

The International Competitiveness of the U.S. Corn-Ethanol Industry: A Comparison with Sugar-Ethanol Processing in Brazil

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ABSTRACT

An indicator of competitive position, the cost difference between ethanol import from Brazil with sugar processing and domestic production with corn in the United States under ideal conditions without tariffs in the ethanol market, is developed conceptually. An ex ante version of the indicator that is based on historical prices and today's technology is calculated for the last 30 years and subjected to time series analysis. Results suggest that there are no trends, but there are cyclical periods of advantage for both industries. Further, long-term averages suggest that profits would be similar in both countries under ideal trade conditions. However, the corn wet-milling industry may have slightly higher profits than other processes and locations. Finally, the U.S. dry-milling industry could improve its competitive position using modified corn varieties with high starch content, and using corn residues for biomass generation of electrical and heat energy. [EconLit Classifications: F140, L650, Q420]. © 2006 Wiley Periodicals, Inc.

The strategic management school defines competitiveness as the ability to profitably create value through cost leadership or product differentiation (Kennedy, Harrision, Kalaitzandonakes, Peterson, & Rindfuss, 1997). In public evaluations of the U.S. ethanol industry, both the quality and the cost dimension are important. Regarding quality, ethanol has survived scrutiny in an additives market where several petroleum-based additives (tetraethyl lead, benzene, and methyl tertiary-butyl ether [MTBE]) have been banned or restricted amid environmental and health concerns. Further, ethanol's fuel performance and air quality attributes create value in the marketplace with existing environmental and performance standards. Ethanol is a distinct additive product, not commodity gasoline. Hence, ethanol prices in the United States should exceed gasoline prices in a well-functioning

market where market standards or incentives reflect the additive ethanol's contribution to automobile performance and environmental quality (Gallagher, Shapouri, Price, Schamel, & Brubaker, 2003b, p. 592).

Even so, international competition and comparative advantage may not point to ethanol production in the United States. For instance, some presume that ethanol production from sugar is more efficient than corn on technical grounds (Kirk & Othmer, 1980, p. 353). Further, other countries' processing sectors could be more efficient. For instance, Brazil has an ethanol industry that contributes to their economy as a gasoline substitute when petroleum prices are between \$15–20/barrel (bbl), and can recover capital costs in the \$40–50/bbl range (da Matta & da Rocha Ferreira, 1988).

In this article we examine the competitiveness of the U.S. corn-ethanol industry, mainly using a comparison with Brazil's sugar-based ethanol industry. The first section develops a model of potential international ethanol trade and suggests an indicator for measuring the competitiveness of the U.S. industry. In the second section we explain the calculation of an *ex ante* indicator that is based on today's technology. We provide a time-series analysis that classifies the variation in the indicator in the third section; our calculations suggest that there would be no persistent competitive advantage to the corn-processing industry or the sugar-processing industry if trade barriers in the ethanol market were removed. However, cyclical episodes of advantage for one industry or another would persist for several years. We then suggest some strategies for improved competitiveness in the corn-ethanol industry; modified corn varieties for ethanol production and biomass power generation offer prospects for substantial cost reduction. Finally, we show that alcohol-based fuel may compete directly with petroleum-based gasoline in future U.S. fuel markets; breakeven-point thresholds of competition in gasoline and petroleum markets are identified.

1. COMPETITIVENESS AND TRADE

Dornbusch (1980) suggests a measure for international competitiveness in a macroeconomic setting. To illustrate, assume there are fixed-proportions production technologies and exogenous factor prices: Country a's production costs (in, say \$/unit output) are given by the exogenous wage (in, say, \$/h), divided by the labor productivity (in, say, output/h). Similarly, country b's variable costs are given by the ratio of domestic wages and productivity, expressed in their local currency units. Next, an exchange rate conversion gives country b's variable costs in country a's currency. Finally, the difference between b's costs and a's costs indicates country a's competitive advantage in its own currency units. Specifically, country A is at a competitive advantage (disadvantage) if the cost difference between b's costs and a's costs is positive (negative).

This cost-related concept of competitiveness can be adapted to trade in a product like ethanol, where a small processing industry relies on a distinct agricultural commodity in each country. To illustrate, consider the ethanol price and trade equilibrium shown in Figure 1; country b is a potential exporter and country a is a potential importer. In panels II and V, the marginal cost of processing schedules (C_p^c and C_p^s) are constant because of fixed proportions—both processing supply schedules are expressed in output units. In panels III and VI, the raw commodity supply curves are also horizontal because each processing industry is small relative to a large world commodity market. Both commodity supply schedules are also expressed in output units, corn price times ethanol yield from corn ($P_c Y_c^e$) for country a's raw material, and sugar price times ethanol yield from

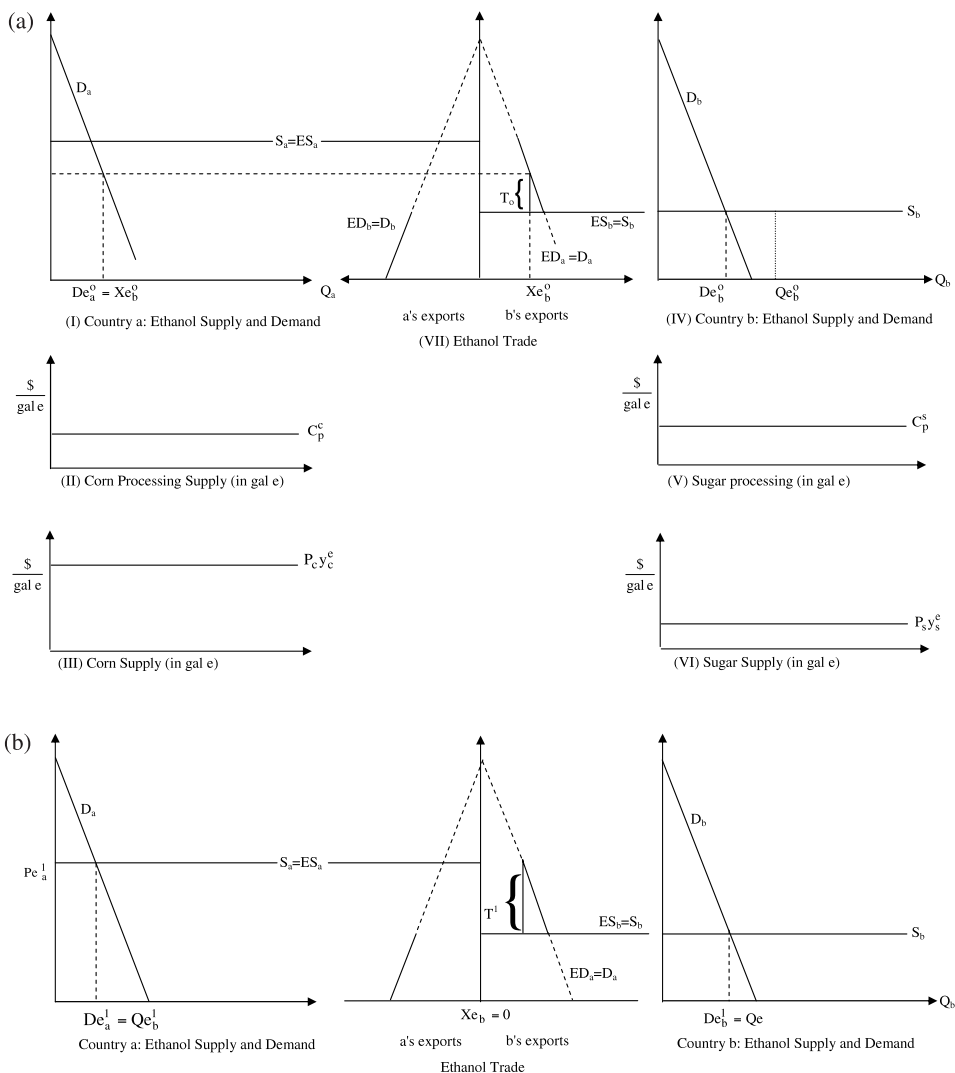


Figure 1 (a) Ethanol Trade Equilibrium with Competitive Exports from Country b (b) The Competitive Margin (T^I)

sugar ($P_s Y_s^e$) for country b's raw material. Consequently, the ethanol (product) supply curves are also horizontal with height defined by the sum of processing and raw material supply schedules. For country a, the supply (marginal cost) of domestically supplied ethanol is $S_a = C_p^c + P_c Y_c^e$ in panel I. Similarly, country b's marginal cost of ethanol production is $S_b = C_p^s + P_s Y_s^e$ in panel IV.

This constant cost analysis can refer to the short run or the long run. For the short run, the processing supply schedules refer to operating costs like processing chemicals and wages. There may also implicitly be a vertical segment of the processing supply schedules defined by the capacity of the fixed capital stock in the processing industry in the short run. The short run is defined by a production period and acreage allocation in commodity markets, but horizontal commodity supply schedules are reasonable in large world

commodity markets for the main processing inputs: corn and sugar. For the long run, the processing supply schedules would also include the incremental capital cost associated with an incremental unit of capacity. The long run in commodity markets likely includes a 5- or 10-year period, that allows for acreage reallocations and livestock population adjustments in feed grain markets.

