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

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Dramatic increases in levels and volatility of gasoline prices observed in recent years may create market incentives for adoption of alternative fuels characterized by lower price volatility. This hypothesis is investigated by applying the real-options pricing approach to develop optimal thresholds for switching from conventional gasoline to alternative fuels such as ethanol blends. The main result of the paper is that given the historical price patterns of conventional gasoline and ethanol, switching to ethanol blends is an economically sound decision provided this does not decrease efficiency of the vehicle. Analysis of data subsamples during the periods of higher volatility of gasoline prices (Gulf War and War on Terrorism) provides even stronger support for this result.

Key words: alternative fuels, decision making under uncertainty, ethanol, price volatility, real options

Introduction

Since the turn of the 21st century, the volatility in gasoline prices causing price "spikes" has become increasingly common (Ashton and Upton, 2004). Gasoline prices tend to exhibit asymmetry, with steep price spikes followed by gentle declines. U.S. Energy Information Administration data confirm this price asymmetry, where retail prices typically rise more rapidly than they fall (Cook, 1999). Such volatility harms the entire macroeconomy and is at least partially responsible for the U.S. economy falling into the 2001 recession. As reported by Ferderer (1996), oil price volatility, which directly impacts 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 (2001) 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, 1999).

Alternative hypotheses have emerged as explanations for the increased gasoline price volatility. Crude oil costs are certainly a contributing factor, but Speir (2004) concludes oil price volatility alone explains less than half of gasoline price movements. This result is supported by Ashton and Upton (2004) who cite changes in inventory carrying levels,

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increased concentration and vertical integration of the petroleum industry, and the advent of boutique fuels as 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, 2004). In such a market, price volatility is reinforced when a boutique of fuel types creates unique local markets with barriers that prevent the reallocation of fuels for meeting changes in short-run regional demands (Hutzler and Shore, 2002).

With upward-trending oil prices and heightened concerns over energy security stemming from the 9/11 terrorists attacks, expanding domestic renewable fuel production has become a major policy objective for the United States. Renewable fuels are generally more expensive than their petroleum counterparts and require government support in order to compete in the U.S. fuel market. For example, since the late 1980s, ethanol producers have enjoyed a motor fuel tax credit, currently standing at $0.51 per gallon.

Efforts to promote renewable fuel production have intensified in the past few years, as the U.S. Congress and many states have adopted numerous policies to increase the use of domestic ethanol and biodiesel in the U.S. transportation sector (Collins and Duffield, 2005; North Carolina Solar Center, 2005). In addition, environmental regulations, such as the Clean Air Act Amendments of 1990, have been passed to encourage the replacement of petroleum fuels with renewable fuels to address air quality concerns.

Recently, ethanol demand received a major boost when a petroleum fuel oxygenate called methyl tertiary butyl ether (MTBE) used to manufacture reformulated gasoline[1] was banned in California because it was contaminating groundwater (Blue Ribbon Panel on Oxygenates in Gasoline, 1999). MTBE has been replaced with an ethanol additive, the only other oxygenate available that does not contaminate groundwater. Following California's lead, 24 other states have also banned MTBE over the past few years, resulting in a significant expansion in the U.S. ethanol market.

Increasingly, renewable energy policies are being implemented to help address energy supply uncertainty. Policy makers tend to focus on energy supply and price differences between renewable fuels and petroleum fuels when developing policy incentives. Little attention, however, has been given to energy price volatility in this context. In the presence of volatile gasoline prices, competitive market forces may speed up adoption of alternative fuels with lower price volatility as substitutes.

A notable exception to this lack of related research is a paper by Tareen, Wetzstein, and Duffield (2000). The authors use a real-options approach to develop decision rules for switching from petroleum diesel to biodiesel. Their study found volatility of alternative diesel fuels is lower than that of petroleum diesel, concluding that price volatility should also be considered when evaluating policy options for substituting petroleum fuels with renewable fuels. However, the switching thresholds calculated by Tareen, Wetzstein, and Duffield proved to be too high to justify transition at the current levels of prices. While their paper provided an interesting insight into the decision-making

[1] Reformulated gasoline (RFG) blends oxygenates into gasoline for emission reductions. RFG, which accounts for approximately one-third of the U.S. gasoline market (Lidderdale, 2003), generally reduces emissions of volatile organic compounds and toxic air pollutants. In 1995, RFG was mandated in the nine worst Clean Air Act non-attainment 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. Prior to 2004, MTBE had been the main additive used to manufacture RFG.

process involved in adoption of alternative fuels, its practical application is somewhat limited.

