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Some long-run effects of growing markets and renewable fuel standards on additives markets and the US ethanol industry

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Abstract

The effects of likely regulatory and policy changes in the US gasoline and additives market are compared to a reference baseline. The baseline reflects existing EPA policies about fuel quality regulation and likely petroleum and gasoline expansions. The market and welfare effects are presented for implementing a renewable fuel standard; imposing a national ban on the additive MTBE; and removing the oxygen standard for reformulated fuel. Market and welfare estimates are based on adjusting product market demands and factor supplies. Product market and price analyses include quality-differentiated products, such as refinery gasoline, chemical additives and ethanol at the wholesale level; and gasoline grades in conventional, reformulated and oxygenated markets at the ratail level. Factor market analyses include supplies for petroleum, natural gas byproducts, and corn. The analysis includes the welfare cost of fuel to consumers and income in agriculture and the petroleum sector.

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Keywords: Gasoline and additives market; Biofuels; Ethanol; MTBE ban; Renewable fuel standard; Oxygen standard

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1. Introduction

The presence of biofuels in the US gasoline and additive market was shaped by environmental regulation and national security concerns. Previous US Clean Air Acts have created new demands for additives with specific attributes. Moreover, ethanol's exemption to part of the excise tax on gasoline, defended on the grounds of national security and infant industry protection, boosts biofuel supply. Ethanol's presence consists of 7% share of the additives market, which is produced with the processing industry using 5% of the US corn supply.

Some new policies may push biofuels beyond a token presence in the fuel and additives markets. First, serious consideration is being given to a renewable fuels standard for US gasoline amidst concerns about global warming and national security. Second, ongoing health concerns and impending bans on a competing additive may restrict other fuel supplies. Analysis of product prices, factor availability and welfare in the gasoline/additives sector may point to the appropriate scale for biofuels in contemporary fuel and farm markets.

We compare the effects of some likely regulatory and policy changes in the gasoline/additives market to a reference baseline situation in this paper. The baseline reflects existing EPA policies about fuel quality regulation and likely petroleum and gasoline expansions during the next decade. Next, we analyze the effects of replacing the current oxygen standard with a renewable averaging policy on the role of biofuels in the gasoline/additives market. Indeed, the current US energy bill includes a "renewable fuel standard" (RFS) (Congressional Record, 2002); a national ban on the additive MTBE is also included in the simulations, to conform with the evolution of health regulations and the current energy bill. Finally, a national MTBE ban without the renewable fuel standard is presented to disentangle the effects of a joint policy change.

The article is organized as follows. First, a review of the gasoline and additives market is given. Next a simulation model suitable for analysis of regulation changes is presented. Then policy alternatives are compared; simulations suggest growth for gasoline/additives demand and the ethanol industry under a future baseline situation. Also, the renewables policy produces a significant increase in ethanol demand over the baseline level. However, the MTBE ban in isolation still could cause a moderate addition to ethanol demand above the baseline. Either policy change from the baseline would detract from measured welfare accruing to factor suppliers, processors, and consumers in the fuel-additives sector. But measured welfare losses in markets may be offset by unmeasured environmental and health benefits. Further, farmers will likely get a boost to farm income in the current environment, under all of the plausible situations considered.

2. Production processes, products, and quality in the gasoline/additives market

The absence of refinery capacity expansion during the last two decades in spite of a growing market is a striking feature of the US fuel sector. Partly, the lack of growth can be traced to increasingly rigid environmental regulation of the refinery process. Additionally, growing demands for clean fuels have shifted capacity expansions towards additives that fill quality gaps in the refinery gasoline supply. An understanding of additive and biofuel demands requires an understanding of refinery products and attributes that are in deficit. So a review of intermediate products and processes for refineries and additives is helpful.

2.1. Processes and products

The gasoline fuel processing complex summarized in Fig. 1 relies on three natural resources: petroleum, natural gas, and biomass.[1] In turn, the production process and environmental characteristics of gasoline/additive components depends on physical characteristics of the resource. For instance, petroleum contains several long and complicated hydrocarbons with a high proportion of carbon; processing is devoted to separating, breaking down, or reshaping into chemicals that are useful for fuel and plastic. Environmental disadvantages of high carbon content are poor air quality with incomplete combustion and global warming when combustion is complete. In contrast, most additives are based on natural gas, or byproducts from natural gas and refinery production. These inputs have simple physical structure with a low proportion of carbon. So complete combustion occurs with lower carbon dioxide emissions. Ethanol also burns clean with a low carbon dioxide content. Further, ethanol production offsets global warming, because photosynthesis reverses the oxygen gas to carbon dioxide processes involved in combustion (Wang, Saricks, & Santini, 1999); a partial offset occurs today, due to the energy used in corn drying and partial blends. But complete carbon dioxide offsets are plausible in the future with biomass processing and blends with high ethanol concentration.

The petroleum refinery is a collection of fixed proportion production processes that separate large petroleum molecules into several smaller molecules. In the primary distillation phase, lighter products (napthas and kerosine) evaporate at low temperatures, heavier products (gas-oils) at higher temperatures and the heaviest products (vacuum bottoms) remain liquid even at the highest temperatures in approximately fixed proportions.

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[1] The process yield and cost estimates are discussed in this section (Cole & Trotta, 2000; Donaldson & Culberson, 1983; Gary & Handwerk, 1994; Hohmann & Rendleman, 1993; John & Thomas, 1993; Ragsdale, 1994; Shapouri, Gallagher, & Graboski, 2001). Details are available from the author upon request.

