3-2007

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We analyze the appropriate size and implied profitability of a representative ethanol processing firm. An analysis based on current processing technology and costs with typical conditions in Iowa product and input markets is useful; because unit production costs have declined 30% in current dollars over the last 15 years; and because discovering a suitable size for processing facilities has been an important part of the cost-reducing process. We apply theoretical plant size rules for a conventional processing business, an integrated producer/processor enterprise, and a processing cooperative. We also introduce a spatial dimension for the corn input market, because ethanol processing facilities can be uniquely large among agri-processing enterprises. The analysis supports three conclusions. First, the most appropriate size may still be larger than many of the recently constructed plants. Second, ethanol processing is a profitable enterprise; for instance, we calculate a return on capital of 14% for a processing business with optimal scale, current costs and technology, and typical market conditions. Third, total producer plus processor profits can be improved moderately, about $0.04/bushel of corn processed, with an integrated producer/processor enterprise; the producer enterprise sets the local corn price through processing capacity, in a fashion that offsets some potential monopsony power.

Nous avons analysé la taille appropriée et la rentabilité implicite d'une usine de transformation d'éthanol représentative. Une analyse fondée sur la technologie de transformation et les coûts actuels tenant compte du marché des produits et des intrants en Iowa s'est révélée utile étant donné que les coûts de l'unité de production ont diminué de 30% en dollars courants au cours des 15 dernières années et que la détermination de la taille appropriée des installations de transformation est un élément important du processus de réduction des coûts. Nous avons appliqué les règles théoriques concernant la taille dans le cas d'une usine de transformation classique, d'une entreprise intégrée de production-transformation et d'une coopérative de transformation. Nous avons également présenté une dimension spatiale du marché de l'intrant de maïs, étant donné que la taille des installations de transformation d'éthanol peut être importante comparativement aux autres entreprises de transformation de produits agricoles. L'analyse a permis de dégager trois conclusions. Premièrement, la taille la plus appropriée pourrait bien être supérieure à celle de nombreuses installations récentes. Deuxièmement, la transformation de l'éthanol est une activité rentable; par exemple, nous avons calculé un rendement du capital de 14% pour une entreprise de transformation exploitant à une échelle optimale, avec une technologie et des coûts actuels optimaux et profitant des conditions du marché typiques. Troisièmement, les bénéfices du producteur et du transformateur peuvent augmenter légèrement, d'environ 0,04 $/boisseau de maïs transformé, dans le cas d'une entreprise intégrée de production—transformation; l'entreprise du producteur établit le prix du maïs local en fonction de la capacité de production de manière à contrebalancer le pouvoir de monopsone potentiel.

Canadian Journal of Agricultural Economics 55 (2007) 63–81

INTRODUCTION

Enterprises in the growing U.S. ethanol industry have experimented with the scale and organization of processing enterprises. In the first expansion of the late 1970s, agribusiness processing firms constructed several large wet mills with capacities ranging from 100 to 350 million gallons per year (MGY). In contrast, farmer cooperatives (co-ops) constructed small dry mills with a typical capacity of about 10 MGY. New producer/processor plants, constructed since 1995, are typically larger (e.g., 40 MGY). Some are co-ops while others are profit-motivated. Agribusiness firms no longer build large and expensive wet mills, because the corn oil, gluten meal, and gluten feed byproduct revenues no longer justify the additional expense. However, some of their new dry mills (100 MGY) are larger than most of the producer-owned plants.

Concern for the appropriate scale and organization underscores a broader issue of the underlying profitability of ethanol processing. Current high energy prices may create a favorable profit climate for ethanol processing. Further, recent technology advances have reduced costs and improved processing yields. However, the ethanol industry did experience a prolonged period of meager profits not so long ago. An enterprise with the appropriate scale and organization is an important element of a long-term competitiveness strategy.

This investigation of ethanol scale, organization, and profitability builds on a representative ethanol processing enterprise. We do apply the classical tradeoff between capital costs and assembly costs in choosing the optimal scale of an agricultural processing enterprise that assembles a geographically dispersed input (Williamson 1962; Bressler and King 1970), but we also consider a new processing industry locating in a region that has a well-developed export market for the corn input. Further, we compare business and producer-owned organizations for processing enterprises. Specifically, we look at the scale choices for a conventional ethanol processing business, a co-op, and an integrated producer-owned corn and ethanol processing enterprise.

We examine the plant size choice for a representative ethanol processing firm facing a typical economic environment in Iowa. The empirical content of the representative Iowa firm analysis includes recent surveys of operating costs, analyses of plant cost–size relationships, and a study of actual corn input pricing in the vicinity of some existing ethanol plants. Hence, we do shed some light on the profitability of a well-scaled, well-organized ethanol processing firm that uses modern technology in the current economic environment. Our results suggest that ethanol is a profitable investment, that most of the recently constructed dry mills are smaller than optimal, and that one of the alternatives to a conventional processing business may choose a plant size that improves the region's economic surplus more than a conventional processing business.

THEORY

Three aspects of the firm choice problem are analyzed. First, we review investment theory in the context of an ethanol processing plant. While new ground is not broken, a preliminary demonstration of the profitability of ethanol processing is provided, and the advanced features of finance theory that are relevant to our problem are evaluated. Second, we show how the classical plant scale problem for an agricultural enterprise can be imbedded in an appropriate finance theory. Specifically, we develop an optimal plant scale rule for a processing business that purchases the bulky input in a corn market that includes exporter competition. Third, we provide plant scale rules for producer/processing enterprises. Specifically, we develop the optimal plant scale rules for a processing co-op and for an integrated corn processing enterprise, an organization chosen by many producer-owned firms.

