Entry of Alternative Fuels in a Volatile U.S. Gasoline Market

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Since the turn of the 21st century the volatility in gasoline prices causing price "spikes" has become increasingly common (Ashton and Upton). Gasoline prices tend to exhibit asymmetry with steep price spikes followed by gentle declines. U.S. Energy Information Administration data indicate this price asymmetry, where retail prices typically rise more rapidly than they fall (Cook). Such volatility harms the entire macroeconomy and is at least partially responsible for the U.S. economy falling into the 2001 recession. As investigated by Ferderer, oil price volatility, directly impacting gasoline volatility, affects the entire U.S. economy through sectoral shocks and uncertainty. Irreversible investment decisions adversely affected by this volatility have placed a significant drag on the economy. This is consistent with the results of Kneller and Young who found that oil price volatility is robustly negatively correlated with economic growth. Not surprisingly, corporate stock prices also respond inversely to increased price volatility of petroleum products (Sadorsky).

Alternative hypotheses have emerged as explanations of the increased gasoline price volatility. Crude oil costs are a factor in this volatility, but Speir indicates that oil price volatility alone explains less than half of gasoline price movements. This result is supported by Ashton and Upton who indicate changes in inventory carrying levels, increased concentration and vertical integration of the petroleum industry, and the advent of boutique fuels are major factors in increased price volatility.

With world demand for oil continuing to increase and U.S. refiners operating at full capacity, a tight market for gasoline currently exists (Speir). In such a market, price volatility is reinforced when a boutique of fuel types creates unique local markets with barriers preventing reallocation of fuels for meeting changes in short-run regional demands (Hutzler and Shore). Such volatility has prompted inquiry and study of possible regulations by Congress and individual states. Regulation options explored are moving to one or two fuels, federal ban on MTBE (methyl-tertiary-butyl-ether), subsidies for supply expansion, and price ceilings (Hutzler and Shore). Proponents of such governmental price regulation stress its calming nature on volatile prices. However, the hypothesis explored in the following sections is that market forces will tend to mitigate this price volatility without any governmental intervention.

In the presence of volatile gasoline prices, competitive market forces will yield alternative less volatile fuels as substitutes. As an examination of this hypothesis, a real-option pricing approach for modeling investment under uncertainty is extended for the case of comparing stochastic prices of inputs that are perfect substitutes in a production process. Based on this methodology, a threshold decision rule influenced by the drift and volatility of prices is developed. Theoretical results establish an empirical link for measuring the tradeoff between a relatively more expensive commodity (alternative fuel) with lower price drift and volatility compared with a lower but more volatile priced commodity (conventional gasoline).

Previous literature applying a real-options approach to energy prices is limited. A related article by Tareen, Wetzstein, and Duffield applies real options to biodiesel as a substitute for petroleum diesel. Their results indicate a threshold price triggering adoption of an alternative fuel can be considerably above the market price for the fuel currently used. In the case of gasoline-price volatility, suppliers are concerned that a phase out of MTBE and a subsequent shift to ethanol would exasperate price volatility. However, Price demonstrates that an ethanol blend would exhibit a reduced price volatility, based on portfolio theory where diversification opportunities can lower a portfolio's total risk. This result provides support for government polices that encourage the expansion of the U.S. ethanol industry. Since the 1970's energy crisis, the United States has adopted a number of tax policies to encourage increases in the production of ethanol and other alternative fuels to help reduce U.S. dependence on oil imports. These polices are primarily focused on increasing domestic energy supplies; however, the potential effect that alternative fuels have on price volatility has largely been ignored. If the expansion of ethanol and other alternative fuels can help stabilize the gasoline market and reduce price spikes, policymakers should account for these additional benefits when considering energy policy options.

Alternative Fuels

Reformulated gasoline (RFG) accounts for approximately one-third of the U.S. gasoline market (Lidderdale). Compared with conventional gasoline, RFG generally reduces emissions of volatile organic compounds and toxic air pollutants. In 1995, RFG was mandated in the nine worst non-attainment clean air acts cities (Los Angeles, San Diego, Chicago, Houston, Milwaukee, Baltimore, Philadelphia, Hartford, and New York City). Other areas with a history of non-attainment have voluntarily joined the RFG program.