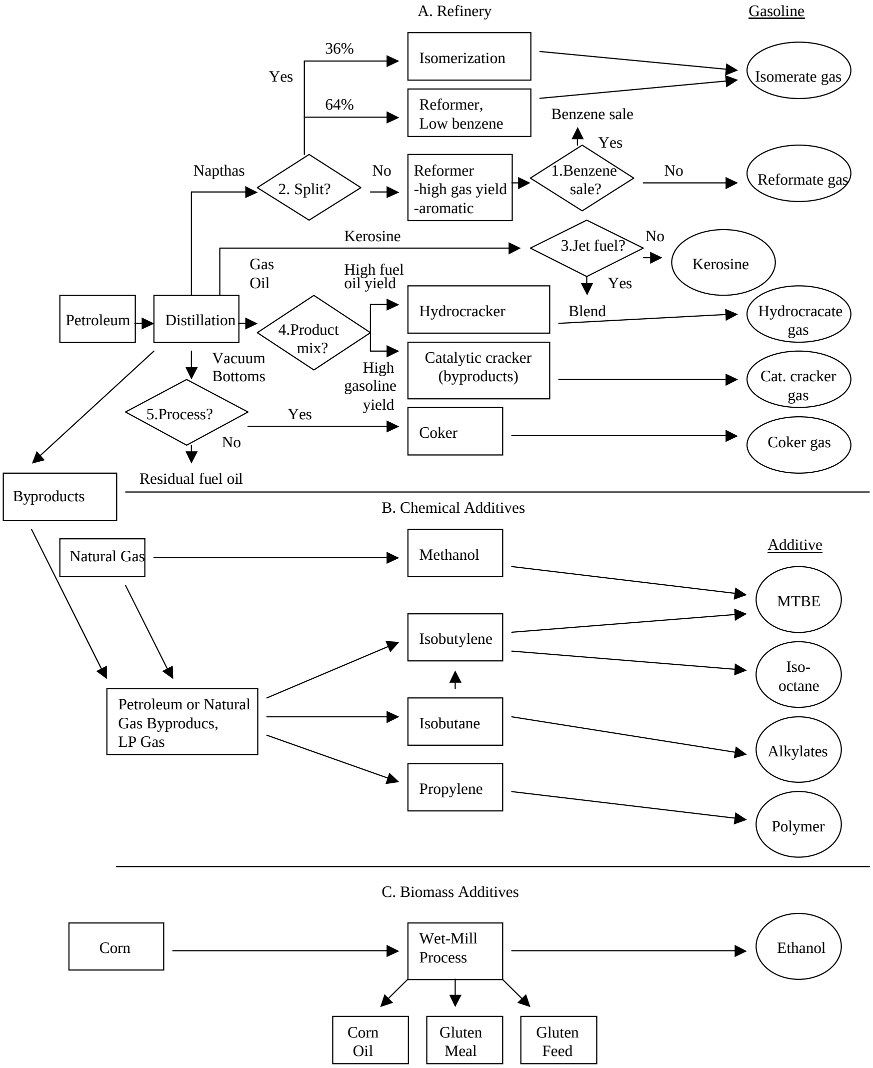

Fig. 1. The gasoline/additive processing complex. (A) Refinery; (B) chemical additives; (C) biomass additives.

Secondary processes use distillation outputs as inputs. First, light napthas are sent to conventional reformers that yield gasoline with high benzene content, which enhances the average octane of gasoline. Further, a new reforming process splits the naptha, removing benzene and satisfying clean air laws. Second, kerosine can be sold or blended with gasoline for jet fuel. Third, the allocation of intermediate weight gas-oils to the hydrocracker or catalytic cracker determines whether diesel fuel or gasoline is emphasized. Fourth, the heaviest distillation output, vacuum bottoms, are sold as residual fuel oil or allocated to the coker. All of the secondary refinery processes yield some gasoline, as shown on the RHS of Fig. 1A.

In the secondary processing steps, refiners do have some flexibility in choosing the product composition and quality of outputs. At the sector level, however, the annual variation in the proportional allocation to secondary processing steps is small. As a first approximation then, the refinery is treated as a composite fixed proportions production process with secondary processing allocations defined by the high gasoline output typical in the United States.

Most gasoline additives combine byproduct chemicals from natural gas or petroleum processing into another chemical with more desirable fuel attributes. Most input chemicals are also produced from natural gas or LP gas directly. The main additives are alkylates, polymers, and MTBE (Fig. 1B). Iso-octane, an alkylate, may replace MTBE under some circumstances.

Bio-processing separates corn into component chemicals. The starch part of corn is used to make ethanol while other components are mostly sold as animal feeds or human food. There are two corn processing technologies. Wet-mills separate the byproducts into three components: corn gluten feed (20% protein), corn gluten meal (60% protein), and corn oil, as shown in Fig. 1. Dry-mills sell one composite byproduct feed, distillers' dried grains, that includes all three components.

The gasoline or additive from each process has a distinct set of performance and environmental attributes, which are given in Table 1. Regarding availability, note that refinery gasolines provide 83% of the fuel supply, with output from the catalytic cracker dominant at 44%. Also, additives combined for 17% of supply, with ethanol providing 7%.

2.2. *Quality and clean air standards*

Two of the attributes of Table 1, octane and vapor pressure, relate to automobile performance. The remaining attributes relate to the EPA's National Clean Air Regulations. Together, performance grades and Federal Clean Air Standards define 36 grades of gasoline (see Table 5), as explained below.

Conventional gasoline, which covers about 3/4 of total gasoline consumption in the United States, is subject to two performance constraints. First, minimum octane content defines the fuel grade with 87 for regular, 89 for midgrade, and 91 for premium. Second, a vapor maximum of 9.5 for winter and 11 for summer fuel must also be satisfied.

Reformulated gasoline is required in the large urban areas on both Coasts and Texas, accounting for about 1/5 of gasoline fuel. These areas have smog problems, in the EPA's view. Then a car's emission rate of target pollutants, volatile organic compounds (VOC), nitrous oxides (NOX), toxic chemicals (TOX), and sulfur oxides (SOX), must be reduced about 20% below recent baselines according to regressions that relate emissions to fuel quality dimensions (Federal Register, 1995; Rhodes, 1998; UOP, 1994). The statistically important fuel quality dimensions are

Table 1
Refinery gasoline and additives: quantity and attributes

	Quantity (bil. bbl)	Attribute content							
		Octane (index)	Vapor (psi)	Benzene (percent)	Oxygen (percent)	Olefins (percent)	Aromatics (percent)	e200 (percent)	e300 (percent)
Refinery gasoline, by process									
Distillation	0.24	82.5	11.2	1.4	0	0	10	94.3	100
Hydrocracker	0.041	82.6	12.9	3	0	0	3	0	7
Catalytic cracker	1.541	86.5	5.2	0.54	0	23	43	62.1	53.5
Coker	0.09	79.8	12.7	1.4	0	44	1.5	31.5	100
Reformer	0.355	91.8	2.2	4.13	0	1	1	19	70.8
Isomer	0.137	82	13.5	0	0	0	35	94.3	100
Benzene red. reformed	0.228	93.9	4.1	0	0	1	35	19	70.8
Additives									
MTBE	0.0766	109	8	0	18	0	0	100	100
Alkylate	0.2237	93	4.6	0.1		0.4	0.4	36.3	95.3
Polymer	0.05	90.5	8.7	0	0	0.5	0.5	36.3	95.3
Normal butane	0.1449	91.7	59	0	0	0	0	100	100
Ethanol	0.0393	114	19	0	35	0	0	0	100

those shown in Table 1: vapor pressure, sulfur content, oxygen, aromatics, olefins, e200 (the fraction of the fuel that evaporates by 200F), e300, and benzene. Generally speaking, manufacturers can blend reformulated gasoline by choosing the fuel quality dimensions to satisfy target pollutant reductions. However, a minimum oxygen content and a maximum benzene content are still included in reformulated gasoline.

