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Technology, Markets, and Ethanol Plants Shutdown Price

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Abstract

Price volatility and policy changes may compromise the ability of corn ethanol plants to operate above average variable cost and avoid shutdown. This study derives a variable cost function capable of accommodating two features of ethanol plants; 1) some inputs are used in fixed proportions and some are not, and 2) supply of different types of byproducts may be subject to unobservable market frictions. The function is estimated based on data from a survey of ethanol plants. Increased size does not seem to lower plants' shutdown price. Frictions in byproduct markets seem to result in sub-optimal byproduct mix choices that increase ethanol shutdown price by up to 10 cents per gallon. Futures and other price discovery instruments in byproduct markets may enhance plants' ability to prevent shutdown.

Key words: corn ethanol, shutdown price, distillers grains markets, ethanol technology.

Introduction

Operating at an average variable cost (AVC) below output price is sufficient for ethanol plants to survive in the market place in the short run and it is necessary for survival in the long run. Understanding technological and market conditions shaping plants' average variable cost is critical to assessing their short and long run vulnerability to price swings caused by market and policy changes. While average capital cost of ethanol plants was quantified and discussed before (Gallagher et al. (2005) and Kotrba (2006)), the relationship between prices of inputs, relative profitability of byproducts, size of the plant, and AVC or ethanol shutdown price has not been quantified.¹ This study attempts to fill this gap.

Up to 2008 crush margins (the ratio of ethanol price over corn price) were very favorable for the ethanol industry. In the period 2008-2009 prices were not very favorable with conditions worsening even further in the first half of 2010. On the other hand, relative prices improved in the second half of 2010 only to fall in the first half of 2011 and recover, once more, in the second part of 2011. Each rise and fall in operating margins triggered entry and shutdowns in the industry (US Federal Trade Commission (2010) and US Federal Trade Commission (2011)). Expiration of the Volumetric Ethanol Excise Tax Credit (VEETC) and the ethanol import tariff in December 2011 may add more uncertainty to an already volatile industry in 2012. The relative importance of technological and market factors in AVC and plant survival is especially relevant for envisioning future industry's dynamics and its impact on related markets such as corn and other agricultural commodities.

Based on a survey of ethanol plants we estimate the plant-level AVC function in this industry which depicts the impact of input prices, output levels, and byproduct market conditions on the

¹ Perrin et al. calculated average shutdown price of a sample of ethanol plants at different points in time. However this study did not econometrically estimate the link between AVC, prices, and output.

ethanol price that would cause plants to shut down. As such this study provides information on factors other than financial (i.e. hedging and risk management) in determining shutdown decisions. To achieve this we exploit technological information to specify input demand and byproduct supply and recover, through integration, a variable cost function. This function is methodologically innovative in that it is capable of accommodating unobservable frictions in byproduct markets resulting from issues such as imperfect price foresight and limited access to wet byproduct markets.

Materials and Method

Modeling of Ethanol Average Variable Cost Function

Because of the existence of long-term supply agreements between ethanol plants and gasoline blenders and some technological constraints, ethanol plants can be modeled as output-taking, cost-minimizing firms. This means that plants choose inputs and mix of byproducts (which result in revenue subtracted from variable cost) so that the cost of producing a given amount of ethanol is minimized. A variable cost function depicts the cost of producing a given output level at certain input and by-product prices and levels of fixed inputs (capital). The objective of this section is to model total (and average) variable cost function in the ethanol industry at the plant level. Because a plant would shut down when output price is insufficient to cover AVC, this measure represents the plant's shutdown price.

As discussed by Chambers and Pope (1993) there are two approaches to modeling firms' cost function. One is to specify a dual indirect cost function and recover inputs demand and outputs supply through differentiation following Shephard's lemma. Another approach consists of specifying input demand and output supply relationships with desirable properties and recover

the cost function through integration which is also consistent with Shephard's lemma. This study follows the second approach. Given our knowledge of ethanol plants' behavior we specify demand and supply relationships and recover cost through integration.

Ethanol plants are characterized by a technology using multiple inputs to produce one main output and, most commonly, two types of byproducts. Given the nature of the chemical transformation process there are more or less fixed proportions among variable inputs and ethanol production (Stewart and Lambert (2011), Lambert et al. (2008), Gardner (2007)). Therefore we rule out substitutability among inputs or price effects in input demands. However there is no a priori knowledge of whether input quantities would increase more or less than proportionally with output; i.e. whether returns to variable inputs are increasing, decreasing, or constant. In addition it is not clear whether the proportions in which inputs are mixed to produce output will remain constant as the level of production of a plant changes; i.e. whether technology is homothetic in variable inputs. Therefore our estimation of the variable cost function should allow for both variable returns and non-homotheticity in variable inputs. We define our first two input demand relationships as:

$$q^c = \alpha_1^c y^{\alpha_2^c} \tag{1}$$

$$q^{el} = \alpha_1^{el} y^{\alpha_2^{el}} \tag{2}$$

Where y is the ethanol production level (in gallons per quarter), q^c is quantity of corn (in bushels per quarter), q^{el} is quantity of electricity (in kilowatt hours per quarter) and the rest are parameters.

Natural gas is used in fixed proportions to produce ethanol and it is also used in the heating of wet byproducts to reduce their moisture content and produce dry byproduct. Therefore the quantity used of natural gas will depend upon ethanol production and dry byproduct production:

$$q^{ng} = \alpha_1^{ng} y^{\alpha_2^{ng}} + \alpha_3^{ng} q^d \quad (3)$$

Where q^{ng} is the quantity of natural gas used (MMBTUs per quarter), α_1^{ng} and α_2^{ng} are parameters determining the quantity of natural gas used for ethanol production, q^d is the quantity of dry byproduct (tons of dry matter per quarter), and α_3^{ng} depicts the quantity of natural gas used per unit of dry byproduct produced. Ethanol production also involves the use of labor and other inputs which are unlikely to be used in fixed proportions and will be modeled below.