RFG blends an oxygenate into gasoline for emission reductions. Prior to 2004, MTBE (methyl-tertiary-butyl ether) was the main oxygenate use. However, detections of MTBE in water supplies have prompted 18 states to restrict or ban its use in gasoline. Currently the only other marketed gasoline oxygenate is ethanol. Ethanol is typically produced from various sugars in agricultural crops (corn in the U.S.) and has a higher octane value compared with MTBE. However, compared with MTBE ethanol increases the Reid vapor pressure (Rvp) of gasoline, an evaporative emission that must be controlled in non-attainment cities during the summer months. Also, ethanol tends to separate from gasoline when stored and attracts water into gasoline making it difficult to ship through petroleum pipelines. The oxygenate requirement for RFG blends is a minimum oxygen content of 2% by weight which can be met by adding 11% MTBE or 5.7% ethanol.

Other ethanol blends include E10 (gasohol) and E85. E10 is a blend of 10% ethanol with 90% conventional gasoline and is mainly available in the Midwest corn producing states for reducing carbon monoxide emissions during the winter months. Gasoline-ethanol blends containing up to 10% by volume of ethanol may be used in any vehicle without modification. In contrast, E85 can only be used in vehicles specifically designed for ethanol. An E85 vehicle requires upgrades to the fuel system components, the addition of a fuel sensor, and reprogramming the computer chip. An E85 vehicle can also use conventional gasoline which is often the only fuel available given its current limited retail supply. According to the National Ethanol Vehicle Coalition website (www.E85.com) a total of 3.5 million E85 vehicles were anticipated to be on the road by the end of model year 2004.

Decision Threshold

The decision threshold of when to switch to an alternative fuel is based on the Dixit and Pindyck approach for real-option pricing and the application by Tareen, Wetzstein, and Duffield. The stochastic nature of fuel choice arises from fluctuations over time in the price for conventional gasoline, C, and the alternative fuel, A. Such uncertainty may be represented by geometric Brownian motion processes

$$dC = \alpha_C C dt + \sigma_C C dz_C, \qquad \text{and} \qquad (1)$$

$$dA = \alpha_A A dt + \sigma_A A dz_A, \qquad (2)$$

where dC and dA represent the changes in the prices of conventional and alternative gasoline, respectively, α is the rate of change or drift rate, σ is the standard deviation (volatility), and the subscripts C and A denote parameters associated with conventional and alternative gasoline, respectively. The increment of a Wiener process is dz, with $E(dz_C^2) = E(dz_A^2) = dt$ and $E(dz_C, dz_A) = \rho dt$, where ρ denotes the correlation coefficient between C and A.

Taking the expected value of (1) and (2) and solving the differential equations for the current prices $C(0) = C_0$ and $A(0) = A_0$ yields

$$E[C(t)] = C_0 e^{\alpha_C t} \qquad \text{and} \qquad E[A(t)] = A_0 e^{\alpha_A t}.$$

Given these price processes and assuming utility maximization on the part of agents, this is a stochastic optimal-stopping problem, where a threshold value for the price of alternative gasoline, A^*, is determined. The problem is determining when to exercise the option of switching to the alternative fuel, and the decision rule is to adopt the alternative fuel if $A \leq A^*$; otherwise do not exercise the option and continue using conventional gasoline. Following Dixit and Pindyck, the Bellman equation for determining the optimal threshold A^* can be obtained by equating the expected capital appreciation to the expected return on adopting the alternative gasoline.

Solving this Bellman equation analytically given the value-matching and smooth-pasting conditions yields the optimal threshold value

$$A^* = \frac{\beta}{\beta - 1}\frac{[e^{T(\alpha_C - r)} - 1](\alpha_A - r)}{[e^{T(\alpha_A - r)} - 1](\alpha_C - r)} C \geq A, \quad (3)$$

where T is the time horizon (possibly the life of an engine), r is the discount rate, and

$$\beta = ½ - (\alpha_A - \alpha_C)/\sigma^2 + \{[(\alpha_A - \alpha_C)/\sigma^2 - ½]^2 + [2(r - \alpha_C)/\sigma^2]\}^{½} > 1. \quad (4)$$

Note that $\sigma^2 = (\sigma_C^2 - 2\rho\sigma_A\sigma_C + \sigma_A^2)$ and the sign is determined by the condition $r > \alpha_A$. Thus, the decision rule for switching to an alternative gasoline is when its price, A, is less than the threshold value A^*. If $\alpha_A = \alpha_C$ and $\sigma_A = \sigma_C$ then (3) reduces down to $A^* = C$, which is the traditional nonstochastic criterion for choosing between two alternatives. When $\alpha_A < \alpha_C$, with $\sigma_A = \sigma_C$, $A^* > C$, indicating the threshold for switching to an alternative fuel becomes less restrictive. The threshold is now higher, so the price does not have to decline as far before the alternative fuel is adopted. The effect of σ_A and σ_C on A^* is indeterminate. An increase in σ_A or σ_C may increase or decrease A^* depending on the magnitude of their ratio and on the sign of ρ.

