



# Roles for Evolving Markets, Policies, and Technology Improvements in U.S. Corn Ethanol Industry Development

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This article reviews changes in markets, technologies, and policies that affect corn ethanol profitability and industry expansion. Historically, the corn ethanol industry was stimulated by high petroleum prices, successful corn and processing technology improvements, and government incentives, such as a blenders' tax credit and mandated markets defined by the leaded fuel ban and reformulated fuel. Presently, the corn ethanol industry has expanded slightly beyond the point of a normal capital return, which is defined by limits on corn resource availability and ethanol marketing infrastructure. A renewable fuel standard, included in a recent energy law, may eventually define minimum consumption levels for ethanol and, implicitly, production levels for corn ethanol. Potentially impending marketing changes, such as voluntary E20 (20 percent ethanol) sales or expanded sales of E85-equipped automobiles, may expand ethanol markets. Potential technology advances include growth of corn yields, corn-processing improvements for lower costs or higher revenue, and development of a corn-stover (leaves and stalks)-based biomass industry. Government policies to induce biomass-fuel capacity investment are economically justified and probably necessary if biofuel industry development remains a public priority. Still, more efficient policy approaches could be developed. (JEL Q11, Q42, Q48)

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**P**rofit assessments in the ethanol industry must account for market and policy developments in the fuel and corn industries because processors are positioned between both commodity markets. At the beginning of the twentieth century, biofuel-based industries such as ethanol were not feasible because a pound of corn could be sold on the market and exchanged for 5 to 7 pounds of petroleum at prevailing market prices. It made more sense to produce the corn for feed and food, sell it for cash, and buy petroleum to process for energy. The circumstances have since changed and today's scenario is quite different: One pound of corn can be exchanged for only about one pound of petroleum

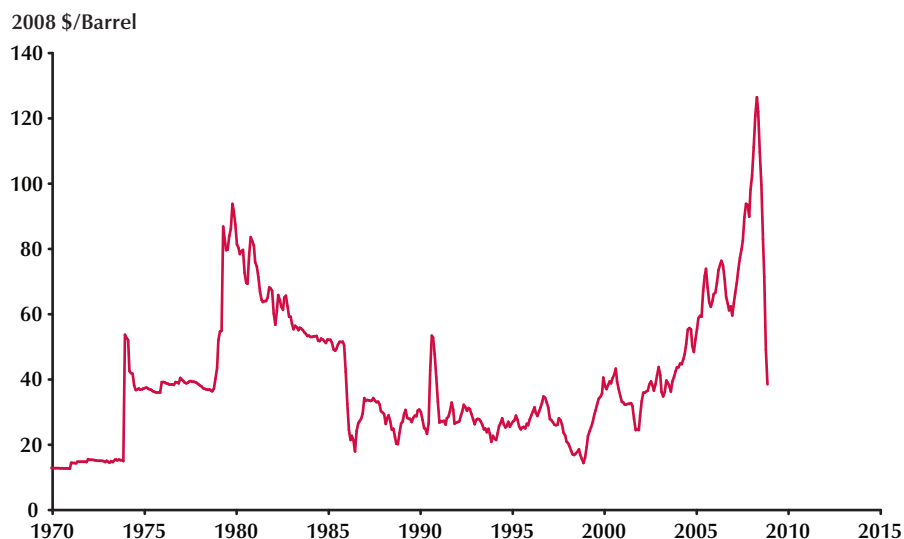
(Gallagher, 2004). A century of declining corn prices and increasing petroleum prices has radically changed society's technology options.

Still, the oil price spike of the late 1970s (Figure 1) is a major event responsible for the birth of the ethanol industry. Ethanol has recently emerged as an equal partner among corn-using industries during the oil price escalation of the early twenty-first century. Technologies that improve input costs or firm and marketing efficiency are equally important in explaining the ethanol industry's birth and expansion because investment in a new processing technology was required. In the ethanol industry, firm strategies have emerged during episodes of narrow profit margins.

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**Figure 1****Saudi Petroleum Prices (January 1970–December 2008)**

This review of profitability in the ethanol industry considers the combination of developments in corn, fuel markets, and policy that led to the recent ethanol expansion. Also, an estimation of the contribution from past firm efficiency improvements is presented as one important factor contributing to the ethanol industry's development. For the present and intermediate future, overall profit and output growth rates in the industry will likely be moderate because of moderate supply growth for the corn input and widening ethanol price discounts to compete with gasoline. Thus, impending innovations in production and marketing practices are also reviewed for an indication of their profit-improving potential in the current economic environment.

## THE MARKETING-GOVERNMENT-TECHNOLOGY MATRIX LEADING TO THE CURRENT U.S. ETHANOL INDUSTRY

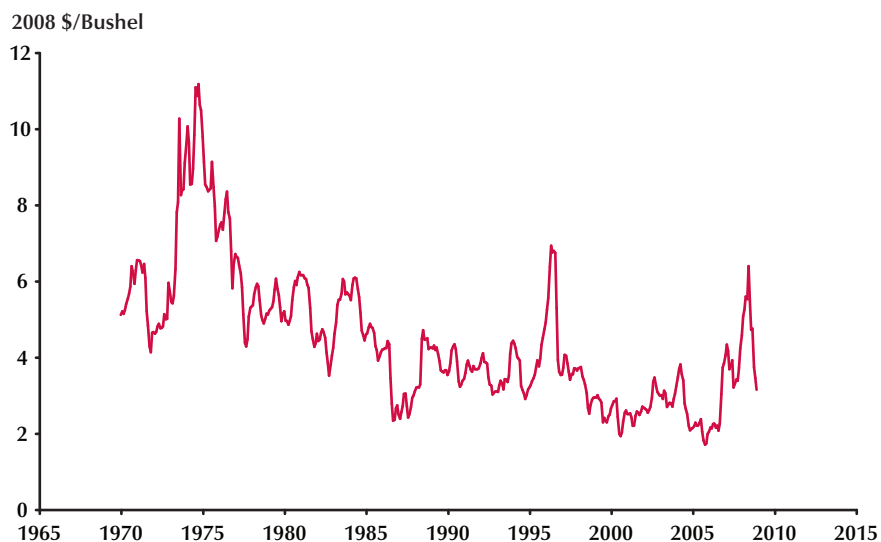
### *Phases of the Ethanol Industry*

Three phases of the U.S. corn ethanol industry are discussed: birth, development, and maturity.

**Birth.** The right combination of petroleum market and corn market events contributed to the initial profitability and birth of the ethanol-processing industry. In the petroleum market, the Organization of the Petroleum Exporting Countries (OPEC) was still pursuing a high-price strategy as a hangover from the 1970s. Meanwhile, corn prices had declined considerably because the export boom of the mid-1970s had collapsed (Figure 2). A generous consumption subsidy in the form of a blenders' tax credit<sup>1</sup> was still needed to achieve profitability (Gill, 1987). Nonetheless, production in the new ethanol industry had expanded to nearly 0.75 billion gallons by 1989.

**Development.** OPEC changed its pricing strategy in the mid-1980s (Stauffer, 1994). Then petroleum and fuel prices declined, which resulted in a much narrower profit margin that allowed the ethanol industry to become more competitive.

<sup>1</sup> A mixture (blend) of 10 percent ethanol and 90 percent gasoline is suitable for most automobiles with gasoline engines. Initially, the U.S. government granted a partial exemption to its gasoline excise tax when an ethanol blend was sold because ethanol was typically more expensive than gasoline. The partial exemption is equivalent to an ethanol consumer subsidy (Gallagher, Shapouri, and Price, 2006b).

**Figure 2****North Central Iowa Corn Prices (January 1970–December 2008)**

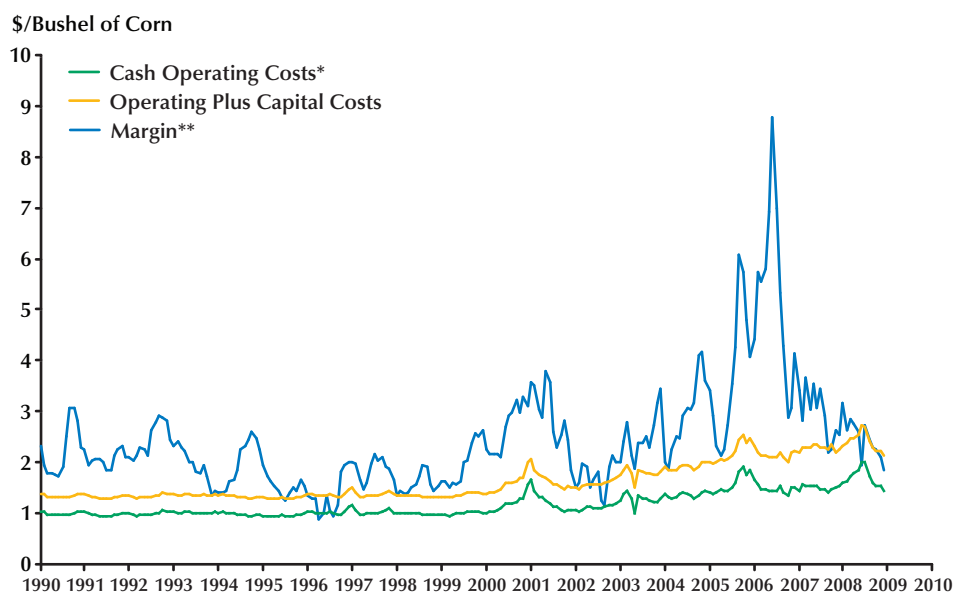
Although this period was not profitable for ethanol processing, the groundwork for future ethanol profitability was laid. Three events stand out in this developmental phase.