Oxygenated fuel, which accounts for the remaining 5% of consumption, satisfies conventional gasoline standards and adds a minimum oxygen requirement for winter fuel. The oxygen requirement helps reduce carbon monoxide emissions. Oxygenated fuel is required in Minneapolis, Denver, and a few mountain locations in the southwest.

The demand growth for additives and biofuels is partly explained by escalating performance demands of gasoline engines. The octane of regular gasoline has increased from 60 in 1930 to 87 today (Gibbs, 1993). There would be an octane deficit with refinery gasolines; refinery gasoline has a volume-weighted average octane of 87 from Table 1 while the average octane demand is above 88 from the consumption data of Table 5. All the additives in Table 1 have octane levels above the demand level; blending fills the deficit.

The evolution of Federal Clean Air Regulation is another cause of demand growth for additives and biofuels. First, The Clean Air Acts of 1967/1970 banned the use of lead as a gasoline additive because it was shown that lead causes cancer (Kitman, 2000). The lead ban created an octane deficit, and spurred expansion in additive production. Second, the Clean Air Act of 1990 created reformulated gasoline, including an oxygen content minimum of 2% and a benzene content maximum of 1%. Oxygen was included on the belief that it improves combustion while benzene was limited because it causes cancer. The oxygen minimum boosted demand for both oxygen-containing additives: ethanol and MTBE. The benzene maximum may boost additive demand slightly because additives do not contain benzene.

Finally, impending policy changes may continue to expand biofuel demand. First, the renewable fuel standard eventually requires that at least 2.4% of the gasoline supply is ethanol. Second, national ban included in the current energy bill reflects a conviction that MTBE (1) will increase in drinking water if used in fuel, and (2) will increase cancer risks. Bans are pending in several major gasoline consuming states, including California and New York (California Energy Commission Staff, 2002). Preliminary evidence is mixed but tends to show that MTBE causes cancer in mice (Davis, 2002).

3. A simulation model for the gasoline and additives markets

It is important that simulation analysis can account for sector wide effects and price changes in factor and product markets. Clearly, changes of the magnitude of the RFS could account for 10% of the corn market. Similarly, health regulations may exclude nearly 1/2 of the additives production while inputs for the chemical additive industries exhausts byproduct supplies from refineries and natural gas production. Finally, technical constraints prohibit substitution across local gasoline markets. If a regulatory change makes an attribute required for a particular type of fuel more valuable then, it could significantly alter the distribution of prices across grades and fuel types. Even so, engineering studies are typically extensions of firm-level analyses that minimize processing costs with fixed product demand quantities and fixed factor prices.

Fortunately, programming models can be used for market-level analysis when quality and environmental regulations are prevalent.[2] This section summarizes methodology discussed in detail by Gallagher et al. (2001). Specifically, constrained maximum welfare implies market outcomes when welfare is defined as consumer surplus from gasoline product markets less costs of supplying inputs and processing services, and the net tax extractions from the fuel sector are subtracted from the sector's welfare. Further, constraints are defined by the quality and environmental standards of the fuel sector.

Solutions to the constrained maximization problem yield insight into decisions in value-added markets operating with quality constraints. For instance, processors of petroleum, corn, and additives expand until marginal processing costs equal the processing margin between product revenues and raw material input costs. Also, wholesalers buy refinery gasolines and additives and sell blended gasoline; they price gasoline at a marginal cost that includes the value of another unit of blended gasoline plus an adjustment for the value of a constrained quality unit. For instance, the wholesale price of blended gasoline equals the ethanol price less the subsidy equivalent of the blender credit less a correction for ethanol's contribution to the octane level in a market with one quality constraint (Gallagher et al., 2001, p. 15). Finally, supply-utilization identities are included for quality attributes. For instance, the number of octane-bbls supplied across refinery gasolines and additives equals the number of octane-bbls demanded across gasoline grades. In this fashion, the shadow values for constraints jointly reflect values in processing and from resource supplies.

The welfare function used for simulation of the US gasoline/additives sector includes detailed costs from supply curves and benefits from demand curves.[3] In particular, demand curves for each of the 32 grades of blended gasoline are included in benefit calculations, because consumers require different gasoline grades and environmental specifications according to the performance characteristics of their automobile.

Also, the three main resources and processing complexes shown in Fig. 1 are included in cost calculations. Processing marginal cost excludes the cost of raw

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[2] Programming models of value added markets have been studied (Cox & Chavas, 2000; Takayama & Judge, 1971). But analyses that include quality regulation are typically focused on the firm level (Ladd & Martin, 1976; Wilson & Prezler, 1992).

[3] Details of the simulation model are available from the authors upon request.

