Panel Discussion: The Future of Biofuel

An Economic Critique of Corn-Ethanol Subsidies

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If corn ethanol is such a wonderful product, why does it require government subsidy?[1] If ethanol is truly economically competitive with gasoline absent government preference—as many of its supporters seem to believe—then private investors will produce ethanol for the market regardless of whether government lends a hand (Tyner and Taheripour, 2008).[2] Subsidies in this case will simply result in more ethanol production than is economically efficient. If ethanol is *not* economically competitive with gasoline, then subsidies distort the market by steering investment away from economically attractive gasoline and toward economically unattractive ethanol. Consumer well-being and overall economic efficiency suffer as a consequence.

Support of ethanol subsidies and consumption mandates offer a mix of arguments to justify government intervention. Those arguments can be neatly sorted into two categories: those that forward wealth distribution claims and those that forward efficiency claims. The former arguments, although interesting, are not addressed in this paper. Ethanol may or may not transfer wealth to rural America, for instance, but preferences with regard to wealth allocation are subjective and not worth much analytic time. The latter arguments, however, are grounded in concrete claims that can be proven or disproven and are, thus, the focus of this paper.

To have any intellectual force, the argument that ethanol subsidies and consumption mandates enhance economic efficiency must begin with a discussion of market failure. Economists broadly agree that, as a general rule, leaving production and consumption decisions to market actors proves more economically efficient than leaving the same to governmental planners. Only if some unique and fundamental failure occurs that prevents gains to trade in a given market is there room for the argu-

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[1] This paper is exclusively concerned with ethanol made from corn. Unless otherwise indicated, all references to ethanol are in relation to ethanol made from corn. When economists discuss ethanol subsidies, they are almost always referring to four subsidies in particular: a $0.51 per gallon blenders' tax credit afforded to refineries that use ethanol in motor fuel (known in the law as the Volumetric Ethanol Excise Tax Credit, it is scheduled to be reduced to $0.45 per gallon in 2009); a Renewable Fuels Standard that requires U.S. refiners to consume a certain amount of ethanol per year (9 billion gallons, for instance, in 2008, rising to 36 billion gallons by 2022); a 2.5 percent ad valorem tariff on ethanol imports; and a $0.51 per gallon tariff on the same. However, a number of other direct and indirect federal, state, and local subsidies afforded to the ethanol industry in aggregate are quite large but are rarely considered in the peer-reviewed literature (Hahn, 2008). That is largely because such subsidies are difficult to quantify in a satisfactory manner and because they are often afforded to other industries besides ethanol, leading to debate about whether it is appropriate to consider them as ethanol subsidies per se. The Energy Information Administration (EIA; 2008) pegs the cost of ethanol subsidies to the taxpayer at $3 billion in 2007. The best guess of the total federal subsidy afforded to the ethanol industry that year, however, is conservatively estimated at $6.9 to $8.4 billion and $9.2 to $11 billion in 2008, or $1.50 to $1.70 per gallon of gasoline-equivalent ethanol (Koplow, 2007).

[2] Tyner and Taheripour (2008) believe that ethanol production in the United States was (barely) profitable without subsidy (defined as operations clearing a 12 percent or better return on equity) for the first time in 2001. From 2002 to 2003 production returned to unprofitability absent subsidies, but from 2004 to 2007 significant profits were realized even without subsidy largely because of the de facto ban on methyl tertiary-butyl ether as a fuel additive and a surge in ethanol demand to provide those blending services. In 2008, however, production again reached the break-even point.

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Federal Reserve Bank of St. Louis *Regional Economic Development*, 2009, *5*(1), pp. 78-97.

ment that government intervention improves the functioning of those markets (Cowen, 1988, and Cowen and Crampton, 2003). Hence, the case for ethanol subsidies hinges on whether concrete market failures exist in transportation fuel markets.

This paper examines the claims made about alleged market failures in transportation fuel markets. Two claims in particular warrant examination: that gasoline prices are too low because they do not account for the national security costs associated with gasoline consumption and that the environmental costs associated with gasoline consumption are ignored in the pricing mechanism. Subsidy proponents argue that if gasoline prices included both the national security and environmental costs associated with gasoline consumption, ethanol would be much cheaper than gasoline and demand for the latter would grow dramatically. Alas, those costs ("externalities" in economic parlance) are not embedded in final consumer prices and thus market actors, left to their own devices, will overconsume gasoline and underconsume ethanol. Other market failures have been alleged but they are altogether less compelling than these two. A cursory examination of a few of them follows.

"BIG OIL" MARKET POWER

We occasionally hear that "Big Oil" exercises their market power to the detriment of motorists by restricting ethanol's entry into end-use fuel markets (Cooper, 2005). The oil industry's reluctance to use high blends of ethanol in gasoline absent a government mandate, build ethanol delivery infrastructure to supply service stations, or provide E85 pumps[3] are often marshaled as evidence that oil companies are unfairly strangling an economic competitor in its bed. The existence of this self-serving oil cartel is said to explain why this otherwise commercially attractive transport fuel—ethanol—requires government subsidies and consumption mandates.

Yet, as of 2007, 38 percent of the retail fuels market was composed of independent service stations, not vertically integrated franchises, and another 13 percent of grocers and other hypermarkets. Only 49 percent of retail fuel was sold by stations associated with major oil companies. Likewise, 56 percent of the refining market was composed of independent, vertically deintegrated refining companies (Lowe, 2008). Big Oil is simply incapable of keeping ethanol out of service stations if profits are to be made by selling ethanol to motorists.

Statistical analysis of market data finds no evidence that market power in the oil sector has any impact on national retail motor fuel prices, although mergers and acquisitions have likely increased fuel prices in some regions while decreasing them in others (Chouinard and Perloff, 2007, and Taylor and Van Doren, 2006). Likewise, metrics regarding market concentration in the refining sector (such as the Herfindahl-Hirschman Index) do not suggest much market power in four of the five refining Petroleum Administration Defense District regions of the United States (Du and Hayes, 2008).

The economic and regulatory hurdles to entering the refining or retail sales markets are modest. Refineries change hands frequently—as do service stations. This factor is important because many economists now believe that, if a market is theoretically contestable, market power is functionally modest to nonexistent (Baumol, 1982; and Baumol and Panzer, 1982), although actual entry may still be important in some industries (Borenstein, 1992).[4]

Finally, ethanol is delivered primarily by rail but also by truck and barge. The oil industry is in no position to block the expansion of that infrastructure or to prevent third parties from investing in dedicated ethanol pipelines (ethanol cannot move through pipelines used for oil or gasoline because ethanol is water soluble).

A variation of the above narrative holds that oil refining capacity is so tight that, absent govern-

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[3] E85 is motor fuel that is 85 percent ethanol and 15 percent gasoline.

[4] Many states prohibit entry to some extent in retail fuel markets by preventing major retailers like Cosco, Sam's Club, and Wal-Mart from selling motor fuel. Likewise, zoning laws and environmental regulations have been identified as barriers to entry in some markets. Those are government failures, however—not market failures—and should be addressed by deregulation. Given the inclination of many major retailers to project "green" images to consumers, it may well be that deregulating entry would increase the availability of ethanol to consumers.

ment efforts to promote ethanol, American consumers would have suboptimal volumes of motor fuel available to them and, accordingly, higher pump prices. Thus, the argument is that ethanol increases the amount of motor fuel available—effectively adding to capacity—and serves the role that, for instance, Hamburger Helper serves in increasing the volume of food on a plate of ground beef.

The argument is superficially true. Assume, for instance, that all ethanol disappeared tomorrow. In the short run, gasoline refining capacity is relatively fixed and consumers do not respond robustly to price increases in the short term. Hence, the highly inelastic short-term supply-and-demand curves for gasoline suggest that gasoline prices would increase dramatically—14.6 percent according to a 2004 analysis circulated by the Renewable Fuels Association (Urbanchuk, 2004), a figure that would be even higher today given ethanol's larger share of the motor fuels market in 2008. Supply and demand are more elastic in the long run, so ultimately, prices would rise only 3.7 percent in the long term according to that same analysis.

What is the market failure, however, that leads industry to underinvest in refining capacity? Sometimes we are told that industry conspires to restrain refining capacity to maximize profit (Cooper, 2007). This is a variation of the previous argument about monopoly power in the oil sector. It is also an argument that, even if true, does not necessarily provide evidence of market failure. The exercise of market power may have an impact on wealth distribution (refinery owners are wealthier and everyone else is poorer), but it likely has little impact on overall market efficiency (Posner, 1999).

Many analysts believe that the lack of excess refining capacity is largely driven by the limited profits historically made by those who invest in refining. To the extent that ethanol programs significantly reduce refining profits (see Du and Hayes, 2008), the problems ostensibly addressed by ethanol subsidies may actually contribute to the existence of the underlying problem.

Other times we are told that government policies discourage the construction of new refineries and the expansion of capacity at existing facilities. Although it is unclear to what extent this is true, if government policies inhibit optimal capacity expansion it is a government failure, not a market failure, and is best remedied by direct assault on the policies in question.

The strongest study offered as evidence that ethanol subsidies have reduced motor fuel prices is by economists Xiaodong Du and Dermot Hayes at the Center for Agriculture and Rural Development at Iowa State University (Du and Hayes, 2008). Their regression analysis concludes that ethanol production has reduced retail gasoline prices by \$0.29 to \$0.40 per gallon from 1995 to 2007 because it has "prevented some of the dramatic price increases often associated with an industry operating at close to capacity" (p. 13).

The Du and Hayes study (2008) does not, however, support the contention that, in a hypothetical world in which ethanol production did not exist, motor fuel prices would be higher. That is because the study assumes that, without ethanol production, gasoline refining capacity would not have grown any more than it did with ethanol production. Given that total refining capacity has historically expanded to meet increased demand (Shore and Hackworth, 2004), it is likely that, absent ethanol production, capacity expansion would have occurred and fuel prices in that counterfactual world would have been no higher than they were historically. The authors acknowledge as much: "Because these results are based on capacity, it would be wrong to extrapolate the results to today's markets. Had we not had ethanol, it seems likely that the crude oil refining industry would be slightly larger today than it actually is, and in the absence of this additional crude oil refining capacity the impact of eliminating ethanol would be extreme" (pp. 13-14).

The Du and Hayes (2008) study also implicitly assumes a fixed amount of oil production. Ample anecdotal evidence, however, suggests that oil producers have responded to U.S. ethanol production by reducing investments in upstream production capacity. This seems reasonable given that ethanol consumption displaces oil consumption and projections about the same heavily affect decisions about investment in future oil production capacity. Consequently, ethanol's impact on oil prices is ambiguous.

Even if ethanol subsidies reduced motor fuel prices, it does not follow that motorists are, on balance, better off. For instance, the two Iowa State economists who produced the aforementioned estimate regarding the reduction of motor fuel prices that has followed from ethanol subsidies (Du and Hayes, 2008) also contend (in Du, Hayes, and Baker, 2008) that the total social costs associated with ethanol subsidies are greater than the aggregated benefits. Cornell economists Harry de Gorter and David Just (2007b) argue that the spread between the two is even greater than alleged by Du, Hayes, and Baker.

This should not be surprising. Subsidies for wheat, corn, soybeans, and other crops produce lower commodity prices, but very few economists argue that gains to consumers outweigh the efficiency losses imposed by those subsidies on the economy as a whole. What consumers gain is more than offset by taxes and the loss as a market actor in other sectors of the economy.

FARM SUBSIDIES

Some have argued that ethanol subsidies actually *reduce* the net burden of subsidies on the taxpayer because the higher corn prices yielded by ethanol subsidies reduce other subsidy payments that would have otherwise gone to corn farmers. This appears to be correct, at least for 2007. Reductions in loan deficiency payments to corn farmers exceeded the costs of the ethanol program by $3.45 billion in that year (Du, Hayes, and Baker, 2008).

Yet it does not follow that ethanol subsidies therefore enhance efficiency. First, the taxpayer savings identified by Du, Hayes, and Baker (2008) do not account for all of the deadweight losses associated with ethanol subsidies.[5] Total deadweight losses are, in aggregate, greater than the advertised savings to the taxpayer (de Gorter and Just, 2007b). Second, although that same study finds a net reduction in farm payments from the ethanol program, it also finds that the net total of social cost associated with the refiners' tax credit, the ethanol consumption mandate, and the ethanol tariff (absent any consideration of the alleged national security or environmental benefits of ethanol) was $780 million in 2007.

One further point should be made. The existence of farm subsidies is not a market failure—it is a government failure. In a narrow sense, ethanol subsidies may reduce the cost of farm subsidies to the taxpayer, but a far more direct and less-costly means of doing the same is simply to dismantle the farm subsidies in question.

LEVELING THE PLAYING FIELD

Ethanol proponents frequently note that government provides substantial subsidies to the oil sector. The belief is that those subsidies provide commercial advantages to oil producers and oil prices are lower as a consequence; that is, oil subsidies distort the market by encouraging excessive oil consumption. Thus, ethanol proponents believe that subsidies for ethanol, beyond simply leveling the competitive playing field, make the economy more efficient by reducing oil consumption from the inefficiently high levels promoted by subsidies to the oil sector.

The EIA pegged federal oil and natural gas subsidies at $2.15 billion in 2007 (EIA, 2008). A more ambitious tally suggests that oil subsidies, broadly defined, were $5.2 to $11.9 billion in 1995, or $1.20 to $2.80 per barrel (Koplow and Martin, 1998; the estimate does not include environmental or national security externalities and, unfortunately, has not been updated). Although laws and outlays have changed substantially since Koplow and Martin's publication (although the EIA's tally finds no appreciable change in the sum of federal oil and gas subsidies since 1999), their estimate illustrates the importance of defining subsidy beneficiaries. To wit, are subsidies programs that exclusively benefit the targeted industry (the EIA definition), or do they also include programs that benefit the recipient and other parties outside that sector of the economy (the Koplow and Martin definition)?

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[5] Deadweight losses arise from the economic distortions associated with tax avoidance and changes in social and economic behavior in response to regulatory intervention. A textbook exposition of deadweight loss can be found in Rosen and Gayer (2008).

