The Renewable Fuel Standard Program:
Measuring the Impact on Crude Oil and Gasoline Prices

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Executive Summary

This paper examines the impact of the Renewable Fuel Standard program (RFS), which began fourteen years ago in 2005, on the prices of crude oil and gasoline. The particular focus is on the period from 2015 to 2019. The conclusions offered from this research are that the RFS program has provided two benefits: lower crude oil and product prices for US and world consumers and greater energy security for the United States.

The paper is divided into three parts. The first frames the discussion by demonstrating the RFS' consumer benefit. Retail gasoline prices are lower thanks to the program. The findings from an econometric model show that the savings to consumers resulting from the RFS averaged $0.22 per gallon from 2015 through 2018.

The second part of the paper addresses the additional energy security benefits derived from the RFS. The availability of renewable fuels reduces the dependence of consuming nations on petroleum. This diversification is important when global production is disrupted by war or political actions such as sanctions. An earlier version of this study prepared in 2014 showed that the availability of renewable fuels during the Libyan government's collapse between 2011 and 2014 reduced global crude oil prices as much as $40 per barrel.[2] This reduction saved US consumers as much as $1 per gallon in fuel costs.

Consumers have enjoyed a similar benefit more recently because the availability of renewable fuels limits the ability of oil-exporting countries to raise crude prices. In the past three years, a group of exporting nations that includes OPEC members and Russia engaged in a joint effort to raise crude prices by cutting production and succeeded.

At the same time, though, the effectiveness of such strategies has been constricted by the availability of renewable fuels. Additional volumes of these fuels can be blended into gasoline when crude prices pass a certain point if regulations allow and refiners will make the

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[2] See Philip K. Verleger, Jr., "The Renewable Fuel Standard: How Markets Can Knock Down Walls," PKVerleger LLC, March 2018 [https://tinyurl.com/ydz2rzqr].

substitution, and the possibility of such replacement dampens how much oil-exporting countries can extort from US and world consumers.

Working against this effect, however, are the competitive conditions in the refining industry, which reduce the potential for renewable substitutions. While some refiners and marketers will use additional ethanol for the good of consumers, others will not.

The final section of this report briefly examines those competitive conditions, noting that in some US regions, the market concentration is high enough to discourage renewable fuel use. In these areas, consumers pay higher prices due to the market concentration and the unwillingness of the dominant firms to increase their renewable fuel blending.

I. QUANTIFYING THE BENEFITS OF RENEWABLE FUELS

The first and most obvious benefit from renewables lies in the price of crude oil. The blending of approximately one million barrels per day of ethanol into U.S. motor fuels over the 2015-2018 period has lowered the average price of crude by $6 per barrel. This reduction has cut the retail gasoline price by $0.22 per gallon from the level that would have obtained absent the presence of ethanol in the motor gasoline supply.

The lowering of gasoline prices confers a second benefit on consumers. Because gasoline demand is price inelastic, consumers have been able to allocate a smaller percentage of their total consumption budget to fuel purchases. This has allowed them to expend more on other goods. Over four years, US consumers have been able to spend almost $90 billion per year more on other goods because of gasoline prices being pulled down by renewable fuel use.

The annual savings in consumption represents 0.33% of the US nominal GDP. Allowing for multiplier effects, one can conclude that the use of renewable fuels has raised the US GDP by 0.5% in each of the last four years relative to the level that would have been observed had the RFS program not required the blending of ethanol into gasoline.

The benefits of ethanol may have been even greater, though, because the use of renewable fuels has reduced global demand for crude oil. Over the last two years, a group of oil-exporting countries (OPEC+) has worked to limit global supplies and boost world prices. Their efforts have had some success. That success would have been greater had almost one million barrels per day of renewable fuels not been blended into the fuels consumed by the public. Since many of the OPEC+ countries seek a higher price than what has been achieved, one can surmise, again, that the economic benefits of renewable fuels may have been greater than the amount calculated here.

These findings are based on a simulation run using a model of the global crude market called the “but-for” or BF model. The BF model is linked to an equation that ties the crude price to the retail gasoline price. The model was first calibrated to actual data and then simulated under the assumption that the volume of renewable fuels in the US fuel supply was reduced due to the ending of the RFS in January 2015 (hereafter, the “No RFS” case).

The simulations produced price scenarios for crude oil and gasoline that would have occurred in a situation where smaller volumes of renewable fuels were blended into the US fuel supply. The higher gasoline prices were then used to determine how much consumers would need to reallocate from purchases of other goods and services to gasoline.

The discussion that follows is divided into four parts.

- The first part explains how renewable fuel use has helped lower the world price of crude oil. The BF model is also introduced.
- The second shows how lower usage of renewable fuels in the "No RFS" case starting in January 2015 would have pushed up crude prices.
- The third shows how lower usage of renewable fuels in the "No RFS" case starting in January 2015 would have pushed up gasoline prices.
- The fourth discusses the cost to consumers of reducing renewable fuels consumption under the "No RFS" case starting in January 2015.

The paper ends by offering conclusions on the impact of lower US renewable fuels consumption on global crude oil prices, US retail gasoline prices, US consumer spending, and US gross domestic product.

The analysis of the RFS program starts from January 1, 2015. This date was chosen because 2015 was a unique year for the global oil market. At the end of November 2014, OPEC abandoned its efforts to control oil prices and began producing at full capacity. For the first time in at least fifteen years, the organization made no effort to limit global crude output. All available capacity to produce crude oil was put into service.

The resulting absence of any surplus productive capacity created a situation where removing any supply source would cause prices to increase. Prices would have risen had the 951,000 barrels per day of renewable fuels blended into US petroleum supplies at that time been taken away because no alternative hydrocarbon sources were available.

These circumstances persisted until late 2016 when Russia and Saudi Arabia began to discuss removing some crude oil from the market to raise global crude prices. Thus, the two-year period from January 2015 to December 2016 provides a unique test of the RFS program's consumer price impact and its benefits to the economy.

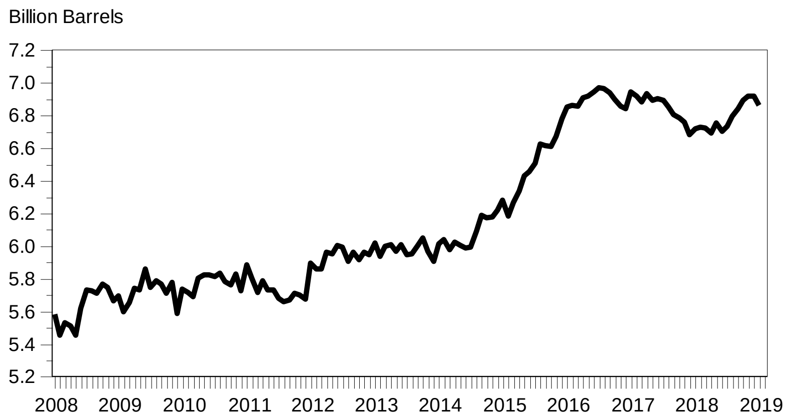
1. Impact of Renewable Fuels Use on Global Crude Oil Prices

To assess the impact of ethanol use and the RFS program on consumer gasoline prices, a model was constructed of global crude oil prices. Renewable fuel use in the US has removed a substantial portion of crude oil demand from the world market, which, under the tight supply environment that existed from 2011 to 2014, reduced the magnitude of the price increase that would have otherwise occurred. The model calculates the Dated Brent (DB) oil prices that would have prevailed "but for" the RFS program using an econometric approach that relates changes in DB prices to changes in inventories and seasonal variables.