Table 2
Refinery and additive processing cost summary

	Basis (feed or output)	Unit	Variable cost	Unit capital	Total
Distillation	Feed	$/bbl	0.353	0.292	0.645
Hydrocracker	Feed	$/bbl	1.625	3.454	5.079
Coker	Feed	$/bbl	0.599	1.399	1.998
Catalytic cracker	Feed	$/bbl	0.682	0.804	1.486
Reformer	Feed	$/bbl	6.506	0.592	7.099
Isomer	Feed	$/bbl	0.818	1.039	1.857
$\mathrm{MTBE_I}$	Output	$/bbl	10.586	1.954	12.540
$\mathrm{MTBE_Y}$	Output	$/bbl	11.690	7.020	18.711
Alkylate	Output	$/bbl	4.775	1.331	6.107
Iso-octane	Output	$/bbl	5.615	1.655	7.270
Polymer	Output	$/bbl	1.347	1.331	2.678
Ethanol	Feed	$/bu	1.100	0.526	1.626

Unit capital costs for distillation
$= 0.1781_{\text{(Primary)}} + 0.1976 \times 0.2105_{\text{(Vaccum)}} = 0.2921$

material inputs. Most additive processes combine two or more chemicals to make a third chemical, so the supply (marginal cost) function for additives processing is stated in terms of additive *output*. But petroleum and corn processing breaks the input molecule into many smaller molecules, making several outputs, so the supply (marginal cost) for petroleum or corn processing is stated in terms of the crude petroleum *input*. The fixed proportions assumption is used for all processes. A summary of year 2000 baseline processing costs is given in Table 2. Variable costs refer to labor, utilities, patent fees and enzymes required for processing. The Unit capital is the annual capital cost for one unit of capacity. Meanwhile, costs are given on an output basis in the case of the additive processes. The total costs per unit help to determine the long-run competitiveness of processes in subsequent simulations.

The factor supply curves are likely upward sloping. First, chemical inputs for additives rely on limited volume of byproducts of natural gas production or refineries and supplementary imports. Similarly, ethanol production is large enough to bid corn away from feed use and the export market. Finally, refinery in the US may be large on the North American Market.

Two important fiscal policies in the gasoline sector are included in the welfare function used for the simulation study: the federal excise tax on gasoline and the rebate for ethanol blends. Net extractions from the fuel sector, consisting of the gas tax rate times the blended fuel quantity demanded less the retail rebate for ethanol blends times the quantity of ethanol blends demanded, are subtracted from net welfare. While the excise tax and ethanol subsidy are taken into account, their removal is not considered in this study. Some economists believe that removal of the ethanol subsidy would improve the efficiency of the grain sector. But renewal of the subsidy still receives political support, perhaps due to the need for domestic energy supplies and parallel incentives in the petroleum industry (National Energy Policy Development Group, 2001, p.6).

The constraints of the US gasoline/additives sector model reflect standards and air quality regulations for various markets. For conventional gasoline, octane and vapor constraints are included. For oxygenated gasoline, a minimum 2.7% oxygen constraint is included. For reformulated gasoline, maximums were included for the air quality constraints on VOX, NOX, and TOX. In effect, quality is endogenous for the main fuel quality parameters influencing air quality (vapor, aromatics, olefins, e200, e300). But explicit constraints for benzene minimum and oxygen maximum are also included in accordance with the current federal law. The octane constraint is also included in reformulated gasoline. Finally, exhaust emissions functions caused convergence problems in preliminary simulations because they are non-linear functions of the fuel quality parameters; Taylor's series approximate the emissions functions.

Static simulations are useful in determining the adjustments that will occur in the time period when processors adjust their capacity to desired levels in response to price signals from product markets, factor markets and government regulations. Thus, the estimates give capacity levels and outputs that are economically sustainable by consumer demand and factor markets.[4]

4. Elasticity estimates and assumptions about market response

Estimates of supply curves for each factor and processing activity, and demand curves for each product are also required for the simulations. Table 3 contains a summary of the elasticities that are used in the simulation model. These estimates are a combination of estimates from the literature, our own estimations, and a few judgments. The position and slope of a supply and demand curve was set using the given elasticity and observed price–quantity pair for the year 2000 baseline year.

The gasoline demand elasticity is a long-run estimate that is based on the literature and our own estimations, which are available from the authors.[5] Some other

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[4] Dynamically adjusting price expectations and capacity are critical to analyses of public inventory policies. However, dynamic models all come to the same long-run equilibrium, some faster than others. Static models are useful in policy analyses because they indicate the viability of industries, the welfare of consumers and the profits to resources in response to sustained policy changes. Further, the adjustment costs associated with new market regulations are avoided when early announcements of policy changes provide producers with sufficient time to adjust. For instance, one study focused on the short run, when the means of importing and transporting additives are fixed; they concluded that California gasoline prices could double in the event of an MTBE ban in California (California Energy Commission Staff, 2002). Another study demonstrated that the local handling system in California could be modified for other additives within 6 months with a transport cost to California of $.15/gal (Renewable Fuels Assn, 1999). Finally, the overall lead time for ethanol production capacity may be about 2 years; capacity can apparently increase about 75% over a 2-year period in response to a demand increase (MacDonald, Yowell, & McCormack, 2001).

[5] Details are available upon request.

Table 3
Elasticity summary

Product	Factor excess supply of input to processing sector	Processing supply	Product demand
Petroleum	2.0	10.0	
Refining byproducts/additive inputs			
Normal butane	2.5		
Isobutane	2.5		
Butylene	2.5		
Propylene	2.5		
Corn	12.0	1.5	
Corn refining byproducts			
Gluten feed			−31.5
Gluten meal			−63.9
Corn oil			−5.2
Additives			
MTBE_I		1.0	
MTBE_Y		1.0	
Iso-octane		1.0	
Alkylates		1.0	
Polymer		1.0	
Normal butane		10.0	
Gasoline			−0.8

estimates of the gasoline demand elasticity are smaller when they assume that technology (miles/gallon) is given. Similarly, most estimates do not include the feedback from gasoline prices to GDP, and reduced gas consumption due to falling incomes. When both of these effects are included, the demand elasticity is about 0.8.

An increase in ethanol production causes an increase in the demand for corn and an increase in the supply of corn byproducts. Hence, estimates of demand elasticities for corn byproducts are provided for estimates of changes in the byproduct revenues of corn processors. Also, a corn supply elasticity estimates the increase in corn refiners' costs and the farm income increase.

For the corn refining byproducts, the elasticity estimates were adjusted after some preliminary simulations. The estimates here assume that the byproduct markets are nearly saturated; gluten feed prices drop to energy equivalence in livestock feed and then compete directly in the corn market; gluten meal prices drop to protein equivalence and then compete directly in the soymeal market; and corn oil prices drop and compete directly in the soy oil market. The elasticities are large because the corn, soymeal and soy oil markets are considerably larger than the corresponding corn byproducts markets. Corn and soy product elasticities are given in Gallagher (1998).