Investment Analysis for an Ethanol Processing Firm

Investment analysis builds on enterprise cash flow, which is the difference between revenues and operating expenses. Processing corn into ethanol requires fixed proportions of ethanol (Ye) and distillers grain (Yd) per unit of corn processed (Qc_t):

$$Qc_t \text{ units of corn} \rightarrow \begin{cases} Qe_t = Ye\,Qc_t \text{ units of distillers grain} \\ Qd_t = Yd\,Qc_t \text{ units of ethanol} \end{cases}$$

Also, marginal processing costs for a fixed proportions process are constant, because fixed proportions of noncorn inputs (labor, electricity, water, and processing chemicals) are required for each unit of corn processed. Hence, the annual cash flow is defined in terms of the processing margin (M_t), noncorn operating expenses (Cp), and the volume of corn processed:

$$\pi_t = M_t Qc_t - CpQc_t$$

$$\text{where} \qquad M_t = Pe_t\,Ye + Pd_t\,Yd - Pc_t \tag{1}$$

The processing margin defines a composite market price for processing one unit of corn. It consists of a composite output price, and ethanol and distillers grain revenues per unit of corn processed ($Pe_t\,Ye$ and $Pd_t\,Yd$), less the corn input price (Pc_t).

The ethanol processor is a price-taker in both of the product markets. There are approximately one-hundred national firms in the U.S. ethanol market, and no one firm has a dominant market share. Also, a large fraction of the U.S. output of distillers' grain is sold on the international protein market. Further, the market price of ethanol does provide a socially desirable price signal for the plant investment problem, since the market price reflects the social benefits of ethanol consumption.[1]

We also assume temporarily that the processor is a price-taker in the corn input market. In the large, this is also a tenable assumption, since ethanol firms are small compared to the scale of an integrated international corn market, but once the investment framework is established, we will focus on the effects of price-setting in a local corn input market on plant scale choices.

Investors seek to maximize the discounted value of the future cash flows less the current cash outlay for the physical capital of the plant ($K(Qc_t)$).[2] A "capitalized profits" form of expected present value follows when expected profits and the anticipated rate of price increase are known:

$$V_t^e = -K(Qc_t) + \pi_t^e / r^* \tag{2}$$

where the superscript "e" refers to the mathematical expectation of a variable. Implicitly, a unit of corn used in the fixed proportions production process also requires one unit of processing capacity, which is also measured in units of corn processed. The capital cost function for the ethanol industry, $K(Qc_t)$, is U-shaped (Gallagher et al 2005). In turn, risk and the rate of product price increase define the adjusted real interest rate, r^* (Dixit and Pindyck 1994, p. 148; Brealey and Myers 2003, p. 197):

$$r^* = r - \alpha + \phi\rho\sigma \tag{3}$$

where α is the anticipated percentage growth (0/1) in the product price (margin), r is the nominal riskless interest rate, Φ is the market price of risk ($\Phi = 0.4$; Dixit and Pindyck 1994, p. 148), ρ is the correlation between ethanol profits and the market portfolio, and σ is the standard deviation of the percent change in the ethanol processing price.

The first order condition from the expected present value criterion Equation (2) provides a rule for optimal capital expansion.[3] In Tobin's investment analysis, capacity should increase until the capitalized value of the marginal investment divided by the purchase cost, i.e., "q," falls to unity (Dixit and Pindyck 1994, pp. 5, 420). Alternatively, marginal profitability can be decomposed to obtain the familiar competitive pricing rule,

$$M_t = Cp + r^* \frac{\partial K}{\partial Qc_t} \tag{4}$$

that price equals marginal production cost. Here, marginal cost includes an operating cost component and a capital cost component.

If there is a significant probability of low margins and plant closure, a modified capital expenditure rule that includes the opportunity cost of investing today instead of in the next period may be required (Pindyck 1988; Dixit and Pindyck 1994), but the current technology margin in Figure 1A exceeds the survey estimate of noncorn operating costs for every year of the historical period, so analysis of plant closure is not urgent. We considered option values in preliminary analyses, but concluded that conventional criteria are sufficient. Detailed calculations of option values are available upon request. Plant closure analysis may have been important in the past; a margin constructed with technology and costs from 1985 (Figure 1B) gave a margin below operating costs for three out of twenty years.

Dry mill ethanol processing is a profitable enterprise and a candidate for new plant capital placement. Consider the three terms in Equation (4). On the left hand side (LHS), a processing margin constructed with historical prices and today's processing yields ranges from \$1.2/bu to \$3.25/bu, with an average of \$2.02/bu (Figure 1A). On the right hand side (RHS), operating costs at $Cp = \$1.1$/bu are considerably less than the margin in Figure 1A; further, minimum average capital expenditures for a dry mill that processes 24 million bushels per year (MBY) are \$2.87/bu in current (2003) dollars (Gallagher et al 2005). So the annual capital cost, the second RHS term in Equation (3), is \$0.32/bu with an 11% annual return. Hence, the sum of operating and capital cost, \$1.42/bu, is considerably less than the average margin, suggesting that ethanol plant investment is profitable. Nonetheless, consideration of marginal capital cost, risk, and spatial aspects of the corn input is still required.

