Research Article

Improving Profitability and Reducing Downside Risks using Statistical Models

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ABSTRACT

Energy demand will increase due to the increasing population, improved standard of living, and rising artificial intelligence applications. The existing energy sources may not be sufficient, and we need multiple sources of energy in the near future to meet the increased demand. The oil & gas energy sector will face several challenges such as stricter regulation, the rise of renewable energy, and aging assets. The industry, therefore, needs sophisticated tools to forecast the price and cost more accurately than ever for reliable and sustainable profits with reduced downside risks. In this paper, we develop statistical models for a profitable refinery to forecast the key cost driver as crude oil price, and the key revenue driver as gasoline/diesel prices, 6 months in advance. We first identify statistically significant variables and then refine further using collinearity to identify key variables. Our analysis indicates that both oil and gasoline prices depend on the Dow Jones industrial average, WTI oil price, average miles used per gallon, average well production per day, number of refineries, refinery capacity, and rig count. These variables are statistically significant with p-values less than 0.05. We tested the 6-month future price and found that the model can predict the oil price within 5% variability and the gasoline price within 7%. For the oil price variation, the Dow Jones industrial average accounts for ~24%, the number of refineries for ~21%, average well production per day for ~20%, and the remaining variation is attributed to other variables. For the gasoline price variation, oil price contributes ~40%, the Dow Jones industrial average covers ~25%, and the remaining variables account for the remaining ~35%. The Dow Jones industrial average impacts both the cost and revenue aspects of a refinery business. Thus, we recommend contracting crude oil and gasoline using an index tied to the broader economy to reduce the downside risk and improve profitability. These results could enable the refinery management team to seek long-term contracts to lock in high-margin crude oil supply and favorable gasoline price contracts with customers when a decline in price is forecasted to improve the profit margin. This methodology and strategy are applicable beyond the refinery business to any cyclical business to maintain margin, particularly in a down cycle.

Keywords: Statistical model; oil price, gasoline price; refinery

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INTRODUCTION

By 2050, the US population is estimated to rise to 438 million (1) leading to a significant increase in energy demand. Products from US refineries, such as gasoline and diesel, will remain critical in meeting the growing energy demand. With growing geopolitical uncertainties and a focus on energy transition, US refineries are under tremendous pressure to maintain profitability (2). Reliable gasoline price forecasting enables an improved refinery profit margin. This is the topic of this paper.

Refineries convert crude oil into various petroleum products through many different processes in distillation towers where the liquids are separated by boiling point (Crude oil IEA 2012). Gasoline, which we will analyze in this paper, is the main product sold with around 45% of crude oil being used to form gasoline, as shown in Figure 1.

The petroleum downstream industry generates a lower return than its upstream counterpart. Low downstream margins are driven by intensified competition, commodity price volatilities, tougher regulations, stronger bargaining power of dealers, and threats of environmental liabilities (4). In addition, national oil companies are adding capacity. Aging refineries need investment to be maintained, and they are not energy efficient. Additionally, after a century of dominance for refined products as a major energy source for transportation, renewable sources now pose an alternative, particularly through electric vehicles. New battery charging stations are gaining market share at the expense of traditional oil downstream players. Shifting to renewable sources such as biofuel will need alternative investment. Tighter regulations for emissions such as: sulfur and nitrogen oxide require refineries to invest in cleaner technology and the disposal of hazardous waste, resulting in byproducts becoming increasingly costly.

Reliable forecasts for oil and gasoline prices are useful for a crude oil refinery in several ways since they cover ~85% of cost and ~50% of revenue of a crude-oil based refinery. The oil price forecast helps in managing and budgeting their cost effectively along with reducing cost through timing and volume of crude purchase through forward contract or hedging. Similarly, the gasoline price helps in supply chain management by ensuring a suitable amount of production by scaling up or down for the future demand. These forecasts are also helpful for profit maximizing through setting up pricing, inventory management, product mix adjustment and their margins. In addition, they can leverage forecasts in their long-term investment and strategy, customer relationship by maintaining consistent pricing, competitive pricing, and securing market share by growth.