The corn supply facing the processing industry is an excess supply, defined as the difference between production and demand at a given price. The demand estimates include both domestic feed demand and export response to a price change from the author's own estimations; the elasticity of total demand used is 0.33, somewhat smaller than most large models of the ag sector. The domestic production elasticity is 0.6, reflecting acreage and yield response to a price change. The corn supply elasticity for the processing industry of 12.0 is large despite inelastic domestic corn market structure for all the reasons that trade elasticities can be large when domestic elasticities are small.

The elasticity of petroleum supplied to the US processors uses the US petroleum supply estimate of Walls (2003). Also, an ologipoly pricing model discusses OPEC and American fringe area countries' (Canada and South America) adjustments to a petroleum price change (Gallagher & Johnson, 1999). An elasticity of about 2 is obtained when OPEC adjustment to demand changes, US domestic adjustment, and fringe adjustments in Canada, and South America are all included in the excess supply curve to US processors.

Some estimations of chemical input supply functions were calculated. The implied supply elasticity to the additives processors was 2.5 for butane and statistically significant. Elasticity estimates for the other chemicals, isobutane, butylene and propylene, were smaller, about 0.5. But the *t*-values were marginal here. Since large price adjustments occurred in preliminary simulations, the butane elasticity estimate was used for these chemical markets; perhaps some elasticities we underestimated due to multicolinearity. Larger elasticities may occur due to the processing connections to large markets, such that natural gas to butylene, and LP gas to isobutane (Donaldson & Culberson, 1983).

Estimates of processing elasticities are sparse. Corn products processing response has an elasticity of 0.5 when capacity is a given explanatory variable; but the additive processing elasticity may be larger during the period of capacity adjustment, reflecting location, labor and regulation advantages. So processing supply is assumed at 1.5 for corn and 1.0 for other additives. For petroleum, a constant cost processing is assumed (elasticity10) due to excess capacity. For butane, no costs are needed for additive use.

A preliminary analysis of gasoline demand by grade showed that each grade of gasoline has distinct and technologically separated demands because a statistical analysis of relative prices and market shares did not suggest any substitution between grades of gasoline.[6] Hence, distinct demand curves were specified for each grade, each EPA formulation, and each region with distinct vapor regulation. Each demand curve depends only on the own price. The overall gasoline elasticity market is used for all local markets.

Quality arbitrage is also included in the model. An arbitrage activity can permit downward grade substitution if high quality inputs are cheap enough. For instance, midgrade gasoline could be used to fill regular gasoline demand in the conventional gasoline market of the north in the winter. However, substitution across

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[6] Details are available on request.

formulations, locations and seasons was not included. Together the assumptions of technologically separate demand and arbitrage across grades generated a system of premium and discounts that are consistent with the observed system of price premiums and discounts (Table 5).

5. Simulation

Assessments of growth potential for additives with simulation models are useful, because the outcome will likely depend several offsetting factors, such as the cost and qualities of fuel components, and the details of regulations on clean fuels. The existing policies are a useful starting point, because the 1990 Clean Air Act just became effective in 2000. It will take more time to fully adjust to these new regulations.

5.1. Baseline: implications of existing policies in a growing market

The implications of existing policies was estimated with a two-step procedure. First, the simulation model was calibrated using year 2000 data to identify the position of demand and supply curves at observed prices in factor and product markets. Second, the condition of overall gasoline demand and world petroleum price came from “reference” simulations for the world energy market (Energy Information Administration, 2002); the demand intercept for each gasoline grade was increased by about 20% to achieve an overall 4.0 bil. barrel gasoline market for the year 2015; the intercept of the petroleum supply curve was adjusted to $24.5/bbl. The estimated price and quantity changes in the input and additive market simulations refer to real changes in prices because the simulation was aligned to real petroleum and gasoline price estimates from the world energy baseline.

Further, the initial corn excess supply curve does not shift from the initial position in the year 2000 level. In effect, we assume that no exogenous changes are shifting the corn supply or demand. Sans changes in agricultural policy, the real corn price estimate would likely have upward bias, because yield increases and real price declines have been occurring on a steady 50-year trend. Put another way, the offsetting effects of another decade of increasing corn yields and the elimination of all corn subsidies would in fact give a corn excess supply curve that is stable.

5.2. Modeling impending policy changes

Two alternative policies are compared to the baseline. Under one version, a national MTBE ban is added to the 2015 baseline with the existing EPA law (including a 2.0% oxygen standard) in place. The MTBE ban is included in the simulation model by adding a restriction that the consumption of this additive is zero in all forms of gasoline demand. In the second option, the oxygen standard is replaced with a renewable fuel averaging policy. With renewable averaging, blenders must sell a given amount of ethanol in all of their gasoline sales (s. 1766, sec. 818). The renewable averaging policy is included in the simulation model by removing the oxygen constraint in reformulated fuel, and adding a restriction requiring that the sum of ethanol used in gasoline consumption across all grades must equal 5 bil. gallons (0.119 bil. barrels). The assumption of a national MTBE is retained in the simulation of a renewables standard.

6. Results

The results of the simulations are summarized in Tables 4 through 8. Table 4 contains the main market prices and quantities in processing, factors and product markets. Table 5 contain the details of gasoline demand and prices by grade. Table 6 shows ethanol utilization by market under various circumstances. Table 7 provide summaries of the welfare measures associated with the policy options. Table 8 provides a summary of the implications for the EPA’s target pollutants. Detailed tables that give endogenous estimates of fuel quality attributes are available from the authors. Recipe tables for all 32 formulations of gasoline are also available.

6.1. *Effects in markets*

Most refinery gasoline and additive prices are somewhat lower in the 2015 baseline than they were in the year 2000, likely because the baseline petroleum price is lower in the future. The overall energy market outlook also suggests a 33% increase in the consumption of gasoline. Our simulations confirm a shift towards the additives industry. In particular, there is a 0.54 bil. bbl expansion of refinery gasoline production and a 0.31 bil. bbl expansion in additives. The ethanol price increases, owing to the stable corn supply function and expanding demand. Hence, ethanol shares in the expansion of the additives industry.

The premium/discount structure among grades of refinery gasoline and additives in the 2015 baseline reflects the value of attributes possessed by the various gasoline components. At the top of the premium structure, ethanol is about $20/bbl above MTBE; this premium is about $2/bbl less than the subsidy differential for ethanol, suggesting that the composite octane, vapor, and oxygen comparison between the two gives MTBE a slight quality advantage. At the bottom of the price schedule, coker gasoline, butane, and catalytic cracker gasoline have low octane content, high vapor pressure and high benzene content, respectively. Also, a comparison of the actual 2000 data with the 2015 baseline shows that the average price of refinery gasoline declines while the prices of additives remains stable or increase. So the demand shift favors additives.