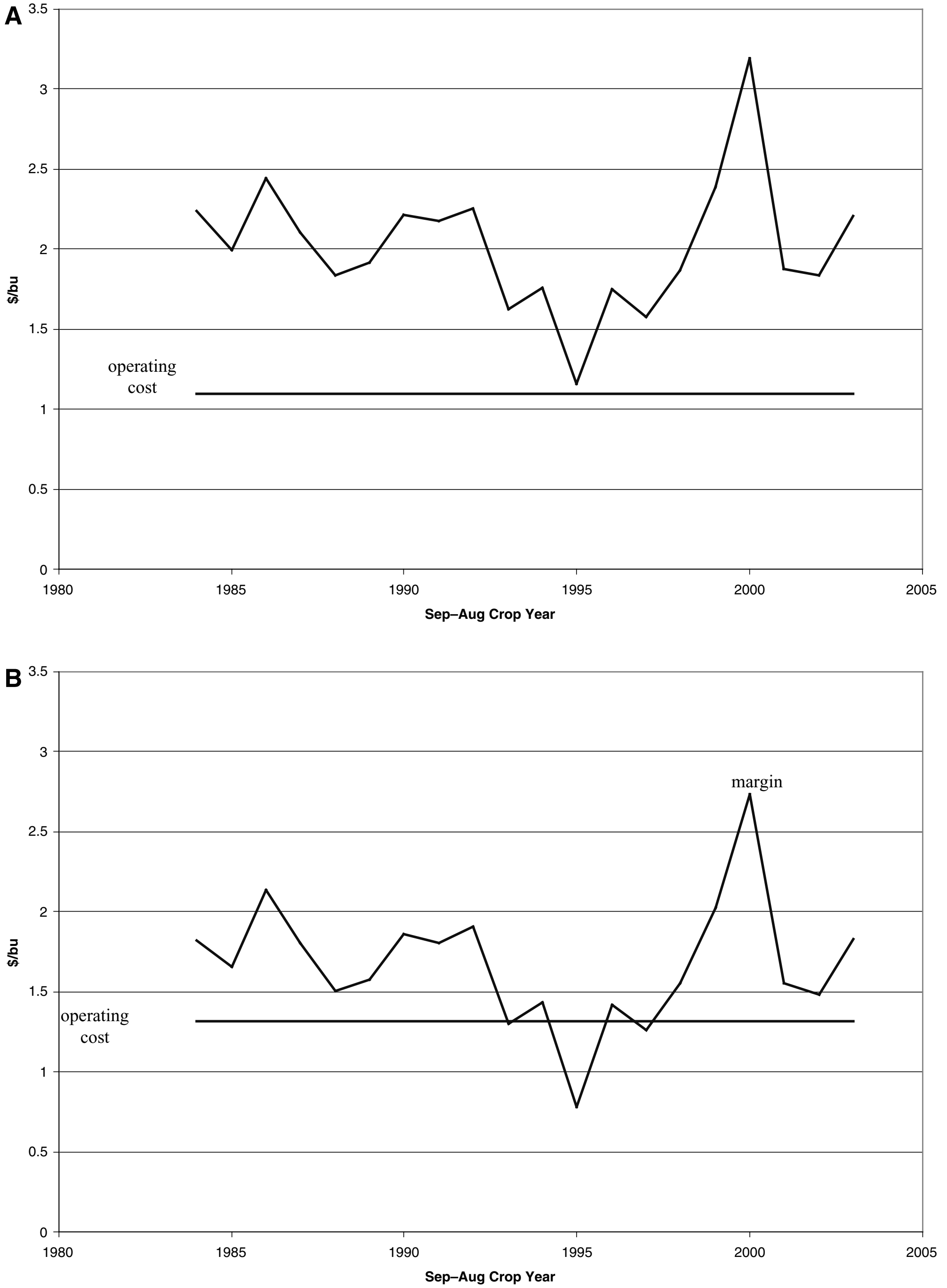

Figure 1. (A) Corn processing margin with today's technology and historical prices (B) Corn processing margin with 1980's technology and historical prices

The Ethanol Processing Business in an Input Market with Exporter Competition

A plant capital scale rule for a processing business that accounts for the dispersed input supply and significant farm-to-plant transport costs requires three elements: a profit function that is redefined to include spatial costs, a specific relation between corn input market area and the corn supply available at the plant, and the specification of corn market price relationships in the local market area.

The enterprise profit function should reflect the spatial dimensions of the investment problem, because ethanol processing facilities are uniquely large among grain processing enterprises (Gallagher et al 2005, p. 138). Hence, we specify a model that binds plant size together with determination of the local corn input market area. Further, the processing firm becomes one buyer among many local farmers. Thus, corn price is no longer fixed in the local market area. Instead, the processing firm has some ability to set prices in the local market area through the plant capacity choice.

A convenient profit function for the agricultural processor has separate terms for revenues (R_t^e), corn costs (Cc_b), and operating costs (Cp). Also, the connection between corn processing capacity and market area ($d_t{}^*$) is specified:

$$\pi_t^e = (R_t^e - Cp)Qc_t - r^* K[Qc_t] - Cc_b(Qc_t)$$

where

$$R_t^e = Pe_t Ye + Pd_t Yd$$

and

$$Qc_t = Qc(d_t^*) \tag{5}$$

The boundary of the market area (d_t^*) defines the corn input capacity that can be sustained by the local input market area when the density of available supplies (e and y) are given. The formula

$$Qc(d_t^*) = \pi d_t^{*^2} ey \tag{6}$$

multiplies the market area inside a circle by the supply available in a typical unit of area. For instance, a market boundary of $d_t^* = 25$ miles and a supply uniformly distributed in space with corn supply density $e = 75$ acre/mi^2 and yield $y = 150$ bu/acre will sustain a processing plant with a capacity of $Qc = 22 \times 10^6$ bushels annually. In practical applications, this physical relationship is used in conjunction with a constant cost/break even point model of farm supply, and the estimated "e" reflects the excess supply of corn available to the processing industry after meeting the needs of local livestock and inventories.

We do assume an early stage of processing industry development, where firms usually choose nonoverlapping market areas (Greenhut et al 1987, p. 263). Investing ethanol firms typically site new plants where direct competition with another plant will not occur, according to our interviews.

The location of the market boundary depends on the presence of competitors for the corn input near the processing plant. For Von Thunnen's isolated central market place, there is no external competition. Then the boundary is defined by producers' average variable costs (C_0) for corn plus freight costs to the market, because farmers pay the freight and are unable to earn profits or land rents when the market price does not exceed production plus marketing costs (Chisholm 1979, p. 15). Areas surrounding Iowa's ethanol plants operated by conventional businesses also tend to end up with delivered, or cargo, insurance, and freight (CIF) pricing rules, but they compete in a region that also exports grain. Then the processor pays the farmer the shipping cost the processor avoids by not obtaining the corn for the export price at the market boundary (Gallagher et al 2005, p. 121–122, Case B). Thus, the corn price at the processing site (Pc_t) equals an exporter's bid price at the market area boundary (Po_t) plus the transport rate associated with shipping from the market boundary (td_t^*):

$$Pc_t = Po_t + td_t^* \tag{7}$$

That is, the processor pays all farmers the same delivered price as for corn obtained at the boundary of the market area and shipped to the plant, but no more. The short-haul transport rate, t, is usually expressed as \$/bu/mile. Thus, the net price to a farmer at distance d_t from the plant is the site price less transport charges, which decline as distance from the processing plant increases.