A typical crude oil-based refinery has 85% cost for crude oil and the remaining 15% as operating cost (5). Gasoline covers around 50% of revenue and the typical historical markup is ~15 cents per gallon of gasoline. In recent years, the refinery margins were much higher (3-4x of historical levels) due to refinery shut-down and supply-chain complexities driven by Covid-19. However, the margin is coming in line with the historical levels. Thus, there is a need for better forecasting of key cost components, i.e., oil price and revenue, i.e. gasoline price. Their variability has increased recently, as shown in Figure 2 and Table 1. The table suggests that the standard deviation, which is a measure of variability around its mean, has more than doubled in recent years.

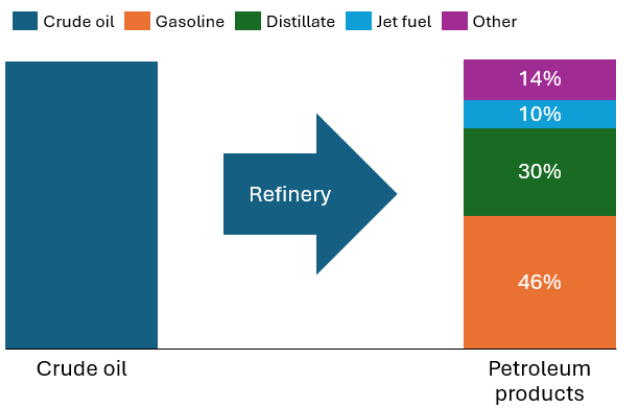

Figure 1. The figure shows different refinery products. One barrel of crude oil produces several products with different quantities (3).

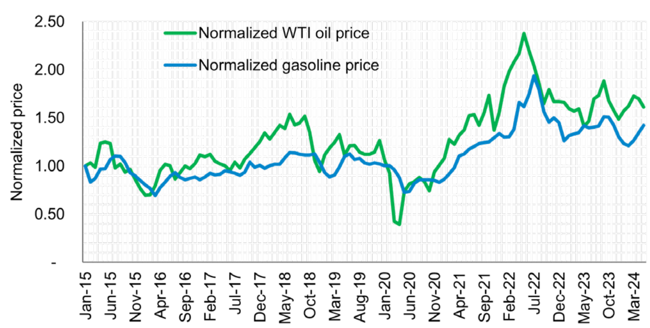

Figure 2. Normalized oil and gasoline price. These prices are normalized with the January 2015 price.

This is driven by crude oil fluctuation driven by global factors and market demand variability due to economic conditions and faster flow of information increases the impact and frequency.

Forecasting the key costs and revenue components can help refineries maximize profitability for the future, so that they can be prepared and optimize their actions according to their predictions. Ali and Maryam (6) analyzed the price of oil. They find that forecasting oil prices is difficult due to the large fluctuations from the various economic and political impact on its price. This fluctuation can be predicted by scheduling the fluctuations from past prices which is investigated by Nilay Shah (7). He used mathematical programming for the crude oil supply which is important since this can allow companies to utilize their information and propel them over their competitors. This is especially necessary with the increasing vulnerability of refineries to margin compression from lots of competition. This vulnerability is why it is important to mitigate risks in these companies, which is explored by Violet C. Rogers and Jack R. Ethridge (8). They give factors that influence risk and measure many different oil companies by their risk tolerance.

In this paper, we forecast the oil price and gasoline price. Thus, the fluctuation in gasoline and oil prices contributes to the profitability of a refinery. This makes it important to have a reliable forecast of the gasoline and oil price to manage the refinery's profit margin. Thus, the operational and investment strategy yields high profit margins and long-term sustainability in the refining business. The goal is to maximize profit by operationalizing these findings with favorable pricing contracts, operational strategies to optimize gasoline output, and short-term capital investments. We first developed a model to understand factors impacting gasoline and oil price and then developed a model to predict the gasoline and oil price in the future. The paper is organized as the following: how we collected the data and how we will use it is presented in the data and methodology Section 2, we will analyze our findings in the results and discussion Section 3, we will summarize the findings in conclusions Section 4.