The Energy Intelligence Group (EIG) publishes detailed data on inventories held across the globe and enables analysts to separate commercial inventories from strategic stocks. Figure 1 shows data on total global commercial stocks of crude and products. Government-controlled strategic stocks, which account for approximately 16% of world inventories, are excluded. Experience shows that these stocks have been "sterilized," that is, they are never used and therefore do not factor into price formation. In this study, the movement of commercial stocks and prices was compared to an indicator of the influence of financial markets on these two items.

The role of inventories and consumption in price formation has been studied by economists for centuries. Invariably, the basic conclusion is simple: prices are less likely to rise if there are ample supplies relative to the amount demanded by consumers than they are if the available supplies are limited compared to the amount demanded. The analytical way of expressing this simple relationship is to compute a ratio between the level of demand and the level of consumption.

Figure 1
Global Commercial Inventories of Crude Oil and Petroleum Products, 2008 to 2019



Source: Energy Intelligence Group.

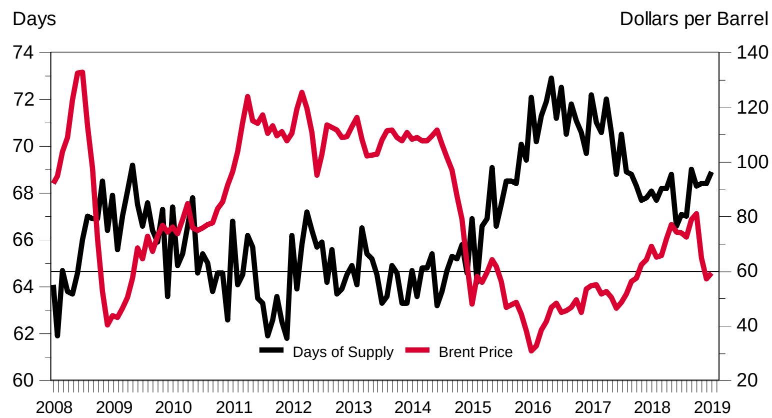
Figure 2 (page 5) compares the DB price movement to the levels of consumption divided by inventories, expressed as the number of days of consumption that are covered by supplies. The data shown in the graph seem to confirm this relationship. Note that DB prices were very high in 2008 when inventories were low relative to consumption. Prices dropped as stock coverage rose in 2009 and 2010 and then rose back to high levels until the end of 2014 when OPEC abandoned production controls. Days of coverage then rose again, and prices fell.

In modeling this relationship, the practice noted in other commodity market models was followed. Specifically, monthly data on the crude price change was regressed on the change in a sequence of current and lagged values of inverse days of supply (the standard method of measuring inventory/consumption relationships) and seasonal dummy variables. The equation takes this form:

$$\Delta P_t = \alpha + \beta_1 \Delta(1/day_t) + \beta_2 \Delta(1/day_{t-1}) + \beta_3 \Delta(1/day_{t-2}) + \beta_4 \Delta(1/day_{t-3}) + \beta_5 \text{ Volatility} + \beta_6 \text{ N14} + \varepsilon$$

P_t represents the DB price; *1/day* represents the reciprocal of commercial days of supply with the subscript identifying days of supply at the end of the current month (current consumption divided by end-of-month stocks), the previous month, two months previous, and three months previous; *Volatility* measures the volatility of oil prices; *N14* is a dummy variable to mark the breakdown in OPEC control of production that occurred in November 2014. The parameters α and β_1 through β_6 are estimated using standard statistical techniques.

Figure 2
Days of Supply of Commercial Crude and Product Stocks vs. Dated Brent Price, 2008 to 2019



Source: PKVerleger LLC>

The model was estimated using the monthly data shown in Figure 2 for the period 2006 through 2013. Table 1 lists the estimated parameters and the standard summary statistics.

In addition to the measures of days of supply, the model includes two additional variables that account for key structural developments in the global oil market. First, the model includes an adjustment for the breakdown of the OPEC cartel in November 2014. At the OPEC meeting held that month, the Saudi oil minister concluded that the organization could not make the cuts in output required to bring the market into balance given the surge in US oil production. As a result, Saudi Arabia announced that it would produce at capacity. The organization's efforts to stabilize prices were suspended. The current model includes a dummy variable for the November 2014 breakdown.

Table 1: Estimated Parameters and Summary Statistics for Inverse Days of Supply Price Model

Parameter	Coefficient	Standard Error	t-Statistic
α	0.06		
β_1	2,671.67	3,240.29	0.82
β_2	2,325.91	3,669.59	0.63
β_3	6,106.65	3,660.04	1.67
β_4	4,937.21	3,229.09	1.53
β_5	-0.24	0.13	-1.81
β_6	-9.35	5.65	-1.65

$R^2 = 0.199$
Standard Error = $6.17 per barrel
Source: PKVerleger LLC.

Second, the model contains a variable measuring price volatility. Price volatility is a surrogate for the demand for futures by the firms that are writing options to producers that have hedged by purchasing puts. At the end of the third quarter of 2018, such hedges covered 700 million barrels.

The introduction of this type of activity in the oil and other commodity markets is a relatively new development that, in the case of oil, has only come into use in the last ten years. It involves the issuance of price insurance to producers such as independent oil companies or consumers such as airlines by financial institutions. These institutions, in turn, buy or sell oil, creating claims on physical barrels with changes in prices. Price volatility provides a way of measuring these unseen but very real determinants of prices. In essence, increases in price volatility can cause an increase in demand for short futures positions given the price levels chosen by oil producers.[3]

Readers may note that the equation explains only 20% of the variance in the dependent variable. This should not come as a surprise because the dependent variable measures the change in DB, not the level of DB. The procedure used here is a standard approach taken to remove the effect of autocorrelation from the data when the predicted values are compared to the actual values after "reconstructing the variables." (In other words, explaining the predicted price based on the data for the current month and the previous month's price, the equation explains 80% of the variance.)

The parameters on the inverse of days of supply remained close to the original values. All had the correct sign, meaning an increase in inverse days of supply caused prices to increase, while a decrease caused prices to decline.

The parameter on volatility was significant and again had the correct sign. An increase in volatility tends to cause prices to decline because those who are writing puts will enter the market and sell futures, effectively adding to the oil supply.[4]

The dummy variable for the OPEC November 2014 collapse was also significant. This suggests that prices dropped by $9 per barrel in each of the two months when the value was one: December 2014 and January 2015.

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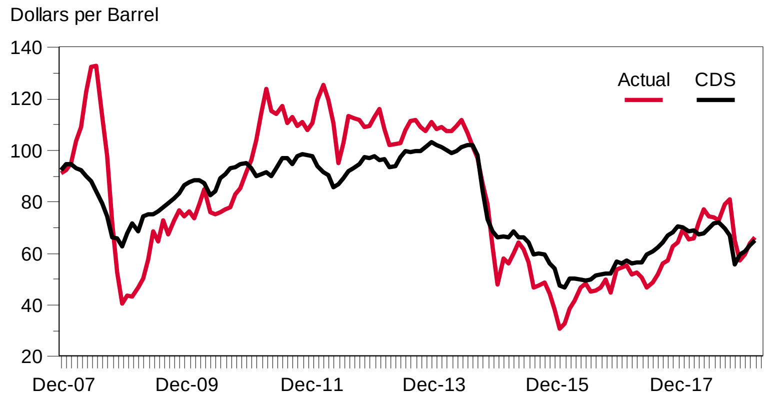
[3] As volatility increased, the firms writing the hedges were forced to sell more futures to remain "delta neutral." The selling sent prices down from $85 per barrel to $50. This activity is now an important determinant of oil prices. The delta measures the number of barrels of crude a firm writing the insurance to a producer or consumer would need to buy or sell as the price of oil changes. For further details, see Franklin R. Edwards and Cindy W. Ma, *Futures and Options* (New York: McGraw Hill, 1992), Chapter 19.

