A technical note on the long run U.S. gasoline - crude oil price relationship [1]

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What determines the price of gasoline? The mechanics of gasoline price are fairly simple. Crude oil is bought by refiners who create a slate of products, of which gasoline is one. Refiners can shift output when possible as long as relative prices indicate it is profitable to do so, but on average in the U.S. gasoline output represents about 46% of total crude processed. The price at which a refiner then sells gasoline output is the wholesale price. The price consumers pay at the pump, the retail price, is the price that receives so much attention in the press. It includes the wholesale price as well as state and federal taxes, distribution and marketing costs, and station premiums related to the cost of operation (property lease rates, labor costs, etc.). Thus, the simple answer to our commonly asked question is "the price of crude oil plus marketing and distribution costs plus taxes". In fact, as we will demonstrate below, the price of crude oil is the single most important factor in determining the price of gasoline.

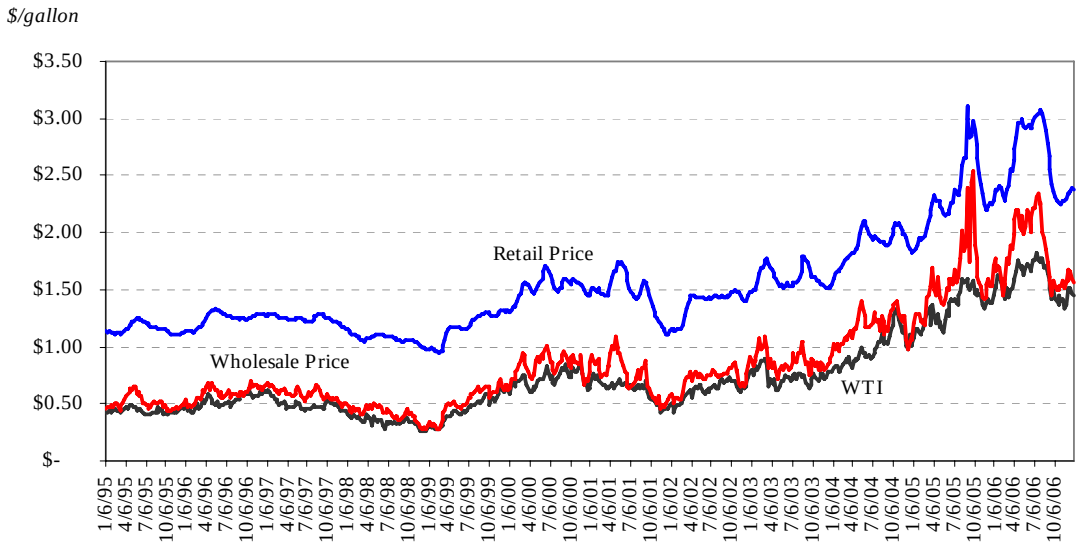
But, this is only part of the story. In fact, there are many factors in the short term that can cause the gasoline price to move independently of crude oil price. For example, lower than normal gasoline inventories, reduced operational refinery capacity, disruptions in import capabilities and surges in gasoline demand can all result in a pronounced increase in the gasoline price at any given point in time, especially when any of these factors occur simultaneously. But, understanding the baseline from which the gasoline

[1] This piece is extracted from a longer working paper titled "U.S. gasoline price in the long and short run".

price will deviate (that is, the price of crude oil) is important to understanding these short run movements in gasoline price.

So, what is the long run relationship between gasoline and crude oil prices? Figure 1 illustrates the West Texas Intermediate price of crude oil and both the wholesale and retail prices of gasoline.[2] This graphic provides visual evidence of the relationship between prices because, in general, when the price of crude oil rises we see that the price of gasoline also increases.

Figure 1: WTI and the price of gasoline (January 1994 – December 2006)



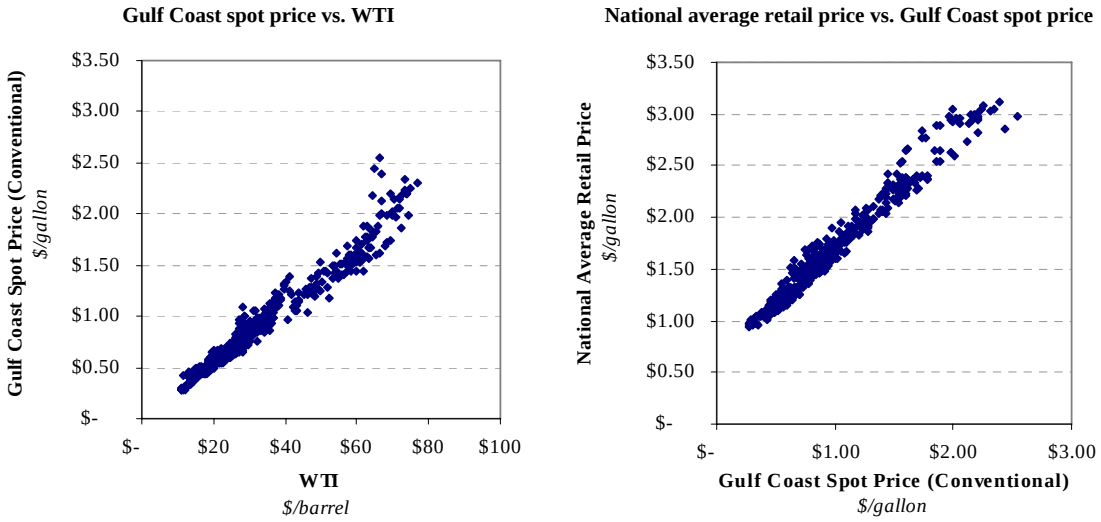
Data source: Energy Information Administration