The supply of dry byproducts affects variable cost through natural gas usage in equation (3). However this is not the only channel through which byproduct supply shapes variable cost. When the production process results in byproducts the revenue stream associated with their sale is subtracted from input costs to determine total variable inputs. Thus modeling of variable cost should include modeling of revenue from byproduct. A byproduct called distiller's grain with soluble (DGS) results from the ethanol production process. Some of the moisture in the byproduct is removed through a centrifuge process resulting in modified wet distillers' grain with soluble (MWDGS) which contains 55% moisture. This byproduct can be sold as is or can be further dried (through heat using natural gas) into dry distillers' grain with soluble (DDGS) which contains 10% moisture. DDGS have a much longer shelf life than MWDGS and can, hence, be stored and/or transported to longer distances. Therefore MWDGS tend to be sold to nearby livestock operations (Konecny et al.).²

The quantity of total byproduct produced has a technical upper bound. Under current technologies only a fraction of corn used can be transformed into byproduct (the rest goes to ethanol and carbon dioxide emissions in accordance with the material balance condition).

² Byproducts can also be sold as wet without centrifuging (WDGS). However none of the plants surveyed sold byproducts as wet (which is in line with findings by other studies such as Schroeder (2009)) and so we limit our analysis to DDGS and MWDGS.

Because this upper bound depends on the production scale of the ethanol facility is usually expressed as a function of ethanol production (Liska et al. (2009), Wang et al. (2007), Kwiatkowski et al. (2006), McAloon et al. (2000)). We depict this upper bound by $\overline{q^b(y)}$. The proportion of all byproduct produced that is sold as DDGS will depend upon its profitability relative to MWDGS. This is, in turn, determined by the price of DDGS, the price of MWDGS and the price of natural gas as this input is involved in additional drying operations necessary to obtain DDGS.

Let us denote the price of DDGS by p^d , p^{ng} is the price of natural gas, p^w is the price of MWDGS, and p^b is the profitability of DDGS relative to MWDGS. Because MWDGS can be transformed into DDGS at a one to one rate (if both are measured in a dry matter basis) corner solutions should be expected in the byproduct mix absent market frictions. Specifically, in absence of market rigidities, if $p^b = p^d - \alpha_3^{ng} p^{ng} - p^w > 0$, then all byproduct will be dried and sold as DDGS. If the reverse is true then all byproduct will be sold as MWDGS. Therefore under no rigidities in by byproduct market the DDGS supply curve would converge to a staircase function where:

$$q^d = \begin{cases} q^d = 0 & \text{if } p^b < 0 \\ 0 < q^d < \overline{q^b(y)} & \text{if } p^b = 0 \\ q^d = \overline{q^b(y)} & \text{if } p^b > 0 \end{cases} \quad (4)$$

Where q^d is the quantity of byproduct sold as DDGS, and $\overline{q^d(y)}$ represents the technical upper bound in byproduct production.

Despite technological substitutability between DDGS and MWDGS corner solutions are hardly observed in reality (Perrin et al.). Interior solutions in byproduct mix may be caused by plants' diversification due to price uncertainty (i.e. imperfect foresight), transaction costs, or the size of nearby livestock operations (which limit the fraction of byproduct that can be sold as

MWDGS). Depending on how strong rigidities are, shifts between DDGS and MWDGS caused by changes in p^b may be drastic or moderate and they may or may not take place when p^b takes values around zero. Based on this knowledge we choose to specify DDGS supply as a particular case of the generalized logistic function. As we will discuss in more detail this function converges asymptotically to the stair case function (4) so its estimation permits gauging of the extent to which market frictions affect byproduct mix choice. The algebraic representation of the supply of DDGS is:

$$q^d = \frac{\overline{q^b(y)}}{[1 + \alpha_3^b \exp(-\alpha_4^b(p^b))]} \quad (5)$$

Where q^d is the quantity of byproduct sold as DDGS, and α_3^b and α_4^b are parameters affecting the position and slope of the logistic curve. This function is depicted in Figure 1 by q^{d1} .

According to (5) DDGS supply is a fraction $\frac{1}{[1 + \alpha_3^b \exp(-\alpha_4^b(p^b))]}$ of total byproduct production $\overline{q^b(y)}$. This fraction converges to one as \tilde{p} becomes positive and large and it converges to zero as p^b becomes negative and large in absolute value. Estimating a generalized logistic function is different from estimating the well-known Probit or Logit functions as the former is a continuous response function while the latter represent occurrences of a binary response random variable.

The inflection point of DDGS supply occurs at a relative profitability $p_{ip}^b = \frac{\ln(\alpha_3^b)}{\alpha_4^b}$. The expression in (5) allows for DDGS supply to have an inflection point at a \tilde{p} different from zero which may be the case due to market frictions. In fact the inflection point will occur at zero if $\alpha_3^b = 1$ or $\alpha_4^b = \infty$. Both of these constitute testable hypotheses after estimation of DDGS supply. Another important fact transpiring from equation (5) is that increases in α_3^b increase the supply of DDGS for all $p^b > 0$ and reduces it for all $p^b < 0$ which, profitability wise, is always

desirable. This amounts to a relaxation of rigidities in by-product mix decisions and is illustrated in Figure 1 by a rotation of the supply curve from q^{d1} to q^{d2} .

The generalized logistic specification (5) converges asymptotically to the stair case function (4) as $\alpha_4^b \rightarrow \infty$. This is because as $\alpha_4^b \rightarrow \infty$ the price at which the inflection point occurs converges to $p_{ip}^b = 0$ and the slope of (5) at the inflection point converges to infinity. These are properties held by the stair case function (4). Therefore the specification in (5) is general enough to nest (asymptotically) the case of no rigidities. In addition the generalized logistic is an integrable function and this property will be exploited to recover the variable cost function. Alternative (integrable) specifications of the DDGS supply have drawbacks. Modeling DDGS supply as a linear function of p^b would result in predicted values of DDGS supply above the technical maximum and below the potentially market-constrained minimum. Specifying DDGS supply with a high order polynomial would increase the amount of parameters to be estimated.