Trade in either direction or autarky could occur with constant cost ethanol industries in both countries, depending on the relative position of supply schedules and transfer charges. So panel VII shows the excess supply (ES_a) and excess demand (ED_b) schedules when country a exports on the left-hand side, and the excess supply (ES_b) and excess demand (ED_a) schedules when country b exports on the right-hand side. Also, the excess supply schedule of each country is perfectly elastic at the level of its domestic supply price. Starting with relatively high prices, country a is willing to supply ethanol to foreign buyers at the relatively high supply price, S_a , but there is no demand. At slightly lower prices, country a becomes an importer and is willing to import its entire consumption, $ED_a = D_a$, at prices below S_a . Similarly, country b will supply ethanol to foreign buyers at the relatively low supply price, S_b . Below that, country b becomes an importer and is willing to import its entire consumption, $ED_b = D_b$.

The case where country b exports (Xe_b^o) to country a is shown in panel VII. Country b's delivered price to country a is country b's local supply price plus a transfer charge (T^o), which is below country a's supply price. Consequently, country a imports all of its consumption ($De_a^o = Xe_b^o$), and country b produces (Qe_b^o) enough to fill the demand of both countries. The ethanol price in country a is $Pe_a^o = S_b + T^o$.¹

The competitive margin for country b's exports is shown in Figure 1b. Here, the demand and cost structure is the same. But now adding the transfer charge (T^1) to country b's supply price implies a delivered price for country b that is incrementally higher than country a's domestic supply price. So ethanol trade ceases and both countries produce to fill their own domestic production.

Hence, the difference between country b's delivered price and country a's supply price is a useful competitiveness indicator because it shows how far the exporter's actual price and transfer charges are above the importing country's supply price, where country b's entry occurs and autarky ceases. For our trade model, the difference is

$$\Delta = (S_b + T^o) - S_a$$

Substituting for the supply prices' components in each country and rearranging yields

$$\Delta = (C_p^s - C_p^c) + (P_s Y_s^e - P_c Y_c^e) + T^o$$

When processing costs, commodity prices, or transfer charges for country b are relatively high, $\Delta > 0$, and country b's imports are not competitive in country a. Then country

¹If country a's demand shifts beyond country b's existing processing capacity, there is a short-run period defined by a vertical segment in country b's processing supply. Further, the ethanol price in country a will be defined by the intersection of ED_a and the vertical segment of ES_b . In this short-run period then, the ethanol price would exceed the sum of transfer charges and country b's costs. But ethanol capacity expands within 2 years (MacDonald et al., 2001). So cost-based pricing would recur after country b's capacity expansion. That is, cost-based competitiveness indicators reflect long-term advantage despite occasional pricing based on capacity constraints.

a produces its own ethanol and there is no trade. Otherwise, $\Delta < 0$ indicates the extent of the cost and price reduction that country a acquires by importing from country b. Actually, processing costs should be similar in both countries because the biochemical conversion process is the same for both sugar and corn. Hence, one would expect changes in commodity prices and transfer charges to dominate evolution of the competitiveness indicator.

The cost difference also has a normative use as a predictor of trade flows under various stages of trade liberalization. At the extreme ideal conditions of free trade in all markets, perfect competition, and a homogenous ethanol product, competition would ensure that output is priced at marginal cost of the low-cost country. Then the country with lower costs would export to the other country.

Under less than ideal conditions, competitiveness indicators define the country's potential to expand its industry and improve its trade position in the event that some trade barriers are removed. Our subsequent empirical analysis focuses on the removal of the import duties on ethanol—U.S. ethanol tariff policy may be changing already in light of expanding ethanol demand in the U.S.

By focusing on the ethanol market, we may actually make a conservative normative assessment of the U.S. ethanol industry's ability to compete in the event of complete trade liberalization in the long run, because we do not include the deregulation of world commodity markets. For instance, Tyers and Anderson (1988) considered both coarse grains and sugar in a long-run simulation of trade liberalization by industrial countries. They calculated that the world coarse grain prices would increase by 3%, and world sugar prices would increase by 23%. But, judging from the slow progress in reducing producer subsidies during 25 years of General Agreement on Tariffs and Trade (GATT) and World Trade Organization (WTO) trade negotiations, removal of all of these trade barriers does not appear imminent.

So far, the competitiveness analysis could apply to any two countries that produce ethanol. But we focus on the U.S. and Brazil because these two countries have established ethanol industries, and because they likely represent resource and processing costs of the industries in other countries that are emerging from a corn or sugar resource base. Accordingly, we account for the particulars of demand policy in the U.S. and Brazil.

Policy-dependent outward shifts in the ethanol demand curves are present in both countries. In the United States, several Environmental Protection Agency (EPA) regulations on fuel blending, including a lead ban, a benzene maximum, a minimum oxygen standard, and state-level MTBE bans have created a market for ethanol as a relatively benign additive that increases octane in gasoline (Gallagher et al., 2003b, p. 7). Hence, ethanol sells at a premium over commodity gasoline. The U.S. government also allows a partial exemption (\$.054/gal) from the excise tax on gasoline when the fuel includes a 10% ethanol content (Gill, 1987). In Brazil, consumers receive a price discount when they buy an ethanol-using car as part of a carbon-trading scheme with Germany (Driven to Alcohol, 2002). Brazil also sets an alcohol-to-gasoline blend ratio that must be maintained in all of their gasoline (Schmitz, Schmitz, & Seale, 2004).

Some would argue that domestic ethanol demand incentives should be removed for a comprehensive evaluation of the ethanol industry under ideal market conditions. However, environmental benefits associated with ethanol consumption include replacement of the carcinogens benzene and lead, reduced carbon monoxide from combustion, and improved global warming (Gallagher, 2004). So, the bans and limits for environmentally dangerous products and consumption incentives likely shift demand and increase producers' ethanol price closer to the full social benefits associated with ethanol consumption. As a

first approximation then, these demand-shifting policies should remain for normative analysis of ethanol competitiveness even though empirical measurement of external benefits and determination of the optimal set of policy instruments still deserves investigation. Removal of the U.S. ethanol demand policies might not improve the positive analysis of competitiveness, either. Renewal of the subsidy still receives political support, perhaps due to the need for domestic energy supplies and parallel incentives in the petroleum industry (National Energy Policy Development Group, 2001, p. 6).

2. ESTIMATING PROCESSING COST DIFFERENCES FOR BRAZILIAN SUGAR AND U.S. CORN

An empirical analysis based on variable cost differences is useful for the U.S. corn: Brazil sugar: ethanol comparison, because processing has fixed proportions that are predetermined at a point in time and factor prices are exogenous to the ethanol industry. Now, differences in raw material costs, processing efficiency and exchange rates are major sources of competitive advantage. Specifically the competitiveness indicator, d , is positive when sugar processing and import transportation to the U.S. is higher than local corn processing. That is, the corn industry has a cost advantage over sugar when:

$$d_t = C_{s_t} + C_{f_t} - (C_{n_t} + C_{e_t})$$

where

$$C_{s_t} = (P_{s_t} E_t) / Y_s^e \text{ and } C_{n_t} = \begin{cases} (P_{c_t} - Y_c^f P_{f_t} - Y_c^m P_{m_t} - Y_c^o P_{o_t}) / Y_c^e, & \text{wet mill} \\ (P_{c_t} - Y_c^d P_{d_t}) / Y_c^e, & \text{dry mill} \end{cases} \quad (1)$$

Variable definitions for the empirical study are given in the Appendix. This indicator is constructed on the assumption that the biochemical process of ethanol conversion and its cost are similar for sugar and corn. But material price differences for sugar, corn, and byproducts are taken into account. The technical efficiency is also taken into account because processing yields for both raw materials are included. Finally, effects of exchange rate fluctuation are included because Brazil's sugar price is converted to dollars.

In comparing sugar processing and corn processing, there are three important differences. First, there are differences in the valuation of byproducts. Specifically, corn processors return the protein and oil components to feed and food markets after using the starch in corn. So, the net corn cost in Equation 1 reduces the corn price by the byproduct revenues obtained per unit of corn processed. Furthermore, there are two corn-processing methods, wet milling and dry milling that return distinct byproducts (Kane, Hrobavcak, LeBlanc, & Reilly, 1988, p. 34; Kane, Reilly, LeBlanc, & Hrobavcak, 1989). The wet mill separates three byproducts: gluten feed, gluten meal, and corn oil—the net corn cost variable for wet mills subtracts revenues from these three byproducts. Similarly, dry mills have one composite byproduct, distillers' grains, whose revenues are subtracted to arrive at the net corn cost variable for dry mills. Separate competitiveness indicators are presented for wet mills and dry mills.

