiency

Since the movement from $\left(x_c^j, u_{Eth}^j\right)$ to C is a hyperbolic one, the measure of overall

economic efficiency, E_v^j , is related to maximum NOR in the following manner:

$$\overline{\pi^j} = E_v^j \, p^j \, x^j + \left(E_v^j\right)^{-1} r^j \, u^j \qquad j = 1, 2, ..., J \tag{6}$$

We can decompose E_v^j into purely technical efficiency TE_v^j (represented graphically

by the distance between $\left(x_c^j, u_{DDGS}^j\right)$ and A) and allocative inefficiency AE_v^j (represented

graphically by the distance between A and C.) Overall efficiency can be expressed as:

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$$E_v^j = AE_v^j \, TE_v^j \qquad\qquad (7)$$

Therefore, we can define allocative inefficiency residually as:[3]

$$AE_v^j = \frac{E_v^j}{TE_v^j} \qquad\qquad (8)$$

Based on the solution to the problem described in Eq. (5) we calculate overall economic efficiency by solving the implicit Eq. (6) for each observation. These measures of economic efficiency and their decomposition, Eq. (7)-(8), are calculated for our sample of surveyed dry grind ethanol plants and reported in Table 3.

Table 3 shows that the economic efficiency of the average DMU is 0.89 which suggests that there may be room for improvement in profitability. Almost all the observed inefficiency comes from allocative sources as indicated by the average value but also by the dispersion observed in this source across DMUs. This in turn means that although most DMUs are operating in the technological frontier they are doing so in points that do not coincide with the NOR-maximizing point (such as point B in Figure 3.) In the following section we address the issue of potential drivers of economic efficiency.

Drivers of Economic Efficiency

Many factors could be driving the differences in economic efficiencies across units. To identify these factors we have conducted an analysis of variance that relates the calculated indexes of overall economic efficiency to four treatment variables: size (big or small), marketing method (third party, direct spot, or direct contract), ownership (whether

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[3] Environmental allocative inefficiency was illustrated in Fig. 2 by the distance between the iso-pollution corresponding to combination A and iso-pollution corresponding to point D.

or not the DMU is owned by a multi-DMU firm), and state in which the DMU is located. Results displayed in Table 4 show that size is the only variable that appears to have an effect on overall efficiency; i.e. size is a variable that seems to be explaining part of the variance of overall economic efficiency.

To find the relationship between size and efficiency we partition the sample into big units and small units. Units are classified as big if they produce more than average production in the sample (13.6 million gallons) and they are classified as small otherwise. Results are presented in Table 5. From inspection of this table we quickly realize that economic efficiency seems to be positively correlated with size. However technical efficiency is not.

Results in Table 5 suggest that for most economically inefficient DMUs an increase in the scale of operations would increase NOR. We proceed now to quantify the reallocation along the frontier (increase in size) that would take the average DMU to the NOR-maximizing point. Table 6 shows that by increasing production of ethanol by 57% and the quantity of corn used by 54% the average DMU may have increased NOR.[4] The average scaling up of operations is rather large.

There are two potential reasons why an increase in scale may be NOR improving. One is when prices are so favorable that the average DMU finds profitable to increase scale as much as possible even when operating at a portion of the technology that displays DRS. The second reason is purely technological. The average DMU finds profitable to increase scale because it's operating at a portion of the technology displaying increasing returns to scale. To identify which of these potential reasons is

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[4] We only show the change required in ethanol production and corn usage as these are the most important revenue and cost categories.

operating behind the results in our sample we measure the degree of returns to scale for each DMU. We do so by calculating technical efficiency under variable, non-increasing and constant returns to scale and combining these results.

Returns to Scale

Calculation of technical efficiency can be done on the basis of a technology displaying constant returns to scale (CRS), decreasing returns to scale (DRS), increasing returns to scale (IRS), or variable returns to scale (VRS). Technical efficiency with variable returns to scale has already been defined and measured.

Technical efficiency with constant returns to scale technology is:

$$TE_c^j\left(x^j, u^j / C, S\right) = \min\left\{\lambda : \left(\lambda x^j, \lambda^{-1} u^j\right) \in \left(GR / C, S\right)\right\}, \quad j = 1, 2, ..., J \tag{9}$$

We calculated the value of $TE_c^j\left(x^j, u^j / C, S\right)$ using MATLAB as indicated in Appendix B.