First, the ethanol industry initiated a series of improvements that enhanced profitability with the existing market prices for fuel and corn. For instance, ethanol yields increased 10 percent between 1984 and 2007. The processing yield increase elevated profits by \$0.31 per bushel. Further, operating expenses decreased by about 50 percent since the late 1980s—energy efficiency improved, labor needs declined, and the cost of processing enzymes dropped (Gallagher, Shapouri, and Brubaker, 2007); the reduction in operating costs was \$0.38/bu. Finally, dry mill processors discovered that they could reduce their average capital costs, or capital costs per unit of capacity, by increasing the size of their plants (Gallagher, Brubaker, and Shapouri, 2005; Gallagher, Shapouri, and Brubaker, 2007). Elsewhere, I have estimated that annual capital costs declined by \$0.27/bu by increasing the plant size from 4 million bu/yr to 19 million bu/yr. Together the yield improvements

and costs reductions increased the processing margin by \$0.96/bu.

Second, since 1980 the corn market has slowly but steadily changed so that ethanol processing is now profitable. Specifically, corn production has grown steadily with yield growth (~224 million bu/yr) while demand growth has remained relatively stable (110 million bu/yr). Export demands have fluctuated from year to year but have exhibited no growth since 1980. Moderate feed demand growth reflected saturation of American diets, limited success of trade negotiations in developed country meat markets, and the shift in livestock feed rations toward more protein (Gallagher, 2000). Since 1980, new corn supplies have gradually pushed corn prices down and pushed marginal corn farmland into other crops. Otherwise stated, the cumulated excess supply growth of corn could supply about 8.0 billion gallons of new ethanol capacity without increasing corn prices. In contrast, ethanol capacity grew by about 1.5 billion gallons by 2000.

Third, ethanol demand and prices got a major boost when a legislated oxygen standard was introduced to reformulated fuel in 1994 as part of the

**Figure 3****Corn Ethanol Processing Margin and Costs for Dry Mills with Current Technology (January 1990–December 2008)**

NOTE: \*Includes electricity, fuel, labor, and chemicals. \*\*Ethanol revenues plus DDG revenues less corn costs.

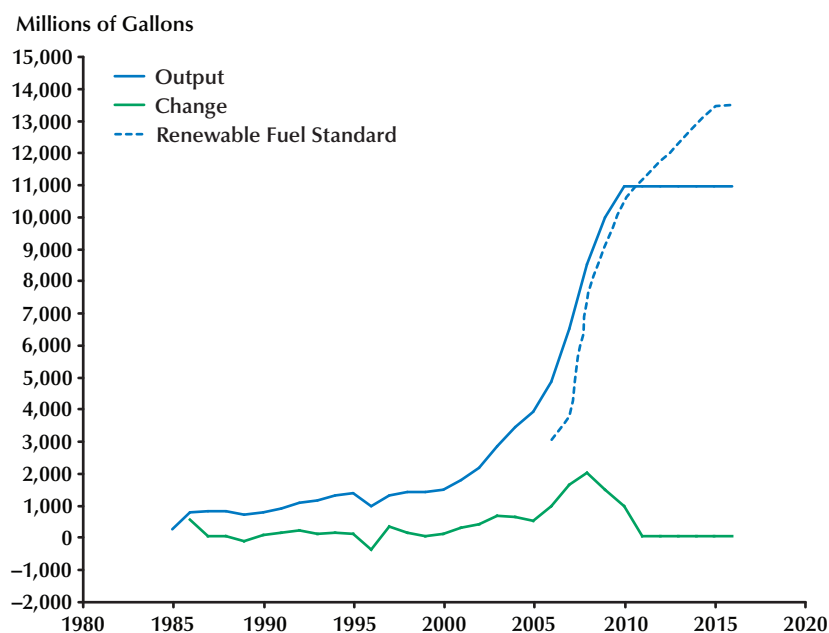
1990 Clean Air Act (Gallagher et al., 2003). In effect, the oxygen standard required that ethanol or methyl tertiary-butyl ether (MTBE, an additive) be blended in the gasoline “recipes” used for cleaner fuels in major urban areas with smog problems. This requirement increased the ethanol demand and capacity by 0.90 billion gallons (Gallagher, Otto, and Dikeman, 2000).

**Maturity.** Two events in fuel markets triggered the large-scale expansions of the twenty-first century. First, a “de facto” national ban on the use of MTBE, the petroleum industry’s chemical for the oxygen standard of reformulated fuel, evolved through a series of public events. The national ban evolved partly because several major states banned MTBE after it was found in groundwater supplies (Gallagher et al., 2000). Then the petroleum industry was unable to obtain a waiver removing their liability for leaking tanks, so the industry decided to phase out MTBE. Ethanol, initially sharing the reformulated fuel market, is still benefiting from

a demand boost because of the MTBE phase-out—the increase will add a total of 3.5 billion gallons of ethanol demand when the 1998 level of MTBE production is completely phased out. By 2000, ethanol-processing margins had increased (Figure 3). Further, returns on an equity investment increased to respectable levels (~20 percent). Consequently, ethanol output expanded to annual production levels of about 1 billion gallons.

Second, petroleum prices crossed the threshold of competition where ethanol could compete directly with other additives in the petrochemical industry (Gallagher et al., 2006a). By 2006, processing margins widened, and the return on an equity investment in an ethanol plant reached eye-catching levels—60 percent—using current corn prices and spot market ethanol prices.

A stunning expansion in ethanol output has since occurred; output is about 8.5 billion gallons for the recently completed 2007-08 corn marketing year (Figure 4). Also, the Renewable Fuels

**Figure 4****U.S. Ethanol Production (and Changes)**

Association (RFA, 2008) reported in October 2008 that ethanol production capacity is 10.26 billion gallons, and the capacity will be 13.66 billion gallons when the processing plants currently financed or under construction are completed.