Second, the main processing cost difference from the theoretical measure, $C_p^s - C_p^c$ concerns energy costs. Specifically, sugar processing does not yield byproducts that have

much value in animal feed markets.² Instead, the residue from sugarcane processing, bagasse, is generally used as the energy for heat and electricity in a power plant with sufficient capacity for ethanol production. But the energy cost in corn processing is subtracted in the corn competitiveness equation because external energy inputs are used for corn processing. Further, wet mills and dry mills have distinct energy requirements. Dry mills are typically smaller than wet mills, so they purchase electricity from the power industry and burn natural gas for other energy requirements (Gadomski, 2001). Wet mills are larger—they typically build a coal-fired power plant for electricity needs and steam-based power (Frey, 2001). Hence, energy costs are defined by the corn-milling technology. They are:

$$Ce_t = \begin{cases} Z_c^k Pk_t, & \text{wet mill} \\ Z_c^e Pl_t + Z_c^n Pn_t, & \text{dry mill} \end{cases}$$

The non-energy component of the processing cost difference in the theoretical measure is excluded from statistical analysis because time-series data are not available. Fortunately, the conversion process is very similar with both resources. Processing of either resource requires similar pretreatment, fermentation, centrifugation, and distillation equipment. Subsequently, we compare benchmarking cost surveys for the U.S. and Brazil, and make a small adjustment to the statistical calculations based on differences in non-energy operating costs.

Third, corn processors are protected from imports by the transport costs for moving ethanol from Brazil to the United States. Consequently, a published transport rate for South American–U.S. petroleum shipment is used to approximate ethanol transport costs (Organization of Petroleum Exporting Countries [OPEC], 1999). The international transport cost is added to sugar processing costs in the corn competitiveness equation.

The competitiveness indicator would indicate the direction of trade flows under ideal conditions without ethanol tariffs. Imports would be more expensive than domestic production when $d > 0$, so autarky (no imports) would occur. Otherwise, imports would occur. The hypothetical no tariff situation is a useful reference point for a competitiveness indicator because it shows how the industry would fare without that trade barrier.

The competitiveness indicator could be converted to a predictor of actual trade flow tendencies under existing trade policies with slight modification. Specifically, the import tariff could be added to the freight charge to obtain a total cost of importing ethanol. Alternatively, a horizontal line at the negative value of the tariff could be constructed on the graph of the ideal indicator—when the actual indicator is below the tariff line, import flows would be profitable. There is a \$0.57/gallon import duty on fuel-grade ethanol for the United States (U.S. International Trade Commission, p. XXII, §99–4). A perusal of Figure 1 and Figure 2 suggests that this level is sufficient to preclude above-quota trade under all historical conditions because the most-extreme negative values of the indicator never reach $-\$0.57/\text{gal}$.

However, there is also a tariff-rate quota up to 7% of U.S. domestic consumption or about 200 million gallons in 2003. Below quota imports from Canada, Israel, Caribbean Basin Economic Recovery Act Countries, and countries covered under the African Growth and

²An opportunity to use residue as a livestock feed may exist in some areas. However, sugarcane bagasse has the lowest animal feed value of all major crop residues because of its low protein and nutrient content. Using U.S. commodity and hay prices, the feed value of bagasse is only 15% of the feed value of sorghum stover, the residue with the highest nutrient and protein content (Gallagher et al., 2003a, p. 338).

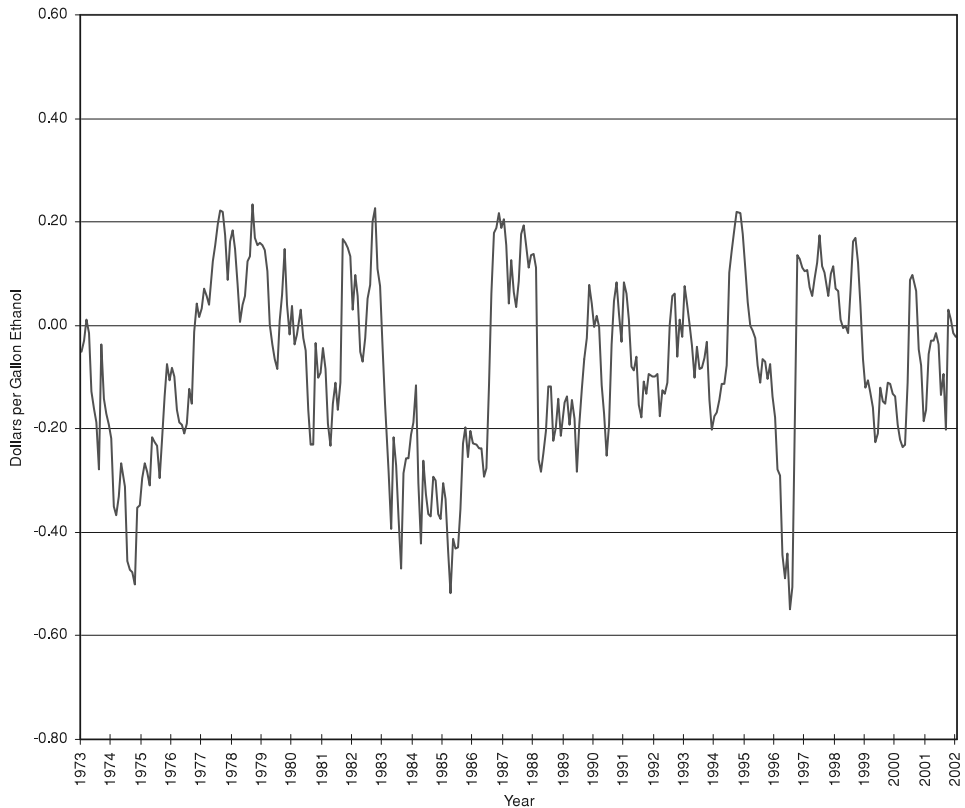


Figure 2 Cost Advantage for Producing Ethanol in the US: Dry Mill (d_1): January 1973–June 2002

Opportunity Act are excluded from the import duty on fuel ethanol. Further, ethanol produced in Brazil and dried in a Caribbean Basin Country, such as Panama, can qualify for the under-quota tariff exemption (IFV Staff, 2004). The quota for Caribbean Basin Countries and Brazil trans-shipments is not yet binding; U.S. imports for 2002 were very modest, at 0.11 billion gallons or 3% of domestic production. But California began importing (0.04 bil gallons) in 2003, after their MTBE ban went into effect.

A related indicator, constructed by subtracting the freight charge in Equation 1 instead of adding it, would be positive when the cost of production from corn and export to Brazil would be less expensive than production in Brazil. Means (M) and standard deviations (SD s) for the components of d , given below, suggest how the character of d would change if converted from an import base to an export base:

| <i>Variable</i> | <i>M</i> | <i>SD</i> |
|-----------------|----------|-----------|
| Cs_t | 0.4801 | 0.112 |
| Cf_t | 0.0260 | 0.0069 |
| Cn_t (dry) | 0.4365 | 0.1646 |
| Cn_t (wet) | 0.3269 | 0.1692 |
| Ce_t (dry) | 0.1288 | 0.0505 |
| Ce_t (wet) | 0.0747 | 0.0177 |

Modest changes in the nature of d would occur for an export indicator because the transport charge, C_f , has a small mean and standard deviation.

The U.S. has had at least one opportunity to export ethanol to Brazil. One arbitrage opportunity occurred when refined sugar prices in Brazil reached their peak for the last decade in June of 2000. The U.S. ethanol price averaged \$1.33/gallon and freight charges were $C_f = \$.03/\text{gallon}$, suggesting a supply price in Brazil for U.S. ethanol of \$1.36/gallon. During the same month, the ethanol price in Brazil was \$1.45/gallon (Schmitz, Schmitz, & Seale, 2002, p. 131). This arbitrage opportunity for U.S. ethanol producers occurred, despite the Brazil government's tendency to adjust the ethanol blend ratio downward to mitigate unusually high sugar prices. Immediately afterwards in 2001, Brazil imposed a 30% tariff on ethanol imports (Schmitz, Schmitz, & Seale, 2003, p. 255). Brazil's import duty may prevent a recurrence of this U.S. export opportunity.

3. THE RECORD

Values of the competitiveness indicator for a historical period are useful in preliminary evaluations of the relative advantages of a sugar-based and a corn-based industry. For instance, the indicator may suggest a persistent advantage for corn or sugar. Or trends may show one raw material is gaining an advantage. A priori classification is not possible because a favorable indicator outcome hinges on macroeconomic conditions and the price cycles in two commodity markets. The *ex ante* indicator we present here combines historical market prices and exchange rates with state-of-the-art technology. In this fashion, information relevant to today's investment decision is provided because the indicator shows how today's technology would compete in the range of commodity and financial market conditions.

State-of-the-art processing yields and energy requirements for corn processing and sugar processing are used in the calculation of d . For instance, Paturau (1982) gives sugar processing yields and input requirements. Piccataggio and Finkelstein (1996) give corn-processing yields based on corn fiber conversion. Previously defined energy requirements are slightly more efficient than today's newest plants. Numerical values for yields and input requirements with new technology are given with variable definitions in the Appendix.

The price and exchange rate data comes from a variety of sources. A north-central Iowa corn price is used because this area has an expanding ethanol industry. Monthly prices for corn byproducts are available from the Economic Research Service's (USDA) Feed Yearbook (Economic Research Service, 1999). The price data for sugarcane comes from FGV DADOS, an online source of economic data for Brazil (Fundacao Getulio Vargas [FGV], 2002). Freight costs of shipping petroleum products from a northern Venezuela port to the US, an important trade route in the petroleum trade of the Americas, come from OPEC's petroleum market statistics (OPEC, 1999). Finally, an exchange rate is used to convert prices from Brazil's local currency, the Real, to U.S. dollars; exchange rate data comes from the International Monetary Fund (2002).