Biodiesel is more of a niche fuel and its use is much less widespread than other alternative fuels such as ethanol. As reported by the National Biodiesel Board (2005), current U.S. dedicated production capacity of biodiesel is a record 0.11 billion gallons. However, this is far short of the 3.41 billion gallons of ethanol produced in 2004, which in turn is more than double ethanol production in 2000 (Renewable Fuels Association, 2005). In contrast to biodiesel, blends of ethanol with gasoline are emerging as major substitutes for U.S. total reliance on fossil fuels. Currently, a blend of 10% ethanol with 90% conventional gasoline (E10 or gasohol) is commercially available mainly in the Midwest corn-producing states for reducing carbon monoxide emissions during the winter months. While use of biodiesel requires modifications to the engine, gasoline/ethanol blends containing up to 10% ethanol by volume may be used in any vehicle without modification (U.S. Department of Energy, 2005), i.e., such blends can be considered as perfect substitutes for conventional gasoline.

Ethanol blends with higher proportions of ethanol—in particular E85, which combines 85% ethanol and 15% conventional gasoline—require additional modifications to the engine. However, the number of so-called "flex-fuel" cars which can operate both on conventional gasoline and E85 has been steadily increasing. Currently, more than 5 million such vehicles are on the roads, with major car manufacturers expected to step up production in the future (Lundegaard, 2006).

The ethanol industry is expanding rapidly. Twelve new ethanol plants were completed in 2004, increasing the total number of plants to 81. With another 16 plants under construction and plans to expand existing plants, ethanol capacity was expected to increase by another 750 million gallons in 2005 (Renewable Fuels Association, 2005). The U.S. Congress has recently passed the Domenici-Barton Energy Policy Act of 2005, which includes a renewable fuel standard (RFS). The Act mandates a renewable fuel phase-in, requiring fuel producers to manufacture a minimum amount of renewable fuel each year, starting at 4 billion gallons in 2006, and reaching 7.5 billion gallons in 2012. The RFS is expected to be satisfied by ethanol and biodiesel, but ethanol will likely provide the bulk of the mandated fuel. The Energy Policy Act of 2005 is considered to be the first step in revamping U.S. energy policy, and more legislation is expected to help address future energy requirements.

This growing importance of ethanol, with the continuing discussion on the necessity and level of ethanol subsidies, requires an accurate evaluation of the market adoption potential of this major alternative fuel. Toward that end, our paper uses a real-options approach (similar to Tareen, Wetzstein, and Duffield, 2000) in order to develop economically optimal thresholds for adoption of ethanol blends by taking into account both drift and volatility of gasoline and ethanol prices. Theoretical results establish an empirical link for measuring the tradeoff between a relatively more expensive commodity (alternative fuel) with lower price drift and volatility and a lower but more volatile priced commodity (conventional gasoline).

The remainder of the paper is organized as follows. The next section outlines the theoretical approach to developing a decision rule for adoption of alternative fuels based on real-options methodology. The data and estimation procedures are then described, followed by a presentation of the results of our empirical analysis. Policy implications and concluding comments are provided in the final section.

Methodology

In this analysis, the decision threshold of when to switch to an alternative fuel is based on the Dixit and Pindyck (1994) approach for real-options pricing, and its application by Tareen, Wetzstein, and Duffield (2000).[2] The underlying assumption here is that the adoption decision is made by a dynamically optimizing economic agent who wants to minimize expected future cost of fuel over a certain time horizon. For purposes of this analysis, the agent is assumed to be a wholesale buyer of fuel, e.g., a trucking company with a fleet of medium-sized (gasoline-powered) trucks, a chain of retail stores, or a delivery company. It is also assumed the agent is considering switching between conventional gasoline and ethanol blends that do not require engine modifications.