## THE ETHANOL INDUSTRY'S CONTRIBUTION TO RESOLVING THE GAP BETWEEN CORN DEMAND AND ETHANOL PRODUCTION CAPACITY

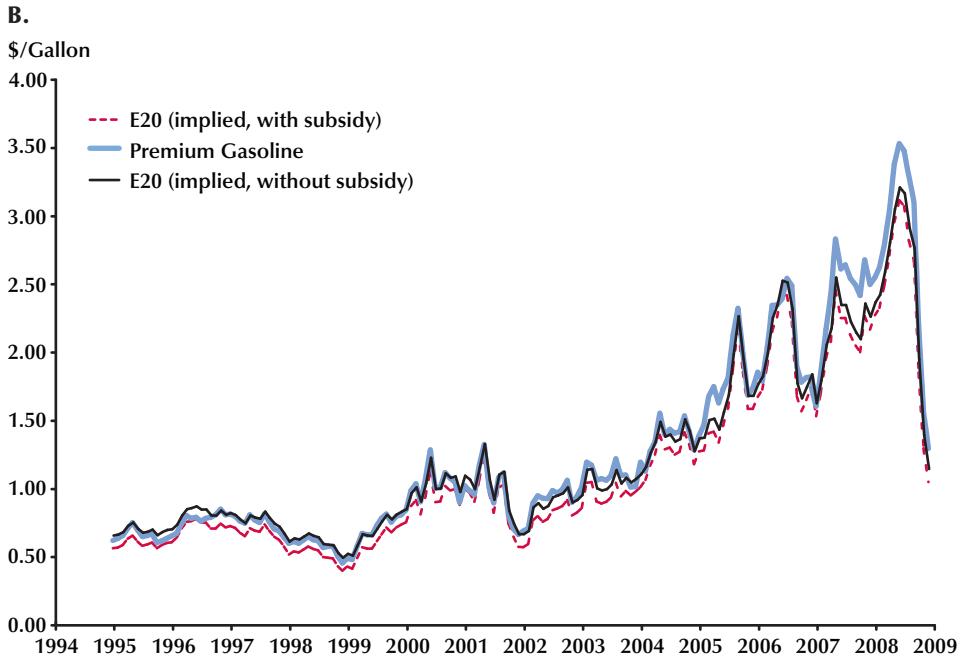
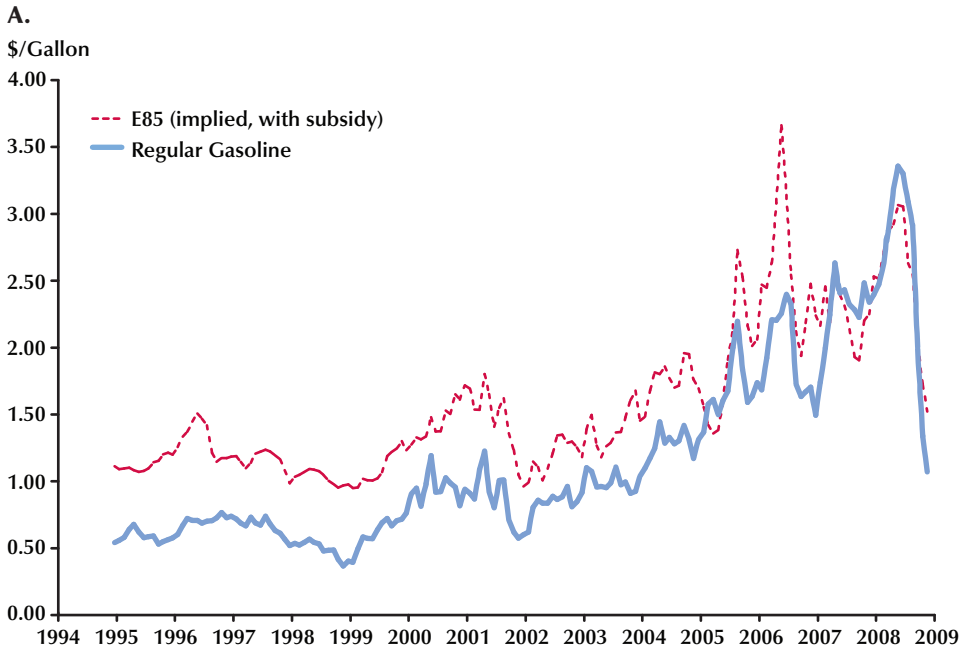
Economic theory suggests that an expanding industry pushes product prices down and input prices up, at least to the extent that product demand and input supply curves are not perfectly elastic. Indeed, wholesale ethanol prices have declined relative to gasoline prices—and even in absolute terms recently (Figure 5). Also, corn prices at the farm level have escalated from typical levels of \$2.50/bu a few years ago to \$5.00/bu recently.

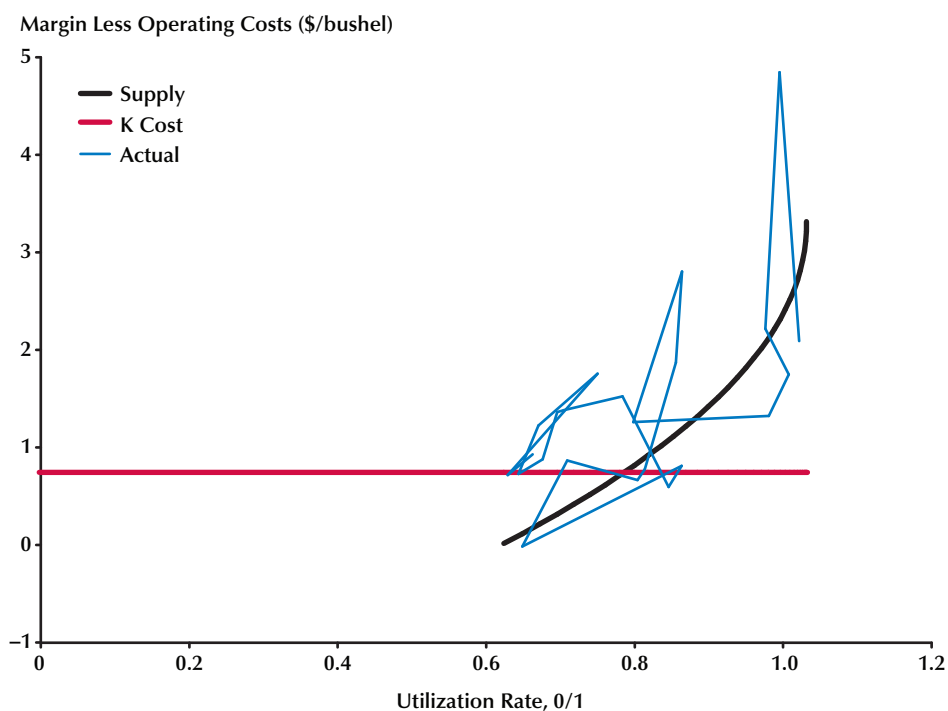
Although several developments are responsible for recent price increases, ethanol expansion was an important cause.

Market equilibrium occurs because declining output prices and increasing input prices squeeze processors' profit margin to the point that the marginal processors' return is exactly offset by their costs. Indeed, the data do suggest an upward-sloping processing supply curve with respect to the processing price (margin): Ethanol price increases (or corn input price decreases) represent upward movements along the processing supply curve (Figure 6 and Appendix A). For instance, the October 2008 average processing margin less operating cost ( $M_t$ ; see Appendix A) was \$0.72/bu after corn prices fell to \$3.73/bu, which is \$0.02/bu above the point of capital cost return. Accordingly, processing near 80 percent utilization could be expected, keeping ethanol prices at moderate levels. During November and December 2008, the margin was \$0.136/bu to \$0.293/bu less than the annual capital cost on a new plant investment. Hence, most plants continue to operate, but new capacity

**Figure 5**

**Wholesale Fuel Prices in Iowa (January 1995–December 2008)**



**Figure 6****Ethanol Processing Supply, Unit Capital Cost, and Processing Equilibrium**

plans were discouraged, as profits were not adequate to repay the annual capital investment cost of \$0.70/bu.<sup>2</sup>

Another point to consider in estimating how long it will take to restore a balance between ethanol capacity and corn supply is the balance between corn production growth and ethanol output growth. Some exploratory calculations are given in Table 1. These calculations exploit three assumptions: (i) an 80 percent utilization rate by ethanol processors continues, (ii) planned capacity is brought online at the recent historical rate but no new production plans are developed (see Appendix A and equation (A2) for profitability calculations), and (iii) trend rates of production and feed demand growth continue.

Starting with the recently completed 2007-08 crop year, corn production growth of 2,539 million

bushels was very large, partly because an additional 10.0 million acres of corn were planted. However, the actual demand growth for 2007-08 was only 1,636 million bushels, so there was a market surplus of 903 million bushels. For subsequent years, 80 percent of ethanol capacity utilization implies a growth in processor demand of 598 million bushels for 2008-09 and 568 million bushels for 2009-10. The external corn production growth between 2008-09 and 2009-10 (325 million bushels) is calculated as the trend yield growth (2.77 bu/acre/yr) on the existing corn land base plus a small allowance for increasing acreage devoted to corn.

The yearly market surplus for 2007-08 was 903 million bushels, but a deficit in production growth is likely for 2008-09 and 2009-10. Thus, falling inventories could be expected as surpluses and inventories are used to fill the demand of additional ethanol plants. However, the external production growth driven by corn-yield growth will begin to

<sup>2</sup> Editor's note: The author has updated prices for this publication since the presentation of the paper in November 2008.



**Table 1**  
**Anticipated, Actual, and External Changes in Corn Demand and Production**

| Variable     | Anticipated changes | Actual changes*  | External changes |             |             |
|--------------|---------------------|------------------|------------------|-------------|-------------|
|              |                     |                  | Anticipated      | Anticipated | Anticipated |
| Crop year    | 07/2008             | 07/2008          | 08/2009          | 09/2010     | 10/2011     |
| Demand       |                     |                  |                  |             |             |
| Feed         | 110 <sup>†</sup>    | 455 <sup>‡</sup> | 110              | 110         | 110         |
| Exports      | 0 <sup>†</sup>      | 300              | 0                | 0           | 0           |
| Ethanol      | 1,681 <sup>§</sup>  | 881              | 598              | 568         | 36          |
| Subtotal     | 1,791               | 1,636            | 652              | 678         | 340         |
| Production   | 1,664 <sup>¶</sup>  | 2,539            | 325 <sup>#</sup> | 325         | 325         |
| Difference   | 127                 | 903              | -327             | -353        | 179         |
| Cumulation** |                     | 903              | 576              | 223         | 402         |

NOTE: Data assume 80 percent utilization of corn-processing capacity (\$2.00/gal ethanol and \$5.00/bu corn).