Monthly values for the competitiveness indicator for the past 30 years are shown in Figures 2 and 3. These calculations used Equation 1. Figure 2 shows a comparison of Brazil sugar processing to corn processing, using dry mill technology. The margin in Figure 3 uses wet-mill technology.

The indicator shows how much production costs in a particular month would be reduced by choosing corn processing in the United States instead of a sugar processing in Brazil for a unit of ethanol output. The range of outcomes is the striking feature of this time

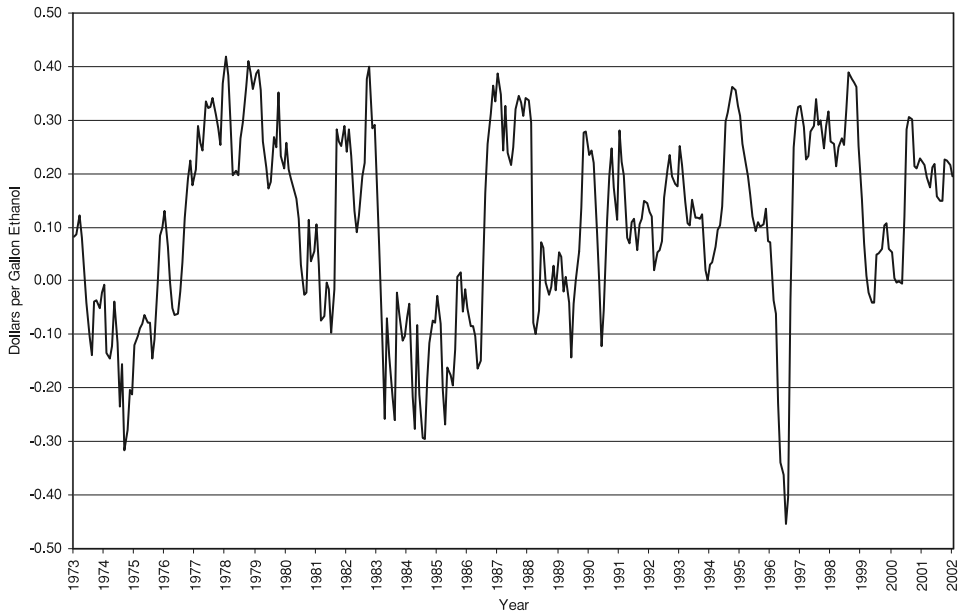


Figure 3 Cost Advantage for Producing Ethanol in the US: Wet Mill (d_1): January 1973–June 2002

series. For example, The wet-mill corn processing advantage rose as high as \$.40/gal in the late 1970s and fell as low as $-\$0.45/\text{gal}$ in 1996. The dry-mill corn processing advantage rises as high as \$.20/gal and falls as low as $-\$0.5/\text{gallon}$. Further, the reference estimate of variable costs for ethanol production is about \$1.00/gallon.

4. TIME-SERIES ANALYSIS

The variable d likely represents a combination of random weather shocks, sugar and corn market cycles, and financial policy changes. Indeed, the lowest value of d in 1996 corresponds to a drought in the US and \$5/bu corn prices. Meanwhile, cyclically low values of d in the mid-1980s correspond to a strong U.S. dollar, which reduced the dollar price of Brazil's sugar cane. Trends in the competitiveness indicator are also a possibility; America's corn market has experienced steady productivity growth and downward pressure on prices; Brazil's sugar market has experienced substantial export growth because of China's growing need for sugar. Accordingly, an elementary time series investigation of d was conducted for an estimate of the contribution of seasonal, trend, cyclical, and random factors.

Preliminary estimates used least squares regression. A trend and monthly dummy variables were included as explanatory variables. The character of the results was similar for both the wet-mill margin and the dry-mill margin. Specifically, a small but significant trend term emerged. Further, several of the monthly intercept shifts were statistically significant. However, the Durbin–Watson statistic suggested autocorrelation. Next, first-order autocorrelation was included with seasonal and trend terms, and estimated using maximum likelihood methods. Then, the autocorrelation coefficient and monthly dummy

variables were statistically significant, but the trend term was not. Further, several of the monthly dummies had about the same magnitude.

Consequently, the reported results shown below feature a cyclical effect measured with a first order autoregressive process and seasonal effects. The seasonal effects were estimated by constraining several similar monthly effects at the same value. However, the trend variable is excluded, because it was not significant. The t statistics given in parentheses in the reported results confirm the significance of included variables.

5. MAXIMUM LIKELIHOOD ESTIMATES

Dry Mill:

$$d_t = -0.0268 - 0.0577 Dt_t - 0.0869 Ds_t + 0.0261 D9_t + 0.0194 D10_t + v_t$$

(0.70) (6.14) (6.57) (2.38) (1.76)

$$v_t = 0.9054 v_{t-1} + \varepsilon_t$$

(40.14)

Est Var (ε_t) = 0.00479 or $\sigma_\varepsilon = 0.069$; Regression $R^2 = 0.1345$; Total $R^2 = 0.8369$

Wet Mill:

$$d_t = 0.1625 - 0.0305 D1_{1t} - 0.0919 Dt_t - 0.1215 Ds_t - 0.0335 D8_t + v_t$$

(3.86) (2.78) (7.26) (7.87) (3.02)

$$v_t = 0.9172 v_{t-1} + \varepsilon_t$$

(43.57)

Est Var (ε_t) = 0.00411 or $\sigma_\varepsilon = 0.0664$; Regression $R^2 = 0.1656$; Total $R^2 = 0.8589$

D.W. = 1.6803

Both estimates have a relatively large value of the autocorrelation coefficient, around 0.9. Hence, the data indicates relatively long cycles. But the autocorrelation estimate has a small standard deviation, which implies rejecting the null hypothesis of unity and a random walk.

Regarding seasonal effects, the reference intercept term holds in the fall and early winter (October, November, December, and January). At the other extreme, there is a constant intercept shift during the spring (March, April, May, and June). Also, there is a transition period (February and July) between spring and fall; it has a negative, but smaller intercept shift.

A decomposition of variability is important for an understanding of the causes of changing advantage. To illustrate variance decomposition procedures, consider the time series model

$$d_t = \sum \alpha_i D_i + v_t,$$

where D_i is the seasonal intercept; ε_t is a disturbance term with zero mean and constant variance σ^2 .

$$v_t = \rho v_{t-1} + \varepsilon_t$$

Using successive backward substitutions (Greene, 2000, p. 532),

$$v_t = \varepsilon_t + \rho\varepsilon_{t-1} + \rho^2\varepsilon_{t-2} + \dots + \rho^n\varepsilon_{t-n} + \dots,$$

so $E(v_t) = 0$ and $\text{Var}(v_t) = E[v_t^2] = \sigma^2/(1 - \rho^2)$.

Consequently, the unconditional mean of the dependent variable is

$$E(d_t) = \sum \alpha_i D_i \text{ and}$$

$$\sigma_d^2 = E[d_t - E(d_t)]^2 = E[v_t^2] = \frac{\sigma^2}{1 - \rho^2}.$$

Now, consider the variance decomposition calculations, using the regression estimates and sample statistics. First, $\hat{\sigma}_d^2$ is measured, the sample variance of the calculated values of d shown in Figures 1 and 2. Next, the estimate of $\hat{\sigma}^2$ comes from the residuals of the time series/regression model. Further, we interpret $E[v_t^2]$ as including current period random shocks and cumulative cyclical effects. So the variation attributable to the cycle subtracts variance associated with the current shock:

$$\text{cycle} = \frac{\sigma^2}{1 - \rho^2} - \sigma^2.$$

Finally, the variation is attributed to seasonal and sampling variation is obtained as total variation less cyclical variation less random variation.

Overall, the time-series results suggest that random, seasonal, and cyclical factors all influence the cost advantage for ethanol processing from corn. Using the time series estimates, the variation in the competitiveness indicator is classified in Table 1. The estimates suggest that about 15% of the variation is caused by current year shocks in the commodity and financial markets. About 75% of the variation is periodic in nature, so

TABLE 1. Sources of Variation in the Competitiveness Indicator

| | Dry Mill | Wet Mill |
|------------------|----------|----------|
| Random | 15.9 | 13.3 |
| Cyclical | 72.4 | 70.6 |
| Other (Seasonal) | 11.8 | 16.1 |
| Total | 100.0 | 100.0 |

Note. In % (0/100).

TABLE 2. Summary Statistics for the Competitiveness Indicator, d_t
January, 1973 to May, 2002

| | Mean | SD |
|----------|---------|--------|
| Wet Mill | 0.1043 | 0.1756 |
| Dry Mill | -0.0053 | 0.1735 |

Note. In \$/gallon ethanol.

that several years of favorable or unfavorable competition outcomes may occur. Finally, seasonal factors account for 10–15% of the variation.

6. PROFITABILITY COMPARISONS

The sample mean of d (Table 2) indicates the long-term profit increase associated with corn processing instead of sugar processing and importing in the absence of the ethanol tariff. For instance, average profit would be \$.104/gallon higher with a wet mill than a sugar mill. Also, profits would be $-\$.005/\text{gal}$ lower with dry mills instead of sugar mills. However, neither mean appears significantly different from zero in a simple t test because means are considerably less than standard deviations.