Figure 2 indicates that the wholesale price of gasoline can be tied very closely to crude oil prices, and the retail price can be closely linked to the wholesale price of

[2] The actual cost of crude to the refiner is not accurately characterized using WTI, but rather as a blend of different crude oils. However, cointegration of crude oil prices should render this irrelevant, and, since WTI is a commonly used marker for the cost of crude and generally moves with other crude oil prices, it will be used throughout this paper.

gasoline. Statistically, if there is a *cointegrating* relationship between the price series, then there exists a stable long run relationship between the price series, where the "long run" is unencumbered by phenomena such as refinery capacity constraints, inventory problems and short run adjustment costs that may occur due to things such as seasonal changes in formulation standards.

Figure 2: Price relationships



Data source: Energy Information Administration

To establish the existence of a stable long run relationship between the prices we must first establish they are integrated of the same order and then establish they are indeed cointegrated. Augmented Dickey Fuller (ADF) tests reveal that each of the three price series is integrated of order one.[3] If the series are then cointegrated, it is possible to

[3] Augmented Dickey Fuller tests indicate that each of the variables is $I(1)$. AIC tests were used to select optimal lag length in the ADF tests. Results are: $p_{GAS} \Rightarrow$ ADF = -1.623 (3 lags); $p_{RETAIL} \Rightarrow$ ADF = -1.749 (3 lags); $p_{OIL} \Rightarrow$ ADF = -0.435 (2 lags).

use OLS to estimate a long run relationship between the wholesale price of gasoline, $p_{GAS,t}$, and the price of crude oil, $p_{OIL,t}$, of the form

$$p_{GAS,t} = a_0 + a_1 p_{OIL,t} + e_t \quad (1).$$

Similarly, the long run relationship between retail, $p_{RETAIL,t}$, and wholesale gasoline prices can be estimated as

$$p_{RETAIL,t} = b_0 + b_1 p_{GAS,t} + u_t \quad (2).^{4}$$

Following the method of Engle and Granger (1987), the residuals from equations (1) and (2), $\hat{e}_t \left(= p_{GAS,t} - \hat{a}_0 - \hat{a}_1 p_{OIL,t}\right)$ and $\hat{u}_t \left(= p_{RETAIL,t} - \hat{b}_0 - \hat{b}_1 p_{GAS,t}\right)$, are found to be stationary, so that the prices are indeed cointegrated.[5] This, in turn, implies the estimates of the parameters a_0 and a_1 in equation (1) and b_0 and b_1 in equation (2) are superconsistent. The estimation results are reported in Table 1.

Table 1: Estimation results of cointegrating equations

Equation	Parameter Estimates (standard errors in parentheses)	R^2
(1)	$p_{GAS,t} = \underset{(0.0078947)}{-0.0058778} + \underset{(0.0002265)}{0.028043}\, p_{OIL,t}$	0.9609
(2)	$p_{RETAIL,t} = \underset{(0.0070065)}{0.630628} + \underset{(0.0071759)}{1.072006}\, p_{GAS,t}$	0.9728

[4] Equations (1) and (2) together imply a relationship between crude oil prices and retail gasoline prices of the form $p_{RETAIL,t} = c_0 + c_1 p_{OIL,t} + v_t$, where $c_0 = b_0 + b_1 a_0$ and $c_1 = b_1 a_1$. This is estimated as $p_{RETAIL,t} = \underset{(0.0090618)}{0.6135744} + \underset{(0.00026)}{0.030408}\, p_{OIL,t}$ with an $R^2 = 0.9564$. In fact, F-tests verify that the parameter estimates of c_0 and c_1 are not statistically different from $b_0 + b_1 a_0$ and $b_1 a_1$, respectively.

[5] ADF tests reveal this to be the case. ADF tests of stationarity of the residuals on equations (1) and (2) reveals: (1) ADF = -7.375 (3 lags); (2) ADF = -8.497 (2 lags). Each is significant at the 1% level.

Equations (1) and (2) imply a set of long run equilibrium prices, which are reported in Table 2. It is important to note that these results are specific to *gulf coast* wholesale gasoline prices and *national average* retail prices. Thus, regional differences may exist. Moreover, fundamental factors such as inventories and demand can push retail and wholesale prices out of their long run equilibrium for periods of time.