\*Office of Chief Economist's Staff, 2008.

<sup>†</sup>Trend rate of increase 1980-2006.

<sup>‡</sup>An increase of 176 million bushels can be attributed to meat export expansion.

<sup>§</sup>Per e-mail from R. Wisner and W. Tierney, December 29, 2006.

<sup>¶</sup>A trend yield increase of 2.77 bu/acre times an acreage base of 81.3 million acres (planted) in 2006, plus an anticipated planted acreage increase of 10.0 million acres times a trend yield of 145 bu/planted acre.

<sup>#</sup>A trend yield increase of 2.77 bu/acre times an acreage base of 93.5 million acres (planted) in 2007, plus an anticipated planted acreage increase of 0.46 million acres times a trend yield of 145 bu/planted acre.

\*\*Implied inventory increase and/or price decline when positive.

catch up with the ethanol-induced expansion in corn demand by the 2010-11 crop year. The production growth exceeds demand growth slightly (by 179 million bushels) when ethanol processors are operating at 80 percent of capacity. At that point, increased profit margins pushed by declining corn prices could begin to lift capacity utilization rates of ethanol processors above the 80 percent rate. Overall, the calculations in Table 1 suggest that the net growth of the corn supply will catch up with the planned ethanol capacity in about 3 years.

### **Clearing Up Some Misconceptions**

The 2007-08 corn market year was one of major forecasting mistakes and other market surprises. First, a mood of hysteria prevailed when planting decisions for the 2007-08 crop year were made. To illustrate, recall that some analysts were suggesting a 32 billion gallon corn ethanol industry by 2014

(Elobeid et al., 2006). If such a decade-long expansion occurred at a linear rate, 3.1 billion gallons of additional ethanol (or 1,150 million bushels of corn) would have been required every year for a decade. Another private forecast anticipated an ethanol production increase of 4.5 billion gallons (1,681 million bushels) for the 2007-08 crop year (Tierney and Gidel, 2006). Even the widely watched United States Department of Agriculture (USDA) *Supply and Demand* report estimated ethanol expansion of 3.4 billion gallons (1,250 million bushels), which was 41 percent above the actual expansion (Office of Chief Economist's Staff, 2007, 2008). It is likely that errors occurred in the corn area (acres planted) and inventory allocations for the 2007-08 crop year. Further, corn prices were likely destabilized; the demand overestimate ensured higher prices and increased inventory carryout, but larger carryin and lower prices for the subsequent market year (Hyami and Peterson, 1972).



Second, the actual feed expansion of 455 million bushels was much higher than long-term trend growth (110 million bushels) or early USDA projections would have indicated. Of the actual expansion in feed demand, 175 million bushels can be attributed to the feed needed for an expansion of U.S. meat exports in pork, chicken, and beef. Both the domestic livestock and foreign livestock components of corn feed demand expanded more rapidly than anticipated.

Third, corn export growth had been nonexistent for 20 years, but the 2007-08 crop year saw a 300 million bushel expansion and a record export level. The shift in corn exports can be explained mostly by events and policy decisions in the European Union (EU) and China. The EU had a production shortfall of 257 million bushels between the 2006-07 and 2007-08 crop years. Furthermore, the EU made up almost all of the domestic production shortfall by increasing imports by 234 million bushels. This is a well-known feature of EU policies—entire shortfalls are made up on the world market because domestic prices are insulated from fluctuations in world commodity markets. China had no production shortfall. However, given their rapidly growing population, and perhaps the opportunity for a quick profit by the state trading enterprise, exports from China declined by 184 million bushels. Even though the U.S. corn export increase may have been sold to other countries, the shift in export position by the EU and China can explain most of the increase in U.S. export demand for corn.

The total demand shock that some analysts feared did actually occur: The total demand shift, initially forecast at 1,791 million bushels, was 1,636 million bushels. However, many accounts hold the ethanol industry responsible. The main point is that all three groups—meat exporters, large corn-trading countries, and the ethanol industry—cannot all expand at the same time. The corn market is not large enough, as price behavior in the past year has shown.

Corn inventory increased (by 320 million bushels) during 2007-08. At first glance, an inventory increase is not typical in a tight corn market. But was the inventory higher than a well-functioning competitive market would have delivered? Offsetting factors complicate the answer. For instance,

inventory holders with good foresight probably could accumulate some inventories to cover the anticipated bulge in ethanol demand over the next three years or so, but several other factors point to the possibility of excess inventory. Specifically, the extent of the future demand expansion was overestimated, so futures prices were high. Also, corn futures prices are systematically biased upward in comparison with the actual cash prices in subsequent periods (Appendix B), so inventory holdings based on the futures price were likely too high. Finally, there was speculation related to macroeconomic concerns about commodity inflation, which would encourage higher inventories unrelated to events in the commodity market. A quantitative analysis of the offsetting factors could be definitive. In the meantime, circumstances seemed to point toward overaccumulation of corn inventories in the 2007-08 crop year.

Fortunately, corn producers responded with more acreage in corn than many thought possible. And good fortune prevailed with an actual production increase that more than offset the demand expansion. Prices were quite high for the 2007-08 marketing year, but they were still considerably lower than they would have been had a production shortfall occurred on top of a simultaneous expansion in three market segments and excessive inventories.

## REORGANIZING THE ETHANOL INDUSTRY FOR THE TWENTY-FIRST CENTURY

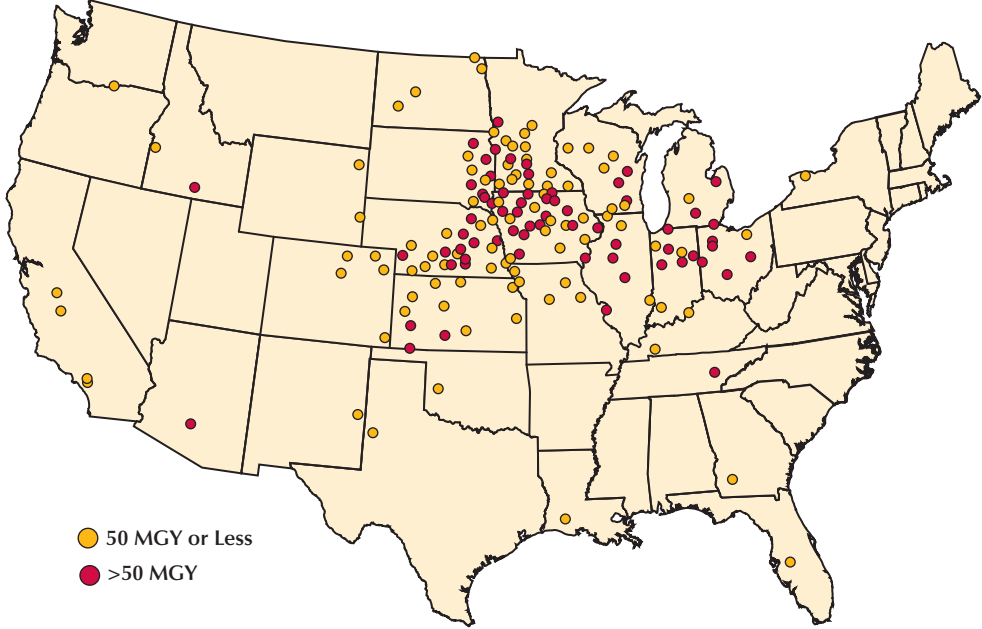
### *Production Changes*

The ethanol industry has changed considerably during its expansion. First, production has become more concentrated in the Midwestern United States (Figure 7). Second, the ownership structure has become less concentrated, which encourages fuel pricing with competitive profit margins. Third, ethanol markets have become more national in scope. Arguably, all of these changes have improved economic performance of the Midwestern economy and provided substitutes for imported fuel.