In turn, corn costs for a processing business are defined by the price–distance function:

$$Cc_b = \int_{d_t=0}^{d_t^*} [Po_t + td_t^*](2\pi d_t)ey\Delta d_t \tag{8}$$

where td_t^* is the transport cost for shipping the corn from the market boundary and export point to the plant site. Derivation of the algebraic form of Equation (8) and appropriate derivatives are given in Appendix A (Section I).

Plant scale is optimized when corn, operating and capital costs offset the incremental revenues from plant expansion. Substituting the corn cost and market area functions into the profit function Equation (5) and the present value Equation (2), and differentiating with respect to d_t^*, yields a capital expansion/pricing rule with a spatial dimension:

$$R_t^e - Cp = r^* \frac{\partial K}{\partial Qc_t} + \frac{\partial Cc_b}{\partial Qc_t}$$

where

$$\frac{\partial Cc_b}{\partial Qc_t} = Po_t + (3/2)d_t^* t \tag{9}$$

Equation (9) still recommends a balance between incremental revenues and production costs for highest profits, but marginal corn cost is now a function that depends on transport cost and the market boundary, instead of an exogenous price. Equation (9) is a plant scale rule suitable for the subsequent empirical analysis of ethanol processing.

Return Maximizing Co-op

Consider a processing co-op that maximizes the total returns to members. Also assume that all producers in the input market area become members. The objective function of this enterprise is processed product revenues less processing costs less farm producer costs (Royer 2001, p. 4). Essentially, this means maximizing the sum of producer and processor profits. Adding the spatial dimension, the net processing and crop production return for a unit of corn located d_t miles from the plant is

$$N(d_t) = (R_t^e - Cp) - r^* \frac{K[Qc(d_t^*)]}{Qc(d_t^*)} - (C_o + d_t\ t) \tag{10}$$

because an individual's distance from the plant defines his transport costs. That is, corn producer-members are paid net processing revenues less the average capital cost, corn production costs, and actual transport costs to the processing plant. The net return could be obtained using two payments. The processor first reimburses corn producers for crop production and transport charges that are specific to an individual's location. Later, the processor distributes all earnings, using the equation above and an individual's location as a guide. Notice that a producer pays transport costs based on his actual distance from the plant (d_t), while he pays average capital costs based on the enterprise's choice of market boundary (d_t^*).

The total surplus to all plant members with a given market boundary, d_t^*, is[4]

$$\Pi(d_t^*) = (R_t^e - Cp)Q(d_t^*) - r^* K[Q(d_t^*)] - Cc_p(d_t^*)$$

where

$$Cc_p = \int_{d_t}^{d_t^*} [C_o + td_t](2\pi d_t)ey\Delta d_t \tag{11}$$

The corn cost equation for the integrated producer/processor is defined by the "initial payment" that the enterprise makes to individual farmers, $Pc_t = C_o + td_t$, which is the actual resource cost of the corn. Derivation of the corn cost equation and its derivatives is given in Appendix A.

To find the optimal scale of this combined producer/processor enterprise, differentiate the objective function (11) with respect to d_t^* to obtain:

$$R_t^e - Cp = r^* \frac{\partial K}{\partial Qc_t} + \frac{\partial Cc_p}{\partial Qc_t}$$

where

$$\frac{\partial Cc_p}{\partial Qc_t} = C_o + d_t^* t \tag{12}$$

Equation (12) is a suitable plant scale equilibrium rule for the integrated producer/processor enterprise.

Our hypothetical enterprise combines elements of a co-op and an integrated corn processing business. The co-op's "business-at-cost" principle motivates a corn payment of production plus transport cost that reflects the actual resource cost and, therefore, provides the appropriate supply-inducing price for the plant scale decision. Also, a co-op could accommodate annual capital payments at the market cost of capital to the firm by making payments to equity, borrowing from members, or borrowing from a bank. Co-op usually have difficulty in obtaining conventional financing, and raise capital using retained patronage refunds instead (Cobia and Brewer 1989, pp. 247–249). The private enterprise "maximum profit" principle guides the capacity and market area decisions, using joint profits from corn production and processing.

Finally, we assume that all producers in the input market area become members and provide their corn to the co-op processing enterprise, "all" referring to production in excess of on-farm feed needs. Producers will have an incentive to provide their production for processing if the corn cost reimbursement and corn processing return payment exceeds the price for export marketing. Persistent excess returns for processing would likely sway producers in a potential area toward complete conversion to processing. However, initial participation rates could be lower in a dynamic choice model that balances a long-run supply commitment against short-run marketing of corn to the export market, accounts for initial uncertainty about long-run net benefits, and considers the risk of price fluctuation in the grain export market. In short, the assumption of high levels of producer participation in processor supply agreements is tantamount to a demonstrated long-term profit advantage for committing capital to the processing enterprise.

Open Co-op

The open co-op does business at cost. In general, the open co-op expands until the net average revenue product—revenues less operating and capital costs per bushel processed—equals the supply price for the input (Helmburger and Hoos, 1962, p. 285). Also, suppose that the co-op pays the same price to all members for corn delivered to the processing plant, regardless of their location, then the private corn cost function, Cc_b, describes the co-op's input expenditures. Consequently, the co-op's equilibrium condition requires that

$$(R_t^e - Cp) - r^* \frac{K(Qc_t)}{Qc_t} = (P_o + td_t^*) \tag{13}$$

That is, the open co-op will expand plant capacity and market area up to the point where plant net operating revenues less annual capital costs balance expenditures on corn input. On the LHS, the average revenue for an incremental bushel of grain capacity is adjusted downward for operating cost and the average annual cost of capital. The average input expenditure for the grain input, $Cc_b(d_t^*)/Q(d_t^*)$, is given in its simplified form on the RHS (see Appendix A, Section I).