Table 1. Standard deviation of oil and gasoline prices

	2015-2020	After 2020
Oil Price	0.22	0.44
Gasoline Price	0.11	0.28

METHODS AND MATERIALS

Data

To forecast oil and gasoline prices, we collected various data impacting them. These variables are DJIA, Oil Price, Gasoline tax, AVG_{MPG}, Milecost, Prodwell, AVG_{BOPD}, Refinery, REF_{CAP}, REF_{UTIL}, $Consumer_{sentiment}$, $US_{Inventory}$, and RIGCOUNT. Table 2 shares the details of these variables such as description, definition and data source.

The numerical details such as average, maximum, and minimum of these variables are in Table 3.

Methodology

We first checked the collinearity of all variables and then developed two statistical models to forecast oil and gasoline prices using statistically significant variables through linear regression. We then reduced variables using collinearity and improved the models' predictive capability by adding interactions and non-linear terms. Subsequently, we validated the model by performing a blind test before estimating the impact of independent variables. At the end, we estimated the impact of key independent variables on the variability of oil and gasoline prices. Following are the detailed steps:

Set up the model: We first performed quality control of input data from other sources. Subsequently we performed the collinearity analysis to identify reasonable variables to forecast. To prepare the data for the regression analysis, we aimed to establish a 6-month forecast capability. We achieve this by placing dependent variables (oil and gasoline prices) behind by 6 months for both models. This step is critical for the users of this model to predict 6 months of future data vs. present data to be able to get sufficient time to make any decisions on their refinery operations. It is noteworthy that we restricted the input variables to the US since lately US oil & gas production is sufficient for the US, which is contrary to the past when the US was heavily dependent on foreign oil.

Identify statistically significant variables: We then perform regression analysis to identify statistically significant variables with p-value less than 0.05. We systematically removed variables with p-values greater than 0.05 one by one and eventually retained only statistically significant variables with p-values less than 0.05.

Reduce statistically significant independent variables using collinearity: The objective of these models is to develop an accurate and usable solution for the refiners which would mean requiring fewer variables

Table 2. List of variables, their description and definition, and source of data

Variables	Description	Definition	Source
Gasoline Price	Gasoline Price ($/gal)	At the pump national average monthly price	American Petroleum Institute
DJIA	Dow Jones Industrial Average	Included to capture broader economic influence	Yahoo Finance
Oil Price	Oil Price ($/bbl)	Monthly average crude oil price of West Texas Intermediate (WTI)	American Petroleum Institute
Gasoline Tax	Federal Gasoline Tax ($/gal)	Average national monthly gas tax on gasoline	
AVG_{MPG}	Average MPG (mile/gal)	Average Miles Per Gallon (MPG) for a gallon of gasoline	Energy Information Administration (9)
Milecost	Average Mile Cost ($/mile)	The average cost per mile of gasoline	
Prodwell	Number of Producing Wells (#)	Number of producing wells in the USA	
AVG_{BOPD}	Average Productivity (bbl/day)	Average productivity of the producing wells	
Refinery	Number of Refineries (#)	Total number of worldwide operating refineries	
REF_{CAP}	Refinery Capacity (kbbls)	Crude oil refining capacity worldwide	
REF_{UTIL}	Refinery Utilization (%)	Percent utilization of the operating refineries	
RIGCOUNT	Rig Count (#)	Active drilling rigs in the US	Baker Hughes/ International (10)
$Consumer_{sentiment}$	Consumer sentiment (#)	Monthly consumer sentiment in US	University of Michigan (11)
$US_{Inventory}$	US crude oil inventory (thousand barrel)	Monthly crude oil inventory	Energy Information Administration (9)

Table 3. List of variables with their mean, max and min

Variables	Mean	Max	Min
Oil Price	63.65	140.00	18.84
DJIA	17,331.61	39,807.93	7,056.48
Gasoline Price	2.62	4.93	1.09
AVG_{MPG}	17.36	17.60	16.90
Milecost	0.15	0.28	0.06
Prodwell	406,443	467,450	365,676
AVG_{BOPD}	17.55	27.73	11.83
Refinery	143.50	158.00	129.00
REF_{CAP}	15,767.76	18,041.00	12,803.00
REF_{UTIL}	89.10	97.50	70.20
RIGCOUNT	1,884	2,696	287
Gasoline tax	0.18	0.18	0.18
$Consumer_{sentiment}$	83.2	112	50
$US_{Inventory}$	1,008,292	1,225,238	768,099

for predictions. This approach reduces the effort required to use the model. We therefore leverage the concept of collinearity to meet this objective. In statistics, collinearity occurs because the independent variables used in building the regression model are correlated with each other (12). We then performed a regression analysis to ensure not much loss of R^2 and variables are statistically significant. Given high correlation factors among variables, we also attempted to keep only one variable such as DJIA, but that resulted in R^2 as 0.03 and thus diminished prediction capability.