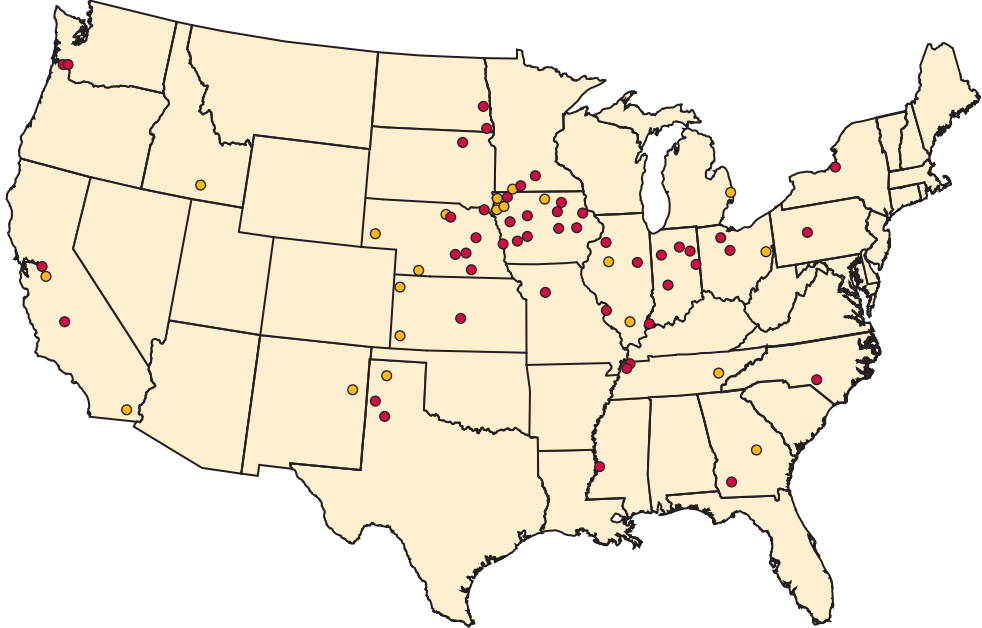
**Location of Production.** Most new plants in the rapidly expanding ethanol industry were placed

**Figure 7**  
**Ethanol Biorefinery Locations**

**A. Currently Operating Ethanol Biorefinery Locations**



**B. Pending Ethanol Biorefinery Projects: Construction, Expansions, and Announcements**



SOURCE: Renewable Fuels Association and Department of Economics, Iowa State University.

**Table 2**  
**Ownership of U.S. Ethanol Capacity in 2000 and 2008**

| Ownership              | December 2000                  |             | December 30, 2008              |                                     |             |
|------------------------|--------------------------------|-------------|--------------------------------|-------------------------------------|-------------|
|                        | Operating<br>(million gallons) | Share (0/1) | Operating<br>(million gallons) | After building<br>(million gallons) | Share (0/1) |
| Large firms            |                                |             |                                |                                     |             |
| Abengoa                | 0                              | 0           | 168                            | 344                                 | 0.026       |
| Archer Daniels Midland | 797                            | 0.397       | 1,070                          | 1,620                               | 0.122       |
| Hawkeye Renewables     | 0                              | —           | 440                            | 440                                 | —           |
| POET (Broin)           | 7                              | 0.004       | 1,467                          | 1,537                               | 0.116       |
| VeraSun                | 0                              | —           | 7,80                           | 880                                 | 0.066       |
| Subtotal (large firms) | 804                            | 0.401       | 3,925                          | 4,821                               | 0.364       |
| Small firms            |                                |             |                                |                                     |             |
| Farmer/local           | 529                            | 0.264       | 1,698                          | 1,898                               | 0.143       |
| External               | 681                            | 0.339       | 5,216                          | 6,516                               | 0.493       |
| Subtotal (small firms) | 1,210                          | 0.603       | 6,914                          | 8,414                               | 0.636       |
| Total—United States    | 2,007                          | 1.000       | 10,839                         | 13,235                              | 1.000       |

in the Midwest, where corn input supplies are ample and cheap. Specifically, 65 percent of ethanol plants are now located in seven Midwestern states (Iowa, Illinois, Indiana, Minnesota, Missouri, Nebraska, and South Dakota).

The production expansion has provided a larger economic base for the rural Midwest. The direct effects of ethanol expansion include wages at the processing plant, farm income derived from additional corn sales, and expanded local transportation. Secondary effects include multiplier effects in retail and service sectors. Local economy benefits of about \$0.20/gallon and reduced fuel consumption expenditures offset the cost of ethanol subsidies (Gallagher, Otto, and Dikeman, 2000).

Some ethanol plants are now near product markets. Locations in Texas, Oregon, and Washington are near ethanol markets and by-product distillers' grains (DG) feed markets. Here, the higher corn costs are offset by the DG drying costs avoided by local feed markets. Also, ethanol transport costs are avoided for refiners with blending requirements from the renewable fuels standard (RFS). Five percent of the ethanol plants in the United States are in Texas, Oregon, California, and Washington.

**Ownership Structure.** The ethanol industry that has emerged from the rapid expansion has a

less concentrated ownership structure. Three equally large firms combined now control about 40 percent of the market, and each has about 12 percent of the market. In contrast, one firm alone controlled 40 percent of the market in 2000 (Table 2). The remaining smaller firms represented about 60 percent of the market in both periods. However, the share of locally owned firms (i.e., firms owned by residents or farmers in the local community where the plant is located) today is 12 percent—down from 26 percent before the expansion in 2000. Externally owned firms now (as of 2008) supply about 47 percent of the capacity, a heightened presence in the industry. Dispersed firms and diverse ownership encourages competition in the ethanol market.

**Ethanol Markets.** Distinguishing between additive and commodity fuel markets for ethanol is useful in understanding episodes of ethanol premiums or discounts relative to gasoline. In the additive market, blending restrictions on scarce quality attributes (e.g., octane and/or oxygen) can create market premiums for ethanol over commodity gasoline (Gallagher et al., 2003). In the commodity fuel market, because high ethanol concentration reduces fuel economy, the market discounts ethanol relative to gasoline (Gallagher, 2007).

Historically, ethanol sold at premiums over gasoline during the replacement of MTBE. More recently, ethanol premiums have turned to discounts relative to gasoline as marketed ethanol volume surpassed the MTBE replacement threshold. Initially, larger sales volumes had to deal with transportation bottlenecks. More recently, ethanol discounts relative to gasoline have stemmed from lower-valued uses in E10 and E85 (see Figure 5).

In the coastal urban areas of the United States, federal regulations were probably responsible for oxygen-based ethanol premiums. For instance, reformulated fuel has an oxygen content standard that is satisfied by a 5.5 percent ethanol blend in Environmental Protection Agency (EPA)–designated markets. For instance, the major population centers in New York, California, and Texas are required to follow the restrictions of reformulated fuel. Even though the oxygen standard was repealed in the Energy Policy Act of 2005, ethanol demand remained high (2.0 billion gallons) in these major population centers during 2006.

Much of the ethanol is voluntarily blended in the Midwest (with subsidy).<sup>3</sup> It has been blended at 10 percent concentration (E10) for 20 years because EPA regulations assume that 10 percent is the maximum level that is compatible with conventional gasoline engines and ignition systems (EPA, 1995). More recent blends of ethanol (up to 85 percent ethanol concentration [E85]) can be used in gasoline engines with modified fuel and ignition systems. Both products are available at retail gasoline outlets around the Midwest. Six million flexible-fuel vehicles (FFVs, which are E85-compatible) are currently in use in the United States. These FFVs could consume up to 6.0 billion gallons of ethanol if fully fueled by E85 blends (based on 15,000 miles driven per car/yr and an average of 15 mpg). Since 2005 and through 2010, blenders of E10 and E85 receive a blenders' credit on the U.S. gasoline excise tax equal to \$0.51/gallon of ethanol used (RFA, 2009).

During the past two years, ethanol price discounts against gasoline have been common (see Figure 5A). Further, the discounts have tended to

widen as the volume of ethanol marketed has increased. In fact, my estimate of the ethanol price elasticity ( $E$ ) of demand with a fixed gasoline price is  $E = 1.0^4$  (see Appendix A, Ethanol Price Discounts). The implication is that revenues tend to remain about constant with increased marketed volume. Reasons for this price discounting include the fact that the requirements of the octane deficit and the E10 market in some Midwestern states have been surpassed. Also, the marketing and consumption infrastructure for using higher ethanol concentrations (gas stations and FFVs) is limited. Marketing practices and government policy are likely to evolve with the combination of price discounting and expanding supplies.

The recent situation was useful because wide price discounts encourage construction of E85 retail outlets. In addition, a subsidy encourages construction of E85 retail fueling stations.<sup>4</sup> But accelerated adoption of FFV technology by consumers will occur only with sustained consumer incentives, such as E85 retailing margins that more closely reflect gasoline retailing margins or a consumers' income tax credit for using ethanol instead of a blenders' tax credit. Rapid adoption of FFV technology given the market conditions of December 2008 is unlikely—Iowa's wholesale price for regular gasoline of \$1.06/gallon was slightly higher than the implied wholesale E85 price, but only after the \$0.51/gallon is subtracted from the weighted ethanol-gasoline price of \$1.51/gallon.