Application

The data used for this study are weekly wholesale prices for conventional gasoline and ethanol at three U.S. locations: Los Angeles, Houston (Gulf Coast), and New York. These locations represent three out of the five Petroleum Defense Administrative Districts (PADDs) as classified by the Energy Information Administration (EIA). The calculated thresholds based on (3) are similar for all three locations, so only the Gulf Coast results are reported for this application.[1] The conventional gasoline prices are collected from the Weekly Petroleum Status Report available at EIA website (EIA 2004). The ethanol prices are collected from *Renewable Fuel News* (formerly *Oxy-Fuel News*). The ethanol price series are available from the first week of April 1989 through the last week of May 2004 for New York, and from last week of March 1989 through last week of May 2004 for Los Angeles and Houston. Conventional gasoline price series starts in February 1987.

The nominal price series have been deflated using monthly Producer Price Index (PPI) data for refined petroleum products (series WPU057) available from the Bureau of Labor Statistics website (BLS 2004). The PPI was normalized so that July 2004 = 100. The real prices for ethanol blends with 10% and 15% ethanol concentrations (referred in the text as E10 and E15, respectively) have been constructed as corresponding weighted averages of real price series for conventional gasoline and ethanol at each location.

Two additional subsamples have been created from each of the data series. The subsamples match periods hypothesized to exhibit higher than average drift and volatility in gasoline prices. The first subsample includes observations from July 1990 through December 1991 and corresponds to the first Gulf War and a period of economic recession. The second subsample includes observations from July 2001 through May 2004 and encompasses events of 9/11, recession of 2000-01, as well as the second Gulf War (Terrorism War). The descriptive statistics of the real price series for gasoline and ethanol are summarized in table 1 both for the Full sample and the two subsamples: Gulf and Terrorism Wars. A graph of real prices from 1989 to 2004 for Gulf Coast conventional gasoline is shown in figure 1.

Unit Root Analysis

Before estimating the parameters of the Brownian motions, we tested the price series for gasoline and constructed ethanol blends (E10 and E15) for unit roots. Following Pindyck, we ran the augmented Dickey-Fuller test with the time trend, t, by estimating the model

N

$$\Delta p_t = \gamma_o + \gamma_1 t + \upsilon_1 p_{t-1} + \sum_{i=1} \delta_i \Delta p_{t-i} + \epsilon_t$$

where p is the logarithm of the corresponding real price, and N is the number of lags. The results of the tests are presented in table 2 for N = 1, 2, and 4. The case N = 0 corresponds to the model with no difference lags. The p-values used for significance testing are interpolated MacKinnon approximate critical values for the t-statistics on υ. The hypothesis of a unit-root is rejected for both the conventional gasoline and two ethanol blends.

Estimation Procedures

The parameters of geometric Brownian motions (1) and (2) along with the correlation coefficients, ρ, have been estimated for the three fuel-price series: Full sample, Gulf War subsample, and Terrorism War subsample. The maximum likelihood estimators for the drift, α, and volatility, σ, are (Campbell, Lo, and MacKinlay)

$$\hat{\sigma}_i^2 = \sum_{j=1}^{n} (r_{ij} - \hat{\mu}_i)^2/n, \qquad i = A \text{ and } C,$$

and

$$\hat{\alpha}_i = \hat{\mu}_i + (\hat{\sigma}_i^2/2),$$

where $r_{ij} = \Delta p_{ij}/p_{ij}$ are the first differences of logarithms of corresponding real prices, and

$$\hat{\mu}_i = \sum_{j=1}^{n} r_{ij}/n, \qquad i = A \text{ and } C.$$

Results

The estimation results for conventional gasoline and the two ethanol blends (E10 and E15) are summarized in table 3. Based on the Full sample, the Gulf Coast gasoline price series has an average drift of 8% per year and a volatility of over 40%. The ethanol blends contain either a 85% or 90% proportion of gasoline, so their price series tend to behave similarly to the corresponding gasoline series. This is reflected both in similar patterns of drift and volatility and in the correlations between the price series. However, even with a small addition of ethanol, both the drift and volatility of the blends decline relative to conventional gasoline. For example, the price series for E15 exhibited a drift and volatility of 4.5% and 33.2% compared to 5.4% and 35.5% for E10 and 8% and 41.8% for conventional gasoline. As the percentage of ethanol increases, both the drift and volatility decline yielding stabler fuel prices for the economy.