From the standpoint of such an agent, the decision to switch to an alternative fuel at time t results in cost savings having the expected present value of:

(1) $$V(t) = \mathrm{E}\int_t^{t+T}\left[P_C(\tau) - P_A(\tau)\right]\exp(-r\tau)\,d\tau,$$

where $P_C(\tau)$ and $P_A(\tau)$ are the prices of conventional and alternative fuels, respectively, at time τ, r is the discount rate, T is the planning horizon, and E is the expectation operator. If the prices are deterministic, then the optimal decision depends only on the sign of V and is essentially equivalent to the net present value approach. However, the situation is different when the prices fluctuate randomly over time.

In particular, we assume that the prices of both conventional and alternative fuels follow geometric Brownian motion processes:

(2) $$dP_C = \mu_C P_C dt + \sigma_C P_C dz_C$$

and

(3) $$dP_A = \mu_A P_A dt + \sigma_A P_A dz_A,$$

where μ is the corresponding rate of change (drift), σ is the volatility, and the subscripts C and A refer to conventional and alternative fuels, respectively. The terms dz_C and dz_A represent increments of respective Wiener processes with properties:

(4) $$\mathrm{E}(dz_C^2) = \mathrm{E}(dz_A^2) = dt \quad \text{and} \quad \mathrm{E}(dz_C dz_A) = \rho dt,$$

where ρ measures the correlation between P_C and P_A.

Using (2) and (3), the expected values of both prices at time t can be derived as:

(5) $$\mathrm{E}P_C(t) = P_C(0)\exp(\mu_C t) \quad \text{and} \quad \mathrm{E}P_A(t) = P_A(0)\exp(\mu_A t),$$

where $P_C(0)$ and $P_A(0)$ are the corresponding prices at time zero. Substituting (5) into (1) and integrating over time yields:

[2] The presentation in this section closely follows Dixit and Pindyck (1994) and Tareen, Wetzstein, and Duffield (2000). Therefore some of the intermediate derivation steps are omitted due to space considerations. Interested readers may refer to the above two sources for more detailed exposition.

(6) $$V = \frac{P_C\left(\exp[T(\mu_C - r)] - 1\right)}{\mu_C - r} - \frac{P_A\left(\exp[T(\mu_A - r)] - 1\right)}{\mu_A - r},$$

which is the discounted present value of savings from switching to the alternative fuel when the current prices of conventional and alternative fuels are P_C and P_A, respectively. The optimal price threshold for switching can now be found by solving the Bellman equation:

(7) $$rVdt = \mathrm{E}(dV),$$

which requires the total expected return from the switch to be equal to the expected capital appreciation (Dixit and Pindyck, 1994, p. 140). Applying Ito's lemma to the right-hand side of (7) and substituting (2)–(4) results in a partial differential equation for V, with P_C and P_A as independent variables:

(8) $$\mu_C P_C V_{P_C} + \mu_A P_A V_{P_A} + \tfrac{1}{2}\left(\sigma_C^2 P_C^2 V_{P_C P_C} + \sigma_A^2 P_A^2 V_{P_A P_A} + 2\rho\sigma_C\sigma_A P_C P_A V_{P_C P_A}\right) = rV.$$

Using the homogeneity of the value function in both prices, (8) can be reduced to an ordinary second-order linear differential equation:

(9) $$\tfrac{1}{2}\left(\sigma_C^2 + \sigma_A^2 - 2\rho\sigma_C\sigma_A\right)\pi^2 v'' + \left(\mu_A - \mu_C\right)\pi v' + \left(\mu_C - r\right)v = 0$$

for $v(\pi)$, where $\pi = P_A/P_C$ is the ratio of prices, and

(10) $$v(\pi) = v(P_A/P_C) = V(1, P_A/P_C) = \frac{1}{P_C}V(P_C, P_A).$$

The general solution to (9) is

$$v(\pi) = A_1\pi^{\beta_1} + A_2\pi^{\beta_2},$$

which, when combined with the limit condition $v(\pi) \to -\infty$ as $\pi \to \infty$, the value-matching condition

$$v(\pi) = \frac{V}{P_C} = \frac{\exp[T(\mu_C - r)] - 1}{\mu_C - r} - \frac{\pi\left(\exp[T(\mu_A - r)] - 1\right)}{\mu_A - r}$$