[4] The following example may help. Suppose Bank A has guaranteed a producer that it will receive at least $60 per barrel for its production in 2019. This means that Bank A will need to pay the producer the difference between the price received and $60 per barrel *if* the price falls below $60. The bank will acquire assets that will provide it with insurance against such a loss. Few assets will be acquired if prices are high, say $90. More assets will be acquired as prices fall. An increase in volatility will predict that the probability of prices being less than $60 has increased. To protect against losses, the bank will need additional assets. One type of asset purchase is a put. A second is a short position against crude oil. One form of the short is the sale of a future.

To test the model's usefulness, a "conditional dynamic simulation" (CDS) was run. In a CDS, one uses the model to compute the predicted price based on the exogenous variables, using the predicted rather than the actual value for the dependent variable for period t-1. Thus, the predicted value for December 2018 is based on the actual price of Brent 121 months earlier in December 2007 and the changes in the exogenous values since the date. There are no corrections for errors in a CDS.

Figure 3 compares actual DB prices to the values calculated by the CDS. As can be seen from the graph, the model tracks the actual price movement, particularly from January 1, 2015, to December 31, 2018. Sixty-five percent of the variance in the DB movement was explained by the CDS.

Figure 3
Actual Dated Brent Prices vs. Prices Predicted by CDS Model, January 2007 to March 2019



Note: CDS = conditional dynamic simulation.
Source: PKVerleger LLC.

2. Impact of Reducing Renewable Fuels Consumption on Crude Oil Prices

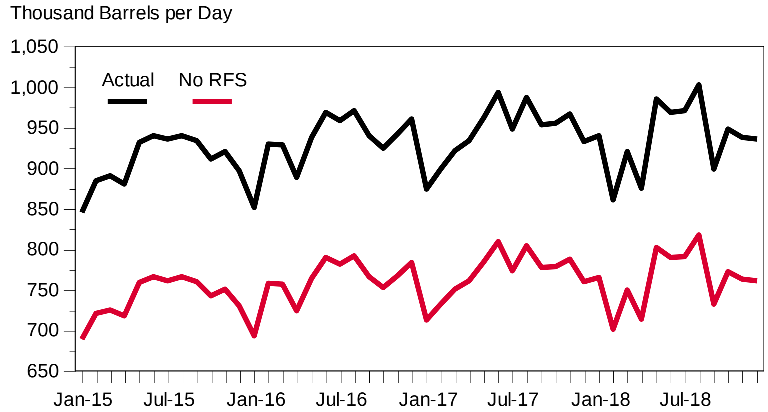
The model linking crude price fluctuations to inventories can also be used to assess the specific impact of the RFS program. Specifically, the cancelation of the RFS on January 1, 2015, would have lifted crude by $8 per barrel by the end of 2018. Over the 2015 to 2018 period, crude oil prices would have been $6 per barrel higher on average.

This assessment assumes that the RFS program stopped on January 1, 2015. At the time, almost one million barrels per day of renewable fuels were being mixed into US petroleum product supplies. Cancelation of the RFS program would lead to a reduction but not a full termination of ethanol blending. It is assumed that market economics, not regulation, drive approximately 80% of current ethanol blending with gasoline, with the RFS prompting the remaining 20%. Thus, some volume of ethanol would presumably continue to be blended even if the RFS had ended. Figure 4 (page 8) compares the actual volumes of ethanol blended with estimates of the volumes that would have been used in the RFS' absence.

Reducing the volume of renewable fuels would have led to a decline in global stocks because there were no constraints on the volumes produced by OPEC members or any other oil-exporting country.

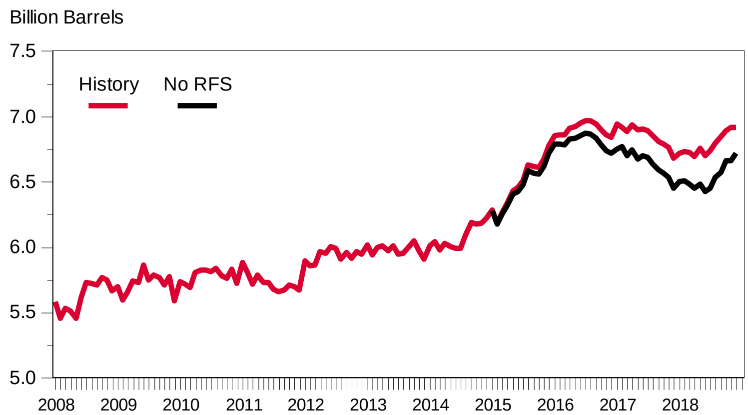
Figure 5 shows the trend that would have occurred in global stocks had the RFS not been in effect after January 2015. By December 2018, global stocks would have fallen to the levels last observed in late 2016. As Figure 6 (page 9) illustrates, the lower inventories would have pushed global crude prices higher. A simulation with the BF model shows that the DB price would have increased by more than $8 per barrel by the end of 2018 and would have been $6 per barrel higher on average over the 2015-2018 period.

Figure 4
Renewable Fuel Volume Blended into US Motor Fuels vs. No RFS Volume, January 2015 to December 2018



Source: US DOE; PKVerleger LLC.

Figure 5
Global Commercial Crude and Product Stocks: History vs. Stock Levels If RFS Program Had Ended after 2014



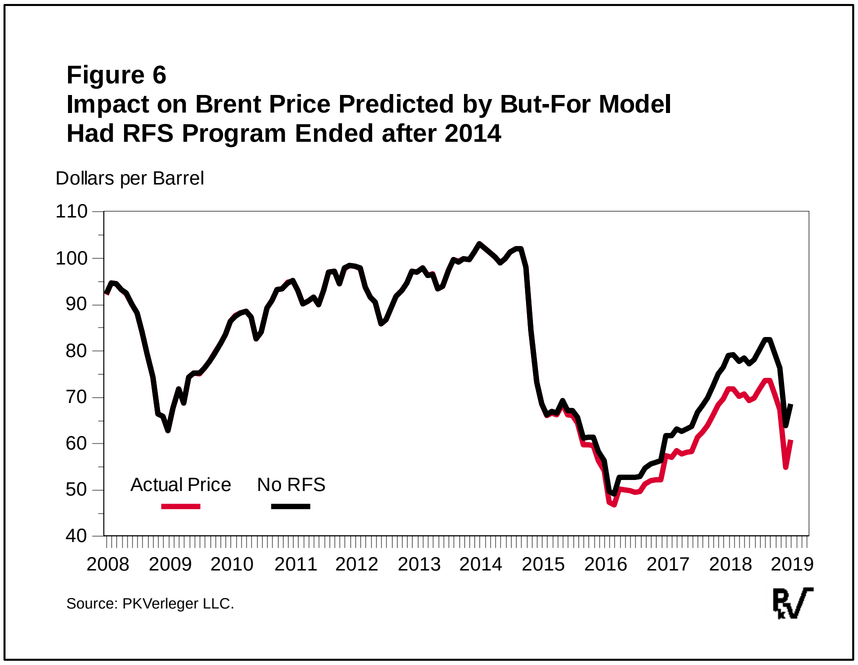
Source: US EIA; PKVerleger LLC.

Actions by OPEC members require that the increase in the crude price associated with reducing renewable fuels blending in US petroleum supply be divided into two intervals: 2015 through 2016 and 2017 through 2018.

During the first two years, there were no constraints on global crude production. Saudi Arabia elected to abandon limits on output, hoping to stop further expansion by the US independent oil producers known as "frackers." This action caused prices to fall as low as $32 per barrel in 2015. The surge in US light tight oil (LTO) production led to the global inventory increase discussed above.