Technical efficiency with non-increasing returns to scale technology is:

$$TE_n^j\left(x^j, u^j / N, S\right) = \min\left\{\lambda : \left(\lambda x^j, \lambda^{-1} u^j\right) \in \left(GR / N, S\right)\right\}, \quad j = 1, 2, ..., J \tag{10}$$

We calculated the value of $TE_n^j\left(x^j, u^j / N, S\right)$ using MATLAB as indicated in Appendix C.

Scale inefficiency can be defined in terms of two ratios. The ratio between technical efficiency with constant returns to scale as defined in (9) to technical efficiency with variable returns to scale as defined in (4):

$$S^j\left(x^j, u^j\right) = TE_c^j\left(x^j, u^j / C, S\right) / TE_v^j\left(x^j, u^j / V, S\right) \tag{11}$$

The second ratio is that between technical efficiency with constant returns (4) and technical efficiency with non-increasing returns to scale (10):

$$S^j\left(x^j,u^j\right)=TE^j_c\left(x^j,u^j \: / \: C,S\right)/TE^j_n\left(x^j,u^j \: / \: N,S\right) \tag{12}$$

As developed by Färe et al. if ratio (11) is higher than one and if, in addition, ratio (12) is lower than (equal to) one, the observation shows decreasing (increasing) returns to scale. The measures defined in (9) and (10) are calculated with the FMINCON routine in MATLAB. The results for all 33 observations are reported in Table 7. This table shows that the overwhelming majority of DMUs (and hence the average DMU) are operating in portions of the technology which are very close to displaying CRS; i.e. the average scale efficiency is very close to 1. A total of 22 DMUs display CRS, 6 exhibit IRS, and 5 display DRS.

These results suggest that the main reason for the positive correlation between economic efficiency and size may be that prices were very favorable for most DMUs making an increase in scale desirable. But although prices were favorable for most of these plants big differentials on prices paid and received across DMUs are also observed and so we focus our attention now on the analysis of price behavior and their potential drivers.

Decomposition of Economic Efficiency with Marketing Efficiency

In the efficiency literature, DEA measures of allocative efficiency determine how DMUs could readjust inputs and outputs to increase profit or revenue or decrease cost given prices. However these measures assume all DMUs face the same prices and in our sample, plants reported substantially different prices. This is due to the fact that plants

use different marketing arrangements (including spot markets, contracts, and marketers as described in Table 1) to procure their inputs and sell their outputs. Therefore we introduce in this section a new concept capturing the ability of plant managers to obtain prices at least as favorable as spot market prices.

Provided we have price observations for different plants located in different states and across time, differences among prices paid and received by DMUs can be due to spatial patterns, managerial efficiency and inflation. The part due to inflation has been controlled for by adjusting all prices to a base quarter (3rd quarter of 2006) using the Producer Price Index (PPI) as calculated by the Bureau of Labor Statistics. The managerial and spatial parts however, are more difficult to deal with.

Since we have one plant per state we have a perfect correlation between space and manager and hence distinguishing between managerial and spatial sources of price differentials requires quarterly data on prices at the State level. State level data on corn prices is publicly available from USDA NASS Agricultural Prices. Ethanol prices, on the other hand, are not publicly available. As a result we construct a proxy for quarterly ethanol spot market prices based on gasoline prices. More specifically the spot market price of ethanol faced by observation j (located in State k at time t) is approximated with the following relationship:

$$r_{eth}^{j,M} = (r_{k,t}^{gas}\alpha + \beta)\theta + (r_{k,t}^{gas}\alpha)(1-\theta) \tag{13}$$

Where $r_{eth}^{j,M}$ denotes market price of ethanol faced by the j*th* DMU, $r_{k,t}^{gas}$ is rack price of gasoline in State k at time t, θ is the proportion of ethanol sold as E10, $(1-\theta)$ is the proportion sold as E85, α is the ratio between energy content in ethanol and energy content in gasoline, β is the subsidy to blenders per gallon of ethanol incorporated into

the blend. In particular, in our analysis, $\alpha = 0.66$ and $\beta = 0.51$. Rack prices of gasoline in different States at different points in time are publicly available from the Energy Information Administration.[5]

We denote market prices (as opposed to prices reported by plants) faced by the jth DMU as $\left(r_M^j, x_M^j \right)$. Output market prices faced by the jth DMU, r_M^j, consist of ethanol market price r_{eth}^j and prices directly reported by plants in all other revenue categories (byproducts). Input market prices x_M^j consist of corn market prices from NASS and prices directly reported by plants in all other cost categories.