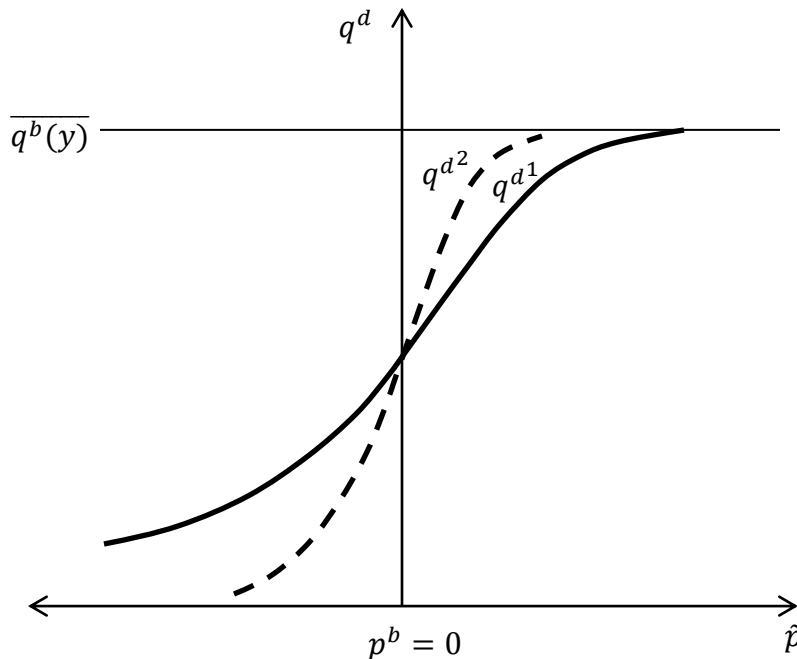


Figure 1. DDGS supply - generalized logistic function

Engineering softwares (Liska et al. (2009), Wang et al. (2007)) describing ethanol technology have assumed a linear relationship between total byproduct production and ethanol production (i.e. $\overline{q^b(y)} = \theta y$, where θ is positive). We put this assumption to the test by specifying the total byproduct production as $\overline{q^b(y)} = \alpha_1^b y \alpha_2^b$, where α_1^b and α_2^b are parameters representing byproduct production efficiency. This specification allows for a non-linear relationship between ethanol production and byproduct yield. Our specification nests the linear case when $\alpha_2^b = 1$. Therefore equation (5) becomes:

$$q^d = \frac{\alpha_1^b y \alpha_2^b}{[1 + \alpha_3^b \exp(-\alpha_4^b(p^b))]} \quad (5')$$

Since $q^d + q^w = \alpha_1^b y \alpha_2^b$, MWDGS supply can be depicted as:

$$q^w = \alpha_1^b y \alpha_2^b \left[1 - \frac{1}{1 + \alpha_3^b \exp(-\alpha_4^b(p^b))} \right] \quad (6)$$

By the Shephard's lemma total variable cost function can be recovered by integrating equations (1)-(3) and (5')-(6) with respect to their corresponding prices. Because inputs and byproducts are depicted by different functional forms there is no parametric constraint that would make the variable cost function obtained through integration homogeneous of degree one. As mentioned before there are "other inputs" that constitute part of the plants' variable cost but these inputs are not expected to be used in fixed proportions. In fact there is no reason to support a priori any particular specification for this composite of inputs. Therefore we use the price index of this composite to normalize all other prices in the system above:³

$$q^d = \frac{\alpha_1^b y \alpha_2^b}{[1 + \alpha_3^b \exp(-\alpha_4^b(\bar{p}))]} \quad (7)$$

³ This procedure was applied, for instance, in studies of dynamic investment demands resulting in the normalized quadratic specification for the optimal value function (for example, Vasavada and Chambers, Stefanou et al.).

$$q^w = \alpha_1^b y \alpha_2^b - \frac{\alpha_1^b y \alpha_2^b}{[1 + \alpha_3^b \exp(-\alpha_4^b(\tilde{p}))]} \quad (8)$$

Where $\tilde{p} = \frac{p^b}{p^o} = \frac{p^d - \alpha_3^{ng} p^{ng} - p^w}{p^o}$ and p^o is the price index of the composite of “other inputs”.

Equations (1)-(3) remain the same.

Integrating demand and supply relationships with respect to normalized prices yields the following normalized variable cost function with homogeneity in prices imposed:⁴

$$\bar{V}C = C_1 + \bar{p}^c \alpha_1^c y \alpha_2^c + \bar{p}^{el} \alpha_1^{el} y \alpha_2^{el} + \bar{p}^{ng} \alpha_1^{ng} y \alpha_2^{ng} - \alpha_1^b y \alpha_2^b \left\{ \bar{p}^w + \frac{\ln[1 + \alpha_3^{b-1} \exp(\alpha_4^b(\tilde{p}))]}{\alpha_4^b} - \frac{\ln[1 + \alpha_3^{b-1}]}{\alpha_4^b} \right\}$$

Where the constant (with respect to normalized prices) of integration was defined as $C_1 + \alpha_1^b y \alpha_2^b \frac{\ln[1 + \alpha_3^{b-1}]}{\alpha_4^b}$. The demand for “other inputs” is calculated residually and is given by:

$$q^o = C + \alpha_1^b y \alpha_2^b \left\{ (\bar{p}^d - \bar{p}^{ng} \alpha_3^{ng} - \bar{p}^w) - \frac{\ln[1 + \alpha_3^{b-1} \exp(\alpha_4^b(\tilde{p}))]}{\alpha_4^b} \right\} \quad (9)$$

The fact that the demand for “other inputs” has a different functional form than the rest of the inputs is not problematic in this context as this composite is not expected to be used in fixed proportions. This is in contrast to other situations in which homogeneity in functional form does matter for economic analysis (Mahmud et al. (1987)).

The un-normalized variable cost function can be obtained by multiplying both sides of the normalized variable cost by p^o :

$$VC = C_1 p^o + p^c \alpha_1^c y \alpha_2^c + p^{el} \alpha_1^{el} y \alpha_2^{el} + p^{ng} \alpha_1^{ng} y \alpha_2^{ng} - \alpha_1^b y \alpha_2^b \left[p^w + p^o \frac{\ln[1 + \alpha_3^{b-1} \exp(\alpha_4^b \tilde{p})]}{\alpha_4^b} - p^o \frac{\ln[1 + \alpha_3^{b-1}]}{\alpha_4^b} \right] \quad (10)$$

Function (10) can be described as a byproduct-including normalized Leontief cost function.

⁴ Derivation of the variable cost function involves substitution of (1) into (7) and (8) before integration of DDGS and MWDGS supply functions and substitution of (7) into (3) before integration of natural gas demand.