The parameters of Brownian motions estimated on the two subsamples (Gulf and Terrorism Wars) confirm the initial hypothesis of higher drift and volatility of gasoline prices during these two disruptive periods. Conventional gasoline experienced the largest increases in drift and volatility as the result of these disruptions, with the portfolio effect mitigating these price changes for the alternative fuels: E10 and E15. Regardless of individual patterns, the addition of even a small amount of ethanol resulted in a decrease in the price drift and volatility of the blends.

The Terrorism War sample yields the largest increases in drift; whereas, the Gulf War period represents the period of the highest volatility. The current tight supplies from oil refining and strong demand from developing countries, such as China and India, explain a major portion of the recent large increase in gasoline-price drift. The relatively high volatility in gasoline prices during the Gulf War indicates the initial spike in price at the start of the war and then a subsequent decline following the war's short duration (figure 1). A similar price pattern has not being observed during the Terrorism War, given major hostilities continue over an extended time period.

The estimated parameters of the price-series processes were used to calculate the switching thresholds (3) for the two ethanol blends. Recall that these switching thresholds are the price levels below which it becomes economically optimal to adopt the alternative fuels. The thresholds are calculated for alternative combinations of risk-free interest rates and time horizons (table 4). The average price levels of conventional gasoline and ethanol blends during 2001-2004 are used to convert the relative thresholds into dollar values (in July 2004 dollars).
As indicated from the table, the optimal thresholds are increasing in length of the time horizon and declining with increases in the discount rate. The thresholds for E15 are uniformly higher than the thresholds for E10, which is consistent with the condition that the former includes a higher proportion of the more expensive ethanol component than the latter. The average price of E10 over the years 2001 - 2004 is $1.169 compared to $1.205 for E15.

These average ethanol prices are below the switching threshold for every scenario across all the sample periods, and do not consider the 5.2 cent federal motor fuel tax exemption. Thus, given the current price patterns, switching from conventional gasoline to either ethanol blend is an economically sound decision provided that this does not decrease efficiency of the vehicle. Furthermore, the increased drift and volatility of gasoline prices in the recent years make such a switch even more attractive and economically justified. The continuing hunger for oil by the developed countries, the marked increase in appetites of developing countries, and projections of oil production peaking in this century are signals that the current drift and volatility in gasoline prices may not be a short-run occurrence. Alternative fuels yielding a portfolio effect on gasoline prices can mitigate this price projection. Even considering the Full sample period, the adoption of E10 and E15 is currently feasible and will lead to stabler fuel prices for the economy.

Policy Implications

The macroeconomic stumbles from petroleum-price volatility are of major concerns, particularly since the energy crisis in the 1970s and ensuing military conflicts in the Middle East. In response to these concerns, Congress has enacted a number of energy policies including the National Energy Act of 1998, the Energy Conservation Reauthorization Act of 1998, and the Energy Policy Act of 1992. However, energy legislation has had limited effect on reducing our dependence on foreign petroleum. As indicated from the results based on real option analysis, increasing price volatility of conventional gasoline will trigger the adoption of alternative available fuels without further government regulation. In the presence of volatile gasoline prices, competitive market forces will yield alternative less volatile fuels as substitutes. Considering the portfolio effect of alternative fuel blends, such as ethanol, current government subsidies should be sufficient in activating widespread adoption. Without considering this portfolio effect, benefits from these government subsidies are underestimated resulting in renewed calls for additional subsidies. The average conventional gasoline price for the Terrorism War period (2001 - 2004) is $1.096 (table 1). Comparing this to the average price of E10 or E15 over the same period of $1.169 and $1.205 (table 4), one would conclude incorrectly (given these alternative fuel prices are higher than conventional gasoline prices) that additional subsidies are warranted for adoption. Thus, ignoring the portfolio effect leads to erroneous results.

A major implication of this analysis is that policymakers should be considering price volatility and associated portfolio effects when advocating spending levels for alternative fuel programs. As an example, the cost of reducing price volatility by using E10, based on a 6% discount rate and a 10-year life, is the difference in the mean Terrorism War value of gasoline of $1.096 and the E10 average price of $1.169, *i.e.* $0.073. In contrast, the benefit to individual firms and households from reduced volatility is the difference between this average price of E10 and the switching threshold for the Full sample of $1.524, *i.e.* $0.355. Thus, the adoption of E10 has a benefit to cost ratio of 35.5/7.3 = 4.87. This value can aid in estimating the cost and benefits of tax credits and other economic incentives for alternative fuels.