Using these prices we are now ready to define our novel concept of marketing efficiency. Overall economic efficiency, E_v^j, does not change. We introduce, however, marketing efficiency as an additional component to this measure. Marketing efficiency denotes the increase in revenue and equi-proportional reduction in cost resulting from the ability of the managers to secure prices more favorable than those corresponding to spot prices. This is illustrated by the distance between $\left(x_c^j, u_{Eth}^j \right)$ and D in figure 4.

The marketing efficiency of the jth DMU is defined as the hyperbolic distance between profit with observed prices and profit with spot market prices:

$$\pi_M^j = \left(r^j u^j \right) \left(ME^j \right)^{-1} - \left(p^j x^j \right) ME^j \qquad\qquad j = 1, 2, ..., J \qquad\qquad (14)$$

Where π_M^j is the profit DMU j would have obtained had it faced market prices (i.e. $\pi_M^j = r_M^j u^j - p_M^j x^j$), ME^j is marketing efficiency of the jth DMU, $\left(r^j u^j \right)$ are revenues

actually obtained by the j*th* DMU, and $\left(p^j x^j \right)$ are costs actually incurred by the j*th* DMU.

Although we have illustrated the case in which profits with market prices are higher than observed profits the reverse may well happen so ME^j will not be bounded between zero and one. In fact if observed profits π^j are higher (lower) than π^j_M then $ME^j >(<)$ 1.

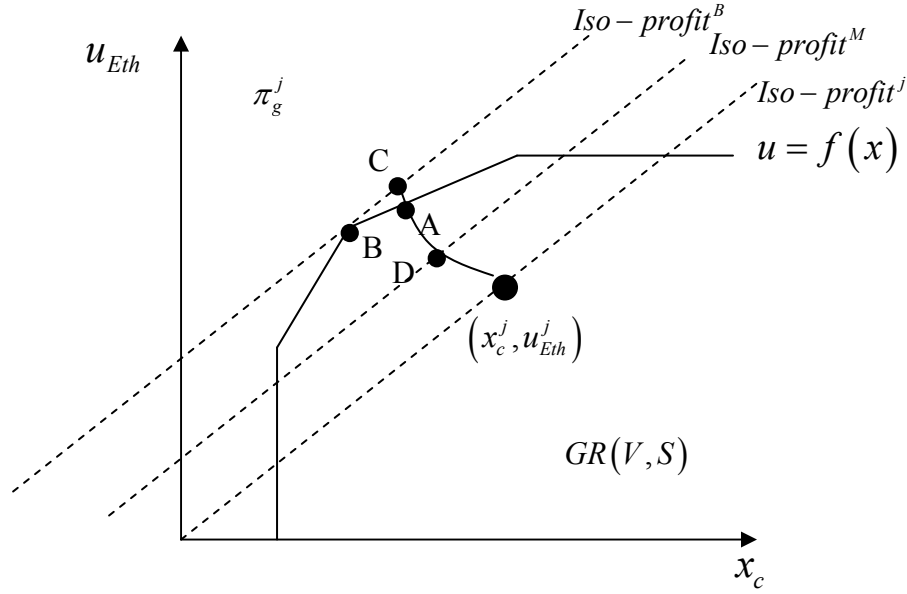**Fig. 4 - Decomposition of Overall Economic Efficiency**

We can decompose E^j_v into purely technical efficiency TE^j_v (represented graphically by the distance between $\left(x^j_c, u^j_{DDGS} \right)$ and A), allocative inefficiency AE^j_v (represented graphically by the distance between A and C), and ME^j. Overall efficiency can be expressed as:

$$E^j_v = AE^j_v \, TE^j_v ME^j \tag{15}$$

Therefore, we can define allocative inefficiency residually as:[6]

$$AE_v^j = \frac{E_v^j}{TE_v^j ME^j} \tag{16}$$

Based on values of π_M^j we calculate marketing efficiency by solving the implicit Eq. (14) for each observation. The FZERO procedure in MATLAB was used in calculations. Technical and overall economic efficiency are the same as before. Allocative efficiency is calculated residually as indicated by Eq. (16). Measures of marketing efficiency and allocative efficiency (along with original values of overall economic efficiency and technical efficiency) are displayed in Table 8.