The EIA calculates that federal oil and gas subsidies outside the electricity sector total $30,000 per million British thermal units (BTUs). Biofuel subsidies outside the electricity sector, however, ($3 billion of the $3.2 billion of which are directed at ethanol via the blenders' tax credit), work out to $5.72 million per million BTU (EIA, 2008, Table 36). Using EIA figures for oil and gas subsidies and estimates of the cost of the blender's tax credit from Koplow (2007), economist Douglas Tiffany (2008) calculates that oil subsidies in 2007 were slightly less than $0.15 per gallon of gasoline while ethanol subsidies totaled $0.588 per gallon. Whether we embrace a narrow or broad definition of subsidy, the conclusion is the same; oil subsidies are relatively trivial while ethanol subsidies are relatively substantial.

Although none of the identified oil subsidies is defensible on economic grounds, they have very little if any impact on oil prices because they do not reduce marginal production costs (Metcalf, 2006). Hence, oil subsidies do not distort the market and do not disadvantage ethanol producers. There is no efficiency problem for ethanol subsidies to correct.

Ethanol subsidies, however, are more pernicious. Unlike oil subsidies, ethanol subsidies reduce marginal production costs and, as a consequence, distort price signals and thus capital allocations in the market. The ethanol subsidy "cure" in this case is far worse than the oil subsidy "disease."

NATIONAL SECURITY EXTERNALITIES

Among the most fashionable preoccupations in foreign policy circles is "energy security." Although the precise meaning of energy security is unclear, foreign policy elites have long been concerned about U.S. reliance on foreign energy (an exception is Gholtz and Press, 2007). Fear of embargoes and supply disruptions affects how Western nations deal with oil- and gas-producing states, what sort of policies are pursued in the Middle East, and even fundamental questions of war and peace.

Proponents of ethanol subsidies argue that if the price of oil included the cost of our "oil mission" in the Middle East, the wars that the U.S. military engages there to protect oil supplies, the costs associated with our need to "kiss the ring" of Middle Eastern oil producers, the economic damage by terrorists from the flow of petrodollars into their coffers, and the harm done to U.S. interests by oil-rich states like Iran, Venezuela, and Russia, then oil consumption would be far less than it is now. Alas, it is believed that those national security externalities are not embedded in gasoline prices and, as a result, gasoline consumption is heavily subsidized. Ethanol consumption is thus suboptimal and ethanol subsidies are an appropriate remedy.

Economists, however, are far less worried about the national security costs of America's reliance on oil (foreign or otherwise) (Bohi and Toman, 1996) and with good reason: Economists understand oil markets far better than do foreign policy elites. The alleged national security externalities associated with gasoline consumption are for the most part a figment of an imagination unmoored from a good understanding of market reality.[6]

Blood for Oil

Many believe that reliance on foreign oil requires the United States to militarily defend friendly exporting states and to ensure the safety of oil supply facilities and shipping lanes. Those marching under banners declaring "No Blood for Oil" seem to believe that is the case, as do most mainstream foreign policy analysts. Delucchi and Murphy (2008) offer a rigorous attempt to quantify the public dollars associated with the "oil mission." They suggest that if motor vehicles in the United States did not consume Persian Gulf oil, the U.S. Congress would have likely reduced military expenditures by $13.4 to $47 billion in 2004 (one of the

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[6] Greene and Leiby (2006) argue that oil-price volatility imposes significant economic losses and that ethanol is less subject to disruption and thus offers economic advantages. Although empirical claims appear to be untrue, U.S. data from 1960 to 2005 demonstrate that corn harvests are far more variable than oil import volumes (Eaves and Eaves, 2007). Even if that were not the case, price volatility does not suggest a market failure. If ethanol were more commercially attractive because its price were more stable, refiners would take that into account when making decisions about optimal motor fuel blends. The claim that oil price volatility imposes an externality on third parties does not comport with the standard definition of market failure in that the same would hold true for all price changes anywhere in the economy (economists refer to this phenomenon as a "pecuniary externality"; Huntington, 2002).

two years examined in the analysis). If U.S. motor vehicles did not consume any oil at all, military expenditures would have, oddly enough, gone down by far less: by $5.8 to $25.4 billion in 2004. The "best guess" of this analysis is that, if U.S. gasoline consumers were forced to pay for the U.S. oil mission, gasoline prices would increase by $0.03 to $0.15 per gallon.

Simple economics, however, suggests that the oil mission—however large it may be—is unnecessary, regardless of what Congress may think. Oil producers will provide for their own security needs as long as the cost of doing so results in greater profits than equivalent investments could yield. Because Middle Eastern governments typically have little of value to trade except oil—oil revenues, for instance, are 40 to 50 percent of Iranian government revenues and 70 to 80 percent of Saudi government revenues—they must secure and sell oil to remain viable (EIA, 2006). Given that their economies are so heavily dependent on oil revenues, Middle Eastern governments have even *more* incentive than do consuming states to worry about the security of oil production facilities, ports, and shipping lanes (West, 2005).

In short, whatever security our military presence provides (and many analysts think that our presence actually *reduces* security; see Jervis, 2005) would be provided by incumbent producers were the United States to withdraw. That Saudi Arabia and Kuwait paid for 55 percent of the cost of Operation Desert Storm suggests that keeping the Strait of Hormuz free of trouble is certainly within their means.

The same argument applies to al Qaeda threats to oil production facilities. Producer states have such strong incentives to protect their oil infrastructure that additional Western assistance to do the same is probably unnecessary. Although terrorists do indeed plot to disrupt oil production in Saudi Arabia and elsewhere, there is no evidence to suggest that producer-state security investments are insufficient to protect their interests.

The U.S. oil mission is thus best considered a taxpayer-financed gift to oil regimes (and, perhaps, the Israeli government) that has little, if any, effect on the security of oil production facilities or, correspondingly, the price of oil. One may support or oppose such a gift, but our military expenditures in the Middle East are not necessary to remedy a market failure.

Foreign Policy Distortions

Many foreign policy analysts believe that U.S. oil imports are dependent on friendly relationships with oil-producing states. The fear is that unfriendly regimes might not sell us oil—a fear that explains why former Federal Reserve Chairman Alan Greenspan supported the two Gulf Wars against Iraq (Woodward, 2007). Others believe, however, that maintaining good relations with oil producers interferes with other foreign policy objectives—such as the defense of Israel and the pursuit of Islamic terrorists—and increases anti-American sentiment in oil-producing states with unpopular regimes (Scheuer, 2007 and 2008). The problem with this argument, however, is that its fundamental premise is incorrect. Friendly relations with producer states neither enhance access to imported oil nor lower its price (Adelman, 1995).

Selective embargoes by producer nations on some consuming nations are unenforceable unless all other nations on Earth refuse to ship oil to the embargoed state or a naval blockade is used to prevent oil shipments into the ports of the embargoed state. That is because, once oil leaves the territory of a producer, market agents—not agents of the producer—dictate where the oil goes, and anyone willing to pay the prevailing world crude oil price can have all he or she wants. The 1973 Arab oil embargo is a perfect case in point. U.S. crude oil imports actually increased from 1.7 million barrels per day (MBD) in 1971 to 2.2 MBD in 1972, 3.2 MBD in 1973, and 3.5 MBD in 1974 (EIA, 2004). Instead of buying from Arab members of the Organization of the Petroleum Exporting Countries (OPEC), the United States bought from non-Arab oil producers. The customers displaced by the United States bought from Arab members of OPEC. Beyond the modest increase in transportation costs that followed this game of musical chairs, the embargo had no impact on the United States (Fried, 1988, Parra, 2004, and Adelman, 1995). In short, all that matters for the majority of consumers is how much oil is produced for world markets, not from whom the oil was initially purchased.

Do oil-producing nations allow their feelings toward oil-consuming nations to affect their production decisions? Historically, the answer has been "no." The record strongly indicates that oil-producing states, regardless of their feelings toward the industrialized West, are rational economic actors. After a detailed survey of the world oil market since the rise of OPEC, oil economist M.A. Adelman concluded, "We look in vain for an example of a government that deliberately avoids a higher income. The self-serving declaration of an interested party is not evidence" (Adelman, 1995, p. 31). Philip Auerswald of George Mason University agrees, stating "For the past quarter century, the oil output decisions of Islamic Iran have been no more menacing or unpredictable than Canada's or Norway's" (Auerswald, 2007, p. 22).

If energy producers are wealth maximizers, what do we make of countries that are selling oil and natural gas to others at below-market rates? For instance, Russia sold oil to Cuba at below-market prices during the Cold War; Russia has long sold natural gas to Ukraine at below-market prices but has ended its natural gas subsidy to Georgia as relations have soured; and China sells oil to North Korea at low rates and used this as leverage to induce North Korea to bargain over its nuclear weapons program.

Two conclusions seem reasonable. First, sellers have leverage in natural gas markets that is not possible in oil markets because oil can be transported easily, whereas natural gas is shipped through pipelines. Buyers have few near-term alternatives if natural gas sellers reduce shipments. As liquefied natural gas gains market share, however, natural gas markets will look increasingly like world crude oil markets, and the ability of Russia or other states to extract concessions from consumers will dissipate.

Second, the Russia-Cuba and China–North Korea cases involve poor countries receiving foreign aid in the form of low-priced oil. We are unaware of any wealthy Western countries receiving such in-kind aid from oil-producing countries.

What if a radical new actor were to emerge on the global stage? For example, if the House of Saud were to fall and the new government consisted of Islamic extremists friendly to Osama bin Laden, the new regime might reduce production and increase prices. But that scenario is by no means certain given that Iran—despite all its anti-Western rhetoric—has not reduced oil output.[7]

Regardless, the departure of Saudi Arabia from world crude oil markets would probably have about the same effect on domestic oil prices as the departure of Iran from world crude oil markets in 1978. The Iranian revolution reduced oil production by 8.9 percent, whereas Saudi Arabia accounts for about 13 percent of global oil production today. Oil prices increased dramatically after the 1978 revolution, but those higher prices set in motion market supply-and-demand responses that undermined the supply reduction and collapsed world oil prices eight years later (Adelman, 1995). The short-term macroeconomic impacts of such a supply disruption would actually be less today than they were then, given the absence of price controls on the U.S. economy and our reduced reliance on oil as an input for each unit of gross domestic product (Dhawan and Jeske, 2006, Walton, 2006, and Fisher and Marshall, 2006).

So while it is possible that a radical oil-producing regime might play a game of chicken with consuming countries, producing countries are very dependent on oil revenue and have fewer degrees of freedom to maneuver than consuming countries. Catastrophic supply disruptions would harm producers more than consumers, which is why disruptions are extremely unlikely. The best insurance against such a low-probability event is to maintain a relatively free economy where wages and prices are left unregulated by government. That would do more to protect the West against an extreme production disruption than anything else in government's policy arsenal.

Oil Profits for Terrorists

Does Western reliance on oil put money in the pocket of Islamic terrorists? To some degree, yes. Does that harm Western security? Probably not—at least, probably not very much.

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[7] While it is true that oil production in Iran was about twice as high under the Shah than it has been under the Islamic Republic, almost all analysts agree that this reflects the damage to the oil infrastructure during the 1980-88 war with Iraq, the "brain drain" that has occurred in response to the revolution, and poor state management of Iranian oil assets—not the intentional result of state policy.

Before we go on, it is worth noting that only 15.5 percent of the oil in the world market is produced from nation-states accused of funding terrorism (Lundberg Survey, 2006). Hence, the vast majority of the dollars we spend on gasoline do not end up on this purported economic conveyer belt to terrorist bank accounts.

Regardless, terrorism is a relatively low-cost endeavor and oil revenues are unnecessary for terrorist activity. That a few hundred thousand dollars paid for the 9/11 attacks suggests that the limiting factors for terrorism are expertise and manpower, not money.

This observation is strengthened by the fact that there is no correlation between oil profits and Islamic terrorism. In Taylor and Van Doren (2007), we estimated two regressions using annual data from 1983 to 2005: the first between fatalities resulting from Islamic terrorist attacks and Saudi oil prices and the second between the number of Islamic terrorist incidents and Saudi oil prices. In neither regression was the estimated coefficient on oil prices at all close to being significantly different from zero.[8]

During the 1990s, inflation-adjusted oil prices and profits were low. But the 1990s also witnessed the worldwide spread of Wahhabi fundamentalism, the buildup of Hezbollah, and the coming of age of al Qaeda. Note too that al Qaeda terrorists in the 1990s relied on help from state sponsors such as Sudan and Afghanistan—nations that are not particularly known for their oil wealth or robust economies.

Producer states do use oil revenues to fund ideological extremism. Saudi financing of madrassas and Iranian financing of Hezbollah are good examples. But given the importance of those undertakings to the Saudi and Iranian governments, it is unlikely that they would cease and desist these activities simply because oil profits were down. They certainly were not deterred by meager oil profits in the 1990s.[9]

The futility of reducing oil consumption as a means of improving national security and energy independence is illustrated by the fact that states accused of funding terrorism earned $290 billion from oil sales in 2006 (Lundberg Survey, 2006). Even if that sum were cut by 90 percent, that would still leave $29 billion at their disposal—more than enough to fund terrorism given the minimal financial needs of terrorists.

Rents to Bad Actors

When oil prices are high, so too are oil profits for inframarginal (low-cost) producers. Even if those profits do not find their way to international terrorists, they prop up many regimes we find distasteful. Oil producers in the Second and Third worlds often use their robust flow of petrodollars to squelch human rights at home and to menace neighbors abroad. Many foreign policy elites argue that oil consumption thus harms our national security by strengthening these bad international actors (Lugar and Woolsey, 1999, and Council on Foreign Relations, 2006).

It is unclear to what extent oil profits are associated with human rights abuses or militaristic activity. Examples abound: Relatively long-lived regimes with terrible human rights records—such as North Korea—have no oil revenues to speak of, and this is the case even within the same socioeconomic region. Denuding Iran and Libya of oil revenues might produce a government that looks a lot like Syria, and denuding Venezuela of oil revenues might produce a government that looks a lot like Cuba. After all, most of the "bad acting" petrostates that foreign policy elites worry about yielded unsavory regimes even when oil revenues were a small fraction of what they are today.

The claim that oil revenues increase the threat posed by such regimes to their neighbors seems reasonable enough, but again, the extent to which this is true is unclear. Pakistan is a relatively poor country with few oil revenues but it has still managed to build a nuclear arsenal and is constantly on the precipice of war with India. Impoverished, oil-poor Egypt and Syria have at various times been

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[8] Unit root tests suggested that fatalities and Saudi oil prices had unit roots but terrorist incidents did not, so the former were first differenced before the regressions. Even after first differencing, autocorrelation existed, so autoregressive terms were added to each regression, which further weakened the insignificant relationships.