Improve forecast capability of models: We enhanced the predictability by adding interactions, using multipliers of independent variables and non-linear terms such as polynomials and logarithmic terms.

Validate models: To test the prediction capability of the models, we ran the model without the last one-year's data and predicted them using prior independent variables data. The model is considered satisfactory since the prediction is much less than the variability presented with the historical data. We also successfully tested the models' predictions for oil and gasoline prices at the end of May. The model formulation assumes this is autoregressive and this is validated using a blind test.

Assess impact of independent variables: Once we have models with reasonable prediction capability for oil and gasoline prices, we estimate the % contribution of the independent variables in forecasting. To estimate the contribution, we first normalize the independent variables between 0 and 10. Accordingly we then adjust the coefficients of these variables. The scaled coefficients provide the impact of these independent variables in the variability of the dependent variable. This offers an opportunity to focus on high impacting variables. More importantly, we identify the common variables impacting oil and gasoline prices. The refinery management could use contract cost and price leading to reduced risk for the business and maximize profitability.

RESULTS AND DISCUSSION

We first examined the collinearity among all variables, as shown in Table 4. We found that the collinearity between diesel and gasoline is ~100% and thus there is no need for a separate forecast for the diesel price instead the gasoline forecast can be used for diesel as well. Gasoline and oil prices have a strong correlation, but not 100%. We also aimed to assess their variability several months in advance. Thus, we forecast oil and gasoline prices in this paper.

WTI Oil price

Prediction of oil price is challenging due to several impacting variables, such as economy, supply, demand, and geopolitical factors. To minimize the factors, we considered WTI oil price and thus kept only factors within the USA. As mentioned in the methodology section, we shifted the oil price by 6 months to perform forecasts at least 6 months in advance. We first performed a regression analysis with all variables. We then removed independent variables one at a time to find statistically significant variables. The regression outputs of WTI Oil price show a multiple R as 0.847, an R-square as 0.718, an adjusted R-square as 0.710, and a standard error of 13.6488. The regression equation for WTI oil price:

$$\text{Oil Price} = -1.49 * 10^2 + 3.79 * 10^3 * DJIA + 5.65 * \textit{Gasoline Price} + 3.57 * 10 * \text{AVG}_{MPG} - 7.25 * AVG_{BOPD} - 2.28 * Refiniery - 3.90 * 10^{-3} * REF_{CAP} + 1.61 * 10^{-2} * RIGCOUNT \quad \text{(a)}$$

All these independent variables have p-values less than 0.05.

We then leveraged collinearity, as shown in Table 5, to reduce the number of independent variables without impacting R^2. We removed AVG_{MPG} since that is correlated with average gasoline price and DJIA, as shown in Table 4, so we replaced them and found an increase in the ability to forecast (not shown).

Resulting regression outputs of WTI Oil price have a multiple R as 0.831, an R-square as 0.690, an adjusted