COST, TECHNOLOGY, AND MARKET ENVIRONMENT FOR A REPRESENTATIVE ETHANOL PROCESSOR

Today's cost, technology, and market environment are used for the analysis of ethanol processing. The local corn input market resembles Iowa during 2003. The evaluation also incorporates a discount rate that reflects ethanol's financial risk and growth potential. The parameters characterizing an Iowa ethanol firm's external environment are given in Table 1. These estimates of exogenous factors are based on recent studies of costs and technologies, and historical averages for market prices. Sources for our estimates of the current situation are reviewed below. Also, moderate improvements in several factors have combined for a substantial improvement in the conditions of ethanol processing over the last two decades. Thus, we also describe the source and extent of improvements in processing yields, operating costs, and capital costs.

Corn processing revenues are expressed per unit of corn processed. They are the composite of prices and yields for ethanol and distillers' grains. We use time series average prices for ethanol and distillers' grain, so that occasional periods of high and low prices are taken into account without undue weight. Survey values are used for ethanol and distillers' grain yields. It is important that current ethanol yields are now 10% higher than a decade ago because fiber conversion to ethanol is now possible (Piccataggio and Finkelstein 1996). The yield improvement of the last decade has increased revenues by \$0.31/bu, when valued using the 1984–2003 average of ethanol and DDG prices.

Similarly, noncorn operating expenses in dry mills have declined by 48% in current dollars or \$0.38/bu since the late 1980s (Shapouri et al 2002, p. 7). The sources of the decline are improved energy efficiency, automation that reduced labor use, and patent expiration that reduced enzyme cost. Two surveys suggest that noncorn operating costs have remained stable over the most recent five-year period, because adoption of cost-reducing technologies offsets rising natural gas prices. We use $Cp = \$1.1/\text{bu}$ to approximate noncorn operating costs of a typical dry mill, according to industry average data from the most recent USDA survey (Shapouri and Gallagher 2005).

Table 1. Parameter values chosen for Iowa case study

Variable	Value/Units	Description
Ye	2.6662 gallons/bushel corn	Ethanol yield
Yd	17.5 lbs/bushel corn	Distillers' grain yield
r^*	0.11 (in 0/1 percent)	Risk and inflation adjusted discount rate
Re	\$4.18/bushel corn	Ethanol and byproduct revenues, in \$/bu
Cp	\$1.10/bushel corn	Noncorn ethanol processing costs, in \$/bu
C_o	\$1.75/bushel corn	Iowa variable costs for corn production, 2003 trend value from a 1990–2003 regression
p_o	\$2.16/bushel corn	Iowa corn price at market area boundary, approximated by the state average corn price from 1984 to 2003
t	\$0.0025/bushel/mile	Short-haul rate for truck transport
y	154.73 bushel/acre	Iowa corn yield, 2003 trend value
e	51.43 acre/mile	Average corn density in Iowa's ethanol processing area

The capital outlay per bushel of processing capacity has also declined since the 1980s. As the typical size of a farmer-owned dry mill increased from 4 MBY in the 1980s to 19 MBY today, the average capital outlay for a bushel of capacity declined by nearly 44% in current dollars, according to an estimate of the relationship between average capital costs and capacity provided by Gallagher et al (2005, p. 569). We use the quadratic function from this study, adjusted to current (2003) dollars, for our analysis:

$$\frac{K(Qc_t)}{Qc_t} = \alpha - \beta Qc_t + \gamma Qc_t^2 \tag{14}$$

where $\alpha = 6.508$, $\beta = 0.3004$, and $\gamma = 0.006175$. According to this estimate and using $r^* = 0.11$, the annual interest cost for a unit of fixed plant capital cost has declined about \$0.27/bu since 1980, as producers have discovered a more appropriate scale.

The conditions facing processors in Central or Eastern Iowa are reflected in our corn market assumptions. For the corn cost function, an actual market area typically extends about $d_t^* = 40$ miles from the plant. Also, the local market rate for truck transport is $t =$ \$0.0025/bu/mi, and processors tend to use CIF pricing (Gallagher et al 2005, pp. 128, 133). Finally, an average of Iowa's corn price approximates the corn price at the boundary of a typical market area: $(R_w - C_p)Q_c - r^* K(Q_c) = CC_b$.

An adjusted discount rate should correct for risk and changing commodity prices. We obtain a real interest rate of $r^* = 11\%$ by summing the long-term average of the riskless interest rate (8%), plus a risk premium (7%), less the anticipated rate of increase in ethanol prices (4%).

For the riskless return component, we use the interest rate on a 10-year note issued by the U.S. government, because the asset length corresponds roughly to the expected life of the plant. The recent lows below 4%, however, seem overly generous. The 40-year average rate of 8% defines representative investment conditions and more conservative profitability assessments.

An ethanol investment should demand risk compensation by some measures of risk. For instance, ethanol price variability, measured by the standard deviation of margin changes at 24.3%, is higher than many commodities and considerably higher than manufactured goods (Bodie and Rosanski 1980). Accordingly, preliminary estimations of a market risk premium for ethanol used the capital asset pricing model (Brealey and Myers 2003, p. 167). The return on equity for agriculture was considered as the market portfolio for β estimation of individual enterprise returns. Regressions with the annual return on equity for the U.S. agriculture sector as the independent variable and annual ethanol returns on capital, gave $\beta = -0.27$, or a correlation between agriculture returns and ethanol returns of $\rho_{\text{ae}} = -0.15$. Ethanol returns were calculated with historical margin data, cost, and capital outlay surveys. Similar results occurred using a more conventional S&P 500 market portfolio with ethanol returns: $\beta = -0.42$ and $\rho_{\text{se}} = -0.06$.

Strictly speaking, the negative correlation suggests that adding ethanol to an agricultural or S&P 500 portfolio may actually reduce the variability of returns. In fact, the portfolio variance (σ^2) is related to the variance of agricultural assets (σ_{a}^2), the variance of the ethanol asset (σ_e^2), the correlation between agricultural and ethanol assets ($\rho_{a,e}$), agriculture's portfolio proportion (x_a), and ethanol's portfolio proportion (x_e), as follows:

$$\sigma^2 = x_a^2\sigma_a^2 + x_e^2\sigma_e^2 + 2\rho_{ae}x_a x_e \sigma_a \sigma_e \tag{15}$$

We estimate $\sigma_a = 0.089$, using sector data from the 1950–2003 period. We estimate $\sigma_e = 0.143$ using ethanol margin and cost data from the 1983–2003 period. The estimate $\rho_{ae} = -0.15$ uses the time period common to both series. With these estimates, additional increments of ethanol will actually reduce the variability of a balanced agricultural portfolio until ethanol's portfolio share reaches 40%.