The average of marketing efficiency indexes is 1.03. This reveals that, in average, plants obtained more favorable relative prices than those observed in spot markets by managing contracts to sell ethanol and buy corn. On the other hand a significant dispersion is observed across DMUs as denoted by a standard deviation of 0.10 and a big difference between minimum (0.80) and maximum (1.23) values. In fact the two main sources of dispersion in plant performance are the allocative and marketing components.

Marketing Efficiency and Size

There are three main results obtained so far that we would like to sum up. First, results suggest that bigger plants tend to be more economically efficient. Second the two main sources of differences in economic efficiency appear to be allocative and marketing

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[6] Environmental allocative inefficiency was illustrated in Fig. 2 by the distance between the iso-pollution corresponding to combination A and iso-pollution corresponding to point D.

efficiency and NOT technical efficiency. Therefore while size seems to be positively influencing overall economic efficiency, it is not clear if this influence is materialized through allocative forces (plants expected high market prices that were later realized) or marketing forces (plants, through marketing channels, obtained prices that were more favorable that market prices rationalizing a big size). To tackle this question we partition our sample into big and small units and compare average values for all three types of efficiencies. Results are condensed in Table 9.

Big DMUs achieved higher average marketing efficiency (1.042) than small ones (1.006) while displaying about the same allocative and technical efficiency. This suggests that a possible source of differential performance across big and small units is their ability to market products and procure inputs using tools such as contracting and future markets. These differences would be manifested as allocative inefficiency if one were not to separately identify the concept of marketing efficiency introduced in this study. This might be a potential reason underlying the recent wave of mergers and acquisitions in the industry.

Conclusions

This study exploits data from a survey of ethanol plants and tries to pinpoint the main drivers of plants' economic efficiency which is of particular relevance for their survival and resulting industry performance. To do so we have decomposed the overall economic efficiency plants into three subcomponents: technical efficiency, allocative efficiency and a new component we call marketing efficiency. Introduction of this concept resulted in

insights that may help understanding the recent history of bankruptcies, plant closings and ownership change in the industry.

Results reveal that DMUs are very efficient from a technical point of view as suggested by a standard deviation of 1% in technical efficiency. However, our results also show dispersion across plants' overall economic efficiency. The size of decision making units seems to be positively correlated with economic efficiency. By calculating returns to scale displayed by each DMU we have concluded that the positive correlation between size and economic efficiency is not due to technological reasons; i.e. increasing returns to scale.

Introduction of a new concept we call marketing efficiency revealed that bigger plants tend to secure more favorable relative prices (relative to spot market prices) than smaller units. In particular we find that big DMUs achieved higher average marketing efficiency (1.042) than small ones (1.006) while displaying about the same allocative efficiency. This suggests that a possible source of differential performance across big and small units is their ability to market products and procure inputs using tools such as contracting and future markets. These differences would be manifested as allocative inefficiency if one were not to separately identify the concept of marketing efficiency introduced in this study. This might be a potential reason underlying the recent wave of mergers and acquisitions in the industry.