The shutdown price of an ethanol plant is depicted by the un-normalized average variable cost function. This function can be calculated by dividing both sides of (10) by ethanol production:

$$AVC = C_1 y^{-1} p^o + p^c \alpha_1^c y^{\alpha_2^c - 1} + p^{el} \alpha_1^{el} y^{\alpha_2^{el} - 1} + p^{ng} \alpha_1^{ng} y^{\alpha_2^{ng} - 1} - \alpha_1^b y^{\alpha_2^b - 1} \left[p^w + p^o \frac{\ln[1 + \alpha_3^{b-1} \exp(\alpha_4^b \tilde{p})]}{\alpha_4^b} - p^o \frac{\ln[1 + \alpha_3^{b-1}]}{\alpha_4^b} \right] \quad (11)$$

This AVC function displays several desirable asymptotic properties. For fixed p^d and p^{ng} when p^w becomes very large (i.e. \tilde{p} converges to $-\infty$) the fraction of byproduct sold as MWDGS converges to one (as depicted by equations (7) and (8)) and the byproduct part of the AVC function converges to $\alpha_1^b y^{\alpha_2^b - 1} p^w$. This amounts to byproduct yield times MWDGS profitability. Revenue from DDGS plays no significant role because the fraction of byproduct sold as DDGS tends to zero. Likewise when p^d becomes very large (i.e. \tilde{p} converges to ∞) the fraction of byproduct sold as DDGS converges to one (as depicted by equations (7) and (8)) and the byproduct part of the AVC function converges to $\alpha_1^b y^{\alpha_2^b - 1} (p^d - \alpha_3^{ng} p^{ng})$.⁵ The latter expression amounts to byproduct yield times DDGS profitability. Revenue from MWDGS plays no significant role because the fraction of byproduct sold as MWDGS tends to zero. Finally when both types of byproduct are equally profitable (i.e. $\tilde{p}=0$) the byproduct part of the AVC function converges to $\alpha_1^b y^{\alpha_2^b - 1} p^w$ which would be equal to $\alpha_1^b y^{\alpha_2^b - 1} (p^d - \alpha_3^{ng} p^{ng})$.

Equation (11) captures features of the ethanol plants' Leontief technology but it also captures behavior and potential rigidities in byproduct markets. Econometric estimation of the system of demand and supply relationships allows us to recover all parameters involved in equation (11)

⁵ This is because $p^o \frac{\ln[1 + \alpha_3^{b-1} \exp(\alpha_4^b \tilde{p})]}{\alpha_4^b} \rightarrow p^o \tilde{p} = p^d - \alpha_3^{ng} p^{ng} - p^w$.

except for C_1 which is calculated residually. Based on these estimates we will discuss the role of plant size, input prices, and rigidities in byproduct mix choice in shutdown prices.

Data and Estimation of Input Demands and Byproducts Supply

We combine equations (7) and (8) to obtain the following two equations which facilitate estimation:

$$\frac{q^d}{q^b} = \frac{1}{[1 + \alpha_3^b \exp(-\alpha_4^b(\hat{p}))]} \quad (12)$$

$$q^b = \alpha_1^b y \alpha_2^b \quad (13)$$

Where $q^b = q^d + q^w$ and the rest is as before.

Equations (1)-(3), (12) and (13) with appended random errors constitute a system of simultaneous equations (some non-linear in parameters) that we intend to estimate. We circumvent the difficulties of estimating non-linear systems of simultaneous equations by using technological information reported by plants to impose additional structure and transform this into a system of seemingly unrelated regressions (SUR). In particular plants have reported values of α_3^{ng} . Because this parameter does not have to be estimated we no longer have to worry about endogeneity of q^d in equation (3). We impose the value of α_3^{ng} and convert equation (3) into:

$$q_{eth}^{ng} = q^{ng} - \overline{\alpha_3^{ng}} q^d = \alpha_1^{ng} y \alpha_2^{ng} \quad (3')$$

Where q_{eth}^{ng} is the amount of natural gas used specifically for ethanol production, $\overline{\alpha_3^{ng}}$ is the sample average of natural gas usage per ton of byproduct dried (average of all the values of α_3^{ng} reported by plants), and $\overline{\alpha_3^{ng}} q^d$ is the amount of natural gas used for drying byproducts.

Because we have panel data on ethanol plants we could control for unobservable fixed effects that may influence their performance. However within-plant changes in production scale were

somewhat limited during the time period covered by our data. Since we are particularly interested in changes in input requirements when the scale of production changes we conduct estimation of this system by pooling the data. Extrapolating relationships between inputs and outputs across plants to intra-plant technology is a valid strategy in this case as there are only a handful of builders of plants in this industry. Therefore if small plants decide to expand capacity they would likely hire the same company that built bigger plants in this sample.

On the other hand plants' unobservable fixed effects affecting the fraction of byproduct sold as DDGS are important and should be controlled for in estimation. Lack of access to a large nearby livestock operation may limit the plant's ability to sell a significant portion of byproducts as MWDGS even if economically profitable. This is denoted by q^{a1} in Figure 2. If, on the other hand, the plant does have access to a thick market for MWDGS it will be able to sell a large fraction of byproducts as such if it is economically convenient to do so. Such a situation is denoted by the function q^{a2} in Figure 2.