In comparing the long-run profitability of alternative processing technologies, some allowances for differential capital costs should be taken into account. First, sugar processing and wet milling should be on about equal footing in regards to capital expenditure for energy processing because similar steam and electricity technologies are required for bagasse and coal. However, only the wet mill requires separation equipment for the three byproducts. Dry mills typically have neither a power plant nor separation equipment.

When looking at the profit difference in the wet mill/sugar comparison then, the corn advantage should be adjusted *downward* by the annual capital cost associated with separation equipment. We estimate this increment at about \$.04/gallon per year.³ Hence, the wet-mill advantage over a sugar mill reduces to about \$.06/gal after taking capital cost differences into account.

When looking at the profit decrease in the dry-mill/sugar comparison, the corn advantage should be adjusted *upward* by annual capital cost increments for a power plant needed by sugar processors. Estimates of \$.03/gallon to \$.15/gallon should be added to the values of d shown in Figure 1. The larger estimate refers to the annual gross capital cost associated with power and steam generation in a Brazilian sugar-processing plant. The

³We developed the annual capital cost associated with separation equipment as follows. Representatives from an equipment supplier informed us that the minimum practical scale for a wet mill is about 80 million gallons. At this capacity level, the equipment associated with converting a dry mill to a wet mill would account for a 30% increase in the dry mill's cost. Separately, we had an estimate for the capital cost of a dry mill of \$1.1/gal. Hence, the separation equipment will cost approximately $\$.33/\text{gal} = 0.3 \cdot \$1.1/\text{gal}$. Next, the life of capital equipment is about 15 years. At 10% interest a mortgage that repays the principle and interest over the life of the loan is \$0.13 per dollar of debt. Finally, the annual capital cost associated with the separation equipment is the product of the capital cost for the separation equipment times the annual payment rate for a dollar of debt. $\$.043/\text{gallon} = 0.33 \cdot 0.13$.

TABLE 3. Nonenergy Operating (Distilling) Cost Comparisons for the United States and Brazil

| | Mid-1980's Cost Estimates | | | 2002 Cost Estimates | | |
|--|--|---|-------------------------------|--|---|-------------------------------|
| | U.S. ^a Small/ Midsize Plants | Brazil ^b Center/ South Autonomous Plants | Brazil/ U.S. Difference | U.S. ^c Large Dry Mills | Brazil ^d Center/ South Autonomous Plants | Brazil/ U.S. Difference |
| in \$/gallon | | | | | | |
| Category: | | | | | | |
| Ingredients | 0.0830 | | | 0.1034 | | |
| Labor/maintenance Management, Tax, Insurance | 0.1860 | | | 0.0952 | | |
| | 0.0510 | | | 0.0380 | | |
| Total | 0.3240 | 0.2990 ^e | -\$0.0250 | 0.2351 | 0.2243 ^f | -\$0.0108 |

^aFrom "Economics of Ethanol Production in the United States" (AER-607) by S. Kane and J. Reilly, 1989, Washington, DC: U.S. Department of Agriculture, Economic Research Service.

^bFrom "Subsidios para fixacao dos precos da cana-de-asucar, do asucar e do alcool, safra 1985/1986" by the Fundacao Getulio Vargas (FGV), 1985, Brazil: FGV/IAA.

^cFrom "The 2002 Ethanol Costs of Production Survey" (AER) by H. Shapouri and P. Gallagher, 2005, Washington, DC: U.S. Department of Agriculture, Office of Energy Policy and New Uses.

^d25% Reduction in "b." Cost forecast suggested in "The Brazilian National Alcohol Programme: An Economic Reappraisal and Adjustments" by R.S. da Matta and L. da Rocha Ferreira, 1988, Energy Economics, p. 251.

^eLiters to gallons, Using 3.785 L/gal.

smaller estimate refers to the annual net capital cost when resale of surplus electricity in Brazil is possible.⁴

Finally, differences in non-energy operating costs point to a slight downward adjustment in corn's profit advantage. We looked at the difference between ethanol processing costs in autonomous plants of the center/south region of Brazil and dry mills of the Midwestern U.S., using surveys from 1985, 2002, and survey adjustments based on adoption schedules for new processing technologies. Estimates of the cost differential are shown in Table 3. The processing cost disadvantage for U.S. processors was \$0.025/gallon for the 1980s. But presently, it is likely around \$0.011/gallon. The difference probably narrowed because of cost reductions in enzymes specific to corn processing. Also, the automation-induced reduction in labor requirements possibly had a larger impact on the higher U.S. wages. Hence, there is a slight downward adjustment to the mean value of *d* in Table 2 because of non-energy operating costs.

⁴A recent survey gives capital expenditure and capacity data for several new 40 million gallon dry-mill ethanol plants that are under construction (Bryan, 2004). Three of these are Midwestern plants using conventional natural gas heat and electricity plants. One of the plants is a coal-fired dry mill in Pennsylvania. The additional capital cost for the coal-fired plant is \$1.2/gal. Similarly, the total capital outlay for the biomass power plant of Table 5 comes to \$1.4/gal without an allowance for the capital cost of natural gas systems. Using a 15-year life and 10% mortgage rate gives an annual cost increment for a coal-fired dry mill of \$0.156/gallon = $1.2 \cdot 0.132$.

For a lower-limit estimate, assume that an opportunity for surplus electricity sales exists. Again, using the case detailed in Table 5, annual electricity revenues would be

$$\$0.131/\text{gal} = \$5.256 \text{ mil}/40 \text{ mil gal.}$$

Then, the net capital cost would be $\$.03/\text{gal} = \$0.156/\text{gal} - \$0.131/\text{gal}$.

7. STRATEGIES FOR IMPROVING THE COMPETITIVENESS OF THE DRY-MILL INDUSTRY

There have been two episodes of investment in the U.S. ethanol industry. The most fundamental cause of both episodes was likely a surge in energy markets and a spike in ethanol prices. However, byproduct prices were considerably more attractive during the first expansion episode in the early 1980s, at least partly because corn byproducts entered Europe without duty, while a high import tariff was charged on corn imports. Byproduct prices have been considerably lower during the capacity expansion of the last 3 years (Figure 4). Consequently, investments have favored smaller dry mills without separation equipment in the recent expansion.

In this section, we consider plausible changes in dry mill management that have a potential to reduce production costs. First, the possibility of using high-starch corn is discussed. Second, the benefits and costs of biomass power generation are considered.

7.1 Corn Composition

Consider how the corn-processor’s profit function depends on process yields. In the most elementary form, profits are revenues from ethanol and distillers’ grain sales less expenditure on corn and other inputs.

$$\pi = Pe_t Qe_t + Pd_t Qd_t - Pc_t Qc_t - \sum w_i X_i$$

Equivalently, the profit function can be written in terms of prices, yields, and operating expenses per input unit:

$$\pi = \left[Pe_t - \left(\frac{Cc_t}{Yc_t} - Pd_t Y_c^d + \frac{\sum w_i X_i}{Qc_t} \right) \frac{1}{Y_c^e} \right] Qe_t$$

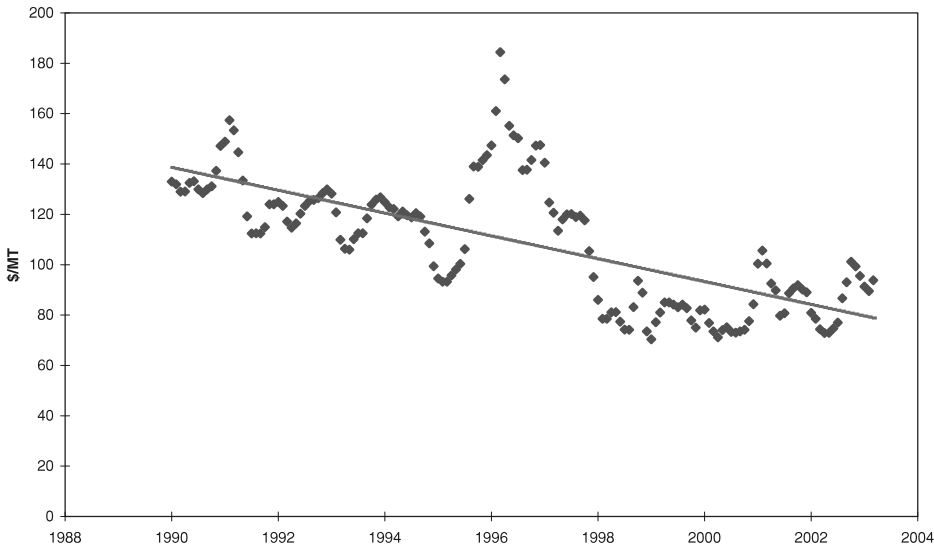


Figure 4 Distillers’ Grains Price Trend

TABLE 4. Regressions with Corn Starch Content (%) as the Independent Variable

| Dependent Variable (Units) | Intercept (t Value) | Starch Coefficient (t Value) | RMSE | Dependent Variable Mean | Independent Variable Mean |
|----------------------------|---------------------|------------------------------|--------|-------------------------|---------------------------|
| Corn Yield (bu/acre) | -220.889 (2.68) | 6.2599 (4.68) | 9.30 | 164.84 | 61.6 |
| Oil Content (%) | 21.171 (13.76) | -0.2854 (11.43) | 0.1734 | 3.58 | |
| Protein Content (%) | 49.255 (22.46) | -0.6691 (18.8) | 0.247 | 8.02 | |
| Moisture Content (%) | -15.378 (1.23) | 0.5202 (2.57) | 1.40 | 16.67 | |

Data for these regressions reported on p. 2, Table 2 of Iowa Crop Improvement Association, 2000.