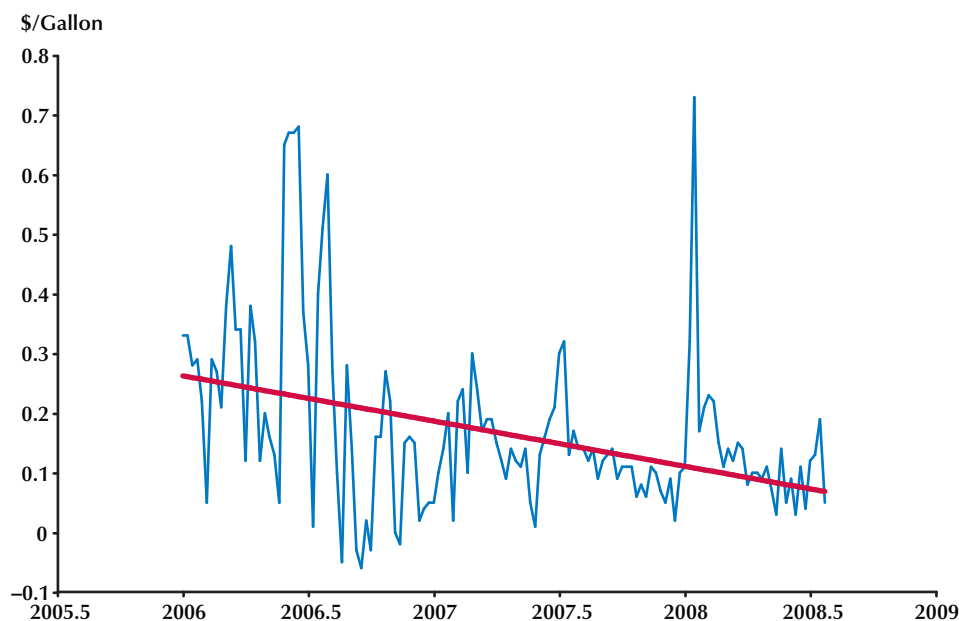
Another alternative is voluntary or mandated use of E20 (20 percent ethanol blend in gasoline) in non-FFV vehicles. A drivability study suggests that E20 could be used in conventional automobiles without mechanical problems (Kittleston, Tan, and Zarlring, 2007). A preliminary emissions test of E20 in 13 late-model (2002 and 2007) vehicles found that (i) there were no statistically significant increases in EPA-regulated auto emissions and some of the regulated emissions actually decreased and (ii) the catalytic converter was consistently cooler for all vehicles, except for a subset of lean-running vehicles during a wide-open-throttle hill-climbing

<sup>3</sup> At moderate and high gasoline prices, ethanol is competitive without the subsidy; but at low gasoline prices, an ethanol subsidy is required to maintain competitiveness (Gallagher et al., 2006a).

<sup>4</sup> A 30 percent income tax credit up to \$30,000 is available until 2010 to businesses that install clean-fuel (including E85) vehicle-refueling equipment (RFA, 2009).

## Figure 8

### Spot Ethanol Price Difference: Texas Less Iowa



experiment (West et al., 2008). Incidental fuel economy calculations from these two studies are mixed; however, a test of late-model vehicles suggests that fuel economy holds up with E20 (Shockey et al., 2007). The E20 blend remains a competitive substitute for premium gasoline with the market conditions of December 2008—Iowa’s wholesale price for premium gasoline was \$1.29/gallon and corresponding E20 prices were \$1.14/gallon without the subsidy and \$1.06/gallon with the subsidy (see Figure 5b).

Marketing policies that encourage E20 or E85 use may reduce ethanol price discounting against gasoline by encouraging ethanol-for-gasoline substitution and expanding ethanol demand. However, additional testing to determine vehicle classes and locations that are suitable for E20 is still needed.

**The Renewable Fuels Standard.** Impending consumption mandates are a second avenue that could boost future ethanol price and demand. Since 2004, an RFS potentially mandates minimum consumption levels for renewable fuels. A minimum level for corn ethanol consumption is also

implied but has not yet bound the minimum level of corn ethanol demand (EPA, 2008; *Federal Register*, 2008; Christian, 2008). Similarly, minimum corn ethanol demand from an RFS is not likely to bind supply for the next few years, according to my calculations based on the 2008 policy rule (Table A1). The existing RFS minimum consumption levels for renewable fuels will likely not constrain the ethanol supply until after 2011 (see Figure 4). If the corn supply continues to grow, however, margins would improve and increase capacity utilization rates toward 100 percent.

The RFS seems to function as a government “investment signal” that defines a potential minimum market size in the future. Indeed, as noted in Table A1, by 2016 the corn ethanol required for the RFS (13.5 billion gallons) almost exactly matches the “after building” capacity shown at the bottom of Table 2 (13.2 billion gallons). Hence, the RFS has been a second-best investment policy that signals potential government support of ethanol prices and offsets some of the risk associated with biofuels investment. The risk justification for the RFS fits



to the extent that there are no well-functioning futures markets for forward pricing.

Presently, the RFS also influences the spatial pattern of ethanol use and prices. Refiners now have a renewable volume obligation (RVO) to (i) prove their own ethanol blending at the refinery (refiners can fulfill their RVO through the purchase of ethanol with renewable inventory number [RIN] certificates) or (ii) prove another blender's use of ethanol through the purchase of that blender's RIN number (RFA, 2008; EPA, 2007).

A look at recent spot market price spreads between Texas and Iowa shows how prices may have been influenced by policies and rapid expansion of ethanol consumption. Initially, margins were wide, but recent margins are about equal to ethanol transportation costs from Iowa to the Texas Gulf Coast, about \$0.05/gallon (Figure 8). Finally, the recent market value of RIN certificates was also about \$0.05/gallon. Apparently, arbitrage has forced equality between the cost of transporting ethanol with an RIN number to a coastal refinery and the market purchase price of an RIN certificate.

## FIRM-LEVEL STRATEGIES TO REDUCE PROCESSING COSTS OR INCREASE REVENUES

Today's narrow margins have induced the development of new technologies and new firm organizations. Seven approaches are listed in Table 3. Together, these modifications have the potential to reduce ethanol production costs by at least \$0.50/gallon. However, some of these cost reductions merely offset recent cost increases that have occurred elsewhere. Further, individual firms may use only some and not all of the new technologies.

Early adoption of high-starch corn varieties for ethanol processing is likely because no capital outlay is required. Typically, high-starch corn will increase the ethanol yield and revenues but decrease by-product (DG) yield and revenues. On balance, the ethanol yield gain from a starch increase offsets the DG loss.

Most new technologies require capital expenditure to retrofit the plant. For instance, biomass

**Table 3**

### Ethanol-Processing Firms: Proposed Strategies for Increased Profits

| Strategies                    | Cost reduction or net revenue increase (\$/gal) |
|-------------------------------|---|
| Cost-reducing technology      |   |
| High-starch corn              | 0.130*  |
| Biomass power                 | 0.191 <sup>†</sup>                              |
| Revenue-increasing technology |   |
| Dry fractionation             | —   |
| Quick germ process            | 0.039 <sup>‡</sup>                              |
| Fiber extraction              | —   |
| Business reorganization       |   |
| Improved diversification      | 0.072 <sup>§</sup>                              |
| Local producer/processor      | 0.042 <sup>¶</sup>                              |

SOURCE: \*Gallagher, Schamel, Shapouri, et al. (2006a, p. 125).

<sup>†</sup>Gallagher, Schamel, Shapouri, et al. (2006a, p. 127).

<sup>‡</sup>Taylor et al. (2001).

<sup>§</sup>Gallagher, Shapouri, and Brubaker (2007, p. 76).

<sup>¶</sup>Gallagher, Shapouri, and Brubaker (2007, p. 75).

power requires the installation of a boiler or gasifier in the ethanol plant instead of gas turbines and market purchases of electricity—a choice that could increase ethanol-plant costs by 50 percent. However, the long-term benefit—replacing more expensive natural gas—could reduce processing costs by as much as \$0.19/gallon.

Another capital-using, but potentially profitable, set of technology options separates elements from the DG by-product stream. The dry fractionation process for a dry mill, which separates bran, grits, and germ in the initial grinding phase, requires additional capital investment, but additional revenues are obtained by producing ethanol from the fiber and a food-grade corn oil from the germ. There are also other processes that extract oil from the DG stream with a smaller capital investment (Taylor et al., 2001). Reduced fiber and oil content in DG is more palatable to livestock and can be fed at a higher (feed per animal) rate.

Retrofitting an ethanol plant to produce butanol is also a possibility. Weighed against the cost of conversion, the benefits would be the increased

price for butanol. Butanol is an attractive blending agent to some gasoline processors because its lower vapor pressure allows more butane use in the fuel.