In addition to macroeconomic stability benefits, the portfolio effects may help the United States achieve its air quality goals and reduce emissions of greenhouse gasses. Further research is required for estimating the value of these environmental benefits in order to make accurate cost and benefit comparisons between petroleum-based fuels and alternative fuels. Combining the macroeconomic stability benefits with the environmental benefits of ethanol blended fuels could increase its value considerably.

Conclusion

The hypothesis underlying this analysis is that in the presence of volatile gasoline prices competitive market forces will yield alternative less volatile fuels as substitutes. A real-option pricing approach was employed for this analysis by modeling investment under uncertainty for the case of comparing stochastic prices of substitute commodities. Based on real options, threshold decision rules were developed for the adoption of portfolio fuels as ethanol and conventional gasoline blends. Considering this portfolio effect, the benefit to cost ratios are above four for the alternative blends under varying discount rates and time spans. This provides a strong indication that consumer demand exists for these portfolio fuels. Competitive markets will then respond to this consumer demand yielding less volatile portfolio fuels. With this demand, competitive markets will incorporate ethanol into our domestic fuel mix.

Portfolio theory was introduced by Harry Markowitz with his paper "Portfolio Selection" which appeared in the 1952 *Journal of Finance*. This theory explores how investors construct portfolios for optimizing expected returns, and has profoundly shaped how financial portfolios are managed. Extending this theory to the adoption of alternative fuels through real-option analysis will also aid in evolving toward optimal government policies and industry management decisions. The results of comparing ethanol bended fuels indicate this extension has considerable effects on adoption. Without considering the portfolio effects, the benefit to cost ratios are less than one indicating little incentives toward adoption. Considering the portfolio effects based on real-option analysis, the benefit to cost ratios are above one indicating a positive incentive. In the development of policies affecting the vehicle-fuel markets, attention is warranted in realizing the desirable reduction in fuel volatility from shifts in blended fuel demand.

Footnotes

[1] Please contact the authors if you are interested in the results for the other two locations: Los Angeles and New York.

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Table 1. Descriptive Statistics for Conventional Gasoline and Ethanol Real Price Series for the Gulf Coast

Fuel	Sample[a]	Observations	Minimum	Maximum	Mean	Standard Deviation
Conventional	Full	757	$0.771	$1.724	$1.071	$0.113
Gasoline	Gulf War	73	0.875	1.724	1.167	0.149
	Terrorism War	146	0.771	1.384	1.096	0.106
Ethanol	Full	753	1.324	2.978	2.107	0.298
	Gulf War	73	1.472	2.348	2.024	0.216
	Terrorism	144	1.324	2.421	1.820	0.274

[a]Full, Gulf War, and Terrorism War samples include weekly observations from April 1989 through May 2004, July 1990 through December 1991, and July 2001 through May 2004, respectively.

Table 2. Augmented Dickey-Fuller Unit Root Test and AR(1) Parameters[a]

Fuel	Number of Time Difference Lags							
	Zero		1		2		4	
	t	υ	t	υ	t	υ	t	υ
Gasoline	-0.156	-8.246	-0.147	-7.433	-0.142	-6.912	-0.142	-6.504
E10	-0.195	-9.314	-0.189	-8.561	-0.183	-7.891	-0.184	-7.371
E15	-0.208	-9.657	-0.203	-8.893	-0.196	-8.155	-0.198	-7.610

[a]Coefficients for parameter υ are all significantly different from zero at the 0.001 level.

Table 3. Estimated Parameters of Geometric Brownian Motion

Fuel	Sample[a]	Drift, α	Volatility, σ	Correlation with Gasoline Prices, ρ
Gasoline	Full	0.080	0.418	1.000
	Gulf War	0.092	0.516	1.000
	Terrorism War	0.248	0.476	1.000
E10	Full	0.054	0.355	0.980
	Gulf War	0.052	0.462	0.991
	Terrorism War	0.196	0.417	0.989
E15	Full	0.045	0.332	0.970
	Gulf War	0.053	0.441	0.986
	Terrorism War	0.176	0.394	0.976

[a]Full, Gulf War, and Terrorism War samples include weekly observations from April 1989 through May 2004, July 1990 through December 1991, and July 2001 through May 2004, respectively.