Table 4. Correlation metrics for all variables

	Date	*Oil Price*	*DJIA*	*Gasoline Price*	AVG_{MPG}	*Milecost*	*Prodwell*	AVG_{BOPD}	*Refinery*	REF_{CAP}	REF_{UTIL}	*RIGCOUNT*	*Gasoline tex*	$US_{Inventory}$	$Consumer_{sentiment}$
Date	1.0														
Oil Price	0.4	1.0													
DJIA	0.9	0.2	1.0												
Gasoline Price	0.6	0.9	0.4	1.0											
VG_{MPG}	0.8	0.6	0.5	0.7	1.0										
Milecost	0.6	0.9	0.4	1.0	0.6	1.0									
Prodwell	0.6	0.3	0.4	0.5	0.7	0.4	1.0								
AVG_{BOPD}	0.9	0.1	1.0	0.3	0.5	0.3	0.4	1.0							
Refinery	1.0	0.3	0.9	0.5	0.7	0.5	0.5	0.9	1.0						
REF_{CAP}	0.4	0.0	0.4	0.2	0.2	0.2	0.4	0.4	0.4	1.0					
REF_{UTIL}	0.2	0.2	0.1	0.1	0.3	0.1	0.0	0.0	0.1	0.8	1.0				
RIGCOUNT	0.9	0.0	0.9	0.2	0.6	0.2	0.5	0.9	0.9	0.4	0.1	1.0			
Gasoline tex	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0		
$US_{Inventory}$	0.4	0.2	0.1	0.2	0.6	0.2	0.6	0.1	0.3	0.2	0.2	0.4	0.0	1.0	
$Consumer_{sentiment}$	0.3	0.6	0.2	0.6	0.5	0.6	0.0	0.1	0.3	0.3	0.4	0.0	0.0	0.1	1.0

Table 5. Correlation metrics for independent variables for oil price

	DJIA	*Gasoline Price*	AVG_{MPG}	AVG_{BOPD}	*Refinery*	REF_{CAP}	*RIGCOUNT*
DJIA	1.0						
Gasoline Price	0.4	1.0					
AVG_{MPG}	0.5	0.7	1.0				
AVG_{BOPD}	1.0	0.3	0.5	1.0			
Refinery	(0.9)	(0.5)	(0.7)	(0.9)	1.0		
REF_{CAP}	0.5	0.2	0.2	0.5	(0.5)	1.0	
RIGCOUNT	(0.9)	(0.2)	(0.6)	(0.9)	0.9	(0.4)	1.0

R-square as 0.683 and a standard error of 14.2643. The regression equation for WTI oil price:

$$\text{Oil Price} = 5.90 * 10^2 + 3.06 * 10^{-2} * DJIA + 1.16 * 10 * Gasoline\ Price - 7.46 * AVG_{BOPD} - 2.93 * Refinery - 4.64 * 10^{-3} * REF_{CAP} + 9.47 * 10^{-2} * RIGCOUNT \quad (b)$$

Finally, we enhanced the prediction capability of the model by adding nonlinear and interactive terms. We found that taking the log of DJIA was helpful in predicting more accurately (within 5%). The regression outputs of WTI Oil price have a multiple R as 0.838, an R-square as 0.703, an adjusted R-square as 0.695, and a standard error of 14.147. The regression equation for WTI oil price:

$$\text{Oil Price} = 5.90 * 10^2 + 3.06 * 10^{-2} * DJIA + 1.16 * 10 * Gasoline\ Price - 7.46 * AVG_{BOPD} - 2.93 * Refinery - 4.64 * 10^{-3} * REF_{CAP} + 9.47 * 10^{-2} * RIGCOUNT \quad (c)$$

We can understand impacting variables in equation (c) using supply and demand factors. Key supply variables are production and rig count. Key demand variables are gasoline price, DJIA, number of refineries, and its capacity. Thus, these variables are significant. Further investigation is needed to quantify the impact. We presented forecasted test results in Figure 3. The prediction of the model is reasonable. Most data points in the plot fall near the 45-degree line and within the 5% variability margin. This gives another validation of the model's prediction capability. Therefore, one could use this model in decision making. We also tested the oil price for May 28, 2024, and found to be within 2% of the actual data. The actual WTI price was $79.83, and the forecasted price is $78.30.

Gasoline price

Similar to the oil price, we first performed a regression analysis with all the variables from six months before to have an estimate for the future. We then removed independent variables one at a time to find statistically significant variables. The regression outputs of Gasoline price have a multiple R as 0.88, an R-square as 0.776, an adjusted R-square as 0.77, and a standard error of 0.3719. The regression equation for gasoline price:

$$\text{Gasoline Price} = 1.8455 + 0.000078 * \text{DJIA} + 0.011 * \text{Oil Price} + 0.639 * \text{Avg}_{MPG} - 0.1247 * \text{AVG}_{BOPD} - 0.062 * \text{REFINERY} - 0.0001 * \text{REF}_{CAP} + 0.00032 * \text{RIGCOUNT} \quad (d)$$