[9] Although little is known about funding trends associated with Iranian support for Hezbollah, the Iranian government probably spends no more than $25 to $50 million on Hezbollah a year (Cordesman, 2006). Less is known about Saudi contributions to Islamic extremism (Prados and Blanchard, 2004).

the most aggressive anti-Israeli states in the Middle East. Russia launched its war with Chechnya before oil revenues engorged its treasury.

While I have little doubt that—all other things being equal—a rich bad actor is more dangerous than a poor bad actor, the marginal impact of oil revenues on "bad acting" might well be rather small. That unsavory petrostates have been fully capable of holding on to power, oppressing their people, and menacing their neighbors during a decade associated with the lowest inflation-adjusted oil prices in history (the 1990s) suggests that nothing short of rendering oil nearly valueless will have any real effect on regime behavior.

For the sake of argument, however, let us assume that there is some incremental benefit associated with reducing oil revenues to bad-acting oil producers. Unfortunately, we have only very blunt and imperfect instruments at hand to achieve that end. Policies that might reduce oil consumption would reduce oil demand—and thus, reduce revenues—for *all* oil producers, regardless of whether they are bad actors. Producers in the North Sea, Canada, Mexico, and the United States (which collectively supplied 20.1 million barrels of oil per day in 2006, or 24 percent of the world's crude oil needs that year) would be harmed just as producers in Venezuela, Iran, Russia, and Libya (which collectively supplied 20.3 million barrels per day in 2006) (EIA, 2007).

Given bad acting aplenty in 1998 with the lowest real oil prices in world history, it is unlikely that even the most ambitious policies to reduce oil consumption would have much effect on bad acting. Accordingly, there is good reason to doubt that the foreign policy benefits that might accrue from anti-oil policies would outweigh the very real costs that such policies would impose on both consumers and innocent producers. There are certainly better remedies available to curtail bad behavior abroad.

The Ethanol Remedy

If significant national security externalities *did* exist and were, as a result, significantly affecting gasoline prices, the most direct and efficient remedy would be a tax on oil imports. That would get gasoline prices "right" and lead to optimal motor fuel consumption patterns. Countervailing ethanol subsidies are an extremely inefficient means of remedying the problem given the deadweight losses and inefficiencies associated with most forms of subsidy. They also substitute prospective market judgments regarding appropriate motor fuel consumption with political judgments that are unlikely to prove correct.

Regardless, ethanol production cannot displace significant amounts of gasoline consumption (Akinci et al., 2008). Even if the entire U.S. corn harvest were dedicated to ethanol production, only 3.5 percent of current gasoline consumption would be displaced (Eaves and Eaves, 2007). All available cropland in the United States would have to be dedicated to corn production if all U.S. vehicles were powered by fuel composed of E85 ethanol. By 2036, all rangeland and pastureland would have to be added to that total to maintain adequate production. By 2048, all land outside of urban centers would be required for corn production (Dias de Oliveira, Vaughan, and Rykiel, 2005). Thus, no matter one's opinions about the dangers of oil dependence (foreign or otherwise), corn ethanol cannot displace enough oil to matter.

ENVIRONMENTAL EXTERNALITIES

Many believe that gasoline consumers are being subsidized because they are not required to compensate third parties for the air pollution associated with gasoline consumption. If those environmental externalities were "internalized" via regulation or taxes, gasoline prices would be far higher, gasoline consumption would be consequently lower, and ethanol production would be far greater. Ethanol subsidies are defended as the second-best means of improving market efficiency.

There are three difficulties with this argument. First, it is very unclear how large the externalities are in monetary terms, making it impossible for analysts to know whether interventions to correct those externalities are actually improving or worsening market efficiency. The best available evidence, however, suggests that the air emissions externalities are probably so low that internalizing them via the first-best policy avenue—a pollution tax—would not affect gasoline prices enough to significantly affect the motor fuels market. Second, ethanol's environmental advantages relative to gasoline are greatly overstated. The negative environmental externalities associated with ethanol may well be even greater than those associated with gasoline.[10] Even if they are not, ethanol's environmental advantages are almost certainly not large enough (in monetarized terms) to significantly alter the fuel mix in motor fuels markets. Third, ethanol subsidies are an extremely inefficient means of addressing the environmental externalities of gasoline; far better means of addressing this market failure exist.

Conventional Air Pollutants

It is unclear to what extent there are uninternalized externalities associated with conventional air pollutants from gasoline. A recent review of the peer-reviewed literature suggests that monetized damages from the same might range from \$0.016 to \$0.184 per mile, which translates into \$0.36 to \$4.20 per gallon (Parry, Walls, and Harrington, 2006). A frequently cited "best guess" regarding the cost of the conventional air emissions generated by gasoline consumption is \$0.16 per gallon (Parry and Small, 2005).

The biggest problem with the above exercises—beyond the uncertainty associated with the human health impacts of exposure to small doses of potentially dangerous air contaminants—is that these studies do not consider the extent to which existing regulation imposes costs on gasoline consumption and the extent to which those costs function as a tax. If, for instance, the conventional air emissions externality were \$0.16 per gallon but regulatory policy reduced emissions to where they would have been had a \$0.16 per gallon tax been imposed in a world without regulation, then there would be no externality: The consumer would, in a sense, be paying for the pollution costs associated with gasoline consumption (albeit indirectly). Accordingly, the above calculations provide limited guidance to policymakers seeking to promote optimal gasoline prices (Nye, 2008).

Regardless, ethanol is a poor remedy for whatever externalities may exist in this arena. A review of the academic literature finds that, when evaporative emissions are taken into account, ethanol in fuel blends sold on the market today

- increases emissions of total hydrocarbons, nitrogen oxides, nonmethane organic compounds, and air toxics (particularly acetaldehyde, formaldehyde, ethylene, and methanol) relative to conventional gasoline; but
- decreases emissions of carbon monoxide (Niven, 2005; other studies broadly consistent with Niven's findings include von Blottnitz and Curran, 2007, and U.S. Environmental Protection Agency [EPA], 2007).

We pause here to note that carbon monoxide emissions are only a very modest problem in the United States today. Because few areas of the United States violate federal air quality standards for carbon monoxide, ethanol provides little benefit on that front. The other pollutants at issue, however, worsen urban smog and the concentration of dangerous air toxics—far more serious human health matters.

Ethanol proponents often argue that stronger ethanol blends—like E85—are cleaner. Those contentions are not consistent with the reviews of the literature cited above. Nor are they consistent with a recent study concluding that universal use of E85 would increase ozone-related mortality, hospitalization, and asthma by 9 percent in Los Angeles and 4 percent in the United States as a whole relative to a world in which the auto fleet were powered entirely by conventional gasoline (Jacobsen, 2007).

Air Toxics

The above studies explicitly consider toxic air emissions in their analyses, but a recent paper for

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[10] Although I only examine conventional air and greenhouse gas emissions in this paper—the main environmental advantages that subsidy proponents allege for ethanol—ethanol has a number of other environmental disadvantages relative to gasoline. The main issues include groundwater contamination (Niven, 2005), water resource use and surface water pollution (National Research Council, 2008; Donner and Kucharik, 2008; and Nassauer, Santelmann, and Scavia, 2007), soil erosion (Patzek, 2004), and habitat destruction (Nassauer, Santelmann, and Scavia, 2007, and Dias de Oliveira, Vaughan, and Rykiel, 2005). Whatever advantages ethanol may have with regard to air emissions (which I believe to be, at best, nonexistent) must outweigh the environmental harms it creates.

the Energy Future Coalition (Gray and Varcoe, 2005) argues that the environmental costs of gasoline-related air toxic emissions total approximately $250 *billion* per year. Although their paper has received little attention in academic circles, it has received modest attention in policy circles, so a brief discussion is in order.

Gray and Varcoe (2005) argue that the direct harms from the various toxic emissions from aromatics in gasoline total about $64 billion a year. But those aromatics also contribute to the formation of particulate matter (PM) in the atmosphere, and the harms from PM that can be traced back to aromatic gasoline emissions are said to equal at least $200 billion a year. Gray and Varcoe round the total sum to $250 billion a year (which was equal to about $1.78 a gallon in 2005) and argue that "leveling the playing field" would justify an equivalent subsidy to the ethanol industry.

The $64 billion estimate for the *benefits* associated with reducing aromatic emissions, however, is derived from the *costs* associated with reducing toxic air emissions in the industrial sector. Yet there is little reason to believe that the costs of emission controls equal the benefits from the same. Gray and Varcoe (2005) justify this leap of faith by citing EPA contentions that the benefits from the regulation of industrial air toxic emissions have in the past exceeded the costs of doing so. But even if the EPA is correct, there is no reason to assume that the cost of reducing toxic air emissions from point sources x years ago has relation to the costs (or benefits) of reducing toxic air emissions from automotive tailpipes today.

Gray and Varcoe's (2005) estimate for the costs associated with PM formation that can be traced back to gasoline aromatics likewise emerges from a problematic set of assumptions. They posit that 40 percent of all $PM_{2.5}$ is carbon based and then assume that half of this mass (when adjusted for population exposures) can be attributed to gasoline emissions.[11] The latter claim appears to be incorrect; their own footnote suggests that only 4 to 33 percent of $PM_{2.5}$ can be traced back to tailpipe emissions.

Using the benefit estimates associated with ambient PM concentration reductions from the recently established off-road diesel fuel regulations, Gray and Varcoe (2005) arrive at about $200 billion in benefits. It is unclear, however, how they trace those costs to aromatic tailpipe emissions from the total universe of motor vehicle tailpipe emissions.

Gray and Varcoe (2005), however, well understand the limitations of their analysis: "We emphasize that these are, necessarily, speculative estimates, based on various heuristic assumptions that cannot easily be proven (or refuted, given basic uncertainties)" (p. 52). Normally, claims that cannot be proven or disproven are called "opinions" or, alternatively, "religious beliefs." Let us posit that we should not use either as the basis for public policy.

If Gray and Varcoe (2005) were familiar with the literature on tailpipe emissions, they would not need such analytic contortions. A review of the literature finds that the environmental costs associated with toxic air emissions from gasoline is likely $0.087 to $1.62 billion annually in 1991 dollars, a tiny fraction of the $64 billion estimate laboriously forwarded by Gray and Varcoe (McCubbin and Delucchi, 1996). While it is unclear to what extent harm from $PM_{2.5}$ can be traced back to gasoline aromatics, the published literature suggests that the environmental costs associated with *all* particulate emissions from motor vehicle tailpipes (not just the aromatics targeted by Gray and Varcoe) is $16.7 to $266.4 billion. The authors who reviewed that literature, however, note that "We are uneasy with this result, even as an upper-bound" (McCubbin and Delucchi, 1996, p. 212) because it is heavily weighted by one study in the literature (Pope et al., 2002) and that study is both anomalous and methodologically problematic (Schwartz, 2006). Likewise, a recent study (Hill et al., 2009) examines the emissions of greenhouse gases (GHGs) and $PM_{2.5}$ from gasoline and corn ethanol. It finds that, for each billion gallons of ethanol-equivalent fuel, gasoline emissions cost $469 million and corn ethanol emissions $472 to $952 million.

There is little reason to accept the $250 billion externality estimate by Gray and Varcoe (2005) and to reject the more careful work in the peer-reviewed literature cited above. Even were we to

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[11] $PM_{2.5}$ means particles less than 2.5 micrometers in aerodynamic diameter.

do so, however, it is worth remembering that the toxic air emissions associated with ethanol are even greater than the toxic air emissions associated with conventional gasoline. Hence, even if Gray and Varcoe were correct, it does not justify countervailing subsidies for ethanol.

Greenhouse Gas Emissions

It is difficult to know for certain how ethanol compares with gasoline with regard to GHG emissions because the data required to perform a satisfactory energy life-cycle analysis simply do not exist. Four fundamental problems exist (Delucchi, 2004 and 2006).

First, limited field and facility data are available. Aggregated data are thus required to fill in the holes, and many data points are based on estimates, not observations. Unfortunately, those estimates are frequently only loosely grounded in reality (Liska et al., 2009).

Second, some important disagreements about methodology cannot be easily resolved. For instance, how far back in the production chain should we go in the course of tallying energy inputs? What is the best way to disentangle the energy inputs and GHG outputs associated with ethanol production from the energy inputs and GHG outputs associated with other coproducts (primarily distillers' grains for livestock feed) associated with ethanol production?

Third—and most important—dynamic variables can significantly affect the life-cycle analysis but are generally completely ignored in the literature because they are difficult to model properly. For instance, how and to what extent will the contemplated policy change prices for millions of goods and services (both directly and indirectly), and how will those price changes affect consumption patterns and, thus, GHG emissions?[12] Answering such complex questions requires a rather sophisticated global general equilibrium model, but none have been produced or used in the life-cycle analyses of ethanol that have appeared in the literature.

Fourth, even if done well, the life-cycle models produce findings that are less relevant to policymaking than advertised. For example, what exact policy is being suggested by the life-cycle analysis and is that policy realistic? How does the execution of that policy impact the dynamic economic factors mentioned above? What are the opportunity costs of the contemplated policy? What are emissions at the margin in response to policy-induced change?

Nonetheless, dozens of studies and several computer models exist to partially inform analysis (for instance, Liska et al., 2009; Adler, Del Grosso, and Parton, 2007; Wang, Wu, and Hong, 2007; Groode and Heywood, 2007; Hill et al., 2006; Farrell et al., 2006; Nielsen and Wenzel, 2005; and Patzek, 2004).[13] The best is a recent study from researchers at the University of Nebraska (Liska et al., 2009). That analysis used the most recent data available on individual facility operations and emissions, observed corn yields, nitrogen fertilizer emissions profiles, and coproduct use; all of which prove important because of improved energy efficiencies associated with ethanol production over the past several years. The authors found that the total life-cycle GHG emissions from the most common type of ethanol processing facility in operation today are 48 to 59 percent lower than gasoline, one of the highest savings reported in the literature. Even without subtracting the GHG emissions associated

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[12] "Whatever the exact magnitude of these price effects, they are potentially important enough that they ought to be taken seriously in an evaluation of the impact of transportation policies on climate. There is no way to escape this conclusion. We cannot dismiss the effects because they occur outside of the U.S., or outside of the transportation sector, because in an analysis of global warming, we care about all emissions, everywhere. We cannot dismiss price effects on the grounds that a policy will not really affect price, because in principle even the smallest change has a nonzero probability of leading to a nonzero effect on price. (In any event, if the price effects are really so small, then the policy must be so unimportant or ineffective as to have no affect on climate worth worrying about anyway.) And we certainly cannot argue that all such price effects are likely to be substantially 'similar' for all policies, and hence of no importance in *comparison* of alternatives, because this clearly is not the case" (Delucchi, 2004, p. 10).