The latter form of the profit function is derived⁵—it shows that net corn costs in ethanol production, the second term in the profit function, depend on ethanol yield, distillers' grain yield, and corn yield. The profit function depends on corn yield because we have assumed that producers who participate in a coop value their corn at cost.

Some regression estimates based on recent Iowa field trials approximate the yield and quality changes that will likely accompany a starch increase. The regressions in Table 4 suggest that an increase in the starch content of corn will increase corn yield. In contrast, starch content increases tend to reduce protein and oil content. The composition changes suggest that a starch increase will increase ethanol yield and reduce distillers' grain yields. Meanwhile, the corn price will fall because corn yield increases and costs decline.

⁵First, multiply and divide all terms of the initial profit function by Q_e to obtain:

$$\pi = \left[P e_t + P d_t \frac{Q d_t}{Q e_t} - P c_t \frac{Q c_t}{Q e_t} - \frac{\sum w_i X_i}{Q e_t} \right] Q e_t$$

Dividing input and byproduct terms by Q_c/Q_c gives

$$\pi = \left[P e_t + P d_t \frac{Q d_t / Q c_t}{Q e_t / Q c_t} - \frac{P c_t}{Q e_t / Q c_t} - \frac{\sum w_i X_i}{Q e_t} \frac{Q c_t}{Q c_t} \right] Q e_t$$

Or:

$$\pi = \left[P e_t + P d_t \frac{Y_c^d}{Y_c^e} - \frac{P c_t}{Y_c^e} - \frac{\sum w_i X_i}{Q c_t} \frac{1}{Y_c^e} \right] Q e_t$$

Factoring Y_c^e outside the net cost term gives:

$$\pi = \left[P e_t - \left(P c_t - P c_t Y_c^d + \frac{\sum w_i X_i}{Q c_t} \right) \frac{1}{Y_c^e} \right] Q e_t$$

If $P c_t = C c_t / Y c_t$, then the advertised result follows.

TABLE 5. The Effects of a 10% Increase in Corn's Starch Content^a

| Corn Composition: Content Proportion | Proportion | |
|---|---------------|-------------|
| | Standard | High Starch |
| Starch | .6246 | .68706 |
| Protein | .0815 | .0536 |
| Oil | .0364 | .0245 |
| Fiber | .1025 | .07979 |
| Yields (units): | | |
| Corn (bu/acre) | 164.7 | 191.8 |
| Ethanol (gal/bu c) | 2.636 | 2.900 |
| Ddg (lbs/bu c) | 16.91 | 11.120 |
| Ethanol Cost (\$/gal) | 1.055 | 0.924 |
| Assumptions: | | |
| Distillers Grain Price | \$79.5/ton | |
| Corn Cost | \$387.83/acre | |

^aAdjusted to 15.5% moisture content.

Table 5 summarizes the composition, yield, and ethanol cost changes associated with a 10% increase in the starch content of corn. The regression estimates were used to approximate the yield and quality tradeoffs. However, composition estimates for corn were adjusted to a moisture basis of 15.5%. To arrive at the ethanol yield, a 49.7% conversion of starch to ethanol (by weight) was assumed, based on chemical relationships. To arrive at distillers' grain yields, the weight of 27% protein content distillers dried grain was calculated from the pure protein weight; then, we verified that residual oil and fiber would be sufficient to fill the blending requirement. The corn-yield estimate is based directly on the regression estimate. The calculated cost reduction for ethanol production is calculated using the trend value for distillers' grain price. Cost savings of \$.12 per gallon are obtained for high-starch corn. The corn cost used for the calculations of Table 5 excludes an allowance for land rent, possibly referring to producers and coop members who own cropland.

To extend this analysis, the breakeven point for starch-increase profitability is given for a range of byproduct prices and two corn cost conditions in Figure 5. The dotted line shows the case where the reference corn price of \$1.22/bu excludes land costs. The solid line gives the breakeven line for the reference corn price of \$2.36/bu when land costs are included. Generally, this analysis suggests that a starch increase is a cost-reducing strategy, regardless of the treatment of land costs and for most distillers' grain prices. However, the breakeven point is approached when land costs are included and when the distillers grain price reaches 2 standard deviations above the trend line (\$100/ton).

7.2 Biomass Power Generation

A second strategy for improving the competitiveness of dry mills is the cogeneration of biomass power. Denmark's power industry is operating six facilities that are essentially large-scale demonstration projects. Most of these plants provide electricity and district

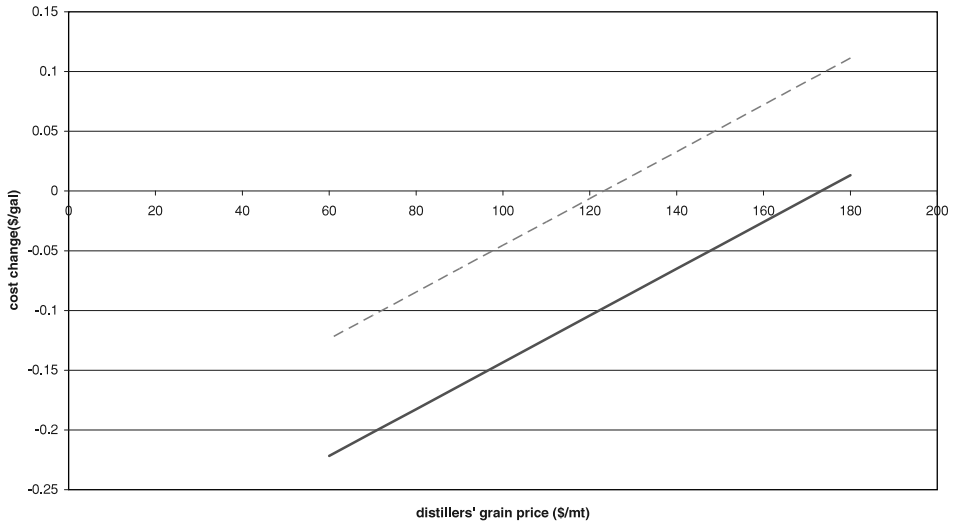


Figure 5 Ethanol Cost Change From a 10% Starch Increase

heating for small communities. But one plant is especially interesting because it provides the electricity and process steam needs of a paper plant and a distiller, as well as the power needs of a small community (Nielsen et al., 1998, p.38). The critical inputs and outputs of the Grenaa plant are:

- Power output: 18.6 MW
- Heat output: 60.0 MJ/s
- Straw input: 55,000 metric tons/year
- Coal input: 40,000 metric tons/year
- Capital cost: \$56,000,000 (at 7 DK per \$1)

A preliminary comparison of biomass power against natural gas and market purchases of electricity suggests that cost savings can be achieved with biomass power (Table 6). First, the steam power output matches the needs of a 40 million gallon ethanol plant, and 12 MW of the electrical power output is a surplus.⁶ Revenues from electricity sales are \$5.3 million if sales to local consumers are possible. Second, expenditures for biomass are \$1.4 million—our calculations use a corn-stover price that reflects farm cost, local transport, and a producer margin under typical corn-belt conditions (Gallagher et al., 2003a). Third, a comparable amount of coal input complements seasonal availability of biomass, and costs about \$1.1 million annually. Finally, an annual capital of \$7.4 million results

⁶The electricity requirements and steam heat for a 40 million gallon ethanol plant are

$$\frac{5936 \text{ Kw/h}}{\text{hr}} = \frac{1.3 \text{ Kw/h}}{\text{gal}} \frac{40 \cdot 10^6 \text{ gal}}{\text{yr}} \frac{1 \text{ yr}}{365 \text{ day}} \frac{1 \text{ day}}{24 \text{ h'}}$$

$$\frac{50.9 \text{ MJ}}{\text{s}} = \frac{38,000 \text{ BTU}}{\text{gal}} \frac{40 \cdot 10^6 \text{ gal}}{\text{yr}} \frac{1 \text{ MJ}}{947.8 \text{ BTU}} \frac{1 \text{ yr}}{365 \text{ day}} \frac{1 \text{ day}}{24 \text{ hr}} \frac{1 \text{ h}}{60 \text{ min}} \frac{1 \text{ min}}{60 \text{ sec}}$$

TABLE 6. Annual Costs for Power and Electricity

| Category | Amount | Rate | Annual Revenue(+) or cost(-) | Net Cost for ethanol ^e |
|--|----------------|---|------------------------------|-----------------------------------|
| Cogeneration of Steam and Electricity With Corn Stover/Coal: | | | | |
| Electricity Sales | 12,000 kw/h | \$.05/kw/h | +\$5,256,000 ^a | |
| Corn Stover | 55,000 mt/year | \$25/mt ^f | -\$1,375,000 | |
| Coal | 40,000 mt/year | \$1.22/10 ⁶ BTU ^c | -\$1,091,168 | |
| Capital | \$ 56 million | \$0.132/year ^b per \$1 debt | -\$7,386,400 | |
| Total: | | | -\$4,596,568 | -\$0.11/gallon |
| Market Purchases of Electricity and Natural Gas: | | | | |
| Electricity Purchases | 1,235 Kw/h/gal | \$.05/kw/h | | .06 |
| Natural Gas Purchases | 36,100 BTU/gal | \$3.579/10 ⁶ BTU ^d | | .129 |
| Total: | | | | -\$0.191/gallon |

$$^a 12,000 \text{ Kw/h} \times \frac{\$0.05}{\text{kw/h}} \times \frac{365 \text{ day}}{\text{year}} \times \frac{24 \text{ h}}{\text{day}} = \$5,256,000$$

^bThe annual payment for a mortgage at 10% interest and length of 15 years.