Table 4. Switching Threshold Prices for Ethanol Blends

Ethanol Fuels	Sample[a]	Discount Rate				
		6%			8%	10%
		10 Years	20 Years	30 Years	20 Years	20 Years
E10	Full	$1.524	$1.742	$1.997	$1.670	$1.615
	Gulf War	1.476	1.821	2.263	1.766	1.714
	Terrorism War	1.730	2.665	4.339	2.556	2.469
	2001-2004	.... Average Price $1.169				
E15	Full	1.640	1.953	2.327	1.862	1.790
	Gulf War	1.571	1.930	2.389	1.857	1.793
	Terrorism War	2.022	3.654	7.146	3.476	3.316
	2001-2004	.... Average Price $1.205				

[a]Full, Gulf War, and Terrorism War samples include weekly observations from April 1989 through May 2004, July 1990 through December 1991, and July 2001 through May 2004, respectively.

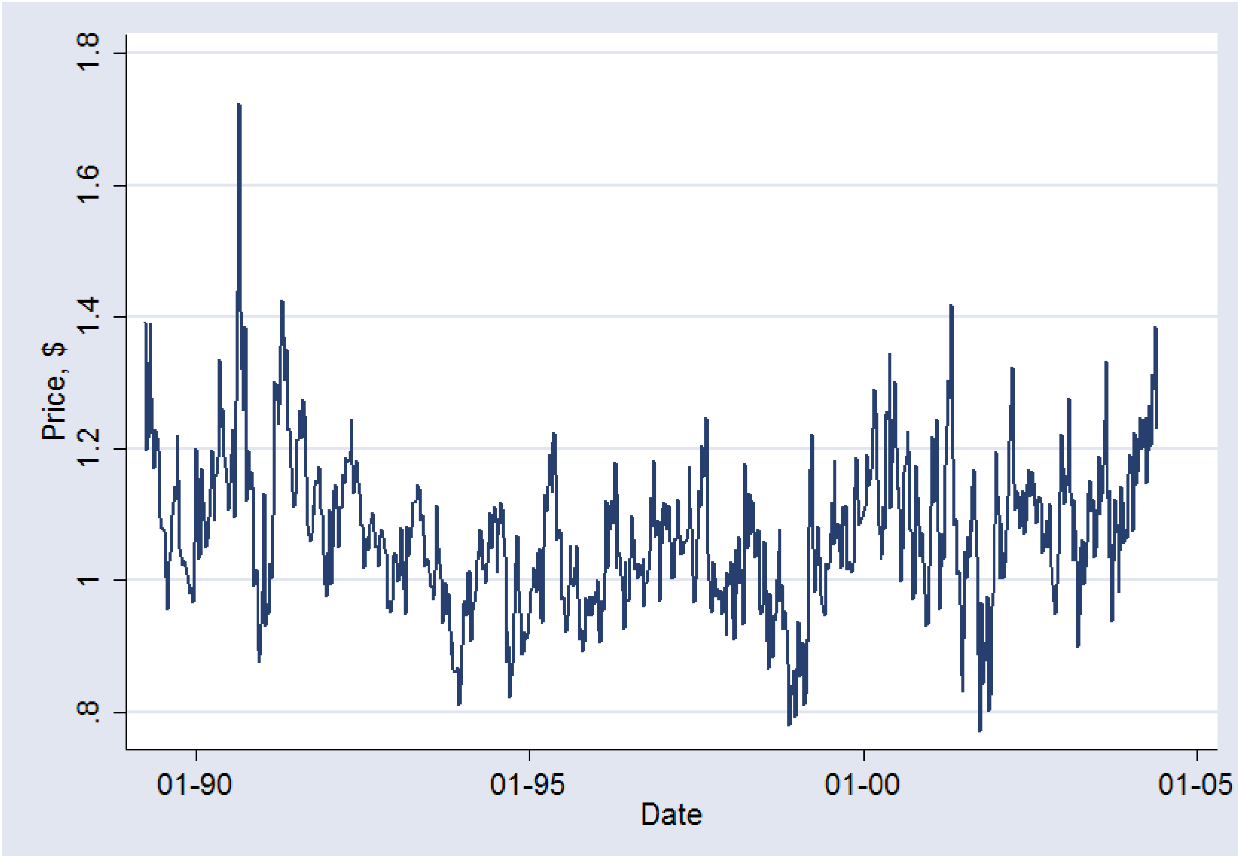

Figure 1. Conventional Gulf Coast Gasoline Prices, 1989-2004 (in July 2004 dollars)