[13] I am interested only in those studies that attempt to quantify GHG emissions, not in those studies exclusively concerned with the net energy balance of ethanol. The latter issue is theoretically interesting but it asks a question that is not particularly relevant for policy analysis. Even if ethanol has a negative energy balance (more energy inputs were required to produce ethanol than is yielded by ethanol on combustion), if the energy inputs were relatively abundant but the energy displaced by ethanol were relatively scarce, ethanol could have a net negative energy balance but still prove profitable and efficient. Likewise, if the energy inputs have modest GHG emissions but the energy being displaced by ethanol had significantly larger GHG emissions, a negative energy balance might still translate into a net reduction of GHG emissions.

with ethanol coproducts (which accounted for 19 to 38 percent of total system emissions), ethanol would still present GHG advantages relative to gasoline.

Although the study by Liska et al. (2009) appears to offer the best current analysis on this question, many problems remain, rendering policy analysis problematic. First, the study examines only a subset of corn production operations and ethanol processing facilities: dry-mill ethanol processors fired by natural gas in six Corn Belt states. Together, those facilities accounted for 23 percent of U.S. ethanol production in 2006. This approach makes the study stronger because the authors are not forced to rely as heavily on estimates and aggregated analysis, but the downside is that the study ignores a large number of older, less-efficient ethanol processing facilities and thus cannot be used to assess the GHG balance of the ethanol industry as a whole. While the findings may well point to where the industry will be in the future as older, less-efficient facilities lose market share and are upgraded or retired (Groode and Heywood, 2007), the bankruptcies that are shuttering many newer facilities at present caution against certainty on this point.

Second, estimates regarding emissions are still relied on to some degree, and one of those estimates in particular—the estimate pertaining to the release of nitrous oxide (N_2O) from fertilizer use in corn production—is problematic. Although the study comports with convention in that it relies on emission estimates offered by the Intergovernmental Panel on Climate Change (IPCC, 2006), a recent study (Crutzen et al., 2007) finds that the IPCC estimates pertaining to N_2O release from fertilizer does not comport with the observed data. Crutzen et al. (2007) find that N_2O emissions from fertilizers used in biofuel production are three to five times greater than assumed by the IPCC and that, if we use those higher emissions in the ethanol life-cycle models (as Crutzin et al. did using the openly accessible EBAMM model constructed by Farrell et al., 2006), "the outcome is that the production of commonly used biofuels, such as biodiesel from rapeseed and bioethanol from corn (maize), can contribute as much or more to global warming by N_2O emissions than cooling by fossil fuel savings" (p. 389). Given that the lead author of the study—Paul Crutzen—is a Nobel laureate chemist who has specialized in fields related to atmospheric science, his findings cannot be lightly dismissed.

Third, Liska et al. (2009) acknowledge the importance of the impact of ethanol production on crop prices and, thus, on global land-use patterns, but they do not account for the GHG emissions associated with those changes. Those emissions are substantial, and no life-cycle analysis of ethanol can credibly ignore them.

A worldwide agricultural model constructed by Searchinger et al. (2008) finds that the increases in crop prices that follow the increased demand for ethanol will induce a global change in the pattern of land use. Those land-use changes produce a surge in GHG emissions that is dissipated only by conventional life-cycle emissions savings many decades hence. Although the study modeled ethanol production increases that were beyond those mandated in existing law, "the emissions from land-use change per unit of ethanol would be similar regardless of the ethanol increase analyzed" (p. 1239).

While critics of Searchinger et al. (2008) rightly point out that (i) the agricultural model employed in the study was crude, (ii) much is unknown about the factors that influence global land-use decisions, (iii) improved yields are reducing the amount of land necessary to meet global crop demands, and (iv) any land additions to crop production do not need to come from forests or other robust carbon sequestration sinks (Renewable Fuels Association, 2008), none of those observations is sufficient to reject the basic insight forwarded in Searchinger et al. (2008). If ethanol demand increases corn and other crop prices beyond where they otherwise would have been, profit incentives will induce investors to increase crop production beyond where production would otherwise have been. If that increased production comes in part from land-use changes relative to the baseline, then significant volumes of GHG will likely be released and those emissions will threaten to swamp the GHG savings found elsewhere in the life-cycle analysis. Even if the upward pressure on crop prices as a consequence of ethanol consumption is more than offset by downward price pressures following from other factors, crop acreage retirement will not be as large as might otherwise have been the case and terrestrial sequestration will be lower as a consequence. Every link in that chain of logic is unassailable.

Changing global land use is but one of the many impacts that ethanol might have on hundreds of industrial sectors worldwide. The work of Searchinger et al. (2008) is ultimately unsatisfying because it is only a crude and partial consideration of those impacts, many of which might indirectly affect global land-use patterns. For instance, if ethanol consumption reduces the demand for—and thus the price of—crude oil in global markets, how much of those "booked" reductions in oil consumption will be offset by increased demand induced elsewhere by the lower global crude oil prices that follow (known as a "rebound effect" in economics)? How might that rebound effect influence all sorts of GHG emissions vectors? None of these types of questions are asked in ethanol GHG life-cycle analyses, but they are clearly crucial to the analysis.

To summarize, a narrow, conventional consideration of the GHG emissions associated with ethanol suggests that ethanol reduces climate change harms relative to gasoline. If the IPCC has underestimated N_2O emissions from fertilizer—as appears to be the case—then ethanol probably is *at best* a "wash" with regard to GHG emissions. Even if that is not the case, consideration of secondary and tertiary emissions impacts strongly suggests that most, if not all, advertised GHG gains are lost in the changes in land-use patterns that follow increases in ethanol production relative to the baseline. Other changes in anthropogenic emissions—positive and negative—would almost certainly follow as well, but existing models do not bother to search for them and thus we do not know enough to say much beyond this with confidence.

First versus Second-Best Remedies

If there are in fact uninternalized environmental externalities associated with gasoline consumption, the most direct and efficient remedy is to impose a tax on emissions (or a cap-and-trade program that functions like a tax) to correct prices accordingly. Countervailing ethanol subsidies are a much less-efficient remedy because they create deadweight losses, do not correct gasoline prices or ethanol prices for environmental externalities, and impose a market share for ethanol that might not have arisen in equilibrium.

One might argue that emissions taxes on conventional pollutants in motor fuel markets are impractical and/or unlikely and that ethanol is a necessary second-best alternative. But even if so, tighter regulation of motor fuel emissions is almost certainly more efficient than ethanol subsidies *if* government intervention is warranted. This is particularly true given that ethanol has substantial air emissions of its own. Nondiscriminatory emission regulations that apply regardless of fuel source are a far more defensible intervention.

Price internalization exercises to address GHG emissions, however, are not only conceivable, they are probable in the near term given the current political makeup of Washington and voter sentiment. Once a federal cap-and-trade program is in place, ethanol proponents will lose the argument that gasoline prices are suboptimal because they do not consider the cost of GHG emissions. Of course, one might always argue that the permit prices yielded from such a regime are too low to adequately reflect the damages, but a recent "best guess" about those damages based on the literature suggests that the uninternalized GHG externalities associated with gasoline amount to only about $0.05 per gallon (Parry and Small, 2005).

If the displacement of gasoline with ethanol is in fact among the most cost-effective means of reducing GHG emissions, ethanol producers should be able to prove that fact in a carbon-constrained, cap-and-trade market without government subsidy. But even if we posit the lowest-bound estimate for total ethanol subsidies and divide that figure by the GHG savings reported in Wang, Wu, and Hong (2007; a 19 percent reduction of total life-cycle GHG emissions relative to gasoline), we find that $300 of subsidy is necessary to displace a metric ton of GHG emissions from gasoline. "Based on historical prices for carbon offsets, this same investment could have purchased 90-120 times as much displacement on the CCX [Chicago Climate Exchange], the most appropriate benchmark for the U.S. carbon market. Even on the more expensive ECX [European Climate Exchange], the subsidies could have purchased 11 metric tonnes of offsets" (Koplow, 2007,

p. 35). If we instead use the high end of the GHG savings reported in Liska et al. (2009) those figures could be cut by two-thirds—still yielding costs that could not be sustained if market actors, rather than political actors, were deciding how best to respond to a carbon-constrained world.

THE POLITICAL ECONOMY OF SUBSIDY

Although there has long been a debate about the merits of ethanol subsidies, most parties in the discussion accepted without question the idea that subsidizing ethanol reduces oil consumption. How much, of course, was open to debate. Yet a rigorous examination of the existing subsidies in place by Cornell economists Harry de Gorter and David Just (2007a) finds that one of those subsidies—the blenders' tax credit—actually *subsidizes* gasoline consumption within the context of the current regulatory regime.

The conclusion is counterintuitive but the analysis is sound. The explanation is as follows. By itself, the blenders' tax credit ensures that ethanol is often cheaper than gasoline from the refiners' perspective. Refiners will thus compete to secure that ethanol, which results in the price of ethanol being "bid up" until it is above the market price of gasoline by at least $0.51 per gallon (the size of the tax credit). In a world with the blenders' tax credit at the 2006 level, retail fuel prices are lower by 1.9 percent ($2.32 per gallon rather than $2.36 per gallon). Ethanol production increases from 653 million gallons to 6.67 billion gallons while gasoline production declines from 141.2 billion gallons to 135.7 billion gallons. The credit serves as an ethanol consumption subsidy with most of the benefits going to ethanol producers and the remainder to motorists.

By itself, the Renewable Fuel Standard (which mandates specified levels of ethanol consumption) produces motor fuel costs that are a weighted average of the cost of ethanol and the cost of gasoline. In a world with the consumption mandate at the 2006 level, retail fuel prices are 0.48 percent lower ($2.31 per gallon rather than $2.32 per gallon). Ethanol production increases from 6.67 billion gallons (assuming a nonbinding mandate in the form of the ban on methyl tertiary-butyl ether as a fuel additive) to 10 billion gallons while gasoline production falls from 135.7 billion gallons to 132.5 billion gallons. The mandate, like the credit, serves as an ethanol production subsidy with almost all of the benefits captured by ethanol producers.

When a tax credit is added to a consumption mandate, however, there is no incentive for refiners to bid up the price of ethanol; the mandated demand for ethanol ensures that ethanol (even with the tax credit) is more costly than gasoline. Because competition in the refining sector is relatively intense, refiners cannot capture the full benefit of the tax credit. Instead, it is passed on to consumers. Using the 2006 blenders' tax credit, this produced retail fuel prices 1.42 percent lower than they would have been without the tax credit but with the mandate: $2.31 per gallon rather than $2.34 per gallon. Ethanol production increases a wee bit—from 9.99 billion gallons to 10 billion gallons—but gasoline production *increases* even more—from 132.1 billion gallons to 132.5 billion gallons. The combined policies are, in effect, a direct gasoline consumption subsidy with all of the benefits captured by motorists.

Such analyses highlight the difficulty of accepting claims about the impact of ethanol production on foreign oil imports or GHG emissions without careful consideration of the indirect impact that subsidies have on the market. Unfortunately, this is an exercise rarely performed in the literature pertaining to the advertised benefits of ethanol (and, implicitly, government preferences for the same).

CONCLUSION

Why should taxpayers subsidize ethanol? The most commonly offered rationales—that ethanol reduces harm caused by our reliance on foreign oil and a host of air pollution problems—do not hold up to scrutiny. Foreign oil dependence is not a substantial foreign policy or economic problem, and ethanol offers little remedy for any problems that might exist. Environmental gains are likewise unclear. The balance of the evidence suggests that ethanol worsens conventional air pollution and offers no net reductions in GHG emissions. In fact, there is good reason to believe that GHG emissions might well go up as we displace gasoline in favor of ethanol.

Even if we were to accept the national security and environmental benefits claimed most frequently for ethanol in the literature, in 2012 ethanol subsidies would still cost $3 billion more than the monetized benefits delivered (Hahn, 2008).

Other justifications for subsidy have even less merit. There is little evidence to suggest that "Big Oil" is strangling ethanol for competitive advantage or that ethanol on balance reduces motor fuel prices by any consequential amount. Ethanol subsidies may in some periods reduce net federal subsidies to corn producers, but the deadweight losses associated with ethanol subsidies more than offset this savings to the taxpayer. Finally, they do not "level the playing field." In fact, they distort the playing field and produce inaccurate price signals which, in turn, lead to less economic efficiency and, by force, less overall wealth creation.

Whatever problems exist in motor fuel markets are better remedied by direct interventions to address identified problems. Ethanol subsidies are extremely poor remedies for those alleged problems.

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The Future of Biofuels

Rick Tolman

CORN SUPPLY AND DEMAND

According to the U.S. Department of Agriculture (USDA), U.S. corn growers produced 12.1 billion bushels of corn in 2008, the second-largest crop ever. This harvest reflects the increasing ability of growers to produce higher yields, measured in bushels per acre (bu/acre), due to improvements in agronomic practices and biotechnology that improve the corn seed itself. The 2008 national average yield, 153.9 bu/acre, is the second-largest on record.

As high as this yield is (by comparison, the 1988 yield was only 84.6 bu/acre), many in the corn industry expect it to nearly double well before mid-century. In fact, many growers who take part in the National Corn Growers Association (NCGA) National Corn Yield Contest routinely score yields much higher than the national average.

Since 1994, corn productivity per acre has accelerated as a result of advances in marker-assisted breeding, biotechnology, and improved farming practices. Growers are harvesting considerably more corn without significantly increasing acreage. Based on past performance, average production per acre is projected (following a 15-year trend) to hit 180 bu/acre by 2015. Some seed

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Federal Reserve Bank of St. Louis *Regional Economic Development*, 2009, *5*(1), pp. 97-102.

researchers foresee corn production near 300 bu/acre by 2030.