The reduction of renewable fuel blending in the United States simulated here would have brought world stocks down and pushed prices higher. The BF model projected that by December 2016 DB would have traded for $56.50 per barrel rather than the $53.80 reported, a 5% difference.

By the end of the simulation period in December 2018, one finds that the price has risen to $68.50 per barrel, 13% higher than the $57 price reported for the year-end. The average increase in oil prices in the no-RFS case over the entire period is $6 per barrel.



3. Impact of Reducing Renewable Fuels Consumption on Gasoline Prices

Changes in crude prices have a direct effect on the gasoline price. The impact of reducing renewable fuel use on this price was tested using a simple regression between the change in the retail gasoline price and the change in the spot crude price. The specification of the model was as follows:

$$\Delta Gas_t = \beta_1 \Delta(P_t) + \beta_2 \Delta(P_{t-1}) + \varepsilon_t$$

where ΔGas_t measures the change in the retail gasoline price from one month to the next and $\Delta(P_t)$ measures the change in Brent crude price.

The equation was estimated for all types of regular gasoline. The estimated parameters are shown in Table 2.

Table 2. Estimated Parameters and Summary Statistics for Gasoline CDS Model

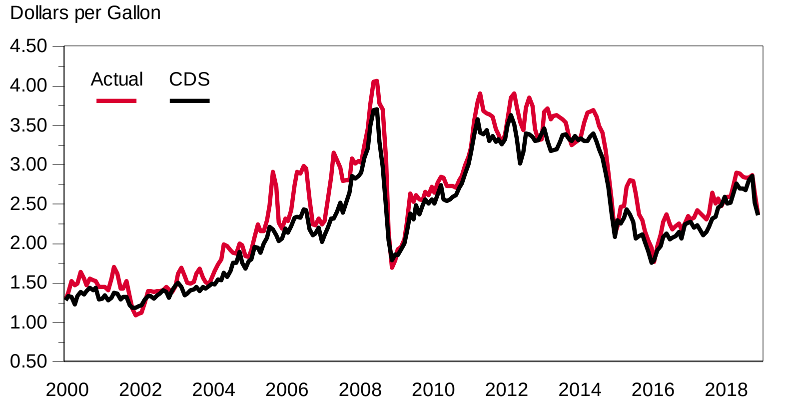
Parameter	Coefficient	Standard Error	t-Statistic
β_1	0.76	0.13	5.66
β_2	0.24	0.13	1.79

R^2 = .27
Standard Error = $0.23/gallon
Source: PKVerleger LLC.

The equation explains 99% of the variance in the level of gasoline prices one month ahead.

Once again, CDS was used to test the model's reliability. The simulations performed well, as can be seen from Figure 7. This graph shows the movement of retail gasoline prices compared to the prices predicted from the simulation. For the simulation period of 227 months, the model explains 95% of the retail price variance even though the simulation used only the actual retail gasoline prices from January 2000.

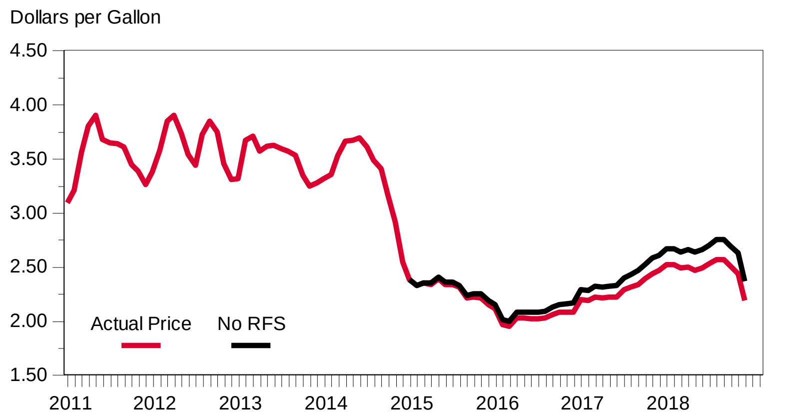
Figure 7
Actual US Retail Gasoline Prices vs. Prices Predicted by CDS Model Linking Changes in Retail Prices to Changes in Dated Brent Prices



Note: CDS = conditional dynamic simulation.
Source: PKVerleger LLC.

A second CDS was then conducted using the DB prices predicted by the crude oil price model under the assumption that the RFS program would have been terminated after December 2014. The results from this CDS appear in Figure 8. In this simulation, retail gasoline prices rose to $3 per gallon in September 2018.

Figure 8
Impact on Retail Gasoline Price Predicted by But-For Model Had RFS Program Ended after 2014



Source: PKVerleger LLC.

The US Energy Information Administration reported that the actual price for retail gasoline sold in September 2018 was $2.83 per gallon. Thus, by September 2018, retail gasoline prices would have been $0.22 per gallon higher (7%) than reported, as Figure 8 shows.

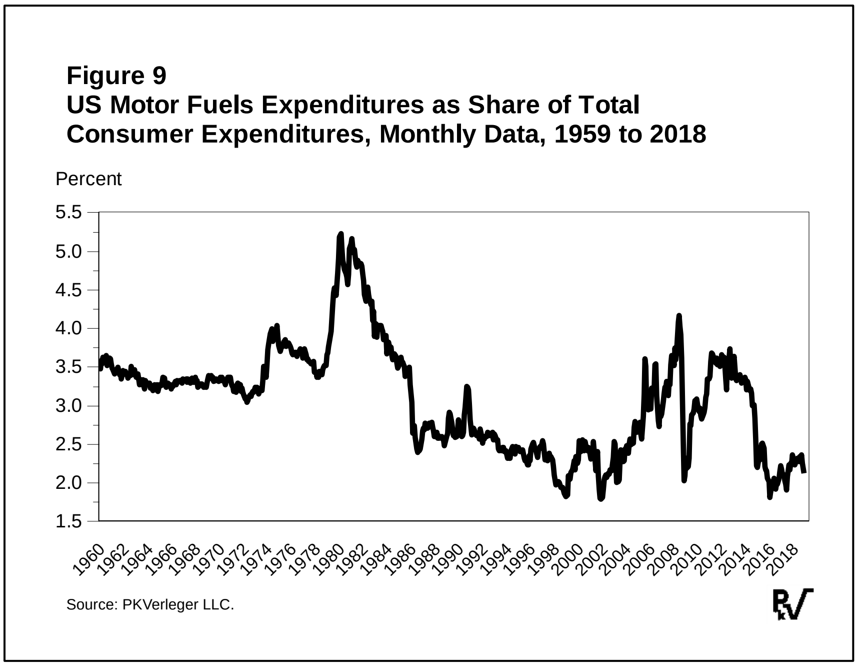
4. The Cost to US Consumers of Reducing Renewable Fuels Consumption

Professor James Hamilton has studied the impact of fluctuating energy prices on US economic activity for decades. Following the rise in US oil prices in 2008, he wrote an important article assessing the increase's effect on domestic economic activity.[5] He began by noting that the National Bureau of Economic Research had concluded that a recession had begun in the fourth quarter of 2007 and then noted that the likelihood of a recession starting at that time would have been low but for the rise in oil prices.

Hamilton then described the critical link between consumer expenditures, economic activity, and oil prices. Starting from the fact that US economic activity is critically tied to consumption, which accounts for 68% of GDP, he explained that increases in energy prices depress consumption of all other goods and services:

> Another key parameter for determining the consequences of an energy price increase is the value share of energy purchases in total expenditure. The fact that the U.S. income elasticity of demand has been substantially below unity over the last quarter century induces a downward trend in that share: for a given relative price, if the percentage growth in energy use is less than the percentage growth in income, total dollar expenditure on energy will decline as a percentage of income. On the other hand, the very low short-run price elasticity of demand causes the value share to move in the same direction as the relative price: if the percentage increase in price is greater than the percentage decrease in quantity demanded, dollar spending as a share of income will rise when the price of energy goes up.