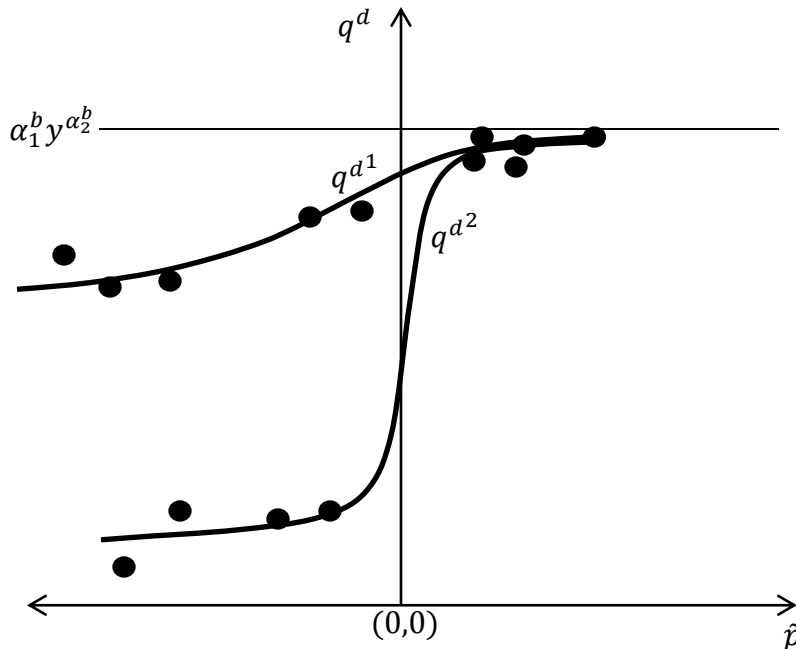


Figure 2. DDGS supply - generalized logistic function

Including a dummy for each plant to control for fixed effects would result in inconsistent estimates with a small sample due to the “incidental parameter” problem (Lancaster (2000)). In addition a within transformation (i.e. time demeaning the data) cannot be used as the function to be estimated is nonlinear. Therefore we include a dummy that represents whether a plant is located in a State with significant livestock inventories or not. While incapable of capturing unobserved fixed effects for each individual plant, this dummy can separate the plants with access to a thick MWDGS market from those without that access. The estimating equation is:

$$\frac{q^d}{q^b} = \frac{1}{[1+(\alpha_3^b+\alpha_4^b I) \exp(-(\alpha_5^b+\alpha_6^b I)\bar{p})]} \quad (12')$$

Where I is a dummy variable that takes a value of one if the plant is located in a State with a large livestock inventory⁶ and a value of zero otherwise. To calculate livestock inventory we include beef and dairy cattle and exclude swine and poultry as the former two are the main sources of ethanol byproduct consumption (Hoffman and Baker (2010)). In equation (12') the dummy variable is allowed to affect both the position (through α_4^b) and the slope (through α_6^b) of the equation depicting the fraction of byproduct sold as DDGS.

To sum up, the system of equations to be estimated is as follows:

$$q_{it}^c = \alpha_1^c y_{it}^{\alpha_2^c} + \varepsilon_{it}^c \quad (1)$$

$$q_{it}^{el} = \alpha_1^{el} y_{it}^{\alpha_2^{el}} + \varepsilon_{it}^{el} \quad (2)$$

$$q_{eth_{it}}^{ng} = q_{it}^{ng} - \overline{\alpha_3^{ng}} q_{it}^d = \alpha_1^{ng} y_{it}^{\alpha_2^{ng}} + \varepsilon_{it}^{ng} \quad (3')$$

$$\frac{q_{it}^d}{q_{it}^b} = \frac{1}{[1+(\alpha_3^b+\alpha_4^b I_{it}) \exp(-(\alpha_5^b+\alpha_6^b I_{it})\bar{p}_{it})]} + \varepsilon_{it}^d \quad (12')$$

$$q_{it}^b = \alpha_1^b y_{it}^{\alpha_2^b} + \varepsilon_{it}^b \quad (13)$$

⁶ Large in this context means that the State has a livestock inventory greater than the median of the 7 States represented in this sample.

Where i denotes the plant ($i = 1, \dots, 7$) and t the time period.

Random errors in equations (1), (2), (3') and (13) are likely to be correlated as these equations depict technological performance of a given plant in a given period. There is, on the other hand, little reason to expect correlation between the random error in equation (12) and disturbances in the rest of the system as the former denotes conditions in byproduct markets rather than technological performance of the plant. Therefore we estimate equations (1), (2), (3'), and (13) as a system of seemingly unrelated regressions and we estimate equation (12) separately.

The data for estimation of the SUR system (1), (2), (3'), and (13) and of equation (12') consist of quarterly reports of seven ethanol plants each located in a different state of the North Central Region of the US. To be selected for our survey a plant must have started production (or been updated) after mid-2005 with a capacity close to 50 million gallons per year or more, so as to represent recent technology. Descriptive statistics of the sample of participating ethanol plants are reported in Table 1. The surveyed plants produced an average rate of 53 million gallons of ethanol per year (MGY), with a range from 42 MGY to 88 MGY. The period surveyed included from the third quarter of 2006 until the fourth quarter of 2007 (six consecutive quarters) but not all plants reported data in all quarters resulting in an unbalanced panel.⁷ On average 54% of byproduct was sold as DDGS, but this ranged from one plant that sold absolutely no byproduct as DDGS to another plant that sold nearly all byproduct (97%) as DDGS with most observations being interior to these extremes. Further information about the characteristics of these plants and the sampling criteria can be found in Perrin et al. Results from estimation of the SUR system (1), (2), (3'), and (13) and of equation (12') based on these data are reported in Table 2.

⁷ Despite the unbalanced nature of the panel we have little reason to be concerned about inconsistency due to self-selection in missing data. Surveys occurred over a period of three quarters, so that some plants could report later periods than others, and one plant had not started up during the first quarter of the survey.

The fact that α_2^c and α_2^{el} are statistically significantly lower than one suggests increasing returns to these inputs. On the other hand natural gas which seems to yield decreasing returns. Byproduct yield seems to decrease with production scale ($\alpha_2^b < 1$) which is consistent with increasing returns to corn as lower quantities of corn per gallon of ethanol would, due materials balance, yield lower quantities of byproduct per gallon of ethanol. Also the null hypothesis $\alpha_2^c = \alpha_2^{el} = \alpha_2^{ng}$ was tested and rejected with a 99% level of confidence suggesting that the Leontief technology is non-homothetic in inputs. This is in contrast with common assumptions made by engineering softwares (Liska et al. (2009) and Wang et al. (2007)) describing ethanol technology. These softwares assume that the quantity of inputs is proportional to output which results in a homothetic technology displaying constant returns to variable inputs. Finally under these parameter estimates function (10) fulfills all the properties of a cost function evaluated at all sample points.⁸

In addition the value and statistical significance of α_4^b and α_6^b suggests that proximity to a thick MWDGS market does seem to make a difference in the byproducts mix choice by the plants. Based on these parameter values Figure 3 plots the fraction of byproduct sold as DDGS by plants with and without a market for MWDGS nearby. This is done for a range of normalized relative profitabilities (\tilde{p}) similar to that observed in our sample. As depicted by Figure 3 plants located nearby large livestock operations can, on average, adjust their byproduct mix choice to the relative profitability of DDGS and MWDGS. When the plant is located nearby large livestock operations the inflection point of the function occurs at $p_{ip}^b = \frac{\ln(\alpha_3^b + \alpha_4^b)}{\alpha_5^b + \alpha_6^b} \cong 5$. This

⁸ Under parameter estimates reported in Table 2 the following properties are fulfilled globally: homogeneity of degree one in prices, continuity, symmetry, concavity in prices, and non-decreasing in input prices and non-increasing in byproduct prices (proof available from the authors). On the other hand the estimated cost function is non-decreasing in output only locally. This property is however fulfilled in all sample points (calculations available from the authors).

means that plants tend to change byproduct mix more abruptly when p^b is close to zero as prior expectations would suggest.