We then performed a collinearity analysis, as shared in Table 6. We found that refineries are correlated with

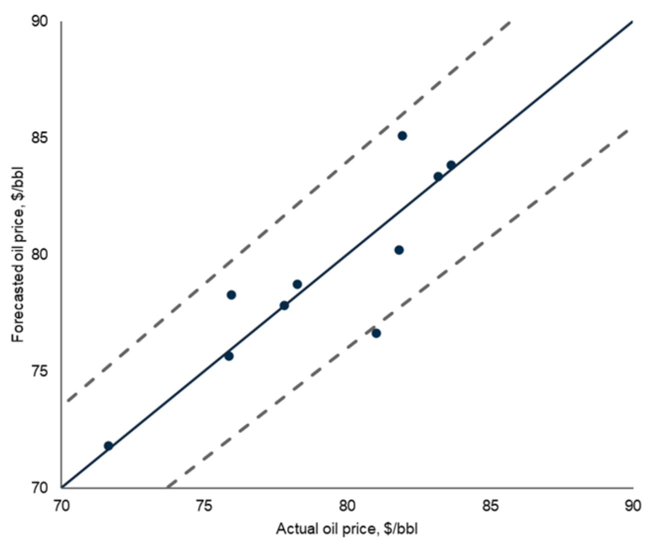

Figure 3. Predicted results and original oil price data. The solid line is a 45-degree line, and two dotted lines are +/-5% error lines with bullets representing predicted and actual data points..

Table 6. Correlation metrics for independent variables for gasoline price

	DJIA	Oil Price	AVG_{MPG}	AVG_{BOPD}	Refinery	REF_{CAP}	RIGCOUNT
DJIA	1.0						
Oil Price	0.2	1.0					
AVG_{MPG}	0.5	0.6	1.0				
AVG_{BOPD}	1.0	0.0	0.5	1.0			
Refinery	(0.9)	(0.3)	(0.7)	(0.9)	1.0		
REF_{CAP}	0.5	0.1	0.2	0.5	(0.5)	1.0	
RIGCOUNT	(0.9)	0.0	(0.6)	(0.9)	0.9	(0.4)	1.0

the rig count, and that the number of refineries is also correlated with the average productivity of the producing wells. We removed these variables one at a time and found the best regression equation by removing refineries.

The equation has little sacrifice in R^2 and the p-values are below 0.05. We found that keeping the rig count results in the best regression, so we keep the rig count. The regression outputs of gasoline price have a multiple R as 0.848756, an R-square as 0.720, an adjusted R-square as 0.715, and a standard error of 0.4115. The regression equation for gasoline price:

$$\text{Gasoline Price} = -12.207 + 0.000044 * \text{DJIA} + 0.01687 * \text{Oil Price} + 0.839 * \text{Avg}_{MPG} - 0.000124 * \text{REF}_{CAP} + 0.0002262 * \text{RIGCOUNT} \quad \text{(e)}$$

We then optimized the regression equation using non-linear terms and pairing the terms and found the best regression equation as below. The regression outputs of gasoline price have a multiple R as 0.8339, an R-square as 0.695, an adjusted R-square as 0.692, and a standard error of 0.428. The regression equation for gasoline price:

$$\text{Gasoline Price} = -12.3728 + 2.466 * \text{Log}(\text{DJIA} * \text{Oil Price} * \text{Avg}_{MPG}) - 0.0002 * \text{REF}_{CAP} + 0.00025 * \text{RIGCOUNT} \quad \text{(f)}$$

All p-values in this case were almost zero, and the forecast was always within 7% of the actual gasoline price (Figure 4). The lines for 7% variability contain most data points, so this is a reasonable model to use in forecasting the gasoline price. It is noteworthy to mention that the variability in the gas forecast is greater than that in the oil price (~5%). This is attributed to a smaller magnitude and localized gas market in contrast to a global oil market. The local nature of the gas commodity increases variability.

CONCLUSIONS

In this paper, we developed statistical models to forecast oil and gasoline prices using publicly available data. The model successfully predicts the blind test forecast data within a +/-7% difference. The refiners could use these models to effectively manage their business. For example, utilization of these equations to predict prices for the business plan and strategy developments to improve profitability, reduce downside margin, and leveraging the common variable of the Dow Jones industrial average for oil and gasoline prices to frame cost and price contracts to reduce the downside impact on profitability. This can help in keeping a part of the business relatively immune to the down cycle.