This effect is captured in two figures. Figure 9 shows total expenditures by US consumers on motor fuels as a percentage of total consumption expenditures by month from 1960. One can observe that from 1960 to 1974 roughly 3.5% of consumer expenditures were allocated to motor fuels. The share then jumped to 4% following the Arab Embargo and 5% in 1980 after the fall of the Shah in Iran. The share plummeted in the mid-1980s at the time of the price collapse and rose back to 4% in 2007. It has oscillated since 2010.



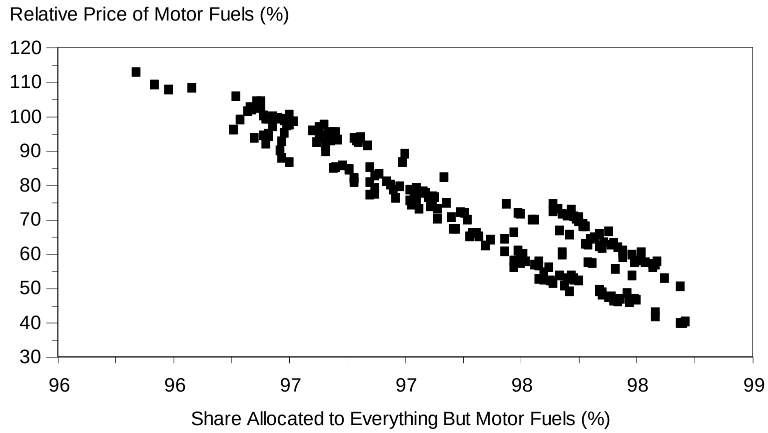
The data used to produce Figure 9 come from the national income accounts. The US Bureau of Economic Analysis publishes detailed statistics on the allocation of consumer spending. Figure 9

[5] James D. Hamilton, "Causes and Consequences of the Oil Shock of 2007-08," *Brookings Papers on Economic Activity*, Spring 2009 [https://tinyurl.com/y3l6uuwn].

was created by taking the amount spent on motor fuels, one of the three hundred spending categories, as a percentage of total consumption.

A key finding of this exercise is that consumers spend less on other items when gasoline prices are high and more on other goods and services when prices are low. Figure 10 shows this effect. This graph shows the share of consumer spending allocated to “everything but motor fuels” as a function of the relative price of motor fuels.

Figure 10
Share of US Consumer Spending Allocated to Goods and Services Other than Motor Fuels as Function of Motor Fuel Price Relative to Price of All Other Consumer Goods



Source: PKVerleger LLC.

The relative price of motor fuels was calculated using the standard approach of comparing the gasoline price to the price of all the items purchased by consumers. The data shown in Figure 10 are for the period from 2000 to 2018. One can note from the graph that 96% of consumer spending goes to items other than motor fuels when prices are high, and 98% of consumer spending goes to items other than motor fuels when prices are low.

The two-percentage-point difference between the amount spent on gasoline when prices are low compared to when prices are high is worth almost $300 billion today. This amounts to 1.4% of GDP. As Hamilton has shown, a rise in the relative price of motor fuels from a low level to a high level that would cut consumption on other goods by 1.4%—specifically, rising from 40% of personal consumption expenditures to 120%—could, after multiplier impacts, lower GDP as much as three percentage points.

This methodology was used to estimate the impact of if the RFS program had ended beginning in 2015. This was done by first translating the 7% increase in gasoline prices calculated in the previous section to the gasoline price deflator.

The effect of the higher gasoline prices on consumer expenditures from 2015 to 2018 can be seen from Figure 11 (page 13). By the end of 2018, consumer spending on all other items would have been reduced by $88 billion. This would represent 0.33% of the US GDP. The impacts on US GDP would be greater, though, due to “multiplier” effects. Economic research has shown that a decline in consumer spending often has these secondary effects because cuts in spending by consumers cause businesses to respond by cutting employment. For example, a decline in purchases at restaurants will lead to layoffs in the sector. The laid-off workers will spend less, adding to the losses begun when gasoline prices increased. US GDP would have been as much as 0.5% lower than the $20.5 trillion reported for 2018.

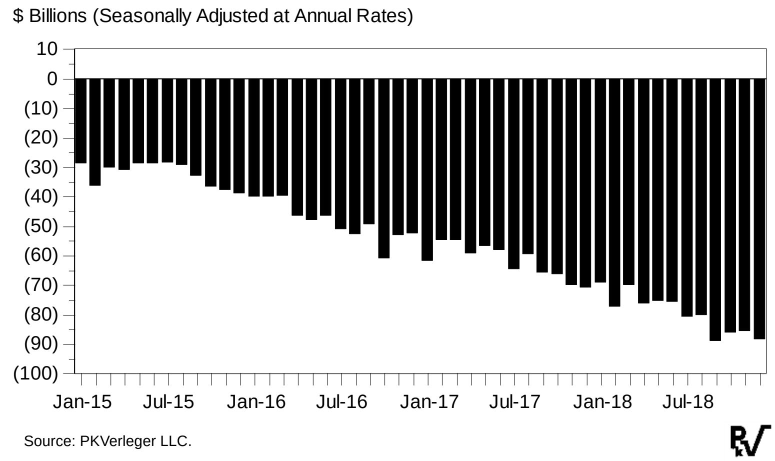


Figure 11
Loss in Consumer Expenditures Resulting Had the RFS Program Ended after 2014

5. Conclusions

In calling for the expansion of the RFS program in his 2006 State of the Union message, President George W. Bush noted that the United States had become "addicted to oil." President Bush couched the proposal to increase renewable fuel use in the context of energy security. The economic value of renewables was not in dispute, though, because the focus of his speech was on "keeping America competitive." The opening sentence in his discussion of energy addiction said everything:

> "Keeping America competitive requires affordable energy."

This analysis has shown that crude oil prices over the last four years have been 11% lower than they would have been had the United States ended the RFS program in January 2015, at a time when oil-exporting countries abandoned their efforts to limit output. The decline in consumption of renewable fuels would have cut the supply of fuels and led to a steady increase in prices.

The almost one million barrels per day of renewable supplies that helped reduce crude prices have also directly affected gasoline prices. Retail prices would have been 10% higher over the last four years had the RFS been suspended in 2015. The lower gasoline prices, in turn, allowed consumers to spend more on the things they wanted rather than motor fuels, which, while essential to their needs, are not an item that provides a sense of satisfaction to most individuals. The economic benefit of lower gasoline prices that is directly attributable to the availability of renewable fuels adds as much as 0.5% to US GDP every year.

The calculations presented here actually underestimate the full benefit of renewable fuels. Crude oil prices are today 44% lower than they would have been had the United States abandoned renewable fuels entirely in January 2015 at a time when oil-exporting countries dropped their efforts to limit output. The removal of renewable fuels would have cut the supply of hydrocarbons and led to a steady increase in price.

The almost one million barrels per day of renewable supplies lost would have also directly affected gasoline prices. Retail prices would today be above $4 per gallon, not $2.90, were renewable supplies removed from the supply mix. The lower gasoline prices, in turn, allowed consumers to spend more on the things they wanted rather than motor fuels, which, while essential to their needs, are not an item that provides a sense of satisfaction to most individuals. The economic benefit of lower gasoline prices that is directly attributable to the availability of renewable fuels adds one to two percentage points to US GDP every year.