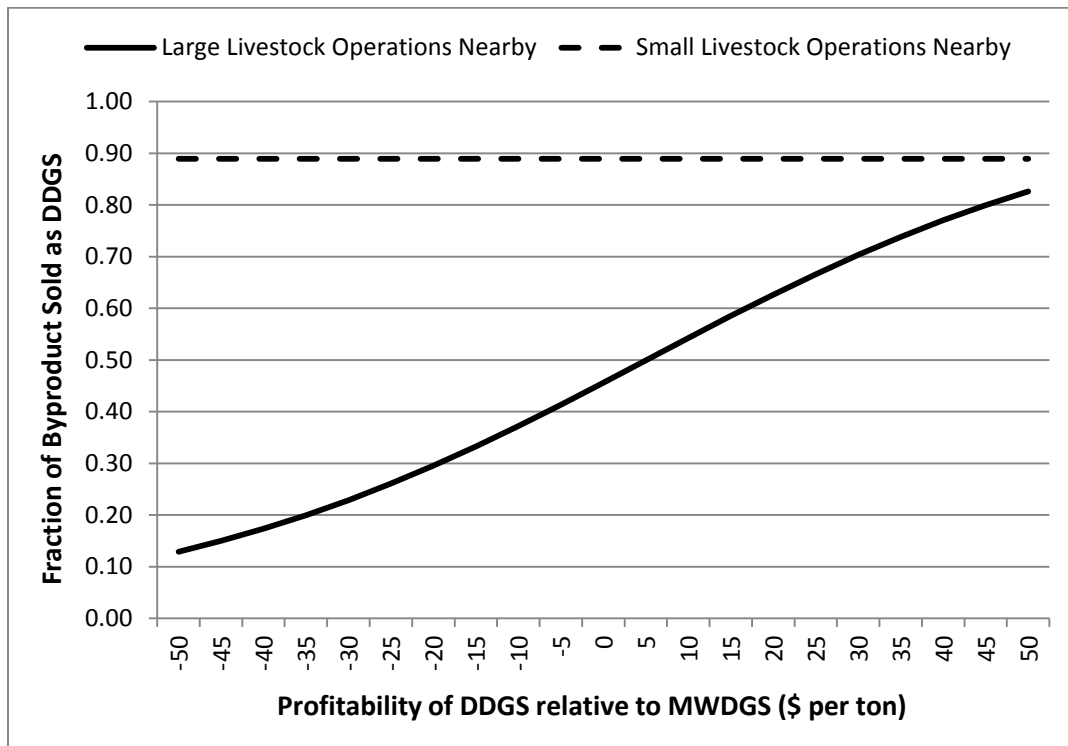


Figure 3. Nearby livestock operations and predicted fraction of byproduct sold as DDGS

Corn Price and Plants' Shutdown Price

About 80% of an ethanol plant's operating costs are composed of the costs of purchasing corn and natural gas. According to USDA data,⁹ corn prices were highly volatile in the last few years. Since 2005 corn prices have escalated from \$2 per bushel to \$6 in 2008. The price declined to \$3 in 2009 and part of 2010 only to climb again to \$7 in 2011. Natural gas price increased from \$8 per MMBTU to \$12 in 2005 and then decreased to \$7. It peaked again at \$12 in 2008 and then stabilized just above \$5 since April 2010. To understand the potential impact of

⁹ Tracking Ethanol Profitability, Agricultural Marketing Resource Center, Iowa State University, <http://www.extension.iastate.edu/agdm/energy/xls/d1-10ethanolprofitability.xls>

these price swings on ethanol shutdown price, Figure 4 depicts the link between the price of these important inputs and the minimum price of ethanol that would prevent a plant shutdown.

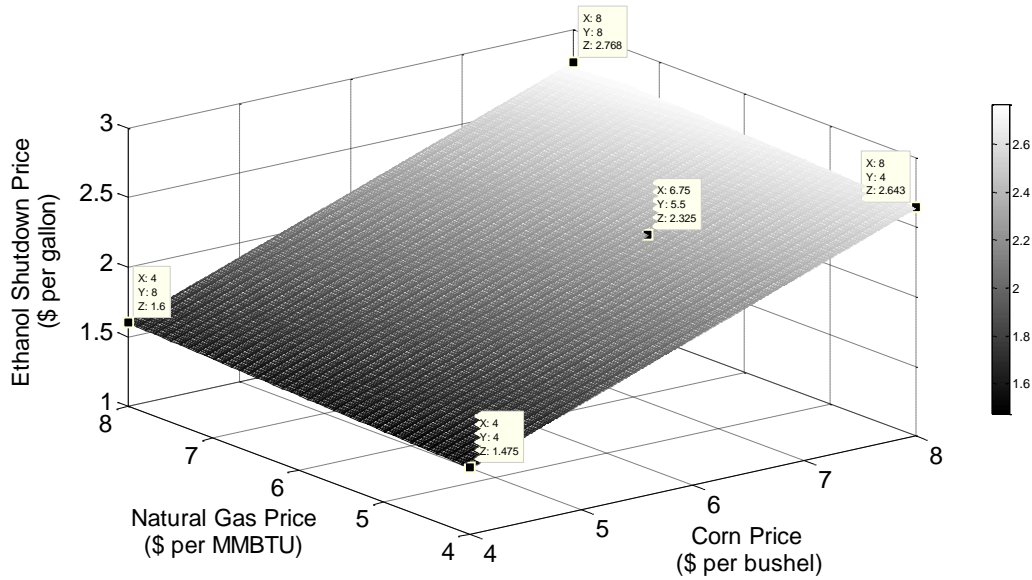


Figure 4. Input Prices and Ethanol Shutdown Price

Figure 4 assumes that changes in prices of corn and natural gas are correlated with changes in the price of DDGS and MWDGS so that they remain equally profitable and no arbitrage opportunities emerge. This assumption is implemented by first assuming that, because DDGS is sold to livestock as a substitute for corn, the price of DDGS is determined as a linear function of the price of corn. Based on estimations by Hurt, Tyner, and Doering (2008) we assume that $p^d = 1.52 + 0.205 p^{sm} + 22 p^c$, where p^d is price of DDGS (\$ per dry ton), p^{sm} is price of soybean meal (\$ per dry ton), and p^c is price of corn (\$ per bushel). Secondly, we assume that $p^b = 0$ or, equivalently, $p^w = p^d - \overline{\alpha_3^{ng}} p^{ng}$. Therefore changes in the price of DDGS brought about by changes in the price of corn are matched by changes in the price of MWDGS so that both byproducts are equally profitable at all times and no arbitrage opportunities exist.