We developed models to understand parameters impacting gasoline and oil prices, and then extended the model to perform forecasts to estimate these prices. First, the developed equations offer reasonable predictions of future prices up to 6 months in advance. In addition, we identified the DJIA variable is important for oil price, i.e., a measure for cost as well as gasoline price, i.e., a measure for revenue, as shown in Figure 5. The US economy is the leading indicator for these prices since the Dow Jones industrial average is a measure for that. We recommend that refinery business contract cost and revenue using an index based on this common variable. This will help the refinery maintain sustained profitability, regardless of business cycles. This helps in mitigating the down cycle and avoids a severe impact on the business during the down cycle. This generic methodology can be expanded to any other cyclical business.

With respect to crude oil refinery, we identified the modeling could be further improved. For example, investigation of the cyclical nature of gasoline prices is to account for the length of the business cycle and isolate the degree of change associated with noise vs. key factors. The seasonality of the gasoline price could be a potential extension of the work. Also, further analysis is needed to assess how and when DJIA could be used as an independent variable. Impact of geopolitics could be imperative as well (13). With limited investments and an appetite to build new refineries, it is necessary to know how to best operationalize the existing refineries with existing headwinds. The chief among them is the access to affordable feedstock (i.e., crude oil) for gasoline production. That is dependent on future technologies such as hydraulic fracking technology (primarily in the US Permian) which made the US the leader in crude production. The other option for feedstock is imports which carries the burden of geopolitical uncertainties. In addition, the sustainability requirements and goal for Net Zero by 2050 will continue to push the refineries to invest more to produce green products, hence impacting the margins. For example, producing gasoline using stringent standards for California and converting refineries to producing renewable diesel.

This model can further improve the prediction capability by adding other variables. However, the intent here was to find key underlying features of the business and minimize the downside. The genetic nature of the methodology is to reduce downside impact of other cyclical businesses.

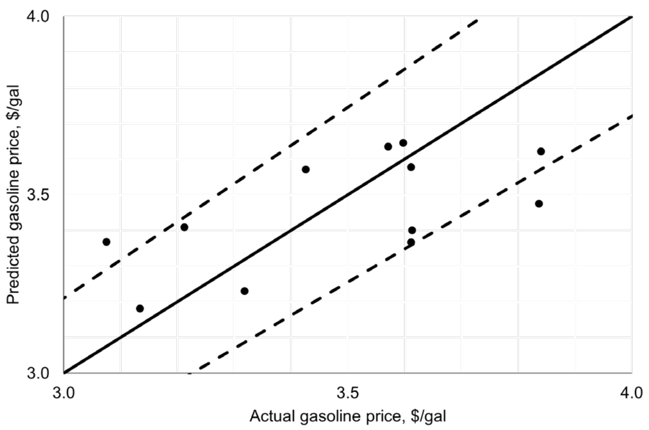

Figure 4. Predicted results and original gasoline price data. The solid line is a 45-degree line, and two dotted lines are +/-7% error lines with bullets representing predicted and actual data points.

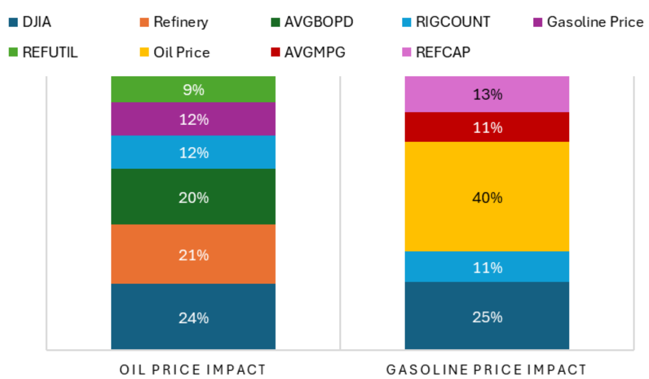

Figure 5. Impact of independent variables in variability of oil and gasoline prices.

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