Modifying the business organization also has profit-increasing potential. For instance, the interest rate charged to an ethanol enterprise in a well-diversified portfolio should be about 3 percentage points lower than a stand-alone ethanol enterprise because the risk premium is lower. In turn, the reduced interest cost would translate to a \$0.07/gallon reduction in annual capital costs for the premium.

Finally, a producer-owned enterprise with a combination of firm and cooperative practices could increase the overall farm/processor return in the local production area by about \$0.015/gallon. The increase occurs because the input market area of the processor can be extended beyond the boundary of the traditional competitive firm for higher joint profits.

## SUMMARY AND CONCLUSION

In the broadest sense, the ethanol industry owes its existence to increasing petroleum prices and a highly successful corn technology industry that sustained corn yield growth in a stagnant market for two decades. The industry has been supported along the way by a complete array of government policies: Consumption subsidies, import duties, and minimum consumption requirements have all supported the demand for ethanol during the industry development phase.

During the past few years, the ethanol-processing industry overexpanded somewhat. First, ethanol sales are large in relation to existing marketing infrastructure and ethanol-using technology. Second, the ethanol-processing expansion is somewhat larger than the corn input market that can be sustained without large-scale displacement of competing uses of corn. Signs already indicate that new capacity plans for ethanol will not be brought to the market for a while. Instead, existing capacity plans will likely be completed. Also, existing plants will likely operate below capacity for a few more years before the balance between ethanol capacity and corn supply is restored.

For the near future, a shift from mandated regional use defined by the RFS and toward voluntary marketing of E85 and E20 in the Midwest may improve ethanol sector profits and economic efficiency generally. Consumer use of E20 is expected to grow because currently the price of this premium-grade fuel is lower than comparable gasoline, even with recent low gasoline prices. However, EPA regulations that limit ethanol blending to 10 percent in conventional automobiles must first be relaxed. In preliminary testing, E20 drivability and emissions results are encouraging, but further evaluation is needed to precisely define the automobiles and locations compatible with E20 use.

Improved production management that squeezes more profits from the existing capacity warrants closer scrutiny in the near future. Given the success of past innovations, the early adopters of new technologies are expected to thrive. Innovations by processors will reduce the margin between corn ethanol and gasoline markets, which in turn, will reduce fuel prices and improve consumer welfare and increase corn prices and improve farm incomes.

The longer-run prospects for corn ethanol expansion will be defined by technologies, market events, and policy choices. For instance, more rapid ethanol growth would be possible with accelerated corn yield growth. But eventually, profitability would still be restored if petro-fuel markets remained above recent thresholds of ethanol competition and corn yields grew at historical rates.

On the other hand, corn ethanol expansion may hinge on some complex policy choices in the corn market. For instance, whether the United States should continue to accommodate the destabilizing behavior of our large trading partners is debatable. Similarly, a prolonged meat export expansion, if it should occur, could carry some adverse consequences. To wit, our land may be approaching its manure-carrying capacity after decades of already expanding meat exports. Also, the expansion of meat exports would likely reduce the carbon dioxide balance and future policies may begin to limit carbon emissions. In contrast, an expanding ethanol industry could improve the carbon balance. A balance of payments gain from petroleum import substitution is also likely.



The development of stover-to-ethanol technology would benefit society in several ways. Use of the sustainable portion of the stover supplies would increase ethanol production in the Corn Belt states by 12 billion gallons and, in turn, increase the U.S. fuel supply by 4 percent of petroleum production and reduce U.S. petroleum prices by 6 percent, yielding a net annual welfare gain to the U.S. economy of \$3.2 billion (Gallagher and Johnson, 1999). Importantly, feed/food and fuel production could become complementary instead of potentially competitive because corn and stover are joint products (National Research Council, 2000).

If left to market forces, the rate and scale of the development of biomass ethanol processing (such as stover-to-ethanol) could be impeded, which underscores the need for government involvement. First, industrial policy could prevent the duplication of investment and dilution of returns under competition and therefore improve the public good by encouraging development of new processing technology at a lower cost (Krugman, 1983). But later, new patents could define monopoly power for technology owners and retard adoption. Second, increased biofuel development/usage would have positive externalities for the environment; for instance, corn ethanol contributes to improvements in greenhouse emissions (Gallagher and Shapouri, 2009). Also, ethanol has contributed to urban air quality improvements (Gallagher et al., 2008). Third, private sector evaluations of the fuel markets do not fully account for the potential of biofuels to stem the macroeconomic instability imposed by petroleum markets and OPEC market power (Gallagher and Johnson, 1999). Fourth, government involvement may lessen the fear of the substantial risks in biofuel processing in the volatile fuel and agricultural markets, thus encouraging innovations. Fifth, new fuel-processing investments directed solely by oil sector profits would deliver the highest profits for petroleum resources—and perhaps for the world economy—but U.S. interests would not necessarily also be served.

The United States now pursues two policies that promote the development of biomass-processing capacity. First, the RFS defines minimum levels of biomass-fuel production for the next 15 years (RFA, 2007). Second, government subsidies for the con-

struction of a few biomass-processing facilities have been provided (U.S. Department of Energy, 2007). Generally speaking, capital subsidies may make more economic sense than market mandates because (i) the full extent of the public commitment is defined up front with a capital subsidy and (ii) the annual revision of minimum production levels in a political process under the RFS is discarded in favor of a market-based determination of fuel production. A shift toward the capital subsidy, and away from the production mandate, would likely improve economic efficiency.

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## APPENDIX A

### Processing Supply Estimate

A statistical estimate of the processing supply function is denoted as follows:

$$U_t = 0.6262 + 0.2505 M_t - 0.3841 M_t^2.$$

(12.6)      (3.5)      (2.3)

$$R^2 = 0.50$$

root mean square error = 0.099

The numbers in parentheses below the coefficients are  $t$ -values.

#### Variable Definitions

$U_t$  = utilization rate =  $Qe_t/S_t$

$Qe_t$  = ethanol production (billions of gallons)

$S_t$  = ethanol production (billions of gallons)

$M_t$  = margin less operating costs (\$/bu of corn processed)

$$M_t = Pe_t Ye_t + Pdg_t Yd_t - Pc_t - Cop_t$$

$Pe_t$  = ethanol price in Iowa (\$/gallon)

$Ye_t$  = ethanol yield (2.7 gallons/bu corn)

$Pdg$  = DG price (\$/lb)

$Yd_t$  = Dg yield (1.75 lb/bu)

$Pc_t$  = Corn price (\$/bu)

$Cop_t$  = operating (non-corn) costs (\$/bu)

### Capacity Adjustment

The estimate of ethanol capacity investment suggests that capacity responds to profits.  $\Delta S_t$ , the rate of capacity increase, will slow and eventually cease when zero profits are sustained.

The estimate is

$$\Delta S_t = 0.0433\pi_t + 0.697\Delta S_{t-1}$$

(2.9)      (5.1)

$$R^2 = 0.77 \quad \text{Root MSE} = 0.070.$$

### Historical Period (Annual Data): 1987-2008

#### Variable Definitions

$\Delta s_t = s_t - s_{t-1}$ , and  $s_t = \ln(S_t)$

$\pi_t = M_t - k_t$

$k_t$  = unit capital cost (\$/bu corn processed)

The constant, which suggests a steady rate of capacity increase when profits are zero, was not statistically significant in preliminary regressions, so it was discarded.

To see how capacity might adjust after 2008, notice that

$$S_t/S_{t-1} = e^{0.043\pi}(S_{t-1}/S_{t-2})^{0.697}.$$

Next, notice that  $S_{08}/S_{07} = 1.36$ , and suppose that  $\pi_t = 0$  is sustained for several years. Then (1 plus) the percentage increase in capacity for the next 5 years would be

$$2009: 1.36^{0.697} = 1.24,$$

$$2010: 1.24^{0.697} = 1.16,$$

$$2011: 1.16^{0.697} = 1.11,$$

$$2012: 1.11^{0.697} = 1.07, \text{ and}$$

$$2013: 1.07^{0.697} = 1.05.$$

Thus, the rate of capacity increase would be only 5 percent after the 2012 crop year.

Suppose prices fall to variable costs ( $\pi_t = -0.7$ ). Then (1 plus) the percentage increase in capacity for the next 5 years would be expressed as follows:

$$2009: 0.97 \times 1.36^{0.697} = 1.21,$$

$$2010: 0.97 \times 1.21^{0.697} = 1.11,$$

$$2011: 0.97 \times 1.11^{0.697} = 1.04,$$

$$2012: 0.97 \times 1.00^{0.697} = 1.00, \text{ and}$$

$$2013: 0.97 \times 1.07^{0.697} = 0.97.$$

Thus, capacity decreases by 3 percent after the 2012 crop year.