Nonetheless, we do add a substantial risk premium to the riskless interest rate; we added the highest risk premium estimated for all classes of manufacturing industries (Brealey and Myers 2003, p. 182). The 7% risk premium from the aircraft industry is a starting point for ethanol profitability analysis, since both industries are highly cyclical and subject to government policy change.

For comparison, we also estimated the ethanol risk premium using mean-variance analysis, the certainty equivalence principle, and an estimate of the financial market's implicit risk preference. The details of this risk analysis are available from the authors, but Figure 2 summarizes the estimations for various levels of ethanol's share in the investor's portfolio. A risk premium of 1.5% to 2% is appropriate when ethanol's share is near zero. One to 1.25% applies when ethanol's share is near 40%, and 4 to 5.2% should be added to the riskless interest rate when ethanol consumes the entire portfolio. Indeed, the aircraft industry approximation is a conservative upper limit.

Lastly, investment analyses based on current profits and real interest rates require an estimate of anticipated increases in commodity prices. There are prospects for increasing ethanol prices (margins). Ethanol should maintain its share of the additives market even with steadily growing gasoline demand priced from $25/bbl oil. Also, ethanol's premium over commodity gasoline should increase due to health-related bans on substitute additives (Gallagher et al 2003). Using estimates of the likely increase in ethanol margins over the next 15 years gives an annual growth rate in the ethanol margin of 4%, i.e., $\alpha = 0.04$.[5]

PLANT SCALE AND ECONOMIC SURPLUS CALCULATIONS

Table 2 summarizes the plant scale, cost, market area, and profit associated with each organization of the ethanol processing enterprise. Iowa prices, costs, and processing yields, given in Table 1, define the economic environment for ethanol processing.

The plant size, cost, and market area estimates of Table 2 are based on the rules derived earlier; for plant size and market area, see Equation (9) for the processing business, Equation (12) for the producer/processing enterprise, and Equation (13) for the open processing co-op. The capital expenditures are calculated using Equation (14), with the appropriate plant scale estimate. Corn cost is calculated using Equation (8) or (11), as appropriate.

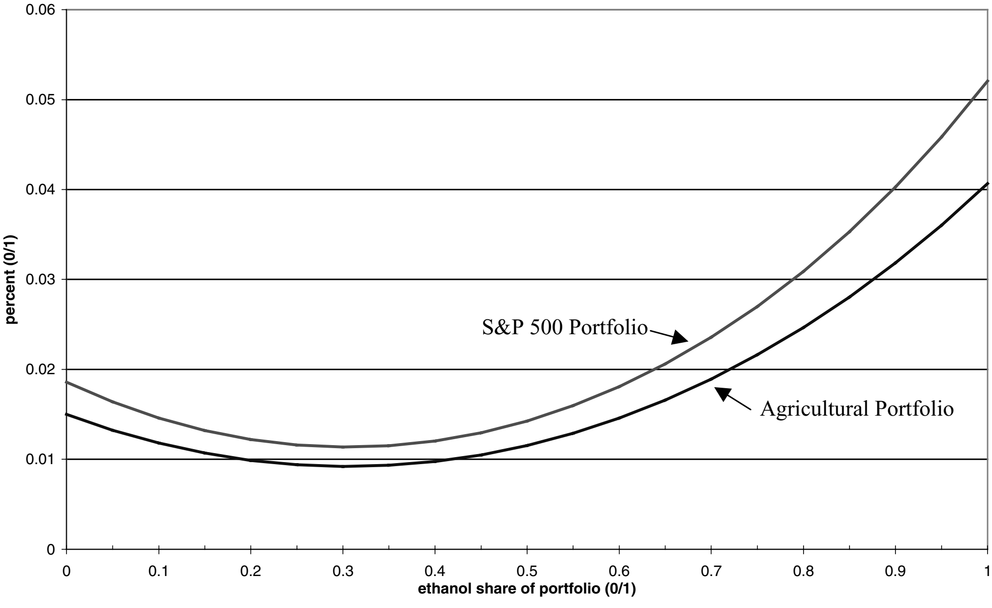

Figure 2. Ethanol risk premium

Most of the relationships for the profit estimates were also given previously. Processing profits for the business and the co-op are both given by Equation (5), although different values for the market boundary are used for each case. Farmer profits for the business and co-op use similar revenue and cost functions with different market boundaries (see Table 2, note (l) and note (n)). The total sector profit for the business and co-op are the sum of producer and processor components. In contrast, Equation (11) defines the total profit for the integrated enterprise. Then the producer profit is estimated as an opportunity cost, which is the return that farmers would earn by selling at the export price throughout the region, paying production costs, and avoiding local transportation (see Table 2, note (m)).

The processing business model calls for a capacity investment of 33.4 million bushels. Meanwhile, the joint producer/processor model suggests a slightly larger capacity of 39.1 million bushels. The processing co-op model gives the largest capacity, at 51.2 million bushels. This same ordering of enterprises ranks processor profits from highest to lowest; the average return on capital, obtained by dividing processors' profits by capital expenditures, is 13.6% for the processing business, 9.2% for the integrated producer/processor firm, and zero for the processing co-op. The producer profit ranking is inverted; the processing co-op is highest at \$23.95 million, the integrated producer/processor enterprise is next at \$16.8 million, and the processing business is lowest with \$15.4 million.

However, joint producer/processor profits are the appropriate indicator for overall welfare. Total surplus, the sum of producer and processor surpluses, is 5% higher with the integrated producer enterprise than the total surplus with the processing business.