II. SECURITY BENEFITS OFFERED BY RENEWABLE FUELS

Energy security has been a key concern in the United States for almost fifty years. Our intensive effort to bolster this security began following the 1973 Arab Embargo. The embargo-related price increase substantially reduced economic activity in the US and other countries.[6] In the following years, the United States worked with other allies to create the International Energy Agency, whose primary purpose was to mitigate future disruptions. The federal government also spent billions to create government-controlled crude inventories, the Strategic Petroleum Reserve, for use in the event of market disruptions. Other energy security measures followed.

Forty-six years after the 1973 embargo, an independent observer must conclude that these measures have failed. As Verleger has noted, there have been nineteen separate market disruptions, each of which led to significant short-run oil price increases. Table 3 (page 15) chronicles these disruptions.

Each market disruption has been characterized by a rise in product prices, which then pulled up crude prices. Verleger previously chronicled the price increases that followed the Iranian revolution and the 1990 Iraqi invasion.[7] Each of these two events was accompanied by a significant increase in product prices. In each case, crude prices followed.

The same effect occurred in 2008 with the introduction of ultra-low sulfur gasoil (diesel fuel). Figures 12 and 13 capture the pull of products on crude. Figure 12 (page 16) traces the percentage increase in gasoil prices in Europe, probably the key spot product price for the last forty years, for each of the three disruptions. Figure 13 (page 16) tracks the percentage change in the gasoil-to-Brent margin by month in each of the episodes.

In each case, the spread between product prices and crude (referred to as the “margin”) increased as the disruption unfolded. The rising margin provides evidence that products lead crude.

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[6] See Edward R. Fried and Charles Schultz, *Higher Oil Prices and the World Economy* (Washington, DC: The Brookings Institution, 1975).

[7] See *Oil Markets in Turmoil* (Lexington, Mass.: Ballinger Press, 1983) for a discussion of the role of products as a cause of the crude oil price increase that followed the political changes in Iran. Re the Iraqi invasion, see “Understanding the 1990 Oil Crisis,” *The Energy Journal* 11, No. 4 (October 1992), pp. 15-32.

Table 3. Effects and Durations of Nineteen Oil Market Disruptions

Event	Start Date	Duration (Weeks)	Price Change (%)	Supply Loss (%)
Arab Embargo	Oct-73	4	231.6	-3.3
Iranian oil strikes	Oct-79	2	15.1	0.2
Saudi Arabia's refusal to increase output	Jan-79	2	64.5	-2.5
Saudi Arabia's cut in supply to major companies	May-79	1	30.7	-0.2
Hostage-taking at US embassy in Iran	Nov-79	14	17.8	-0.3
Outbreak of Iran/Iraq War	Sep-80	2	28.4	-1.5
Iraq invasion of Kuwait	Aug-90	6	58.4	-0.5
OPEC unilateral production cut	Jan-99	12	43.5	0.1
Venezuela oil strike	Nov-02	2	117.5	-5.1
Hurricanes Katrina/Rita	Aug-08	4	11.2	-1.2
Unexpected cut in Nigerian production	Early-07	4	18.8	-1.1
Surge in Chinese distillate demand	Late-07	6	31.1	0.7
EU enforcement of 10-ppm sulfur diesel	Spring-08	6	45.2	-1.3
Collapse of Libyan production	Jan-11	3	27.7	-0.7
Second Libyan collapse	Jul-14	3	15.8	1.3
OPEC 2017 production cut	Jan-17	Ongoing	7.8	-1.7
Hurricane Harvey	Sep-17	3	12.7	-0.6
First Venezuelan production collapse	Nov-17	Ongoing	12.7	0.5
Conoco attachment of Venezuelan assets	May-18	Ongoing		-0.9

Source: PKVerleger LLC.

One can also illustrate this effect by comparing refinery netbacks[8] to spot crude prices. The clear but often misunderstood process is that price spikes begin with aggressive bidding for products by end-users. The importance of products can be explained by two well-known effects of market disruptions: buyers want to boost precautionary stocks, and sellers seek to retain more of their inventories. This phenomenon can be characterized as "hoarding."

The product price boost caused by the hoarding impulse of anxious consumers allows refiners to bid more for crude. Refiners examine the value of the products produced from their facilities daily if not hourly. They will up the price they offer for crude when the products' value rises and cut it when the value falls.

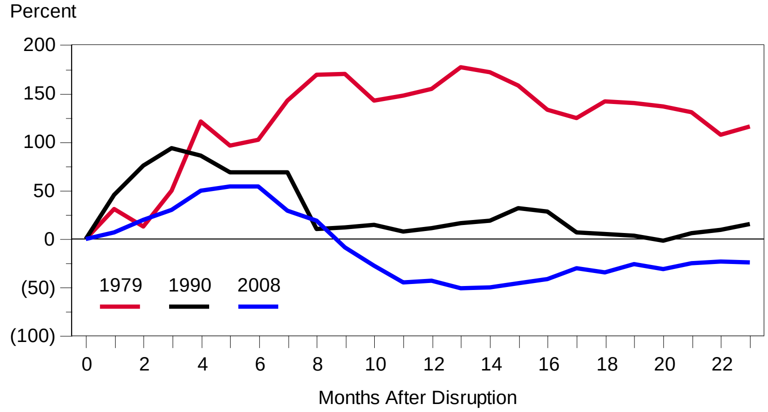
Renewable fuels can limit the process that pushes product prices higher. The suppliers of products, especially gasoline, can and will increase the amount of ethanol blended into motor fuels if the regulations allow and ethanol can be obtained at a favorable price.

[8] Refinery netbacks are the value of products produced from a specific crude less the cost to transport the crude to the refiner.

Statistical tests show that the percentage of ethanol blended with gasoline has varied depending on the ethanol price.[9] Thus, when ethanol has been plentiful and the price relatively low, additional ethanol has been blended into the gasoline supply as gasoline prices have increased.

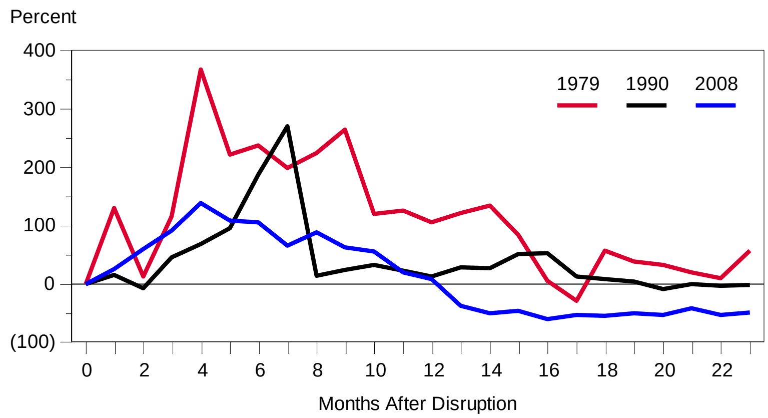
The amount of ethanol would likely have been even greater in the past, though, had the EPA regulations not limited how much ethanol could be blended into gasoline. Historically, the ethanol content of gasoline for use in non-flex-fuel vehicles was limited to 10% (E10). In 2011, the EPA approved the use of 15% blends (E15) for model year 2001 and newer vehicles, but at first sales of E15 were limited. As ethanol hit the 10% "blend wall" in recent years, it has been difficult to push past that even with lower prices; additionally, the fuel supply chain has become configured around using sub-octane blend stocks plus ethanol.

Figure 12
Change in European Gasoil Prices during Three Oil Market Disruptions



Source: Energy Intelligence Group.

Figure 13
Change in European Gasoil Margin during Three Oil Market Disruptions



Source: PKVerleger LLC.