Modern farm management practices play an important role in increased productivity, along with new and improved production tools, such as global positioning systems, yield mapping, and precision nutrient-application methods. Nationwide, corn growers are harvesting more corn per acre while making great strides in efficient input use. This is resulting in a more sustainable environmental footprint.

Although corn production is expanding, some uses for it are not expanding at the same rate. Other corn demand categories, such as livestock production and exports, have shown limited future growth—meaning that increased corn supplies will result in more corn available for biofuel production. Demand for corn in the livestock and poultry sectors has been relatively flat in the past 10 marketing years. The amount of raw field corn fed to livestock is expected to decline slightly as more corn is displaced by distillers' grains, a co-product of ethanol production. Furthermore, the amount of corn used for human food has been flat, and corn exports have trended up only slightly.

Even as corn use for ethanol has risen dramatically over the past 10 years, American farmers have continued to be the world's top exporter of corn—satisfying the demands of foreign customers. Corn exports have remained steady or expanded slightly and, through exports of distillers' grains, the ethanol sector is helping satisfy foreign demand for high-protein, high-energy livestock feed. The United States exported about 2.4 million metric tons of distillers' grains in 2007.

The Food and Agricultural Policy Research Institute's (FAPRI) *2008 U.S. and World Agriculture Outlook* (Carriquiry et al., 2008) provides projections for agricultural commodity production and disappearance. It considers average weather patterns, existing farm policy, current trade agreements, and customs unions.

FAPRI projects that the nation's corn growers will harvest 15.2 billion bushels in 2015. This is congruent with NCGA's vision of corn growers being able to harvest 15 billion bushels by 2015. FAPRI projects corn volume to produce ethanol to reach 5.2 billion bushels in 2017. This increase will result in 10 billion bushels of corn for all non-ethanol use categories. And this is projected to be accomplished with only a limited increase in planted acres over the 93.6 million acres used in 2007.

The growing demand for ethanol is projected to keep pace with the projected increases in total corn production into 2017. FAPRI projects that most of the historic non-ethanol uses of corn will provide little growth. Given the rising cost of production, absent a market for ethanol the nation's corn producers would once again face marginal profits from high production and insufficient demand.

THE VALUE OF ETHANOL

Ethanol is a significant market for U.S. corn, but its value goes far beyond its role as a major use of corn. Developing this new value-added industry not only creates a new market for our corn producers, it lessens our dependence on foreign oil and helps revitalize rural America.

Ethanol plants are helping rejuvenate rural communities across the country by creating high-paying jobs, boosting local tax revenues, and creating partnership opportunities for local businesses. Rural communities across America face an increasing challenge (brain drain) as they strive to create opportunities for their youth to remain in their local communities. The ethanol industry is the single most important industry created by the agricultural sector in decades allowing rural American communities to continue to remain economically viable.

The demand for corn ethanol production was originally created in response to the oil crisis of the 1970s. After the crisis was resolved, oil prices dropped to a level that challenged the economic viability of biofuels. This situation has now changed, however, as oil prices have moved erratically and the viability of biofuels has strengthened. In conjunction with positive economics, public policy initiatives have helped break oil companies' control of the liquid transportation distribution systems.

Even with the Renewable Fuel Standard passed by the U.S. government and the subsequent rise in the demand for corn, the long-term economic health for corn producers is far from secure. With the production efficiency increases stated above combined with the steady acreage dedicated to corn production, supply will either continue to match demand or problematically outpace demand.

According to the USDA's pricing models based on more than 30 years of data, corn prices over the next 10 to 15 years will reach a new plateau, but farm profitability will remain tight mainly because of increases in input costs driven by the price of oil. Raw material costs for inputs like nitrogen fertilizer are reaching record gains and do not move through the distribution system as quickly as, say, conventional gasoline, while other inputs like diesel fuel are already affecting producers. Thus, the rise in corn prices had a positive impact on corn growers in 2007-08, but the long-term reality in the current environment is that producers will see very tight to negative margins.

Continued strong growth in the ethanol sector will keep corn producers viable, which can keep oil consumption in check while continuing to provide a substantial amount of feed to the livestock industry through distillers' grains. This will be a challenge in the current economic environment, where the subprime mortgage crisis had increased the cost of capital. Farming is a capital-rich proposition and producers now require two to three times more capital just to produce a crop.

Ethanol has revitalized the rural landscape, provided a new market for domestically produced grain, and dented our need for imported oil, but it has not done so irresponsibly. Corn to ethanol is—and will remain—a healthy economic growth tool, not a get-rich-quick scheme for producers, and the ripples from this positive market will reach those beyond the farm gate to benefit anyone who uses energy and eats food.

RESPONDING TO THE MYTHMAKERS

Food versus Fuel

Diverting agriculture crops from the table to the fuel tank has been the focal point of critics stirring the so-called food-versus-fuel controversy. Any discussion of corn ethanol, however, must consider two factors: the shifting nature of our country's crops and the price of corn (specifically, its impact on overall food prices).

Farming acreage has been trending downward during the past few decades. In 1932, when corn reached its highest acreage count, 320.4 million acres of farmland were under cultivation countrywide; in 2007 total acreage under cultivation was an estimated 278.1 million. The development of suburban communities in the second half of the twentieth century was a major contributor to the decrease of both farmland and parkland acreage.

Crop production, however, is an even more significant issue regarding demand for certain crops and how it is met: Corn yield increased more than fivefold between 1932 and 2007. The average yield, represented as bu/acre, grew from 26.5 bu/acre in 1932 to an estimated 151.1 bu/acre in 2007, and experts believe average yield can increase to 180 bu/acre or more over the next decade, as noted above.

As consumers, we all understand the pinch to our pocketbooks when food prices increase. Grocery shoppers and restaurant diners need to understand that the cost of food ingredients in products they buy represents less than one-fifth of the price at checkout. So how much of an impact do rising corn prices have on overall food prices? Food prices are largely determined by costs and profits after commodities leave the farm. On average, only about 19 percent of the price of food can be attributed to ingredients. Marketing and transportation costs comprise a much higher portion of total costs. For example, consider the impact of rising corn prices on a box of corn flakes as outlined in Table 1 and the following significant facts about food production.

About 50 percent of the corn crop is used for animal feed. Corn makes up a relatively large share of the product prices of eggs, pork, and poultry. Beef and dairy products also contain significant costs for corn, but the prices of processed foods are largely determined by the cost of other components:

- International demand for dairy products has outstripped international supply. Moreover, the world demand for dairy products has put U.S. products onto world markets, thereby raising prices.
- Agriculture is playing a large role in the supply of U.S. fuel. Agriculture's involvement will help offset any increase in food

prices, with lower fuel costs and cleaner, less-polluting renewable fuels. Moreover, government payments to farmers will be reduced as a result of higher crop prices, for example, they were $6 billion less in 2007.

- Combining the efficiencies at the farm with increased ethanol yields from grain, an acre of corn can produce more than 400 gallons of ethanol, compared with 320 gallons only 10 years ago. With the implementation of biomass conversion and increased grain yields, the grain ethanol industry is expected to reach 600 gallons of ethanol per acre in the next decade.

Net Energy/Liquid Petroleum Displacement

A key metric for judging the success of alternative fuels is whether the product supplies more energy than is needed to produce it. This may seem like a straightforward calculation, but it has been hotly debated because of different methods of quantifying energy value. Another layer of complexity is that today's accounting for energy inputs versus outputs is no longer satisfactory. One must also look at the quality of that energy in terms of nonrenewable carbon dioxide (CO_2) and CO_2 equivalents generated in fuel production and use. The common terms used for these analyses are "net energy" and "liquid petroleum displacement."

First, a few clarifying points will aid the discussion of ethanol and liquid petroleum displacement. The common metric of British thermal units (BTUs) per gallon is used when measuring the total energy content of a liquid fuel. Analysis of current transportation fuels—mainly conventional gasoline—yields a value of approximately 110,000 BTUs per gallon.

Ethanol, by comparison, yields only 84,000 BTUs per gallon. This fact is interpreted by many to imply that ethanol is a lesser energy product than gasoline. In reality, all this shows is that ethanol has a lower energy density than gasoline. Depending on the engine using the ethanol and ethanol-blended fuels, efficiencies in converting the liquid potential energy into kinetic energy can be almost on par with each other. Today the engines in the North American fleet capable of burning the higher-blend ethanol fuel, E85, are not yet optimized for ethanol. They run more efficiently on conventional fuel. As flexible-fuel vehicle (FFV) adoption increases and ethanol availability becomes more widespread, this performance discrepancy will be addressed.

Understanding the energy density discrepancy between the two fuels is necessary to better understand the second part of this issue, net energy balance. The core of net energy balance is this: How much energy do you get out compared with how much energy you put in? Since the late 1980s, more than 25 studies have examined the energy balance of ethanol. Only six have shown ethanol to have a negative energy balance (more energy used in production than is delivered to the vehicle). The most recent study (Liska et al., 2009) reviewed several different ethanol production examples, and found that eight corn-ethanol scenarios had net energy ratios from 1.29 to 2.23. For the most common biorefinery types, the net energy ratio ranged from 1.50 to 1.79.

Nevertheless, media outlets have consistently cited both sides of this argument in an attempt to be "balanced"—while not informing the public of the discrepancy in study results. It frustrates the ethanol industry that media outlets continue to focus on studies that cite a negative energy balance for ethanol even though these studies are few in number. Beyond the net energy argument, it becomes exceedingly clear that the net CO_2 emissions for biofuels such as ethanol are significantly lower than petrochemicals, which are nonrenewable CO_2 sources in and of themselves.

It does take energy to produce ethanol: Natural gas and electricity are used to power ethanol plants, and fertilizer and diesel engines are needed to grow and harvest corn. Studies repeatedly have shown the energy required to produce ethanol is less than the energy ethanol delivers for personal vehicle use. Moreover, most critics of ethanol on net energy grounds fail to perform similar analyses of petroleum-based gasoline's net energy. In fact, petroleum performs worse than ethanol under this direct comparison. Ethanol's biggest advantage is that it can continue to use less and less fossil energy for production through greater efficiencies, as well

Table 1

The Impact of Rising Corn Prices on a Box of Corn Flakes

	Corn costs				Estimated retail price	
Item	$2/bu = $0.035/lb	$4/bu = $0.07/lb	$6/bu = $0.107/lb	As of April 2008	Increase (%) in the past 17 months	Increase (%) due to corn costs
Corn Flakes cereal, 18-oz box: 12.9 oz of milled corn produces one 18-oz box (USDA)	$0.028	$0.056	$0.086	$3.69	$1.06 (40%)	$0.06 (6%)

as the use of other renewable sources of energy to power ethanol plants.

POLITICAL ISSUES

Two salient political issues will have a tangible impact on the future of ethanol: higher blends and FFVs.

Higher Blends

With the passage of the 2007 energy bill, the Renewable Fuel Standard will require the United States to use 36 billion gallons of biofuels by 2022. With this schedule now law as of January 1, 2009, major infrastructure changes must take place to facilitate implementation of the standard.

Moving to higher blends of ethanol will be critical to the industry. The United States uses roughly 145 billion gallons of gasoline each year. By 2015, ethanol will comprise at least 15 billion gallons, or roughly 10 percent of the fuel market. Because the highest level of ethanol certified for conventional automobiles is currently 10 percent (E10), the industry must move rapidly to secure certification for higher blends (such as E20) for the market to readily absorb the increasing volumes of ethanol available beyond a nationwide 10 percent blend. Otherwise, the ethanol industry will likely hit a "blend wall" at 10 percent.

Flexible-Fuel Vehicles

Currently, most American, Japanese, and European auto manufacturers allow only 10 percent ethanol to be blended into gasoline because of the composition of rubber sealing joints in fuel systems. These joints can become compromised with higher ethanol blends, leading to engine damage. Engine manufactures will void engine warranties if higher blends are used. However, technology now exists to use up to 100 percent ethanol in automobiles—as has been implemented in Brazil for several decades.

In the United States, auto manufacturers produce FFVs that can use E85 (a gasoline blend that is 85 percent ethanol). The incremental cost of building a FFV versus a non-FFV is estimated at approximately $150. Once a conventional vehicle has been manufactured, however, the conversion to flexible-fuel can cost much more.

The reality is that FFV technology is readily available at a low cost and has been implemented in Brazil by the same auto manufacturers that produce cars in the United States. The issue of fuel flexibility is not technological—rather, it is political. The current U.S. fuel infrastructure (which is owned by oil producers and refiners) widely resists energy products not manufactured from within the petroleum system. It also is clear that in the current economic environment, the oil network is well funded to keep allies aligned with its interests.

Because of the political barriers to expanded use of ethanol, the NCGA supports the open fuel standard. Enabling biofuels to break the current oil monopoly may require even more than that effort. It may, for example, require "legislation requiring all major oil companies to convert pumps for E85 at 50 percent of their owned or branded stations" (Sandalow, 2007, p. 93) or "legislation prohibiting franchise agreements that limit pumps for biofuels at service stations" (p. 94)—as Brookings Institution energy and environment scholar David Sandalow recommends in his important book, *Freedom from Oil*.

Biofuels are already ready to play an important role in freeing us from our dependence on foreign oil, and the relevant technologies are only going to improve. But political action is clearly needed to allow them to reach their potential.

CONCLUSION

Ethanol sourced from corn has become the primary and most successful biofuel to date. As such, it has generated the most focus, criticism, and scrutiny. It is important to realize that corn ethanol is still a formative and nascent industry that is undergoing rapid transformation and technological change.

Critics tend to focus on old metrics and unequal comparisons. The future of ethanol sourced from cellulosics[1] is bright and necessary, but it is theoretical at this point. Cellulosics will evolve from the success of corn ethanol, not as a revolution displacing it. Cellulosic ethanol will not occur without the technological advances developed in current plants that are producing corn ethanol.

The biofuels market is broad and wide, requiring both corn ethanol and sugar-based ethanol as well as other sources of cellulosics. Sources are complementary and should not be cast as competitors, particularly in an unequal fashion.

The future for corn ethanol in the United States is bright. The trends in the cost of production, productivity, and sustainability are all moving in a positive direction. Corn ethanol is the bridge to second- and third-generation biofuels, but it will continue to play a key role for the foreseeable future as we develop alternative sources to petrochemical feedstocks.

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[1] Cellusosic ethanol is produced from a wide range of biomass, such as agricultural plan waste (e.g., corn stover—the leaves and stalks of corn plants left in the field after harvest) or “energy crops” (e.g., switchgrass).