^c24.648 × 10⁶ BTU/mt

^d1.020 BTU/cubic foot

^eBased on a 40 million gallon ethanol plant.

^f15.4 × 10⁶ BTU/mt. The BTU price of corn stover is

$$\frac{\$1.624}{10^6 \text{ BTU}} = \frac{\$25}{\text{mt}} \cdot \frac{\text{mt}}{15.4 \cdot 10^6 \text{ BTU}}$$

from a 10% mortgage on the plant with a length that corresponds to the plant's useful life of 15 years.

Constructing a biomass power plant may be a cost-reducing strategy for an ethanol producer. The annual net expenditure for this capital equipment comes to about \$.11/gallon with a 40 million gallon ethanol plant. Presently, modern dry-mill ethanol plants are spending about \$.19/gallon for market purchases of electricity and natural gas. Hence, a \$.08/gallon cost savings may be possible with biomass/coal generation of steam and electricity.

8. EMERGING AVENUES OF COMPETITION

Presently, ethanol occupies a niche in a quality-differentiated U.S. gasoline market. Ethanol is an additive; it has some desirable attributes, such as octane and oxygen, which improve the automobile and environmental performance of gasoline. Direct competition of ethanol in the gasoline market has been limited; alcohol fuel vehicles, such as those in Brazil, have required extensive modifications of internal combustion engines. But new flexible fuel vehicles (FFV) can use either gasoline or E85, a mixture of 85% alcohol and 15% gasoline. The flexible fuel vehicles have a sensor that identifies fuel properties and the car's computer adjusts the fuel system accordingly. A few gas stations in the Midwestern U.S. now sell E85. So the technology for direct alcohol-gasoline fuel substitution is emerging.

But can E85 compete with commodity gasoline directly? For an answer, we first compare the wholesale prices for premium-grade gasoline with production costs for E85. We focus on premium gasoline because E85, with an octane rating of 105, can replace premium. So premium fuel is likely the first market where alcohol fuel can compete directly. According to Figure 6, E85 has been on the margin of potential competition over the last 5 years. During several months of 2001 and 2005, wholesale prices for premium gasoline has exceeded E85 production costs.

Our method of calculating E85 costs deserves comment. Recent estimates of operating costs and capital costs for U.S. ethanol plants are available (Gallagher, Brubaker, & Shapouri, 2005; Shapouri & Gallagher 2005). Annual capital cost, the yearly allowance for mortgage repayment over the life of the plant, was divided by plant capacity, and added to unit-operating costs for an estimate of total unit costs. Hence, the ethanol cost estimate includes an allowance for a normal return to capital. Next, E85 cost is a (85%:15%) weighted average of ethanol costs and the wholesale price of regular (conventional) gasoline in Iowa.

Also, E85 costs are expressed in “dollars per gallon of gasoline equivalent.” That is, the ethanol cost estimate has been adjusted to reflect the reduced fuel economy using E85 instead of gasoline. There is a range for the fuel economy discount. A 25% discount is typical for cars tested as they are manufactured, adjusted for primary use of gasoline (Energy Information Administration Agency and U.S. Environmental Protection Agency, 2004, p. 17). A discount of 5% to 15% is given for flexible fuel vehicles (FFVs) that have been optimized for E85 as the primary fuel (National Ethanol Vehicle Coalition, 2004). We use a 15% discount

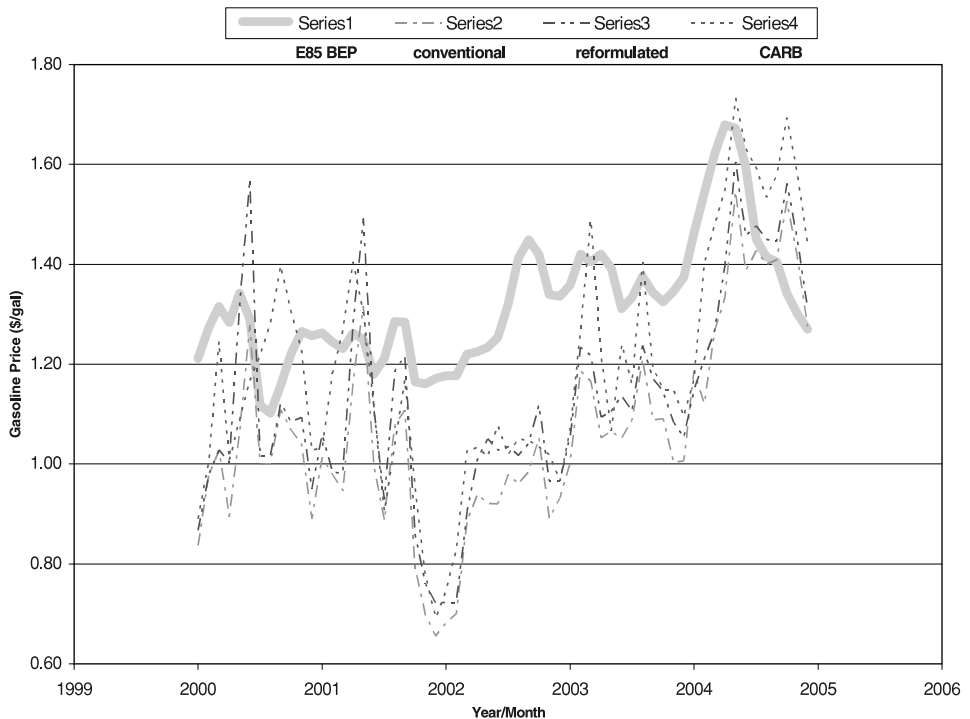


Figure 6 Wholesale Price of Premium Gasoline (Various Grades) and E85 Breakeven Price: 2000 to 2004

in our analysis, which seems appropriate for a long-run analysis. However, a short-run analysis looking at the ability to dispose of ethanol surpluses, which omits capital costs and uses a fuel economy 25% discount, would give about the same cost estimate.

Another question is “At what price can ethanol compete with petroleum as a commodity fuel?” An answer to this question requires two steps. First, we regress for a marketing margin relationship between the petroleum price and the price of reformulated premium gasoline. Second, we set the E85 cost equal to the dependent variable from the wholesale gasoline price regression, and calculate the implied value for the independent variable, the petroleum price.

The marketing margin regression gives the wholesale price of premium-grade reformulated gasoline as the independent variable. The main independent variable is the price of petroleum, which is expressed in the same (\$/gal) units as the dependent variable. Dummy variables indicate stricter environmental regulations on gasoline recipes that went into effect beginning in 2000, and that occur each year with summer fuel recipes. The regression below was estimated using monthly data from the 1995–2004 period:

$$Pr_t = 0.2136 + 0.1432D00_t + 0.0895 DSUM_t + 0.9565(Pp_t/42)$$

(6.4) (5.4) (4.9) (6.4)

$$\bar{R}^2 = 0.84 \quad \bar{s} = 0.10$$

The implied breakeven price (BEP) for petroleum is calculated by setting e85 cost equal to the dependent variable in the regression. The calculated petroleum price in Figure 7 is the BEP where E85 begins to compete with premium gasoline. The BEP varies somewhat from period-to-period, with variables that affect ethanol cost and the gasoline–petroleum price relationship. In the early 1990s, E85 was not even close to petroleum as a commodity fuel. The BEP declined to the \$35/barrel range in 2000 though, with tighter refining regulations and wider gasoline-refining margins. The BEP briefly rose above \$55/bbl with springtime corn prices that rose to \$3.40/bushel. But the BEP has returned to the \$40/bbl range after the 2004 reduced corn prices.

This simple BEP analysis sheds some light on the ability of ethanol to compete without subsidies. Ethanol costs, which do not depend on the subsidy, are used to identify BEPs. An important competitive threshold was crossed recently, as increasing petroleum prices and tighter environmental restrictions have intersected with relatively stable ethanol costs. However, ethanol would likely compete in the additives market with lower petroleum prices; the shadow values associated with ethanol’s quality attributes must also be included, but such an analysis is beyond the scope of this article.