The EIA data indicate that the blending limit has been reached. Figure 14 (page 17) shows the percentage of renewables blended into gasoline by Petroleum Administrative Defense District (PADD) by month from 2009. Recently, the percentages in all regions have approached or surpassed 10%, indicating that the amount blended was at the previous maximum.

[9] The price elasticities are all statistically significant. The results indicated that firms blending ethanol will seek to increase the share of ethanol in gasoline by 1% if the spot price of gasoline rises by 5% if the blending percentage is allowed. The results are limited, though, because the share of ethanol blended in some regions was at the maximum allowed by regulation.

Without the regulatory constraint, the blend percentage would be higher when the discount of ethanol to spot gasoline is large.

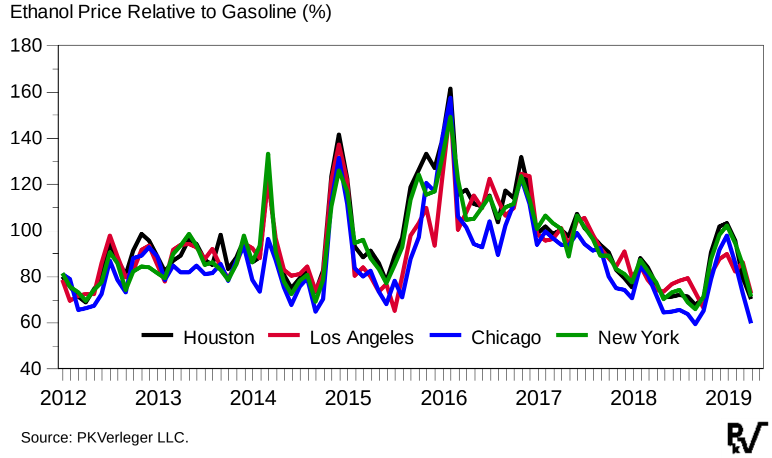


Figure 14
Ethanol Prices Relative to Gasoline Blendstock Prices in Four US Cities, January 2012 to April 2019

EPA's finalization of regulations permitting E15 to be sold year-round, issued May 30, 2019, will give blenders more flexibility going forward.[10] An additional five hundred thousand barrels per day of renewables might be substituted for conventional gasoline if conditions are favorable. This will offer increased protection against future disruptions.

The very low price elasticity of demand for gasoline would likely assure that a modest increase in renewable fuel blending would limit the rise in gasoline and crude prices. This impact is illustrated in Box 1 (page 18).

The flexibility offered to gasoline marketers to vary the amount of renewable fuels blended into gasoline depending on the ethanol price compared to the price of the conventional petroleum-based gasoline provides insurance against very large gasoline price increases during a disruption. Such increases can, as Hamilton has shown, cause significant economic losses as measured by employment or GDP.

Renewable fuels, then, provide a very large measure of protection against the economic impact of future disruptions.

[10] EPA, "Final Rulemaking of Modifications to Fuel Regulations to Provide Flexibility for E15 and to Elements of the Renewable Identification Number Compliance System," May 30, 2019 [https://tinyurl.com/y4zga4t8].

Box 1. Illustrative Impact of Ethanol Blending on Gasoline and Crude Prices during a Market Disruption

The large contribution that renewable fuels could have in mitigating market disruption impacts is captured in Table 4.

Table 4. Calculation of a Disruption Gasoline Price Impact with/without Additional Ethanol Volumes

	Base Case	1% Supply Loss – No Ethanol	Crude Supply Loss Offset by Ethanol
Retail price of gasoline ($/gal)	2.80	3.36	2.80
Markup for taxes and margin ($/gal)	0.97	0.97	0.97
Spot gasoline price ($/gal)	1.83	2.39	1.83
Maximum increase in crude price ($/bbl)		23.52	0.00
Volume sold (MBD)	10.00	9.90	9.90
Incremental ethanol (MBD)		0.00	0.10

Notes:
Base-case price from EIA weekly gasoline prices for all areas, all formations, July 15, 2019.
Spot price average of New York, Chicago, Gulf, and California spot prices on the same date.
Margin calculated as difference between retail price and spot price.
Maximum impact assumes the change in gasoline price is fully reflected in crude prices. See text.

Source: PKVerleger LLC.

The initial data in the "Base Case" column are based on mid-July data for the US market. The gasoline price for July 15 was reported as $2.80 per gallon. The average spot price in the four major markets (New York, Houston, Chicago, and Los Angeles) was $1.83.

The markup shown in Row 2 was calculated as the difference between the average spot price and the retail price.

The initial volume was assumed to be ten million barrels per day. The "1% Supply Loss" column shows the impact of a 1% reduction in supply due to a disruption. The volume falls to 9.9 million barrels per day. The supply loss would lead to a 20% increase in prices if one uses a short-run price elasticity of demand of -0.05.[11]

The low price elasticity of demand would require prices at retail to increase from $2.80 per gallon to $3.36. If markups were unchanged, the spot price would need to increase to $2.39.

[11] Many estimates of the price elasticity of demand have been published. Most studies that focus on the short run find that the price elasticity of demand is very low.

Crude prices could rise $24 per barrel in this example if the gasoline price increase price were matched by prices of other key products. With a crude price of $63 per barrel, roughly the current price of Brent, one finds that a 1% reduction in supply could boost crude prices to almost $90.

The entire increase, though, could be eliminated by blending an additional one hundred thousand barrels per day of renewable fuels into the gasoline pool. On average, this could increase the amount of renewables in gasoline from 10% by volume to 11%. The one-hundred-thousand-barrel-per-day increase would represent approximately 10% of the amount being blended today.

Of course, changes in the assumptions will alter the result. The difference between the retail price and the spot price (the markup) can vary, changing the result. Elasticities can also be different. A review of these items, though, reveals a general consistency. Thus, one can conclude that a modest amount of renewable fuels can significantly moderate the price impact of market disruptions.

III. THE CONSUMER-FRIENDLY EFFECT OF RENEWABLES ON REFINER MARKET POWER

The refining industry has become increasingly concentrated over the last twenty years. Absent the RFS, consumers today would pay significantly higher gasoline prices. The situation in California, where renewables use is more complicated due to the state's low-carbon fuels program, particularly illustrates the impact of the increased concentration.

From the time of BP's acquisition of Amoco in 1998, the FTC has required merging multinational oil companies to dispose of refining assets. This policy transformed the refining industry. For example, on January 2, 1999, Valero had a refining capacity of four hundred ninety-two thousand barrels per day, according to DOE.[12] Twenty years later, Valero has a capacity of 2.2 million barrels per day, an increase of 422%. In 1999, Marathon Petroleum had a refining capacity of nine hundred nine thousand barrels per day. Today, its capacity has more than tripled to three million barrels per day.

Table 5 (page 20) shows the change in refinery ownership and capacity.

The FTC required the refinery divestitures based on its belief that competition would be promoted by requiring integrated firms to transfer these assets to independent refiners such as Valero. This policy, though, seems to have had the reverse effect.

[12] These data are published in the EIA's *Petroleum Supply Annual*.