Table 2. Estimated plant capacity and market area choices

Variable	Units	Organization		
		Processing business	Joint return maximizing co-op	Open processing co-op
Corn input	mil bu	33.38[a]	39.11[b]	51.20[c]
Corn cost	mil $	75.15[d]	70.23[e]	116.39[f]
Capital expenditure	mil $	112.59[g]	164.99[h]	375.58[i]
Market radius	miles	36.54[a]	39.55[b]	45.25[c]
Profit				
Processors	mil $	15.27[j]	15.25	0.00[k]
Producers	mil $	15.37[l]	16.81[m]	23.95[n]
Total	mil $	30.64	32.07[a]	23.95
Return on capital	Percent	13.6%	9.2%	1.0%

[a]Equation (9) with $d^* = 36.54$.
[b]Equation (12) with $d^* = 39.55$.
[c]Equation (13) with $d^* = 45.25$.
[d]Cc_b with $d^* = 36.54$. See Appendix A, Section (I).
[e]Cc_p with $d^* = 39.55$. See Appendix A, Section (II).
[f]Cc_b with $d^* = 45.25$. See Appendix A, Section (I).
[g]Equation (14) with $d^* = 36.54$.
[h]Equation (14) with $d^* = 39.55$.
[i]Equation (14) with $d^* = 45.250$.
[j]Equation (5) with d*=36.54
[k]Equation (5) with d*=45.25
[l]$Rf_b - CoQc(d_t^*)$ using $d^* = 36.54$. See Appendix C, Section (III).
[m]$(Po - Co)Qc(d_t^*)$ using $d^* = 39.55$.
[n]$Rf_b - CoQc(d_t^*)$ using $d^* = 36.54$. See Appendix C, Section (III).

Similarly, total surplus in the integrated enterprise is about 30% higher than the surplus of the processing co-op.

CONCLUSIONS

This paper looks at the appropriate scale and implied profitability of ethanol processing, using current conditions for technology and costs with typical product-market conditions, in a major ethanol-processing region of the United States. The optimal decision rules presented for plant capital investment are also shaped by joint producer–exporter competition in the local corn input market. Simulations estimate the plant scale choices and profitability implications of a well-organized processing business, a joint producer/processor enterprise, and a processing co-op.

Our plant scale estimates for all organization types for dry mills are higher than the actual size of most new dry mills. The estimates for the processing business and producer/processor enterprise, 35 and 41 MBY of corn (91 and 108 MGY of ethanol), respectively, are larger than most of the new dry mills—new dry mills usually process 20 MBY of corn (produce 50 MGY of ethanol).[6] The capacity estimate for the processing co-op is 50% larger than the estimate for the processing business.

There are some plausible reasons for overestimation of plant scale. For example, there may be a risk-based underinvestment if investors cannot diversify their risks, the banking sector demands a risk premium that exceeds our risk adjustment, or the diversification benefits of a moderate ethanol investment are not understood. Also, the United States Environmental Protection Agency's emission standards limited dry mills to about one-half of their optimal scale until recently. However, emission control technology has improved, and the size of some of the newest plants does correspond to our optimal scale estimates. The gap between the estimated and actual plant scale for the processing co-op is the widest, which may be related to the well-known difficulty associated with co-op financing of capital-intensive enterprises.

The simulations confirm that an optimally scaled ethanol plant, operated as a processing business or producer-owned enterprise with resource conditions similar to those of Iowa in 2003 is profitable. An earlier study questioned ethanol's potential for cost reduction and profitability (Kane et al 1989), but the actual processing cost reductions and technology-based revenue improvements of the last two decades have, in fact, been substantial; a 30% reduction in overall production costs has occurred. Nonetheless, the density of corn supply may still be insufficient to exploit economies of plant size in some other areas of the United States (Gustafson 2002).

The joint producer/processing enterprise provides the largest net benefit (producer plus processor surplus) for the area near the plant. The total area welfare is 5% higher when a representative producer/processor enterprise invests instead of a processing business. It is known that a joint producer/processing enterprise maximizes total welfare when the processor has potential monopsony power in the input market and takes prices in the product market (Royer 2001, p. 6). We show that setting the corn price through plant capacity choice is still moderately important in a local corn market, even when processors use CIF plant pricing and when export competition for the local corn supply is present. Separately, the total benefit improvement associated with producer-owned processing ($0.04 per bushel of corn processed) is not overwhelming, but it is comparable to the other component processing cost or technology improvements that have added up to a substantial improvement in ethanol processing returns.

The joint producer/processing organization is a hypothetical enterprise that combines business and co-op elements. It returns the joint corn production/processing surplus to members, pays for capital at the market cost, and secures a high participation rate among local farmers. This ideal situation does provide a benchmark for understanding the causes and remedies for underinvestment in value-added enterprises, but actual producer-owned ethanol businesses in the United States may or may not have an organization conducive to optimal scale. The general proposition that co-op can improve vertical coordination appears elsewhere (Schrader 1989, p. 128). Our result is a special case of this general proposition.

Based on profitability, continued ethanol processing investments should and will likely be considered by the private sector. Investments in larger plants, near 39 MBY, should be considered for highest profitability. Investors should also consider enterprises that include joint producer and processor activities, especially when plant expansion decisions are based on the resource cost of the corn input. Initial producer payments for corn costs should include production cost plus location-specific transportation charges.

Public interventions aimed at better resource allocation might encourage continued ethanol processing investments. Perhaps, incentives for integrated producer/processor enterprises should be considered. Otherwise, investment incentives for processing businesses or co-ops might stem investment in undersized plants. Finally, public education about ethanol's diversification benefits in the financial marketplace might stem over-discounting for risk.

NOTES

[1]Some do argue that clean air regulation and the consumption subsidy for ethanol distort the market, so that the ethanol price exceeds its social benefit in consumption. However, environmental benefits associated with ethanol consumption include replacement of the carcinogens benzene and lead, reduced carbon monoxide from combustion, and improved (reduced) global warming (Conway and Erbach 2004, p. D2). As a first approximation then, these demand-shifting policies should remain for normative analysis of ethanol competitiveness. However, empirical measurement of external benefits and determination of the optimal set of policy instruments still deserves investigation.