Long-Term Sustainability in the U.S. Corn Ethanol Industry: Some Key Determinants

Nicholas Kalaitzandonakes, James Kaufman, Wyatt Thompson, and Seth Meyer

The U.S. ethanol industry has changed dramatically in the past five years. Driven by the need for national energy independence, concerns over air quality, and an interest in rural development, a number of government policies were introduced within the span of a few years and had significant impact. The 2004 ethanol tax credits, the Energy Policy Act of 2005, the 2006 ban of methyl tertiary-butyl ether (MTBE), and later the Energy Independence and Security Act of 2007 all significantly expanded the opportunity for ethanol use in the United States.

A positive macroeconomic environment also played a role. Robust global economic expansion led to strong and sustained growth in the demand for oil and gasoline for the better part of this decade. Gasoline prices grew steadily in the United States from 2002 on and along with them ethanol prices. The fast-expanding market for ethanol and strong prices led to large investments in new productive capacity. From the beginning of 2002 to the end of 2008, the ethanol industry grew from 61 plants with a combined capacity of 2.3 billion gallons per year to 170 plants with 12 billion gallons of capacity (Renewable Fuels Association [RFA], 2009a).

The decline of gasoline and ethanol prices from their meteoric rise in the summer of 2008 and the softening demand for fuels amid the worst recession in decades have raised concerns about overcapacity and the long-term sustainability of the ethanol industry. Government policies and macroeconomic conditions will continue to influence the future profitability of the corn ethanol industry in the United States, but so will the strategies that firms pursue in the coming years.

This article examines the recent cyclical movements in the revenues and capital outlays of the U.S. corn ethanol industry and evaluates their likely trends and impacts on the industry's sustainability. It also examines the potential contribution of factors under the control of ethanol firms: the pursuit of efficiencies and technical innovation.

DRIVERS OF PROFITABILITY IN THE ETHANOL INDUSTRY

Industry sustainability starts the drive for profitability at the ethanol plant. For any dry grind ethanol plant, the bulk of the revenues comes from two products: ethanol (85 percent) and coproduct dried distillers' grains with solubles (DDGS; 15 percent). Similarly, a single input—corn—accounts for 65 percent of a plant's variable costs (Hofstrand, 2008). Because DDGS are used as feed for livestock, they can substitute for corn in animal rations. For this reason, corn and DDGS prices tend to move together. This correlation simplifies the calculation of plant profitability.

Plant managers and analysts alike can approximate plant profitability with the simple calculation shown in Table 1. For example, if corn were $3.25 per bushel and ethanol $1.80 per gallon, then a dry mill's return over operating costs would be $0.35 per gallon. A combination of corn at $3.25 and ethanol at $1.60 would cut the per gallon return by more than half, to $0.15. Assuming that the average payment to capital invested is equal to $0.20 per gallon, this net return would not attract investment. Corn at $3.25 and ethanol at $1.40 or less would result in outright losses per gallon of ethanol produced, likely leading to plant closures if such prices and losses persisted.

A higher ethanol price or lower corn price would tend to increase profitability. In 2006, for instance, when ethanol was around $2.50 per gallon

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Federal Reserve Bank of St. Louis *Regional Economic Development*, 2009, *5*(1), pp. 103-115.

Table 1

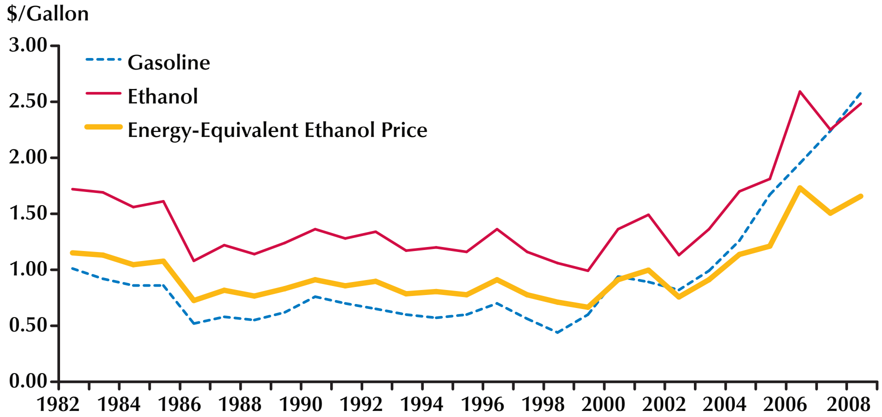
Dry Mill Ethanol Plant Returns Over Operating Costs, 2008-09

Corn ($/bushel)	2.00	2.25	2.50	2.75	3.00	3.25	3.50	3.75	4.00	4.25	4.50	4.75	5.00	5.25
DDGS ($/ton)	73.54	81.83	90.12	98.41	106.69	114.98	123.27	131.56	139.85	148.13	156.42	164.71	173.00	181.28
Ethanol($/gallon)						Net returns over operating costs								
1.25	**0.13**	**0.06**	0.00	–0.07	–0.13	–0.20	–0.26	–0.33	–0.39	–0.46	–0.52	–0.59	–0.66	–0.72
1.30	**0.18**	**0.11**	**0.05**	–0.02	–0.08	–0.15	–0.21	–0.28	–0.34	–0.41	–0.47	–0.54	–0.61	–0.67
1.35	**0.23**	**0.16**	**0.10**	**0.03**	–0.03	–0.10	–0.16	–0.23	–0.29	–0.36	–0.42	–0.49	–0.56	–0.62
1.40	0.28	**0.21**	**0.15**	**0.08**	**0.02**	–0.05	–0.11	–0.18	–0.24	–0.31	–0.37	–0.44	–0.51	–0.57
1.45	0.33	0.26	**0.20**	**0.13**	**0.07**	**0.00**	–0.06	–0.13	–0.19	–0.26	–0.32	–0.39	–0.46	–0.52
1.50	0.38	0.31	**0.25**	**0.18**	**0.12**	**0.05**	–0.01	–0.08	–0.14	–0.21	–0.27	–0.34	–0.41	–0.47
1.55	0.43	0.36	0.30	**0.23**	**0.17**	**0.10**	**0.04**	–0.03	–0.09	–0.16	–0.22	–0.29	–0.36	–0.42
1.60	0.48	0.41	0.35	0.28	**0.22**	**0.15**	**0.09**	**0.02**	–0.04	–0.11	–0.17	–0.24	–0.31	–0.37
1.65	0.53	0.46	0.40	0.33	0.27	**0.20**	**0.14**	**0.07**	**0.01**	–0.06	–0.12	–0.19	–0.26	–0.32
1.70	0.58	0.51	0.45	0.38	0.32	0.25	**0.19**	**0.12**	**0.06**	–0.01	–0.07	–0.14	–0.21	–0.27
1.75	0.63	0.56	0.50	0.43	0.37	0.30	**0.24**	**0.17**	**0.11**	**0.04**	–0.02	–0.09	–0.16	–0.22
1.80	0.68	0.61	0.55	0.48	0.42	0.35	0.29	**0.22**	**0.16**	**0.09**	**0.03**	–0.04	–0.11	–0.17
1.85	0.73	0.66	0.60	0.53	0.47	0.40	0.34	0.27	**0.21**	**0.14**	**0.08**	**0.01**	–0.06	–0.12
1.90	0.78	0.71	0.65	0.58	0.52	0.45	0.39	0.32	0.26	**0.19**	**0.13**	**0.06**	–0.01	–0.07
1.95	0.83	0.76	0.70	0.63	0.57	0.50	0.44	0.37	0.31	**0.24**	**0.18**	**0.11**	**0.04**	–0.02
2.00	0.88	0.81	0.75	0.68	0.62	0.55	0.49	0.42	0.36	0.29	**0.23**	**0.16**	**0.09**	**0.03**
2.05	0.93	0.86	0.80	0.73	0.67	0.60	0.54	0.47	0.41	0.34	0.28	**0.21**	**0.14**	**0.08**
2.10	0.98	0.91	0.85	0.78	0.72	0.65	0.59	0.52	0.46	0.39	0.33	0.26	**0.19**	**0.13**
2.15	1.03	0.96	0.90	0.83	0.77	0.70	0.64	0.57	0.51	0.44	0.38	0.31	**0.24**	**0.18**
2.20	1.08	1.01	0.95	0.88	0.82	0.75	0.69	0.62	0.56	0.49	0.43	0.36	0.29	**0.23**
2.25	1.13	1.06	1.00	0.93	0.87	0.80	0.74	0.67	0.61	0.54	0.48	0.41	0.34	0.28
2.30	1.18	1.11	1.05	0.98	0.92	0.85	0.79	0.72	0.66	0.59	0.53	0.46	0.39	0.33
2.35	1.23	1.16	1.10	1.03	0.97	0.90	0.84	0.77	0.71	0.64	0.58	0.51	0.44	0.38
2.40	1.28	1.21	1.15	1.08	1.02	0.95	0.89	0.82	0.76	0.69	0.63	0.56	0.49	0.43
2.45	1.33	1.26	1.20	1.13	1.07	1.00	0.94	0.87	0.81	0.74	0.68	0.61	0.54	0.48
2.50	1.38	1.31	1.25	1.18	1.12	1.05	0.99	0.92	0.86	0.79	0.73	0.66	0.59	0.53

NOTE: The table shows net returns over variable operating costs for various combinations of ethanol and corn prices. To calculate plant profits, capital and other fixed costs would also need to be subtracted from these figures. In the area above the bold type, negative numbers indicate the average plant is not able to cover operating costs. In the area with bold type, net returns over operating costs are less than $0.25 per gallon, which may be less than required to cover fixed costs. In the area below the bold type, net returns over operating costs are more than $0.25 per gallon, thus likely exceed fixed costs. The matrix assumes DDGS prices change as a function of corn prices. Other operating costs (fuel, electricity, labor, etc.) are included in the calculations. The matrix assumes a constant DDGS yield of 17 pounds per bushel of corn converted to ethanol and a linear relationship between DDGS and corn prices.

Figure 1

Ethanol and Gasoline Prices



NOTE: Prices are Omaha prices to fuel blenders; the energy-equivalent ethanol price is two-thirds the price of gasoline. Prices are not adjusted for the ethanol tax credit.

SOURCE: Nebraska state government (www.neo.ne.gov/statshtml/66.html), with 2008 preliminary data from the Food and Agriculture Policy Research Institute (FAPRI) at the University of Missouri–Columbia (MU).

and corn around $3.00 per bushel, average returns over operating costs for a dry mill were $1.12 per gallon—a rather hefty return to capital.

These calculations of operational profitability illustrate a simple reality in the corn ethanol industry: Understanding the long-term sustainability of ethanol requires knowledge of the factors that shape the price of ethanol and its relationship to the price of corn. Recent history provides some guidance.

The Price of Ethanol and the Factors That Shape It

The ethanol market evolved quickly over only a few years, often clouding the exact relationship between ethanol prices and the market forces that shape them. Historically, ethanol has been more expensive than gasoline on a per-gallon basis (Figure 1). However, an energy-equivalent price reflecting ethanol's energy content offers a better comparison of value.[1] The energy-equivalent price of ethanol was also higher than the price of gasoline during the 1980s and 1990s. Ethanol and gasoline burn differently and as a result ethanol-blended fuel improves the performance of some cars. Accordingly, consumer demand for ethanol as a fuel supplement resulted in price premiums over the 1980-2000 period (Tyner, 2007).

As ethanol production capacity rose from less than one billion gallons in the mid-1990s to almost double that by 2000, ethanol price premiums eroded, suggesting the fuel-supplement market segment was more than saturated (see Figure 1). As ethanol supplies mounted, with production and imports growing to about four billion gallons by 2005 (Figure 2), the energy-equivalent price of ethanol began to lag gasoline prices. The price of ethanol, however, did not fall during the early part of the decade. Rather, it rose by more than 80 percent between 1999 and 2005—but it did not keep pace with the price of gasoline, which nearly tripled over the same period.

Then in 2006, regulatory changes led fuel blenders to discontinue the use of MTBE in some markets and replace it with ethanol (Westhoff et al., 2007). Previously, MTBE had been required as a

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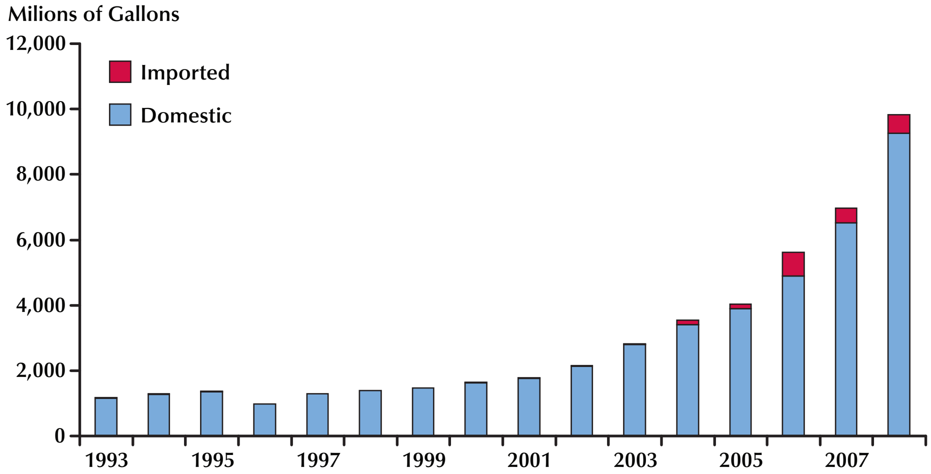
[1] Ethanol is not exactly the same as gasoline. One difference is energy content. A gallon of ethanol has about two-thirds the amount of energy as a gallon of gasoline, which implies that ethanol usually propels a car only two-thirds of the distance of an equivalent volume of gasoline.

Figure 2

U.S. Domestic and Imported Ethanol



SOURCE: Data for 1993-2007 are from the Department of Energy (DOE), Energy Information Association (EIA); tonto.eia.doe.gov/dnav/pet/pet_pnp_oxy_dc_nus_mbbl_m.htm). Data for 2008 are from FAPRI-MU baseline projections.