Figure 4 reveals that increases in corn price have a more significant impact on shutdown price that increases in the price of natural gas. Therefore reductions in natural gas prices in 2011

are unlikely to have compensated in full increases in corn price. Additionally, under these assumptions, increases in corn price are partially compensated by an increase in byproduct prices. Assuming no correlation between corn and byproduct prices an increase in corn price from \$4 per bushel to \$8 would raise ethanol shutdown price from \$1.47 to \$3.26.¹⁰ However under the assumption of efficient byproduct markets (no arbitrage is possible) an increase in corn price from \$4 to \$8 per bushel would only raise ethanol shutdown price from \$1.47 to \$2.64 as depicted by Figure 4.

Results in Figure 4 also suggest that some plants may, at present, be facing the possibility of shutdown in the short run. According to data from the Agricultural Marketing Resource Center at Iowa State (AMRCIS), by December of 2011, corn price was \$6.75 per bushel and natural gas price was \$5.5 per MMBTU. At these prices Figure 4 suggests that ethanol shutdown price would be about \$2.32 per gallon. Since November of 2011 ethanol rack prices dropped from \$2.8 (above shutdown) to \$2.1 (below shutdown) according to data from AMRCIS. Some of the causes of this drop may remain in the long run but some may not. In December of 2011 the US Congress eliminated the Volumetric Ethanol Excise Tax Credit (VEETC) and the ethanol import tariff in effect since December of 2004. In addition, since 2011, ethanol sold in the US is already close to 10% of total gasoline sold which is known as the “Blending Wall” or maximum amount of ethanol to be blended into gasoline.¹¹ This means that only export markets can consume additional ethanol production. Export markets on the other hand are being negatively affected by the global financial crisis. Therefore since the recently observed reduction in ethanol price may

¹⁰ This is calculated, under estimated parameters and 2011 prices, by increasing corn price in equation (11) from \$4 to \$8 without changing prices of DDGS and MWDGS.

¹¹ Because of uncertainty on the effect of higher blends on automobile engines and the legal liabilities associated with it gasoline blenders and retailers are unlikely to adopt higher blends even if approved by EPA.

be partially explained by long run forces it may significantly reduce plants' operating margins and even trigger some shutdowns in the industry.

Byproduct Mix and Shutdown Price

Because market forces seem to have reduced operating margins in the ethanol industry plants are paying more attention to their choice and marketing of byproduct mix (Stroade et al. (2010), Hoffman and Baker (2010)). While analysis in the previous section was conducted under the assumption of efficient byproduct markets, limited evidence suggests that byproduct markets are not highly efficient and that arbitrage opportunities do seem to exist at different points in time (Schroeder (2009)). There are, however, market and contracting factors that may limit a plant's ability to exploit arbitrage opportunities which is why these arbitrage opportunities exist in the first place. These factors are access to a large nearby livestock operation and the portion of byproducts that has already been sold by contract when an arbitrage opportunity appears.

Econometric estimation of plants' byproduct mix choice has been conducted and plotted in Figure 3.¹² This figure depicts optimal byproduct mix for plants with ample access to markets for MWDGS (dummy equals one) and those with limited access to such markets. Access to markets for MWDGS allows plants to adjust their byproduct mix to price signals. However these choices are still somewhat constrained by imperfect foresight and/or contract incompleteness. The optimal choice of byproduct mix is depicted by the staircase function (4) which is in turn what function (7) converges to as α_6^b converges to infinity. The staircase function corresponds to a situation where the plant has unlimited access to both DDGS and MWDGS markets and operates under perfect foresight in these markets.

¹² This estimation does not control for potential spatial correlation in byproduct prices as previous studies (Schroeder (2009)) found no evidence of such correlation.

Figure 5 plots ethanol shutdown price at different relative profitabilities (p^b in our model) between DDGS and MWDGS for plants under the three situations previously discussed: 1) optimal choice (resulting from staircase function which corresponds to access to both markets and perfect foresight), 2) access to DDGS and MWDGS markets but imperfect foresight (which corresponds to upward sloping function in Figure 3), and 3) limited access to MWDGS markets (which corresponds to horizontal line in Figure 3). Simulations plotted in Figure 5 suggest that plants with limited access to MWDGS markets may see their shutdown price increased by as much as 6 cents per gallon (relative to a situation with complete access and perfect foresight) when returns from MWDGS are \$25 per ton higher than those from DDGS. In contrast plants with ample access to MWDGS markets may see their shutdown price increased by only 2.5 cents per gallon. Losses from lack of access to MWDGS markets become bigger as MWDGS becomes more profitable than DDGS.