[2]In general, the value of the plant investment is the discounted value of future cash flows less the current outlay for the physical capital of the plant: $V_t = -K(Qc_t) + \sum_i \pi_{t+i}/(1+r)^i$

[3]The first order condition from the expected present value criterion Equation (2) is

$$\frac{\partial V_t^e}{\partial Qc_t} = \frac{\partial K_t}{\partial Qc_t} + \frac{\partial \pi_t^e}{\partial Qc_t}\frac{1}{r^*} = 0 \tag{15}$$

Rearranging gives the ratio form of the profit condition:

$$q_t = \frac{\dfrac{\partial \pi_t^e}{\partial Qc_t}\dfrac{1}{r^*}}{\dfrac{\partial K}{\partial Qc_t}} = 1$$

[4]To see this, add all corn units at each distance from the plant:

$$\Pi(d_t^*) = \int_{d=0}^{d^*} [R_e - Cp - r^* \frac{K[Qc(d_t^*)]}{Qc(d_t^*)} - (C_o + d_t t)]2\pi dey\Delta d_t \tag{13}$$

Separating terms gives:

$$\Pi(d_t^*) = (R_e - Cp)Q(d_t^*) - r^* K[Q(d_t^*)] - \int_{d=0}^{d^*} [C_o + d_t t]2\pi d_t ey\Delta d_t \tag{14}$$

Total corn cost for the integrated processing enterprise is the third term Cc$=\int_{d=0}^{d^*} [C_o + d_t t]2\pi d_t ey\Delta d_t$, which is evaluated in Appendix A (Section II).

[5]Alternatively, the 11% overall discount rate is consistent with a 3% risk adjustment, if the 4% adjustment for anticipated ethanol price increases is removed. More precise estimates of ethanol's discount rate and risk premium in future research might also explore arbitrage pricing theory (Brealy and Meyers 2003, pp. 177–181).

[6]The capacity data for old and new ethanol plants is summarized by Gallagher et al (2005, p. 569). Also, see Bryan (2003).

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APPENDIX A. DERIVATION OF CORN COST FUNCTIONS

For the cost–distance relationship, notice that the production obtained from a ring of a given distance from the plant is given by the product of the circumference of the circle, the width of the ring, and the density of corn: $\Delta Qc = (2\pi d)\,(ey)\,\Delta d$. Then the marginal cost of expanding the outer circle by the increment Δd is given by $C'(d) = P(d)\,(2\pi d)(ey)$. $P(d)$ is a general price gradient function describing the price–distance surface. In general, the total cost function is $Cc_z = \int_{d_t=0}^{d_t^*} P(d_t)(2\pi d_t)ey\Delta d_t,\ for\, z = b,\, p.$

I. In the case of the processing firm that buys its corn input in the presence of exporters, the corn cost function becomes $Cc_b = \int_{d_t=0}^{d_t^*} [Po_t + td_t^*](2\pi d_t)ey\Delta d_t$.

It is important to realize that the d_t^* in the price function is a constant for the mechanics of integration because it is the upper limit of the definite integral. Hence, the integral becomes

$$Cc_b = (ey)[Po_t + td_t^*][2\pi]\int_{d_t=0}^{d_t^*} d_t\Delta d_t = Po_t\pi d_t^{*2}ey + t\pi d_t^{*3}ey$$

So, $\frac{\partial Cc_b}{\partial d_t^*} = 2Po_t\pi d_t^* ey + 3t\pi d_t^{*2}ey$. Also $\frac{\partial Qc}{\partial d_t^*} = 2\pi d_t^* ey$, from Equation (6).

Hence, the marginal corn cost with respect to expanding the plant's capacity is given by dividing the above two partial derivatives: $\frac{\partial Cc_b}{\partial Qc} = Po_t + (3/2)td_t^*$.

The average corn cost with respect to expanding the plant's capacity is given by dividing Cc_b by Equation (6): $\frac{Cc_b(d_t^*)}{Qc(d_t^*)} = Po_t + td_t^*$.

II. In the case of the combined producer/processing firm, the general price gradient function becomes $P(d_t) = Co + td_t$. So, the corn cost function becomes $Cc_p = \int_{d_t=0}^{d_t^*} [Co_t + td_t](2\pi d_t)ey\Delta d_t$.

Now, the variable d_t in the price function is a variable for the mechanics of integration. Hence, the integral becomes

$$Cc_p = (2\pi)(Co_t)(ey)\int_{d_t=0}^{d_t^*} d_t\Delta d_t + (2\pi)(t)(ey)\int_{d_t=0}^{d_t^*} d_t^2\Delta d_t + = Co_t\pi d_t^{*2}ey + (2/3)t\pi d_t^{*3}ey$$

So, $\frac{\partial Cc_p}{\partial d_t^*} = 2Co_t\pi d_t^* ey + 2t\pi d_t^{*2}ey$. Also, $\frac{\partial Qc}{\partial d_t^*} = 2\pi d_t^* ey$, from Equation (6).

Hence, the marginal corn cost with respect to expanding the plant's capacity is given by dividing the above two partial derivatives: $\frac{\partial Cc_p}{\partial Qc} = Co_t + td_t^*$.

The average corn cost with respect to expanding the plant's capacity is given by dividing Cc_b by Equation (6): $\frac{Cc_p(d_t^*)}{Qc(d_t^*)} = Co_t + (2/3)td_t^*$.

Also, see Gallagher and Johnson (1999, p. 117) for a derivation of this average cost function.

III. In the case of the farmer selling to the processing firm, the general price gradient for the farm price at a particular location becomes (Gallagher et al 2005, p. 122): $Pf(d_t) = Po + td_t^* - td_t$. So the farm revenue function becomes $Rf_b = \int_{d_t=0}^{d_t^*} [Po + td_t^* - td_t](2\pi d_t)ey\Delta d_t$.

Now, the variable d_t in the price function is a variable for integration while d_t^* is a constant. Hence, the integral becomes $Rf_b = (2\pi)(Po + td_t^*)(ey) \int_{d_t=0}^{d_t^*} d_t \Delta d_t - (2\pi)(t)(ey) \int_{d_t=0}^{d_t^*} d_t^2 \Delta d_t = Po_t \pi d_t^{*2} ey + (1/3)t\pi d_t^{*3} ey$. Also producer profits are $\pi_f = Rf_b - CoQc(d_t^*)$.