9. CONCLUSIONS

The competitiveness indicator of this article measures the performance of the U.S. corn-processing industry under a hypothetical situation that excludes the present tariffs on ethanol trade. First, the competitiveness measure accounts for the processing-cost effects of changing conditions in commodity and foreign currency markets with today’s technology. So, it defines the direction of trade in the event that there are no tariffs. Second, the competitiveness measure can be adjusted to indicate the long-term profit advantage for a corn-processing investment relative to a sugar-processing investment, under a no-trade

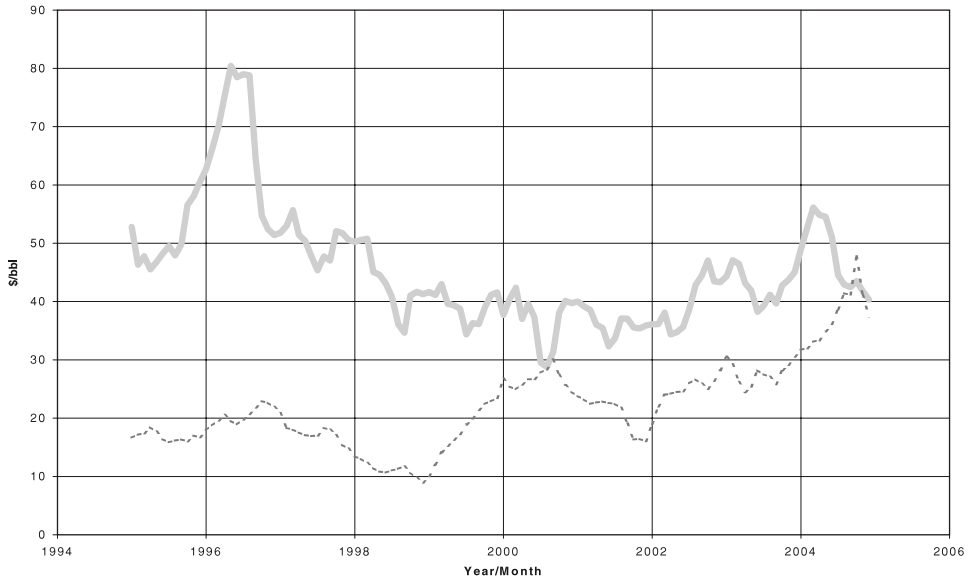


Figure 7 Petroleum Prices: Actual Landed Cost of Saudi Crude (—) and Implied Breakeven Price Between E85 and Premium Reformulated Gasoline

barrier regime. Hence, it is useful for accessing the relative strength of the U.S. corn-processing industry.

A main result of the empirical investigation is that there is no trend in cost advantage towards producing corn-ethanol in the US, or producing sugar-ethanol in Brazil and exporting to the US. However, there are seasonal patterns of advantage. Further, cycles that are several years in length suggest periods of several years where processing costs could be reduced substantially by choosing one location or the other. These cycles are likely caused by corresponding cycles in corn prices, sugar prices, or foreign currency prices.

According to long-term averages of the statistical competitiveness indicator, wet mills appear to have a slight advantage over sugar, while dry mills have a slight disadvantage. However, the wet-mill advantage is partly offset when the capital costs for separation equipment and a slight disadvantage for non-energy operating costs are taken into account. Similarly, the statistical average of the indicator suggests that dry mills have a slight disadvantage relative to sugar. But the dry-mill disadvantage is jointly offset by the capital costs avoided by using natural gas for power generation and reinforced by a slight disadvantage in non-energy operating costs. We estimate the net advantage in long-term profits at \$.05/gallon for wet mills and +\$.03/gallon for wet mills and dry mills, respectively. Hence, ethanol-processing investments might gravitate towards a corn-processing region, such as the US, if there were no trade barriers in the ethanol market. However, no statistically significant difference exists for wet mills or dry mills.

For the future, the cost advantage for dry mills could be improved by changes in firm management. First, a strategy of using higher starch content in the corn could reduce ethanol production costs by nearly a \$.12/gallon. Generally, desired quality improvements can be achieved through contracts and premiums for particular quality characteristics, but attention

to uniformity and achievable quality targets are also important (Wilson & Dahl, 1999, p. 217). In this instance, corn processors could pay suppliers for starch content. However, the cost-reduction estimates given in this article assume a cooperative organization of ethanol processing with corn pricing at marginal costs. Other economic organizations of processing, or oligopoly pricing of new corn seeds could reduce the cost savings.

Second, biomass power generation has the potential to reduce ethanol production costs in dry mills if high natural gas prices are sustained during the next decade. Under current conditions, ethanol costs are reduced by \$.08/gallon with biomass power because corn stover has an effective BTU-price that is much closer to coal than natural gas. Further, a quantum leap in the energy balance and environmental benefits of corn-ethanol production could result, especially when the proportion of coal in the input mix is low.⁷ However, cogeneration of power in larger dry mills may be a long-term strategy because integration with the surrounding community's electrical power generation may be required.

The time-series analysis of the competitiveness indicator helps predict trade flows under alternative policy regimes. It is likely that the quota on tariff-free ethanol imports from Caribbean countries and transshipments from Brazil will often be filled, for instance, because the sans-tariff processing costs favor sugar processors about one half of the time. Similarly, the time-series analysis also suggests that the US would often be an ethanol importer without U.S. or Brazil duties on ethanol imports. Strictly speaking, though, the results also suggest that the US could take an occasional or cyclical export position in the ethanol market.

Presently, the substantial U.S. and Brazilian tariffs on ethanol preclude direct trade in either direction. Both tariffs could be reduced for the mutual advantage of both countries, but Brazil may have little incentive for change as long as their re-export under the Caribbean Basin Agreement grows. Still, it is useful to know that the economic performance of both industries would be about equal if ethanol trade barriers were removed.

The United States may not emerge as a persistent ethanol exporter, however, especially if petroleum prices continue to increase beyond a \$35/bbl to \$40/bbl threshold in the petroleum market. Beyond the threshold, the alcohol-based fuel, E85, will begin to substitute directly for commodity gasoline in the US on nearly a one-to-one basis. Then, domestic ethanol consumption in the US would increase while gasoline consumption and petroleum imports would decrease; the increasing domestic market for ethanol would likely preclude ethanol exports. Ethanol could compete directly in the commodity fuel market at this juncture, even without a subsidy.

APPENDIX

Variable Definitions for the Statistical Analysis (In Order of Use)

d_t : sugar (plus freight) loss corn (plus energy) cost difference, in \$/gallon ethanol

C_{s_t} : cost of sugar in ethanol production, in \$/gallon ethanol

C_{n_t} : net cost of corn in ethanol production, in \$/gallon ethanol

C_{f_t} : cost of ethanol transport, South America to US, in \$/gallon ethanol

⁷For sugar-ethanol production the energy balance ratio between net energy produced in ethanol over energy consumed in the agricultural phase of production is 4.8 for Brazil's sugar-ethanol system, which uses bagasse instead of external energy for processing energy (Rothman, Greenshields, & Calle, 1983, p.122). Similar calculations for the U.S. corn ethanol industry, which uses external natural gas, are about 1.3.

- C_{e_t} : cost of energy in corn ethanol production, in \$/gallon ethanol
 P_{s_t} : price of sugar in Brazil, in real/mt
 Y_s^e : yield of ethanol from sugarcane, 20.1 gal/mt
 E_t : Brazil-U.S. exchange rate, in \$/real

 P_{c_t} : price of corn in United States, in \$/bu corn
 P_{f_t} : price of gluten feed, in \$/lb
 P_{m_t} : price of gluten meal, in \$/lb
 P_{o_t} : price of corn oil, in \$/lb
 P_{d_t} : price of distillers' grains, in \$/lb

 Y_c^e : yield of ethanol from corn, 2.8 gal/bu
 Y_c^f : yield of gluten feed from corn, 13.5 lb/bu
 Y_c^m : yield of gluten meal from corn, 2.65 lb/bu
 Y_c^o : yield of corn oil from corn, 1.55 lb/bu
 Y_c^d : yield of distillers' grains from corn, 17.5 lb/bu

 P_{k_t} : price of coal, in \$/ton
 P_{l_t} : price of electricity, in \$/kw h
 P_{n_t} : price of natural gas, in \$/ccf

 Z_c^k : coal input requirement for wet-mill ethanol production, 17,500 BTU/gallon
 Z_c^e : electricity input requirement for dry-mill ethanol production, 1.1 kw/h gallon
 Z_c^n : natural gas input requirement for dry-mill ethanol production, 36,100 BTU/gallon

 $D_{i_t} = \begin{cases} 1; & \text{in month } i \text{ (} i = 1, \text{ in Feb; } i = 2 \text{ in Mar; } \dots \dots; i = 11 \text{ in Dec)} \\ 0; & \text{otherwise} \end{cases}$
 $D_{s_t} = D3_t + D4_t + D5_t + D6_t$ [Spring/Summer variable]
 $D_{t_t} = D2_t + D7_t$ [Transition Season variable]

 P_{e_t} : price of ethanol, in \$/gallon
 w_{i_t} : price of input i feed, in \$/lb
 Q_{e_t} : quantity of ethanol, in gallons
 Q_{d_t} : quantity of distillers' grain, in lbs
 Q_{c_t} : quantity of corn, in bu
 X_{i_t} : quantity of input X_i , in lbs.
 C_{c_t} : cost of production for corn, in \$/acre
 Y_{c_t} : corn yield, in bu/acre

 P_{r_t} : wholesale price for reformulated gasoline in Illinois, premium grade, in \$/gallon
 P_{p_t} : landed price of Saudi Petroleum in the US, in \$/barrel

 $D00_i = \begin{cases} 1; & \text{when year} > 2000 \\ 0; & \text{otherwise} \end{cases}$
 $D_{sum_i} = \begin{cases} 1; & \text{April-to-September} \\ 0; & \text{otherwise} \end{cases}$

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