To understand the changes estimated for the long-run effects of a national MTBE ban, one must first look closely at the gasoline demand by grade and retail prices in Table 5. Specifically, there is a fairly large reduction in the quantity and an in-

Table 4
Gasoline and additive products: prices and quantities

Variable (units)		Actual 2000 baseline	2015 Baseline	National ban	Renewable std.
Corn processing	Quantity (bil. bu)	0.6150	1.6480	1.6870	1.8650
	Price ($/bu)	1.7320	2.1020	2.1140	2.1690
	Margin ($/bu)	1.6400	4.3680	4.4590	4.8720
Corn products, price	Gluten feed ($/ton)	65.7600	70.6570	70.9860	72.4780
	Gluten meal ($/ton)	277.3500	270.0520	269.7760	268.5210
	Corn oil ($/lb)	0.1170	0.0790	0.0780	0.0710
	Ethanol ($/bbl)	66.3600	86.3270	87.9460	95.2950
Corn byproducts, output	Gluten feed (bil. ton)	0.0042	0.0111	0.0110	0.0130
	Gluten meal (bil. ton)	0.0008	0.0022	0.0020	0.0020
	Corn oil (bil. lb)	0.9540	2.5547	2.6150	2.8910
	Ethanol (bil. bbl)	0.0393	0.1050	0.1080	0.1190
Petroleum processing	Quantity (bil. bbl)	5.5840	6.7440	6.3680	6.4590
	Price ($/bbl)	28.2300	24.5430	23.8710	24.0340
	Margin ($/bbl)	3.1750	3.1630	3.1460	3.1510
Refinery gasoline, wholesale price	Distillation		44.8830	43.7920	44.2000
	Hydrocracker		44.7120	43.5590	43.9590
	Catalytic cracker		47.8470	47.1840	47.3700
	Coker		43.2330	42.0100	42.5270
	Reformate		51.2020	50.8040	50.7640
	Isomerate		44.3020	43.0430	43.5460
	Reformer, no benzene		52.1040	51.5400	51.5900
	Average retail price	53.1100	48.3990	47.8420	47.7110
Refinery gasoline, quantity	Distillation	0.2400	0.2900	0.2740	0.2780
	Hydrocracker	0.0410	0.0490	0.0470	0.0470
	Catalytic cracker	1.5410	1.8620	1.7580	1.7830
	Coker	0.0900	0.1090	0.1030	0.1040
	Reformate	0.3550	0.4280	0.4050	0.4100
	Isomerate	0.1370	0.1660	0.1560	0.1590
	Reformer, no benzene	0.2280	0.2740	0.2590	0.2630
Sum		2.6320	3.1780	3.0020	3.0440

Table 4 (*Continued*)

Variable (units)		Actual 2000 baseline	2015 Baseline	National ban	Renewable std.
Byproducts, price ($/bbl)	Normal butane	21.0200	43.2680	38.7110	41.2400
	Isobutane	64.4800	52.8130	59.1780	59.2610
	Butylene	54.0800	32.4480	32.4480	32.4480
	Propylene	36.8800	33.3700	38.0070	38.084
Natural gas plant supply (bil.)	Normal butane	0.0584	0.2130	0.1810	0.0550
	Isobutane	0.0690	0.0380	0.0550	0.0000
	Butylene	0.0192	0.0000	0.0000	0.0560
	Propylene	0.0515	0.0390	0.0550	0.5600
Additive, price ($/bbl)	Butane	21.0200	43.2680	38.7110	41.2400
	MTBE (isobutylene)	63.6730	60.0420	46.9280	46.9940
	MTBE (butylene)	73.2240	66.3850	32.7080	32.7080
	Iso-octane	62.2710	55.5230	54.8390	55.1020
	Alkylates	76.3950	54.8790	61.6100	61.6280
	Polymers	64.8500	52.2750	57.3090	57.5260
Additive, output (bil. bbl)	Butane	0.1449	0.3270	0.2920	0.3120
	MTBE (isobutylene)	0.0389	0.0560	0.0000	0.0000
	MTBE (butylene)	0.0383	0.0690	0.0000	0.0000
	Iso-octane	0.0100	0.0140	0.0060	0.0060
	Alkylates	0.2237	0.2160	0.3030	0.3080
	Polymers	0.0500	0.0670	0.0740	0.0760
	Ethanol (bil. bbl)	0.0393	0.1050	0.1080	0.1190
Sum		0.5451	0.8540	0.7830	0.8210
Gasoline	Quantity (bil. bbl)	3.0740	4.0980	3.8260	3.9
	Price ($/bbl)	61.9108	63.6434	66.0774	62.8982

crease in the price of reformulated gasoline in the summer, reflecting the increased cost of making summer reformulated fuel without MTBE. In preliminary simulations, refiners and blenders no longer provided these categories of gasoline, which suggests some non-linearities in gasoline demand. In view of existing problems in the simulation model that are likely associated with non-linear restrictions, we assumed a maximum reduction in gasoline demand of 25%, to avoid over adjustment; large adjustment in urban areas is plausible, as people adjust to more fuel efficient cars and use mass transport. In contrast, the retail gasoline price falls in conventional areas and consumption increases in response.

In Table 4, overall gasoline consumption falls. Thus, the factor markets also indicate reduced prices and quantities. Specifically, outputs of both refinery gasoline and most additives declines relative to the baseline. Ethanol output and price increase slightly, because there are no other sources of oxygen for reformulated fuel.

When the renewables standard replaces the oxygen standard, some of the large price increases in reformulated fuel are reversed (Table 5). Hence, total gasoline consumption increases slightly from the oxygen standard case in Table 4, and the average retail gasoline price is reduced from the oxygen standard case. Both additives and refinery gasoline outputs are higher with renewable averaging. However, ethanol output and price are about 10% higher with renewable averaging, compared to the oxygen standard.