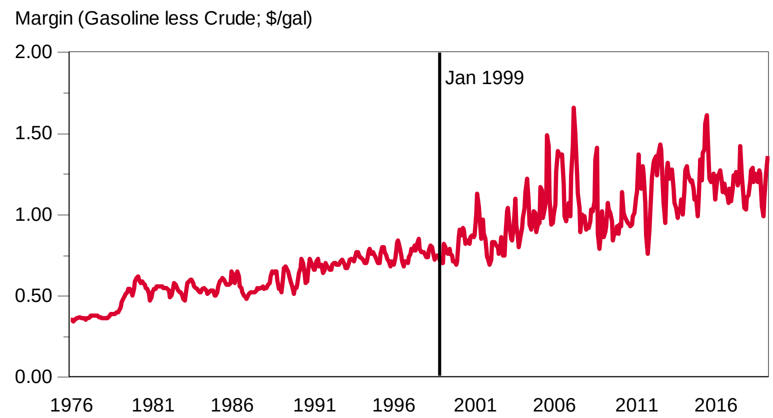
Table 5. Various US Refinery Firm Capacity in 1999 and 2019

Rank in 1999	Company	1999 Capacity (mbd)	Rank in 2019	2019 Capacity (mbd)	Comment
1	BP	1,419	9	678	Acquired Arco, sold most refineries
2	Exxon	1,119	3	1,732	
3	Chevron	1,049	5	925	
4	Marathon (USX)	935	1	3,024	
5	Tosco	909			Purchased by Phillips, which merged with Conoco and then became Phillips 66
6	Motiva	849		607	Owned by Saudi Aramco
7	Equilon	837			Combined with Shell
8	Sun	724			Closed, sold to various buyers
9	Mobil	705	8		Merged with Exxon
10	Citgo	699	10	755	
11	Koch	557		840	
12	Clark (Blackstone)	509			Closed, sold to various buyers
13	Conoco (Dupont)	506	2		Phillips
14	Valero	492		2,181	
15	Arco	486			Merged with BP, most refineries sold to Tosco
16	UDS	464	4		Merged with Valero
17	Phillips	355		1,668	
18	Williams	336	15		Sold refineries to Koch, Valero
19	Deer Park	274		275	
20	Tesoro	273	16		Merged with Marathon
21	Lyondell	268		263	Closed
22	Coastal	251	17		
23	Fina	237		225	Owned by BBF
24	Chalmette	181			Refinery owned by Delek, Chevron
25	Crown Central	155	28		
26	Sinclair	142	7	99	
27	Shell	130		829	Reacquired Equilon without Wood River, IL
28	Murphy	128	22		Sold to Valero
29	Cenex	117	6	159	
	PBF Energy		11	866	Purchased Chalmette Refining, ExxonMobil's Torrance CA Refinery, Sun Toledo, Valero Paulsboro
	Holly Frontier		12	514	
	WRB LP		13	502	Combo of Conoco and Phillips 66
	PES		14	355	Acquired from Sun
	Delek		18	311	Various acquisitions
	Husky		19	215	Acquired Lima, OH from Clark
	CVR Energy		20	206	From Farmland Industries
	Delta Airlines		21	190	Acquired from Conoco
	Par Pacific Holdings		23	165	
	BP-Husky		24	155	Shared with BP
	Calumet Specialty		25	132	
	Transworld		26	128	
	Petrobras		27	122	
	Suncor			103	

Source: US EIA.

From 1976 to the end of 1998, the average margin between retail gasoline and refiner acquisition costs of crude oil was $0.59 per gallon. From 1999 to May 2019, the average was $1.06 per gallon. Some of the increase can be explained by rising federal and state taxes, which went from $0.38 per gallon to $0.655, a change of $0.27. Still, refiners and marketers captured a margin increase of $0.20 per gallon. (Figure 15 illustrates the gasoline margin change from 1976 to 2019.)

Figure 15
Average Margin between US Retail Gasoline Prices and Refiner Acquisition Cost for Crude, Jan 1976 to May 2019



Source: Monthly Energy Review; PKVerleger LLC.

The margin impact of the FTC policy has been especially dramatic in California, where the share of refining capacity owned by the independent refiners has increased from 21% to 72%. Professor Borenstein has noted that the margin increase in California has been almost double the increase in other states.[13]

Consumers would likely pay even higher prices if the mergers that created the large oligopolistic independent refiners had not been accompanied by a second trend: the creation of an aggressive, competitive petroleum marketing sector. Over the last twenty years, the integrated oil companies sold or abandoned control over almost all their retail assets. A very large marketing sector independent of major oil companies and refiners has replaced these firms in most states—one exception being, perhaps, California.

This petroleum marketing sector is unconcentrated. While it includes large marketers such as Costco and Wal-Mart, the Herfindahl-Hirschman Index (HHI) computed for the nation as a whole for this sector is 311 based on OPIS market-share data. The HHI in California is three times higher at 1047, based on data published by the California Energy Commission.[14] Neither market, though, would be deemed concentrated under the DOJ/FTC merger guidelines, which define a market as unconcentrated if the HHI is below 1500.[15]

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[13] Severin, Borenstein, "The Mystery Gasoline Surcharge Gets Some Respect" Energy Institute Blog, UC Berkeley, May 20, 2019 [https://tinyurl.com/y3g6tqfq].
[14] CEC, "Petroleum Market Advisory Committee Final Report: December 2014 to November 2016," August 2017 [https://tinyurl.com/y4ylhrqp], p. 27.
[15] US Department of Justice and FTC, *Horizontal Merger Guidelines*, August 19, 2019 [https://tinyurl.com/y5ndb8fe].

The procedures used for introducing renewable fuels into gasoline allow the competitive petroleum marketing sector to counter the market power enjoyed by US refiners. Ethanol, the primary renewable fuel, is blended into gasoline at the terminal, not at the refinery. The blending is often done by a larger marketer or an independent party such as the terminal owner. This independence allows the marketer to vary the amount of ethanol blended depending on the price of gasoline and the price of ethanol, that is, the amount of ethanol blended may be lower when ethanol prices are high relative to gasoline but higher when the ethanol price is low relative to gasoline.[16]

Consumers will see increasing benefits from lower prices as marketers are allowed to blend additional incremental ethanol into gasoline (or other renewables into motor fuels) when the ethanol can be acquired at a discount to the price of the petroleum-based blendstock. The benefit results from the high level of competition in gasoline marketing and the absence of refinery control over marketers.

IV. BENEFITS OF USING ETHANOL AS AN OCTANE BOOSTER

Ethanol is a cheap source of octane relative to other gasoline blendstocks. Most states require a minimum gasoline octane of 87. Further, premium-grade gasoline, with octane typically greater than 90, has become increasingly important as automobile manufacturers recommend or require its use in higher-compression engines.[17] When blended into gasoline at 10%, ethanol increases gasoline octane by two to five points, depending on the chemical composition of the gasoline into which it is blended.[18] This allows refineries to produce conventional blendstock for oxygenate blending (CBOB) of lower octane, which is then blended with ethanol to meet gasoline octane requirements.

Refiners have optimized their operations to produce lower-octane CBOB by, for example, reducing the severity (i.e., reaction temperature) of catalytic reformers, resulting in fuel savings and extended catalyst life. This has yielded significant cost savings for refiners. A study by Jacobs Consultancy for the Department of Energy found that without ethanol blending into CBOB, a refinery's variable cost to increase the octane of finished conventional gasoline would be 3.7 cents per gallon higher.[19] To put this in perspective, given the approximately ninety-one million gallons of conventional gasoline produced by US refiners in 2018[20], the refiners' ability to optimize production to reduce octane saved them on the order of $3.3 billion.

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[16] The blending flexibility is limited by the blendstock octane and the maximum amount of ethanol blenders are allowed to mix with gasoline.

[17] "Selecting the Right Octane Fuel," US Department of Energy, Office of Energy Efficiency & Renewable Energy [https://tinyurl.com/y3ulmmad].

[18] American Petroleum Institute, "Determination of the Potential Property Ranges of Mid-Level Ethanol Blends," 2010, p. 26.

[19] US Department of Energy, "Refining Economics of Reducing Ethanol with Rising Ethanol Prices" [https://tinyurl.com/y4jpvzox].

[20] US EIA.