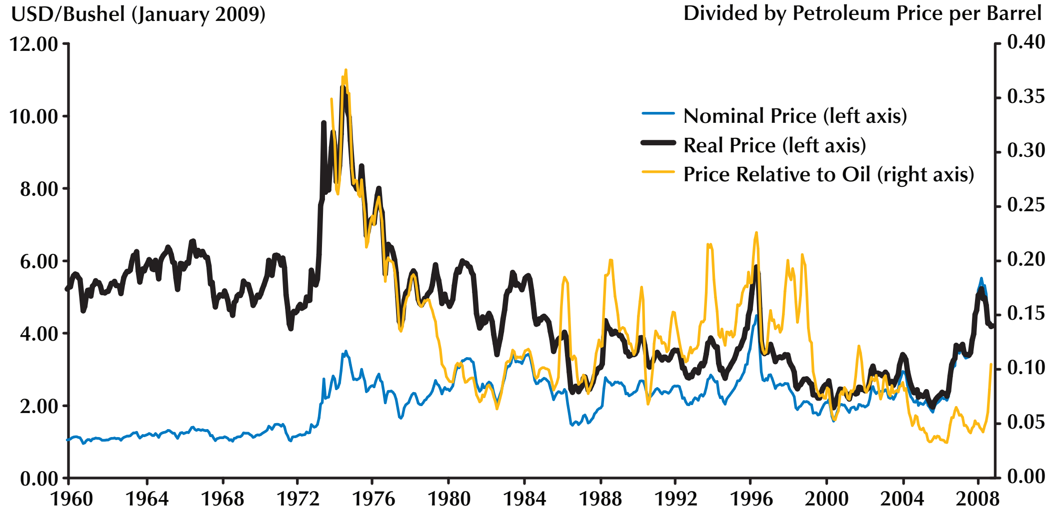
fuel additive to reduce certain pollutants emitted by gasoline. Its use was concentrated in urban areas and periods when air pollution levels were high. MTBE replacement led to a sudden expansion in the demand for ethanol that pushed the limits of domestic production capacity. Ethanol prices spiked in 2006 as blenders outbid one another for ethanol to use as an additive (see Figure 1). Increased profitability in 2006 helped spur increases in production. Additive use was met and quickly exceeded, so the premiums associated with additive use once again eroded, and analysts do not expect them to return (de Gorter and Just, 2007; and Thompson, Meyer, and Westhoff, 2008). The energy-equivalent price of ethanol has since continued to lag the price of gasoline as an increasing amount of ethanol-blended fuel has been purchased simply as a substitute for gasoline.

A number of federal and state policies have facilitated the expansion of corn ethanol from the supplement, to the additive, and, more recently, the fuel replacement market segment. Significant policies include tax credits for fuel blenders ($0.45 per gallon of ethanol used), an import tariff ($0.54 per gallon of imported ethanol), and, more recently, via the Renewable Fuel Standard (RFS) legislation, a mandated volume of renewable fuel that must be blended with gasoline (10.5 billion gallons of corn ethanol for 2009). Both the tax credits and the RFS mandate have expanded the demand for corn ethanol, and the import tariff has maintained ethanol prices at slightly higher levels.

Because of such structural shifts in the demand and supply of ethanol, the exact ethanol price mechanism remains somewhat uncertain. For instance, analysts disagree about how ethanol in E10 (fuel that is 10 percent ethanol by volume) is effectively priced. It could be reasonable to assume that the price of ethanol is determined by the price of E10 relative to the price of gasoline and the energy content of E10 relative to that of gasoline. However, two points may indicate otherwise. First, in areas where air-quality regulations require that local fuels contain an additive, consumers have no choice but to buy fuel with ethanol. Second, consumers might not realize the lower energy content of E10 because it is still 90 percent gasoline, so the negative effect on miles per gallon may be 3 percent or so. If this reasoning holds, then ethanol is priced according to the volume of gasoline it displaces (Tyner, 2007).

Figure 3

Corn Prices in Nominal and Real Terms and Relative to Petroleum Prices



SOURCE: Average corn prices are from the USDA Economic Research Service; www.ers.usda.gov/data/feedgrains/FeedGrainsQueriable.aspx. Petroleum prices are from the DOE EIA; tonto.eia.doe.gov/merquery/mer_data.asp?table=T09.01. The producer price index for finished goods is from the Federal Reserve Bank of St. Louis; research.stlouisfed.org/fred2/series/PPIFGS/downloaddata?cid=31.

The opposing view addresses both these points. First, the ethanol market has expanded well beyond the additive segment and the price of ethanol must be low enough to induce demand in markets where ethanol-blended fuels must compete with gasoline. Second, because enough buyers are both informed and discriminating, the price of E10 at retail should be lower than the price of gasoline. This opposing view, then, suggests that the price of ethanol is increasingly set according to its energy content (de Gorter and Just, 2007; and Thompson, Meyer, and Westhoff, 2008).

Looking ahead and barring major changes in the current policy environment, further expansion in ethanol use beyond the E10 market is likely to occur only by increasing sales of E85.[2] This fuel, which has as much as 85 percent ethanol, causes a clear reduction in mileage, so it is likely to sell in large volumes only if competitively priced on an energy-equivalent basis with gasoline. Regardless of their position on E10, analysts tend to agree that a large expansion of the E85 market would drive the price of ethanol to compete with the price of gasoline on an energy-equivalent basis (Tyner, 2007; and Thompson, Meyer, and Westhoff, 2008).

The Relationship of Ethanol and Corn Prices

The price of ethanol is an important determinant for the long-term profitability of the U.S. corn ethanol industry, and its relationship to the price of corn is as essential. For the most part, manufacturing industries that add value to agricultural commodities price their products based on processing and marketing margins, which are added to the price of the commodity feedstock. Accordingly, their revenues and costs are closely linked. In the case of ethanol production, such a link does not exist because the bulk of revenue is determined in the petroleum (gasoline) market, while most of its cost is determined in the corn market—two markets that have historically exhibited little association (Figure 3). Wide fluctuations in corn and petroleum

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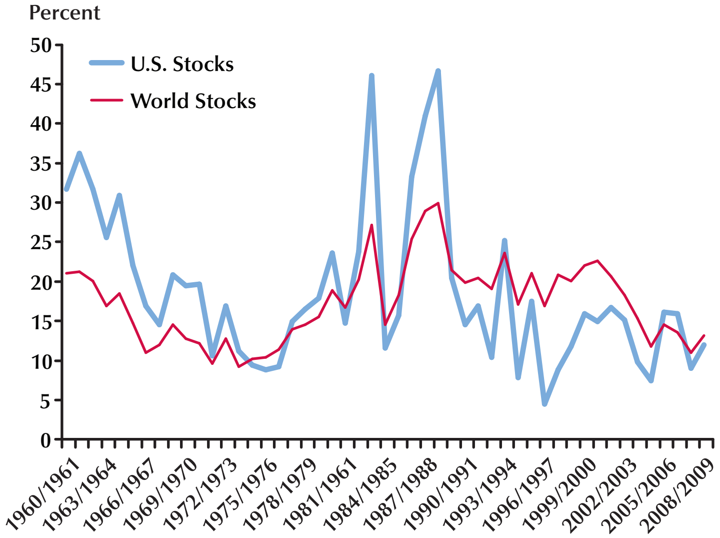
[2] It is estimated that the current E10 market could be saturated by approximately 15 billion gallons of ethanol a year.

Figure 4

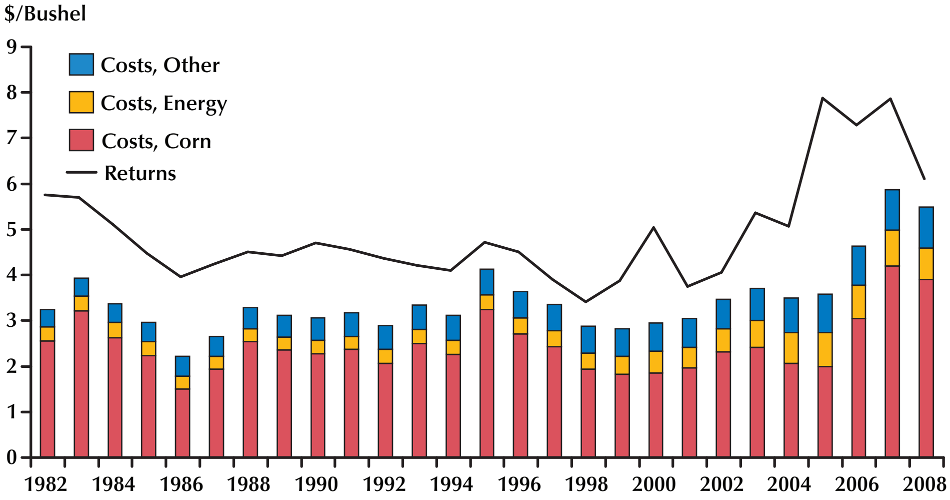
Corn Stocks-to-Use Ratio



SOURCE: USDA Foreign Agricultural Service *Production, Supply, and Distribution* database.

Figure 5

Ethanol Dry Mill Costs and Returns per Bushel of Corn Processed



NOTE: Returns include the value of ethanol and DDGS sold per bushel of corn.

SOURCE: Authors' calculations using various sources, including Nebraska state government ethanol plant price and USDA cost data.

prices in recent months have put this lack of association in sharp focus.

Petroleum price variability is not new, but it may have been largely forgotten when the cost of a barrel was $20 or less in the early part of this decade. The runup to over $140 per barrel in 2008 ended any complacency. And the subsequent drop to $40 per barrel shocked perhaps the ethanol industry as much as anyone because ethanol prices quickly followed suit.

Price swings in the corn market are similarly not new (see Figure 3). Both demand and supply factors influence corn prices over time. Changes in the demand for corn are generally incremental and anticipated; however, shifts in the supply due to weather, pest infestations, and other shocks are more abrupt and can have significant short-term effects on corn prices. Demand and supply factors and even speculators have been viewed as key drivers of the recent volatility in corn markets (e.g., Sanders, Erwin, and Merrin, 2008; and Trostle, 2008). Moreover, the current environment of low buffer stocks might also be playing a role because demand and supply shocks are magnified under such conditions (Figure 4).

If the prices of petroleum and corn moved in concert, their variability would have limited effects on the ethanol industry. Yet, historical movements in corn and petroleum prices have been largely unrelated (see Figure 3), leaving revenues and costs in ethanol production unlinked and causing large swings in the profitability of ethanol plants (Figure 5). The magnitude of this problem is not easily overstated. When the price of corn relative to the price of petroleum has increased, ethanol profitability has suffered. Further, this inverse relationship has become progressively stronger as ethanol has progressed from a supplement to an additive to a fuel replacement. As price premiums for the more inelastic supplement and additive segments eroded and corn prices increased relative to gasoline, profitability declined more abruptly (e.g., first in the early 1990s and more recently in 2008; see Figures 3 and 5).

The inverse relationship of corn and petroleum prices suggests that sustained high petroleum (ethanol) and low corn prices could yield windfall profits for the ethanol industry. At the same time, any random sustained confluence of high corn prices and low petroleum (ethanol) prices could be quite damaging to the U.S. corn ethanol industry. Hedging could guard against some undesirable corn-to-ethanol (or petroleum) price spreads, albeit at some cost. Nevertheless, such strategies can provide only short-term relief because futures contracts for certain commodities (e.g., corn and ethanol) may not extend long enough to cover the sustained trends in relative corn/petroleum prices that have been observed in the past (see Figure 3); and if they did, they could be quite costly.[3]

Probably the most significant "hedge" against the possibility of unprofitably high relative corn prices is currently provided by the renewable fuels mandates. They indirectly link ethanol and corn prices because blenders must use the required corn ethanol irrespective of price.[4] However, such a hedge is generally most effective when the mandate is greater than the productive capacity of the industry. Because the productive capacity of the U.S. corn ethanol industry has exceeded the mandated limits up to now, the level of protection afforded by the RFS remains uncertain.

THE PURSUIT OF EFFICIENCIES

As the U.S. corn ethanol industry has grown to its current capacity and increasingly competes with gasoline as a replacement fuel, the pursuit of efficiency and cost effectiveness has become central to its success and long-term sustainability. The potential for efficiency gains can be evaluated only through a careful assessment of the current state of the industry and of the areas where gains

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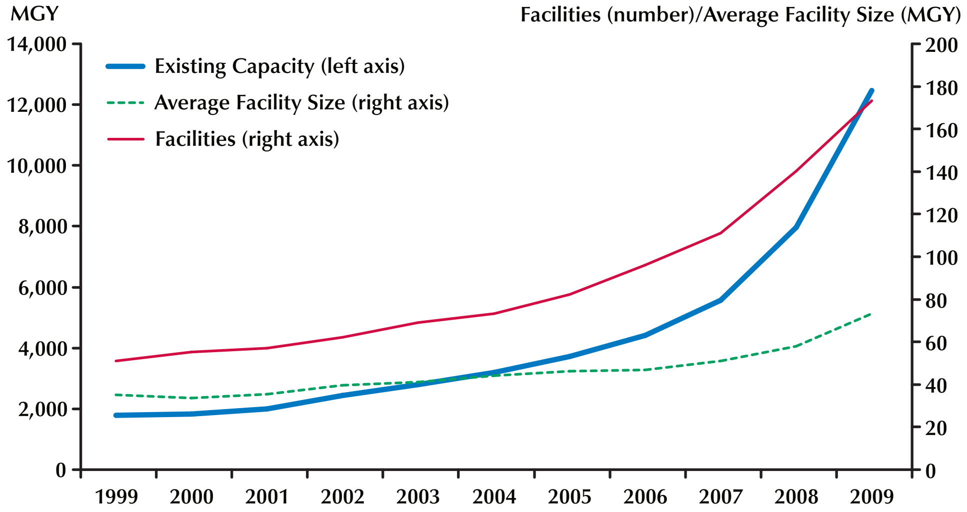
[3] There are also some natural hedges in ethanol production that reduce the industry's risk exposure and are worth noting. DDGS and corn are substitutes and as such their prices are closely correlated. Another natural hedge, albeit a less pronounced one, is the link between petroleum and ethanol prices, which helps to drive ethanol prices, and the cost of natural gas and other fuels that fire ethanol plants. While such prices tend to move together, the correlation between petroleum and natural gas prices is not very strong, particularly for short-term shocks.

[4] Several factors may diminish the effective hedge provided by the RFS against high relative corn prices in any given year. First, fuel blenders can use renewable identification number credits from previous years to meet up to 20 percent of the mandated quantities in subsequent years and may be permitted briefly to fall short. Second, the legislation allows mandates to be waived if broad conditions are met.