Table 5

Variable units	Actual 2000	Baseline 2015	National ban	Renewable std.
		Quantity consumed (bil. bbl)		
(a) Gasoline demand, by grade, season, EPA classification				
RGC	0.5324	0.6740	0.6830	0.6800
MGC	0.0636	0.0840	0.0850	0.0850
PRC	0.0965	0.1300	0.1320	0.1310
RGR	0.2636	0.3510	0.3540	0.3530
MGR	0.0399	0.0550	0.0550	0.0550
PRR	0.0630	0.0880	0.0000	0.0000
RGO	0.0263	0.0370	0.0370	0.0370
MGO	0.0039	0.0000	0.0000	0.0000
PRO	0.0040	0.0060	0.0000	0.0060
RGCS	0.3602	0.4770	0.4810	0.4800
MGCS	0.0405	0.0550	0.0560	0.0550
PRCS	0.0606	0.0840	0.0840	0.0840
RGRS	0.1675	0.2290	0.1670	0.2300
MGRS	0.0250	0.0350	0.0250	0.0000
PRRS	0.0389	0.0550	0.0390	0.0000
RGOS	0.0052	0.0070	0.0070	0.0070
MGOS	0.0009	0.0010	0.0010	0.0010
PROS	0.0009	0.0010	0.0010	0.0010
RGCN	0.3836	0.5040	0.5100	0.5080
MGCN	0.0362	0.0490	0.0490	0.0490

Table 5 (*Continued*)

Variable units	Actual 2000	Baseline 2015	National ban	Renewable std.
		Quantity consumed (bil. bbl)		
PRCN	0.0468	0.0640	0.0650	0.0650
RGRN	0.1949	0.2600	0.2620	0.2610
MGRN	0.0270	0.0370	0.0370	0.0370
PRRN	0.0422	0.0590	0.0590	0.0590
RGON	0.0374	0.0530	0.0000	0.0530
MGON	0.0054	0.0050	0.0050	0.0050
PRON	0.0024	0.0030	0.0000	0.0000
RGCSN	0.2560	0.3470	0.3490	0.3490
MGCSN	0.0230	0.0320	0.0320	0.0320
PRCSN	0.0311	0.0440	0.0440	0.0440
RGRSN	0.1243	0.1730	0.1240	0.1740
MGRSN	0.0166	0.0240	0.0170	0.0000
PRRSN	0.0255	0.0370	0.0250	0.0370
RGOSN	0.0240	0.0330	0.0330	0.0330
MGOSN	0.0033	0.0050	0.0050	0.0050
PROSN	0.0015	0.0020	0.0020	0.0000
Sum	3.0741	4.1000	3.8250	3.9160
		Retail price ($/bbl)		
(b) Gasoline retail price, by grade season EPA classification				
RGC	56.421	62.997	61.889	62.315
MGC	60.878	63.830	62.727	63.194
PRC	64.119	64.951	63.864	64.314
RGR	61.058	63.282	62.428	62.604
MGR	65.239	64.354	63.494	63.684
PRR	68.536	65.376	0.000	0.000
RGO	68.740	63.924	63.146	63.269
MGO	71.311	0.000	0.000	0.000
PRO	72.817	66.461	0.000	65.954
RGCS	60.584	63.374	62.482	62.737
MGCS	64.198	64.229	63.328	63.613
PRCS	67.307	65.385	64.460	64.754
RGRS	63.727	63.241	92.404	62.549
MGRS	68.727	64.315	99.654	0.000
PRRS	70.766	65.335	102.611	0.000
RGOS	64.050	64.117	63.182	63.523
MGOS	67.490	65.214	64.273	64.622
PROS	70.208	66.444	65.517	65.867
RGCN	59.503	62.958	61.796	62.236
MGCN	62.372	63.884	62.777	63.169
PRCN	66.015	65.040	63.933	64.304
RGRN	61.102	63.271	62.390	62.580
MGRN	65.077	64.344	63.489	63.677
PRRN	67.838	65.367	64.534	64.718
RGON	68.170	63.873	0.000	63.139
MGON	70.214	101.810	101.810	101.810
PRON	71.673	66.541	0.000	0.000

Table 5 (*Continued*)

Variable units	Actual 2000	Baseline 2015	National ban	Renewable std.
		Quantity consumed (bil. bbl)		
RGCSN	63.091	63.421	62.850	62.821
MGCSN	66.034	64.357	63.568	63.845
PRCSN	69.490	65.525	64.700	64.980
RGRSN	65.713	63.255	95.284	62.557
MGRSN	69.613	64.348	100.939	0.000
PRRSN	72.191	65.348	104.677	64.689
RGOSN	66.365	64.292	63.536	63.736
MGOSN	69.224	65.438	64.573	64.891
PROSN	71.241	66.629	65.811	0.000

Gas type UWXYZ. UW = RG: regular, MG: migrade, PR: premium; X = C: conventional, R: reformulated, O: oxygenated; Y = blank for winter, S: for spring; Z = blank for South, N: for north.

Table 6
Ethanol utilization, by fuel type policy

Fuel type	Actual 2000 (in bil. bbl)	Baseline 2015 (in bil. bbl)	Ban with oxygen std. (in bil. bbl)	Ban with averaging (in bil. bbl)
Conventional	0.0291	0.075	0.039	0.115
Reformulated	0.0096	0.025	0.065	0.000
Oxygenated	0.0006	0.004	0.004	0.004
Total	0.0393	0.104	0.108	−0.119

The changing pattern of ethanol consumption is summarized in Table 6. About 3/4 of ethanol is used in the conventional gasoline market under the baseline. With the ban and the oxygen standard, the dominant market is reformulated fuel. With the RFS, ethanol use shifts back to conventional fuel.

The RFS involves the largest corn demand expansion and price increase because the ethanol output increase is largest. The 1,250 mil. bu expansion of corn demand is substantial, amounting to 12% of year 2000 corn production. The estimates suggest an increase in the real corn price of $.35/bu, which would restore the real corn price at levels of the mid 1990s.

6.2. Surplus measures

Table 7 contains a comparison of welfare measures. Moving from the baseline to the ban suggests reductions in consumer surplus, profits and tax collections, which are partly offset by increased marketing margins. There is a net welfare loss of about $60 per person annually. The renewable averaging provision with the ban allows consumers and profits to recover some of the welfare loss associated with the ban and the oxygen standard but the marketing margin declines. Further, the high net welfare suggests an efficiency gain with RFS of about $2 per person annually.