### **Ethanol Price Discounts**

In a market with well-informed consumers and uniform blending of ethanol into gasoline, the percentage price discount of ethanol compared with gasoline is positively related to the ethanol blending rate (Gallagher, 2007). Statistically, the ethanol price discount can be explained by ethanol's share of the gasoline marketing volume:

$$d_t = -0.589 + 12.96X_t$$

(30.7) (16.57)

$$R^2 = 0.95 \quad \text{Root MSE} = 0.15.$$

### **Historical Period (Monthly Data): 2000-08**

#### **Variable Definitions**

$$d_t = (Pg_t - Pe_t)/Pg_t^r, \text{ where}$$

$Pg_t$  = wholesale price for regular gasoline in Iowa (\$/gallon)

$Pg_t^r$  = retail price for regular gasoline in Iowa (\$/gallon)

$$X_t = De_t/Dg_t$$

$De_t$  = ethanol demand in period  $t$  (billions of gallons)

$Dg_t$  = gasoline demand in period  $t$  (billions of gallons)

In general, the price elasticity of ethanol demand from the price-discount estimate is

$$E_{Qe.Pe} = -\frac{1}{12.96} \frac{Pe}{Pg^r} \frac{1}{X}.$$

Using data from October 2008 yields the following:

$$E_{Qe.Pe} = (-0.0769)(0.75)/(1/0.0646), \text{ or } E_{Qe.Pe} = 0.893.$$

**Table A1****RFS for Renewable Biofuel and Its Components**

| Year | Renewable biofuel* | Biodiesel credit | Ethanol imports† | Corn ethanol production | Soy oil for biodiesel (bil lb) | Biodiesel production (bil gal)‡ | Biodiesel RFS credit§ | Actual anticipated corn production |
|------|--------------------|------------------|------------------|-------------------------|--------------------------------|---------------------------------|-----------------------|------------------------------------|
| 2006 | 4.00               | 0.73             | 0.19             | 3.09                    | 3.10                           | 0.43                            | 0.73                  | 4.86                               |
| 2007 | 4.70               | 0.73             | 0.22             | 3.75                    | 3.10                           | 0.43                            | 0.73                  | 6.49                               |
| 2008 | 9.00               | 0.73             | 0.47             | 7.80                    | 3.10                           | 0.43                            | 0.73                  | 8.49                               |
| 2009 | 10.50              | 0.73             | 0.55             | 9.22                    | 3.10                           | 0.43                            | 0.73                  | 9.97                               |
| 2010 | 12.00              | 0.73             | 0.64             | 10.63                   | 3.10                           | 0.43                            | 0.73                  | 10.93                              |
| 2011 | 12.60              | 0.73             | 0.67             | 11.20                   | 3.10                           | 0.43                            | 0.73                  | 10.93                              |
| 2012 | 13.20              | 0.73             | 0.71             | 11.76                   | 3.10                           | 0.43                            | 0.73                  |                                    |
| 2013 | 13.80              | 0.73             | 0.74             | 12.33                   | 3.10                           | 0.43                            | 0.73                  |                                    |
| 2014 | 14.40              | 0.73             | 0.77             | 12.90                   | 3.10                           | 0.43                            | 0.73                  |                                    |
| 2015 | 15.00              | 0.73             | 0.81             | 13.46                   | 3.10                           | 0.43                            | 0.73                  |                                    |
| 2016 | 15.00              | 0.73             | 0.81             | 13.46                   | 3.10                           | 0.43                            | 0.73                  |                                    |

NOTE: All production data listed in billions of gallons unless otherwise stated.

\*Defined by Energy Independence and Security Act (2007).

†Six percent of corn ethanol production.

‡0.43 bu/gal biodiesel = 3.10 billion lb soy oil × (0.985 lb biodiesel/1 lb soy oil) × (1 gal biodiesel/7.114 lb biodiesel).

§1.7 × biodiesel production.

**APPENDIX B**

In a widely used test of future market performance, Tomek and Gray (1970) proposed a regression comparison of actual post-harvest cash prices and the futures price quotation in the planting period for delivery in the post-harvest period. To update, we used the following regression:

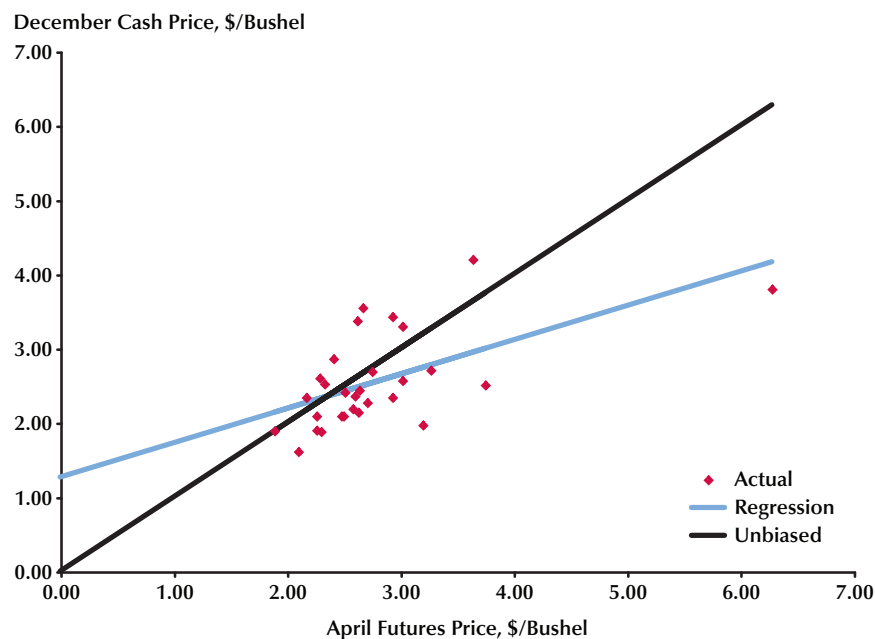
$$P_{C_{t+1}} = \alpha + \beta P_t^{f^{t+1}} + \varepsilon_t,$$

where  $P_{C_{t+1}}$  is the actual corn cash price (December futures price) on December 11 (November 18 for 2008) of the following crop year,  $P_t^{f^{t+1}}$  is the April 30 corn futures price for delivery in the following December, and  $\varepsilon_t$  is a random disturbance term.

The idea is that the parameters take on particular values when the futures market is performing adequately. Specifically,  $\alpha = 0$  and  $\beta = 1$  when futures prices are an unbiased forecast of the upcoming market price.

The significance of this result is that economic agents who use the futures price as an expected price can shed the risk associated with production or inventory holding under uncertainty (Holthausen, 1979). Further, the producer who sees future output on future markets will, on average, produce the same output or hold the same inventory as a risk-neutral agent.



**Figure B1****Corn Futures Prices, Cash Prices, and Cash Price Predictions**

We estimated the following price relationship for the 1980-81 to 2007-08 period:

$$P_{C_{t+1}} = 1.269 + 0.462 P_{F_t}^{t+1} \quad (3.6) \quad (3.8)$$

$$R^2 = 0.32 \quad DW = 2.01 \quad s = 0.52.$$

$t$ -Tests reject the unbiased futures price hypothesis. The statistic is  $t_\alpha = 3.0$  under the null hypothesis that  $\alpha = 0$ . Similarly, the test statistic is  $t_\beta = 4.37$  under the null hypothesis that  $\beta = 1$ .

The upshot is that the springtime futures price tends to be above the actual cash price, especially when futures prices are above their mean for the historical period (Figure B1), so corn producers can increase their average returns by forward pricing in the futures market. In contrast, corn users such as ethanol plants will reduce their average returns by forward pricing in the futures market.

Oddly, the variability in the springtime futures price is higher (SD = \$0.80/bu) than the variability of the December cash price (SD = \$0.63/bu). Hence, routine hedging by producers or consumers would tend to be more risky than unhedged sales or purchases on the cash market.

For comparison, Tomek and Gray (1970) found that the corn futures market performed well over the 1952-68 period. That is, estimated values approximately verified the unbiased forecast result with  $\alpha = 0$  and  $\beta = 1$ . Furthermore, the SD of the cash price exceeded the SD of the futures price, so using the futures reduced price variability.

Overall, results suggest that the corn futures market performed better in the 1952-68 period. For reasons to explain the difference, notice that trading was limited to futures contracts in the early period and speculators focused mainly on upcoming corn market conditions. In contrast, options and derivatives trading was prevalent over the past two decades. Further, speculation on the macroeconomic inflation rates in commodity markets has become commonplace in recent years.