Figure 6

Industry Growth and Average Firm Size in the U.S. Corn Ethanol Industry



SOURCE: RFA, "Industry Statistics"; www.ethanolrfa.org/industry.statistics/.

might be possible. Nevertheless, some initial useful observations can be made.

With the swift growth of the U.S. ethanol industry in the past decade, the average ethanol plant size grew rapidly. Facilities built just 10 years ago were comparatively small in size: The average facility produced just over 30 million gallons per year (MGY). A few large ethanol facilities, mostly wet mills, pushed the average firm size upward. The average facility size gradually increased until the mid-2000s and then dramatically accelerated (Figure 6). By early 2009, the average facility produced 72 MGY (RFA, 2009b), with at least 37 facilities topping 100 MGY (*Ethanol Producer Magazine*, 2009).

These newer and larger facilities were built to take advantage of scale economies. Capital costs per gallon of capacity for a 100 MGY facility are 20 percent lower than those for a 50 MGY facility (Eidman, 2007). Larger facilities also have lower operating costs. When corn was priced at $4 per bushel, a 100 MGY facility had 3.5 percent lower variable costs than a plant half that size—with the variable cost savings increasing as corn prices decreased (Eidman, 2007).

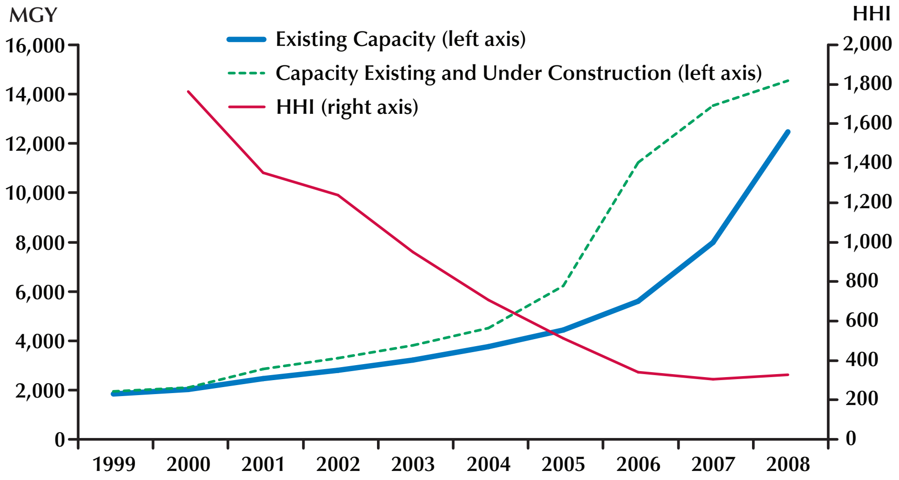
The continued entry of new ethanol firms during this period of fast growth also produced a dispersed and increasingly competitive industry, as evidenced by a fast declining Herfindahl-Hirschman Index (HHI; Figure 7). Much of the pre-2000 ethanol production capacity was at large wet mills owned by major agribusinesses. In this environment, the industry was relatively concentrated, with an HHI above 1,800 (U.S. Federal Trade Commission, 2008). As new dry mills were built, the HHI fell rapidly, ultimately bottoming out in 2007 at 292—indicating minimal levels of industry concentration and disperse ownership of assets.

Not all ethanol firms have responded well to the recent economic downturn. Many have experienced financial problems from eroding and even negative margins and several have filed for bankruptcy, including a few large firms such as VeraSun (filed in October 2008), Renew Energy (filed in January 2009), and Panda Ethanol (filed in January 2009). As a result, by the end of 2008 roughly 1.8 billion gallons, or 16 percent, of total U.S. ethanol production capacity had been idled (RFA, 2009a).

The need to improve the performance of existing capital assets under the pressure of overcapacity,

Figure 7

Entry and Industry Concentration in the U.S. Corn Ethanol Industry, 1999-2008



SOURCE: Authors' calculations and the U.S. Federal Trade Commission (2008).

uncertain demand, and weak processing margins has fomented an environment ripe for industry restructuring and consolidation that will ration existing assets and capitalize on scale and scope economies. Given the low level of industry concentration and the dispersed location and ownership of capital assets, the potential efficiency gains are large. Sources of such scale and scope economies include (i) superior management and other human capital; (ii) improved sourcing of inputs (e.g., yeast, chemicals, and credit); (iii) centralized grain origination; (iv) advanced supply-chain management through multiple plant locations; (v) improved ability to market and price ethanol; (vi) enhanced potential for development and commercialization of coproduct value streams; (vii) centralized and more sophisticated hedging of inputs, outputs, and spreads; and (viii) increased capacity to manage research and development and regulatory compliance.

Each of these factors can improve the operational effectiveness and profitability of ethanol firms. For instance, optimal plant size and location must account for distance to urban markets where most ethanol is consumed and rural locations where corn is sourced and DGGS are used. Consolidation of multiple plants in selected locations under common ownership could therefore yield sizeable economic gains through improved market access and supply-chain optimization. Similarly, larger firms are generally better positioned to fund and perform research and development, which involves large up-front fixed costs. Already, many of the larger U.S. ethanol firms have active research programs, some cofunded by the U.S. government, to develop and implement new technologies such as cellulosics (which uses the non-starch, typically fibrous, structural parts of plants to make ethanol) and fractionation (a process that removes nonfermentable components from fermentable ones). Consolidation into larger firms could therefore accelerate innovation, improve efficiency, and make the industry more competitive.

Industry consolidation has already started, but at a slow pace. As tight credit markets continue in the wake of the recent economic crisis, financing for mergers and acquisitions remains constricted. As credit markets begin to thaw, consolidation in the industry could accelerate. The restructuring of the corn ethanol industry could therefore occur quite quickly. Efficiency gains from restructuring and consolidation, however, would likely be more gradual and ongoing and therefore take longer to contribute to the competitiveness and sustainability of the industry.

THE IMPACT OF INNOVATION

Another key source of sustained productivity gains in the corn ethanol industry is technical innovation. Some of the innovations have been developed by the ethanol industry while others by allied industries. Indeed, corn has been an attractive ethanol feedstock due, in large part, to an advanced and efficient system of breeding, production, and handling. Between 1980 and 2008, the average U.S. corn yield rose from 104 bushels per acre to 153 bushels per acre (United States Department of Agriculture [USDA], 2008a). Over the same period, processing improvements at ethanol facilities produced steady efficiency gains, raising ethanol yields from 2.5 gallons a bushel in 1980 to 2.8 gallons a bushel in 2007 (Wu, 2008). These two improvements alone increased the amount of ethanol derived from an acre of corn by 62 percent.

The pipeline of future technical innovations that could improve the cost competitiveness of corn ethanol production is even more promising. Historically, farm-level improvements have come from improved hybrids, precision agriculture, improved machinery, integrated pest management, reduced tillage, and other innovations. One recent addition is biotechnology, which has already demonstrated its ability to lower production costs, increase yields, and reduce the environmental footprint of corn production (Fernandez-Cornejo and Caswell, 2006; and Kalaitzandonakes, 2003). Because of such advances, in 2008 four of five corn acres in the United States were planted with biotech hybrids (USDA, 2008b). Continuing research and development promises a burgeoning pipeline of novel corn traits. While the pipeline builds on the efficacy of first-generation offerings such as insect and herbicide resistance, it also promises new traits such as drought resistance, increased nitrogen utilization, and improved yields. Ultimately these technologies promise to accelerate the growth in corn yields and productivity.

Innovative technologies that offer significant productivity gains are also expected at ethanol facilities and include the following:

- **Corn Oil Extraction.** With this technology, a conventional dry mill will be able to remove corn oil after the ethanol distillation process. This will not only produce a second coproduct and revenue stream but also decrease the costs associated with drying DDGS.
- **Raw Starch Hydrolysis.** With this technology, increased/improved enzymes eliminate the need for liquefaction and saccharification; biotechnology facilitates the hydrolysis process through corn engineered to produce amylase enzymes in the seed. High-amylase corn eliminates the need for additional enzymes in raw starch hydrolysis.
- **Dry Mill Corn Fractionation.** This technology separates the starch from nonfermentable portions of the corn. High-starch slurry allows for increased ethanol yield and capacity utilization. Corn oil and fiber can also be separated with this technology.
- **Corn Kernel Fiber to Ethanol.** In combination with fractionation this technology could convert fiber to ethanol, further increasing the ethanol yield.
- **Highly Fermentable Corn.** This biotechnology produces corn hybrids with improved fermentation characteristics that allow ethanol to be produced more efficiently. Existing highly fermentable corn hybrids derived from traditional breeding have, on average, a 5 percent higher starch content, which can result in a 2.7 percent increase in ethanol yield (Haefel et al., 2004).

The potential effects of these and other technologies on the efficiency and profitability of ethanol production is sizeable.

We now measure the potential effects of new biotech corn traits and certain process engineering innovations on ethanol production while accounting for all relevant market effects. We use two scenarios to evaluate the potential aggregate yield effects of new biotech corn traits; however, we ignore other potential efficiency gains from lower input use (e.g., pesticides), changes in agronomic practices (e.g., tillage), and the like.

Table 2

Potential Impacts of Innovations in Ethanol Production and Operating Returns

Variable	Percent change with 1.8% corn and 1% ethanol yield growth	Percent change with 3.0% corn and 1% ethanol yield growth
Corn yield (bushels/acre)	2.5	10.2
Dry mill yield (gallons/bushel)	2.8	2.8
Corn market		
Planted area	–0.1	–0.6
Production	0.0	9.5
Total domestic use	1.7	6.7
Fuel	1.9	8.2
Feed	1.9	7.2
Food	0.3	1.0
High-fructose corn syrup	0.0	0.2
Exports	4.7	17.4
Corn farm price	–2.9	–11.7
Ethanol Market		
Production	4.4	10.8
Ethanol price	–1.0	–2.5
Ethanol dry milling returns (per gallon)		
Ethanol revenue	–1.0	–2.5
DDGS revenue	–7.2	–17.5
Corn cost	–5.4	–13.9
Net operating returns	7.7	30.1

Prevailing long-term trends show that U.S. corn yields have grown 1.35 percent per year for the past 40 years (USDA, 2008a). Specific biotechnology innovations and experimental field data indicate that 1.8 to 3.0 percent growth in yields might be possible in the near future (e.g., Korves, 2008; and Edgerton, 2008). We use these figures as the lower and upper bounds for our analysis. To account for the efficiency gains from process engineering and other innovations that improve the efficiency of the ethanol plant, we analyze the additional effect of 1.0 percent annual growth in the ethanol yield per bushel of corn.

As corn innovations are introduced in the market place, they change the relative productivity of the crop, and farmers respond through their planting decisions. These in turn shift the aggregate supplies of corn and other crops, change their relative prices, and shift their demand. Similar, though more limited, changes occur in response to process innovations at the ethanol plant. To account for such complex market changes, we use the FAPRI-MU model of crops and biofuel markets (Thompson, Meyer, and Westhoff, 2008). This partial-equilibrium model covers supply and demand quantities, including acreage planted, production, other domestic uses, trade, stocks, prices, and policies. In this context we evaluate the economic implications of the innovation scenarios discussed above for the 2009-18 period. This empirical analysis allows us to examine the potential effects of innovation on the supply of ethanol and the average profitability of the U.S. ethanol industry. The results are presented in Table 2 and are expressed as changes relative to a baseline where corn and ethanol yields grow at their historical averages—1.35 percent and 0.5 percent per year, respectively.

The empirical results from the partial-equilibrium analysis suggest that accelerating corn and ethanol yield growth rates shift corn and ethanol supplies upward. Given that aggregate corn demand is somewhat inelastic, when corn prices decline, demand increases. In domestic markets, the use of corn for food, feed, and fuel all increases. Exports of corn increase even faster as export markets respond to movements in U.S. corn prices. The reduction in corn prices also reduces the cost of ethanol production, lowering the price of ethanol and increasing demand for the biofuel. The magnitude of the change is influenced by the responsiveness of demand in the ethanol market. Given that the industry now supplies the supplement, additive, and the more responsive E10 markets, the outward shift is absorbed by an elastic demand and the resulting effect on the price of ethanol is small. The reduced input costs and relatively small decline in output prices lead to a 7.7 to 30 percent increase in net operating returns per gallon. It is worth emphasizing that these effects are over and above the improvements in operating returns that are expected with the continued growth of corn and ethanol yields at their historical rates.

The results of the partial-equilibrium model illustrate the potentially significant impact of new technologies on the level of efficiency and profitability of the U.S. ethanol industry. As firms continue to develop and adopt such new technologies, the industry will become more competitive and its sustainability will significantly improve.

SUMMARY AND CONCLUSION

Fueled by government policies and a positive macroeconomic environment, the U.S. ethanol industry has experienced strong and ongoing growth since the turn to this century. Over this nine-year period, the industry transformed itself from a niche player to a significant supplier of fuel to compete with gasoline in the U.S. market. As the macroeconomic environment worsened in the later part of 2008, the industry's growth stalled and the viability of some of the newly installed capacity became uncertain as petroleum, ethanol, and corn prices declined and ethanol processing margins with them.

This last stage of the industry cycle has created an environment where consolidation could follow. Industry consolidation could yield sizeable efficiency gains from scale and scope economies, as well as technical improvements and better allocation of resources. A full pipeline of innovations could bring large productivity gains to the U.S. ethanol industry—some targeting the operations of the mill and some its key feedstock—corn. Together, efficiency gains from industry consolidation and productivity growth from innovation could strongly improve the competitiveness and sustainability of the industry.

A possible threat to the stability and sustainability of the industry, however, is its unlinked revenue-cost structure, which is increasingly driven by changes in the relative prices of petroleum and corn. A random and sustained low-corn, high-petroleum price combination results in windfall profits for the industry. A similarly random and sustained high-corn, low-petroleum price combination results in lasting losses. Given the wide variation in the petroleum and corn markets, this characteristic could make the industry prone to boom-bust cycles. This issue has attracted little attention so far, possibly due to the implicit "hedge" currently offered by the RFS mandates. As the industry continues to improve its competitive edge and grow, effective means for linking costs and revenues might become necessary to prevent this subtle industry feature from becoming its Achilles' heel.

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