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Table 1. Characteristics of the seven surveyed plants

States Represented	Iowa, Michigan, Minnesota, Missouri, Nebraska, S. Dakota, Wisconsin				
Annual Production Rate (m. gal/y)	Smallest	42.5			
	Average	53.1			
	Largest	88.1			
Number of Survey Responses by Quarters	03_2006	5			
	04_2006	6			
	01_2007	7			
	02_2007	7			
	03_2007	7			
	04_2007	2			
Percent of Byproduct Sold as Dry DGS	Smallest	0			
	Average	54			
	Largest	97			
Primary Market Technique		Corn	Ethanol	DDGS	MWDGS
	Spot	0	0	3	1
	Customer Contract	5	1	0	1
	Third Party/Agent	0	5	2	2

Table 2. Descriptive Statistics: Inputs and Outputs

	Corn (million bushels)	Natural Gas (thousand MMBTUs)	Electricity (million kwh)	Ethanol (million gallons)	DDGS (thousand tons)	MWDGS (thousand tons)
Average	4.8	361	7,8	13.7	21.3	14.5
Std Dev	0.9	61	1.5	2.8	10	15.4
Min	3.6	297	6.7	10.6	0	199
Max	8	569	13.3	22,9	34.2	56.2

Table 3. Decomposition of Economic Efficiency

DMU	Overall Graph Efficiency	Technical Efficiency	Allocative Graph Efficiency	Maximum Increase in Profits (cents per gallon)
1	0.82	0.977	0.84	59
2	0.84	1	0.84	67
3	0.79	0.985	0.80	91
4	0.72	1	0.72	120
5	0.80	1	0.80	82
6	0.85	0.979	0.87	61
7	0.95	1	0.95	21
8	0.82	1	0.82	63
9	0.83	1	0.83	68
10	0.80	0.997	0.80	80
11	0.86	1	0.86	53
12	0.94	1	0.94	23
13	0.96	1	0.96	17
14	0.95	1	0.95	21
15	0.91	1	0.91	32
16	0.92	1	0.92	27
17	0.90	1	0.90	37
18	0.88	1	0.88	44
19	0.88	1	0.88	51
20	0.996	1	0.996	1
21	0.93	1	0.93	28
22	0.92	1	0.92	32
23	0.93	1	0.93	23
24	0.89	1	0.89	47
25	0.91	1	0.91	35
26	1	1	1	0
27	0.96	1	0.96	8
28	0.95	1	0.95	18
29	0.92	1	0.92	25
30	0.94	1	0.94	19
31	0.912	0.99	0.92	31
32	0.80	1	0.80	92
33	0.94	1	0.94	24
Average	**0.891**	**0.998**	**0.893**	**42.52**
Std Dev	0.07	0.01	0.07	28.54
Min	0.72	0.98	0.72	0
Max	1	1	1	119.79
% of Eff Points	6.1	84.8	27.3	

Table 4. Drivers of Economic Efficiency

	Prob>F[1]
Size (Big/Small)	0.0553
Marketing Technique (Contract/Spot/Third Party)	NaN
Ownership (Single Plant/Multiple Plant)	NaN
Location (State)	0.3786

[1] This column displays the p-values of the hypothesis that the corresponding variable has no effect on overall economic efficiency. Therefore the closest this value to zero the stronger the effect of the treatment variable on efficiency.

Table 5. Average Input-Output Reallocation (NOR maximization)

	Ethanol	Corn
% Change in Category	57	54

Table 6. Profit Efficiency of DMUs Grouped by Size

DMU Size / Statistic	Economic Efficiency		Technical Efficiency	
	BIG	SMALL	BIG	SMALL
Average	0.92	0.86	0.99	0.99
Efficient Points (%)	11	6	76.5	76.5

Table 7. Returns to Scale of DMUs

DMU	Technical Efficiency VRS	Technical Efficiency NIRS	Technical Efficiency CRS	Scale Efficiency VRS/CRS	Category
1	0.968	0.959	0.959	0.991	IRS
2	1	1	1	1	CRS
3	0.9858	0.9858	0.9857	0.999	DRS
4	1	1	0.999	0.999	DRS
5	1	1	1	1	CRS
6	0.984	0.977	0.977	0.993	IRS
7	1	1	1	1	CRS
8	1	1	1	1	CRS
9	1	1	1	1	CRS
10	0.996	0.996	0.996	0.999	IRS
11	1	1	1	1	CRS
12	1	1	1	1	CRS
13	1	1	1	1	CRS
14	1	1	1	1	CRS
15	0.999	0.999	0.989	0.989	DRS
16	1	1	1	1	CRS
17	1	1	1	1	CRS
18	1	1	1	1	CRS
19	1	1	1	1	CRS
20	1	1	1	1	CRS
21	1	1	1	1	CRS
22	0.997	0.996	0.996	0.999	IRS
23	1	1	1	1	CRS
24	1	1	1	1	CRS
25	1	1	1	1	CRS
26	1	1	1	1	CRS
27	1	1	1	1	CRS
28	0.999	0.999	0.999	1	CRS
29	0.9999	0.9997	0.9997	0.999	IRS
30	1	1	1	1	CRS
31	0.994	0.985	0.985	0.990	IRS
32	1	1	1	1	CRS
33	1	1	0.987	0.987	DRS
Average	0.998	0.997	0.996	0.998	