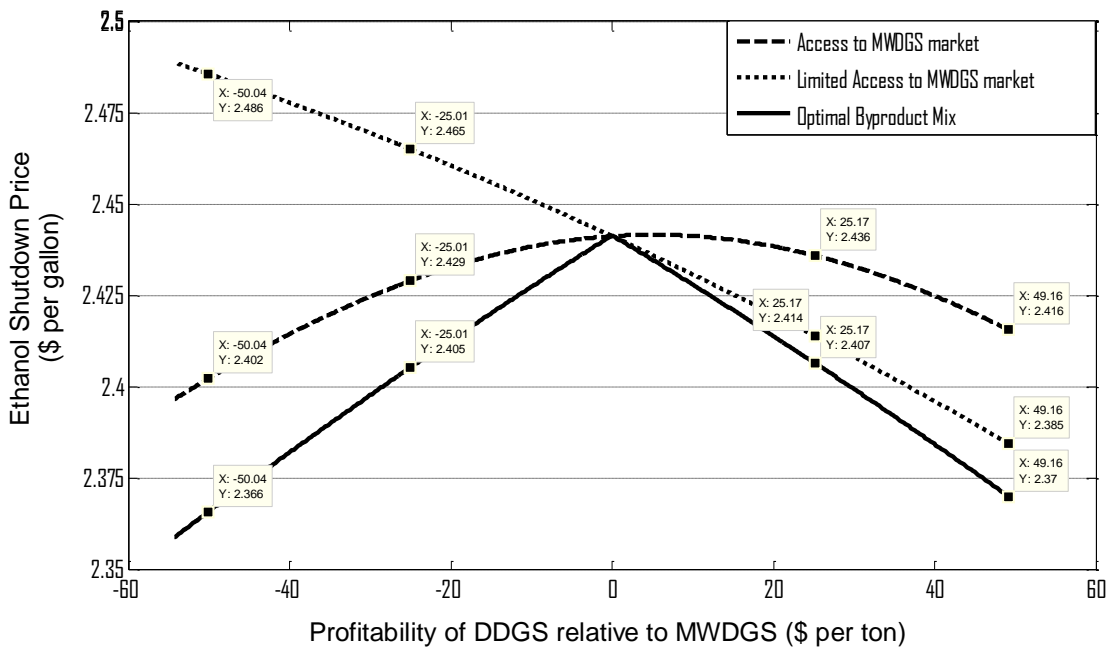


Figure 5. Rigidities in Byproduct Markets and Ethanol Shutdown Price

Plants with limited access to MWDGS markets do not suffer significant deviations from the optimal byproduct mix when DDGS is more profitable than MWDGS ($p^b > 0$). As shown in Figure 3 these plants, on average, tend to sell most of their byproduct production as DDGS. On the other hand, when $p^b > 0$, plants with access to MWDGS experience a greater deviation from the optimal mix. This is because these plants tend to (presumably due to imperfect foresight) diversify their byproduct sales between DDGS and MWDGS as shown in Figure 3. This strategy can result in increases in ethanol shutdown price of about 3 cents per gallon when returns from DDGS are \$25 per ton higher than those from MWDGS. The wedge between predicted and minimum shutdown price approaches zero for both types of plants as both byproducts become equally profitable. When $p^b = 0$, any choice of byproduct mix is optimal.

The above analysis considers a rather wide range of relative profitabilities of byproducts but remains silent regarding the plausibility of such range. To explore this issue we use data on prices of DDGS, MWDGS, and natural gas. Data on natural gas price are readily available and combination of these data with the drying parameter reported by plants yields an estimate of drying cost at any given time. Data on byproduct prices is scattered. Schroeder (2009) and Hoffman and Baker (2010) provide information on price differential between DDGS and MWDGS since 2007 to 2010. We combine these with estimates of drying costs to obtain a time series of relative profitabilities. This time series is depicted in Table 3. Deviations from the no-arbitrage point ($p^b = 0$) do seem to exist and, in addition, they seem to have ranged from -\$40 to \$30. Therefore increases in ethanol shutdown price due to sub-optimal byproduct mix choice may range from 0 to 10 cents per gallon. This is a non trivial amount as, according to USDA data, ethanol plants obtained in this period an average return over variable costs of 35 cents per gallon.

Conclusions

While previous literature has addressed the issue of potential economies of size in capital cost of ethanol plants (Gallagher et al. (2005) and Kotrba (2006)) there is still a dearth of information on the relative importance of size, and input and byproduct prices on plants' shutdown price. To address this lack of information we exploit technological information to specify input demand and byproduct supply and recover, through integration, a variable cost function. The derived variable cost function is capable of accommodating frictions in byproduct markets such as imperfect price foresight and limited access to wet byproduct markets. We estimate this function based on data from a survey of technologically modern ethanol plants.

Several important results are derived from this study. In contrast to assumptions in previous literature our estimates suggest that the Leontief technology characterizing plants' production process seems to be non-homothetic. In particular as plants increase in size they tend to use less corn (and, hence, produce less byproduct) and electricity and more natural gas per gallon of ethanol produced. As a result increases in the size of ethanol plants may not improve returns over variable inputs (though they may yield economies of scale in capital costs as found by Gallagher (2005)). This is because savings in corn and electricity seem to be compensated by higher usage of natural gas and lower byproduct yields. Additionally, the more efficient byproduct markets become (i.e. the higher the correlation between corn and byproduct prices) the lower the impact of corn price increases on plants' shutdown price. This is because the increase in cost is partially compensated by increases in revenue from byproduct sales.

Existing information suggest that arbitrage opportunities in byproduct markets seem to appear frequently. Plants located nearby large livestock inventories seem to better adjust their

byproduct mix to price signals when compared to plants that do not have access to those markets. However plants without access to MWDGS markets tend to outperform those with access when this type of byproduct is more profitable than DDGS. This may be explained by the fact that plants with access to MWDGS markets tend to diversify due to imperfect price foresight. Ethanol shutdown price may increase by up to 10 cents per gallon due to sub-optimal byproduct mix choice. This is a quantitatively relevant amount as a fraction of returns over variable inputs.

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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 (million gal/year)	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	6			
	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. Results from Estimation

Parameter	Coefficient	T-ratio
α_1^c	0.429	7.80
α_2^c	0.988	28.81
α_1^{el}	2.865	11.14
α_2^{el}	0.902	13.95
α_1^{ng}	0.0000069	4.44
α_2^{ng}	1.481	15.64
α_1^b	0.012	2.33
α_2^b	0.91	11.45
α_3^b	0.125	2.00
α_4^b	1.069	4.80
α_5^b	-0.003	-0.14
α_6^b	0.035	1.46

Table 3. Relative Profitability of Byproducts

Date	Relative Profitability, p^b (\$ per dry ton)
Nov-07	-6.6
Jan-08	-0.2
Feb-08	-16.0
Apr-08	-14.3
May-08	-34.2
Aug-08	-38.5
Oct-08	-8.6
Nov-08	-22.8
Dec-08	-24.5
Jan-09	-33.0
Feb-09	-21.0
Mar-09	-18.6
May-09	17.7
Jul-09	29.0
Sep-09	-11.6
Nov-09	-8.4
Jan-10	8.6
Feb-10	-3.6
Apr-10	0.5
Jun-10	13.3
Aug-10	22.7