Table 2: Long run price relationships

Crude Oil ($/bbl)	Wholesale Gasoline ($/gallon)	Retail Gasoline ($/gallon)
$10.00	$0.27	$0.92
$20.00	$0.55	$1.23
$30.00	$0.84	$1.53
$40.00	$1.12	$1.83
$50.00	$1.40	$2.13
$60.00	$1.68	$2.43
$70.00	$1.96	$2.73
$80.00	$2.24	$3.03
$90.00	$2.52	$3.33
$100.00	$2.80	$3.63

It should be noted that the existence of a long run cointegrating relationship between the price of crude oil and the price of gasoline is well established. In fact, many studies use the long run relationship between gasoline and crude oil prices as a starting point to investigate, in particular, asymmetry between changes in crude oil prices and changes in gasoline prices (see, for example, Borenstein *et al.* (1997) Radchenko (2005), Bacon (1991), Peltzman (2000), Balke *et al.* (1998) to name a few). While these studies do not necessarily all conclude the same thing regarding asymmetry, they all highlight the

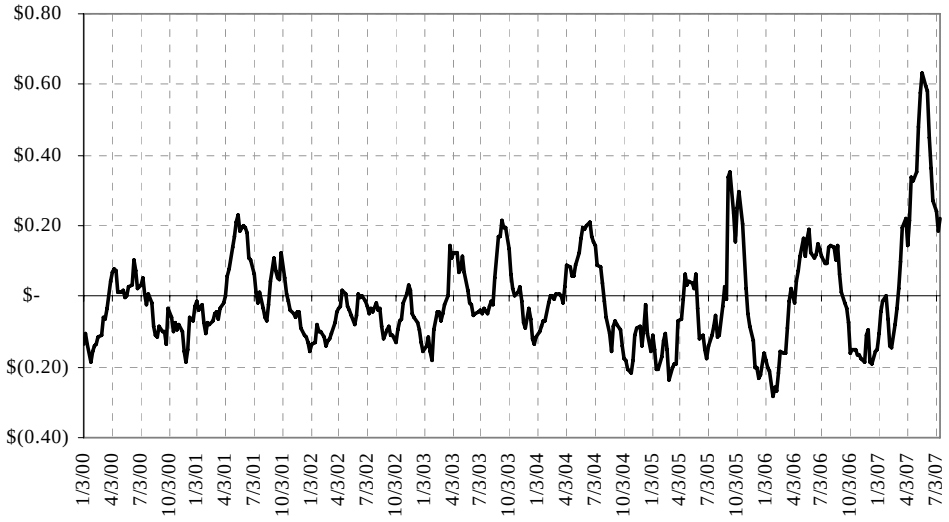
existence of factors that drive gasoline price away from its long run equilibrium with crude oil price.

One study in particular, by Bulow *et al.* (2003), highlights the fact that the determination of gasoline prices is complicated by the many facets of refining, distribution and marketing. They argue that the run-up in the price of gasoline in the US Midwest during the spring of 2000 was not the result of collusive behavior on the part of refiners, as was widely speculated, but rather that such factors as limited refining capacity, refinery outages, disruptions in pipeline capacity, and new federally mandated reformulation standards were the culprit.

The price relationships outlined in Table 2 indicate the prices we *ought* to *on average* expect to pay at the pump for a given price of crude oil. So, if the price of crude oil for the week of July 16th is at about $74 per barrel, should we be surprised when the national average retail price of regular gasoline is $3.05 per gallon, or about 20 cents above the long run relationship? The answer is "probably not", especially if we consider the fundamental forces that have been acting in the market recently. Undoubtedly, the recent run-up in gasoline prices is unprecedented. But, if we consider the fundamental forces that have transpired in the last six months, we can understand the nature of the increase in gasoline price. In particular, summertime demands are typically higher than normal with this year being no different, there were numerous refinery outages (not just in the U.S. but also globally) this past spring for a variety of reasons, and gasoline inventories are currently a little below average. All of these forces have contributed to the current price environment.

Figure 3 illustrates the departure of retail gasoline price from its implied long run equilibrium with crude oil price. As recently as February, gasoline price was below its long run equilibrium level. In fact, it is apparent from the figure that the deviation demonstrates some seasonality. This is consistent with the notion that as gasoline markets tighten (that is, demand rises in the face of a fixed production capacity, as is the case during the spring and summer) the gasoline price will rise relative to crude oil. One striking feature of Figure 3, however, is the fact that the magnitude of the deviations appears to be growing over time. This is symptomatic of U.S. demand is outgrowing domestic refinery capabilities, leaving the domestic market to rely increasingly on gasoline imports to balance.

Figure 3: Deviations from long run equilibrium (Jan 2000 – July 2007) (Actual retail gasoline price minus the long run equilibrium retail gasoline price)



In summary, if we want to understand the price of gasoline, we must look no further than the price of crude oil. Departures from the normal long run relationship

between the prices are going to occur, especially when the gasoline supply-demand balance tightens. But, by understanding the fundamental long run relationship between crude oil price and gasoline price, at least we can begin to look for answers in the appropriate places. In particular, by understanding the long run equilibrium, we can begin to address the factors that push us away from it.

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