Table 8. Returns to Scale of DMUs

DMU	Overall Economic Efficiency	Technical Efficiency	Allocative Eff. w/o Marketing Efficiency	Allocative Eff. With Marketing Efficiency	Marketing Efficiency
1	0.82	0.968	0.85	0.91	0.93
2	0.84	1	0.84	0.80	1.06
3	0.79	0.986	0.80	0.77	1.05
4	0.72	1	0.72	0.65	1.11
5	0.80	1	0.80	0.76	1.05
6	0.85	0.984	0.86	0.73	1.17
7	0.95	1	0.95	0.90	1.05
8	0.82	1	0.82	0.67	1.23
9	0.83	1	0.83	0.80	1.04
10	0.80	0.996	0.80	0.66	1.21
11	0.86	1	0.86	0.77	1.11
12	0.94	1	0.94	0.81	1.15
13	0.96	1	0.96	0.85	1.13
14	0.95	1	0.95	0.89	1.07
15	0.91	0.999	0.91	0.82	1.12
16	0.92	1	0.92	0.92	1.01
17	0.90	1	0.90	0.85	1.06
18	0.88	1	0.88	0.79	1.11
19	0.88	1	0.88	0.86	1.02
20	0.996	1	0.996	1.02	0.98
21	0.93	1	0.93	0.98	0.95
22	0.92	0.997	0.92	0.95	0.96
23	0.93	1	0.93	1.16	0.80
25	0.89	1	0.89	0.91	0.98
26	0.91	1	0.91	0.96	0.95
27	1	1	1	1.10	0.91
28	0.96	1	0.96	1.03	0.93
29	0.95	1	0.95	1.01	0.94
30	0.92	0.999	0.92	1.03	0.90
31	0.94	1	0.94	1.03	0.91
32	0.912	1	0.91	0.97	0.94
33	0.80	0.994	0.81	0.67	1.20
34	0.94	1	0.94	0.99	0.95
Average	**0.891**	**0.998**	**0.893**	**0.88**	**1.03**
Std Dev	0.07	0.01	0.06	0.13	0.10
Min	0.72	0.97	0.72	0.65	0.80
Max	1	1	1	1.16	1.23

Table 9. Size and Efficiency

Size Group / Efficiency Component	Marketing Efficiency	Technical Efficiency	Allocative Efficiency
Average - Whole Sample	1.024	0.998	0.889
Average - Big	1.042	0.999	0.894
Average - Small	1.006	0.997	0.883
Efficiency Big/Efficiency Small	1.036	1.002	1.012

Appendix A

The measure in (4) can be computed as the value of λ in the following non-linear programming problem:

$$\underset{\lambda,z}{Min}\ \lambda \qquad s.t. \quad \lambda^{-1}u^j \leq zM$$

$$\lambda x^j \leq zN$$

$$z^j \varepsilon\ \Re^+, \quad j = 1, 2, ..., J$$

Appendix B

The measure in (9) can be computed as the value of λ in the following non-linear programming problem:

$$\underset{\lambda,z}{Min}\ \lambda \qquad s.t. \quad \lambda^{-1}u^j \leq zM$$

$$\lambda x^j \leq zN$$

$$z^j \varepsilon\ \Re^+, \quad j = 1, 2, ..., J$$

Appendix C

The measure in (10) can be computed as the value of λ in the following non-linear programming problem:

$$\underset{\lambda,z}{Min}\ \lambda \qquad s.t. \quad \lambda^{-1}u^j \leq zM$$

$$\lambda x^j \leq zN$$

$$\sum_{j=1}^{J} z^j \leq 1$$