Table 7
Surplus measures

Fuel type	Actual 2000	Baseline 2015 w/EPA reg/ oxy std.	Ban with oxygen std.	Ban with averaging
Consumer surplus (bil. $)	118.966	212.809	191.721	202.755
Gasoline	118.95	212.695	191.602	202.609
Reformulated	41.159	76.606	56.685	65.09
Conventional	74.368	129.829	132.385	131.409
Oxygenated	3.424	6.261	2.532	6.111
Corn byproducts	0.016	0.114	0.119	0.146
Profits	25.134	37.927	34.826	37.113
Petroleum				
Producers	43.75	40.606	36.204	37.246
Processors	4.263	2.864	6.448	6.498
Additives				
Producers	−25.1	−12.868	−14.939	−15.065
Input chemicals	1.723	3.751	3.367	3.857
Corn				
Producers	0.059	0.421	0.441	0.539
Processors	0.439	3.153	3.305	4.038
Net marketing margin	5.859	63.316	69.434	56.576
Retail gasoline revenues	190.32	260.85	252.873	246.335
Wholesale expenditures	184.461	197.534	183.439	189.759
Additives	29.282	38.27	34.497	36.579
Refinery gasoline	158.36	152.565	141.91	144.531
Ethanol	1.713	9.086	9.476	11.35
(Less)subsidies	−4.894	−2.387	−2.444	−2.701
Extraction from sector: excise tax	48.502	64.663	60.313	61.778
Net sector surplus	189.462	249.391	235.668	234.668
Total welfare	237.964	314.054	295.981	296.446

6.3. Emissions implications

EPA standards that restrict the rate per mile traveled effectively constrain emissions per gallon of gasoline used with given auto technology (fuel economy and emission control technology). Accordingly, the total emissions estimate (Table 8) equals the constrained emission rate per mile multiplied by fuel economy and total gasoline consumption. Total emissions can still increase with higher gasoline consumption, even when EPA constraints are satisfied.

In the baseline solution, the VOC constraint binds in all reformulated summer fuel. Also there is a binding vapor constraint in conventional gas. However, TOX was not constraining, and NOX constrained the solution only in winter reformulated fuel. In comparing the emissions for 2000 and the 2015 baseline, VOC emissions increase about 20%, reflecting the increase in total gasoline consumption with a slightly lower emission rate. The toxic emissions actually decreased from 2000 to 2015; the rate of toxic emissions was generally not constraining for

Table 8
Emissions

Fuel type	Actual 2000	Baseline 2015 w/EPA reg/ oxy std.	Ban with oxygen std.	Ban with averaging
Volitile organic compounds				
Reformulated area (mil. met. ton)	0.905	1.130	0.936	0.970
Conventional area (mil. met. ton)	3.975	4.088	3.981	4.156
Toxics				
Reformulated area (mil. met. ton)	0.051	0.047	0.040	0.043
Conventional area (mil. met. ton)	0.145	0.094	0.091	0.093
Nitrous oxide				
Reformulated area (mil. met. ton)	1.159	1.469	1.225	1.267
Conventional area (mil. Met. ton)	2.626	2.892	2.853	2.905

either solution. Finally NOX emissions increase between now and 2015. Imposition of an MTBE ban seems to reduce all categories of pollutants in all types of gasoline, perhaps due to the reduction in the quantity of gasoline consumed.

7. Summary and conclusions

Ethanol competes on the basis of quality and cost in the gasoline additives markets. The potential for demand expansion resides in clean air regulations, health restrictions aimed at safe drinking water, and the notion that renewable fuels may help stem energy supply and global warming problems. Some likely developments in markets and revisions in policies are investigated, using a simulation model that accounts for the effect of changing prices on the demand for gasoline; competition in additives markets and processing; and developments in the factor markets for petroleum, corn and chemicals.

The first scenario assumes that the year 2000 EPA clean air regulations are in place (complex model including oxygen standard), the most likely petroleum market conditions occur and expansions in gasoline demand over the next 15 years are plausible. The demand expansion favors additives. Additives expand relatively more (56%) than refinery gasoline output (20%), even though petroleum becomes more competitive. Also, the ethanol industry could double from its present size by 2015. The ethanol demand growth occurs partly in reformulated fuel for oxygen content, but the demand expansion for conventional fuel is larger.

In the second scenario, the MTBE ban extends nationally. This causes increasing gasoline prices and welfare losses for consumers of reformulated gasoline that are only partly offset by reduced gasoline prices and welfare gains for consumers of conventional gasoline; the net welfare loss for the US gasoline and additives sector is on the magnitude of $60 per person annually. Interestingly, the long-run expansion in ethanol demand associated with a national MTBE ban is moderate compared to the 2015 baseline, on the order of 3.5%; when ethanol replaces MTBE in the reformulated fuel market, falling chemical input prices make other additives, such as alkylates, more competitive in the conventional fuel market. Hence, the long-run welfare gains for corn producers and processors associated with a national ban are also slight.

In the third scenario, a renewable fuel requirement for 5.0 bil. gallons (0.119 bbl) was considered in conjunction with a national ban. Then the overall welfare loss associated with the MTBE ban declines; efficiency is improved some; ethanol demand reorients towards the conventional octane market without the oxygen restriction and reformulated gasoline is produced using alkylates. Thus, summer reformulated gasoline prices return to the baseline levels.

Overall there is a net reduction in market-based welfare when the renewable fuel standard or the national ban are implemented. But the economic cost may be more than offset by environmental improvement; emissions of the EPA's clean air criteria pollutants all improve with the renewable standard or the ban; removal of MTBE may reduce cancer risk; and expanding ethanol production likely improves global warming. The policy judgment must weigh the market costs against more intangible environmental benefits.

In any event, the simulations suggest that ethanol will be a source of improving profits for corn producers and processors under all three policy scenarios. According to these estimates, gasoline additives will continue to have a growing role in gasoline supplies, and ethanol participates in this expansion. The largest corn demand expansion is associated with the 5.0 bil. Gallon mandated ethanol market, which would restore real corn prices to mid-1990s levels. A previous study concluded that competition for the land and corn resource should limit the ethanol industry to the present size (Meekhof, Tyner, & Holland, 1980). But the economic environment has changed to a stagnant export market with growing productivity; therein lies the potential for expanding biofuels.

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