[cf. (6) and (10)], and the corresponding smooth-pasting condition

$$v'(\pi) = -\frac{\exp[T(\mu_A - r)] - 1}{\mu_A - r},$$

can be solved for the optimal switching threshold:

(11) $$P_A^* = \frac{\beta}{\beta - 1} \times \frac{\exp[T(\mu_C - r)] - 1}{\exp[T(\mu_A - r)] - 1} \times \frac{\mu_A - r}{\mu_C - r}P_C,$$

where

$$\beta = \tfrac{1}{2} - \frac{\mu_A - \mu_C}{\sigma^2} + \sqrt{\left(\frac{\mu_A - \mu_C}{\sigma^2} - \tfrac{1}{2}\right)^2 + 2\frac{r - \mu_C}{\sigma^2}} > 1$$

and

$$\sigma^2 = \sigma_C^2 - 2\rho\sigma_C\sigma_A + \sigma_A^2.$$

The optimal decision rule can then be formulated as follows. Switch to the alternative fuel when its price is below the threshold in (11); continue to use the conventional fuel otherwise.

Empirical Analysis

Data

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 of the five Petroleum Administration for Defense Districts (PADDs) as classified by the U.S. Energy Information Administration (EIA, 2004). Because the calculated thresholds based on (11) are similar for all three locations, only the Gulf Coast results are reported here.[3] The conventional gasoline prices are taken from the "Weekly Petroleum Status Report" available at the 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 the last week of March 1989 through the last week of May 2004 for Los Angeles and Houston. The conventional gasoline price series starts in February 1987.

The nominal price series were deflated using monthly Producer Price Index (PPI) data for refined petroleum products (series WPU057) available from the U.S. Department of Labor's Bureau of Labor Statistics (2004) website. The PPI was normalized so that July 2004 = 100. The real prices for ethanol blends with 10% and 15% ethanol concentrations (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, the 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 for both the full sample and the two subsamples (Gulf War and Terrorism War). Graphs of real prices for Gulf Coast conventional gasoline and ethanol from 1989–2004 are shown in figures 1 and 2, respectively. The 13-week (quarterly) moving averages are also shown on both graphs to illustrate longer-term tendencies.

[3] The results for the other two locations—Los Angeles and New York—are available from the authors upon request.

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

Fuel	Sample[a]	No. of Observations	Minimum ($)	Maximum ($)	Mean ($)
Conventional Gasoline	Full	757	0.771	1.724	1.071
	Gulf War	73	0.875	1.724	1.167
	Terrorism War	146	0.771	1.384	1.096
Ethanol	Full	753	1.324	2.978	2.107
	Gulf War	73	1.472	2.348	2.024
	Terrorism War	144	1.324	2.421	1.820

Note: Prices are normalized to July 2004 dollars.
[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.

During this period, the conventional gasoline prices varied between $0.771 and $1.724 (in 2004 dollars) with a mean of $1.071 (table 1). As expected, both the Gulf War and Terrorism War subsamples were characterized by higher average prices than the full sample. The ethanol prices over this same period varied between $1.324 and $2.978 (in 2004 dollars) with a mean of $2.107. However, the Gulf War and Terrorism War subsamples had lower average prices than the full sample, reflecting the fact that changes in oil prices do not have a direct impact on ethanol. The graph of gasoline prices (figure 1) exhibits visibly higher oscillation than the graph of ethanol prices (figure 2). The moving average graph of gasoline prices also reflects the price asymmetry (Cook, 1999), as the increases in gasoline prices are generally steeper than the declines. Both the Gulf War and Terrorism War periods are characterized by increased volatility, and the Terrorism War period also exhibits substantial upward movement of prices. In contrast, the graph of ethanol prices (figure 2) exhibits less oscillation, and long-term changes in prices are less asymmetric.

Unit-Root Analysis

Before estimating the parameters of the Brownian motions, we tested gasoline and constructed ethanol blends (E10 and E15) price series for unit roots. Following Pindyck (1999), we ran the augmented Dickey-Fuller test with the time trend (t) by estimating the following model:

$$\Delta p_t = \gamma_0 + \gamma_1 t + \upsilon p_{t-1} + \sum_{i=1}^{N} \delta_\tau \Delta p_{t-i} + \varepsilon_t,$$

where p_t is the logarithm of corresponding real price at time t, Δ is the difference operator, and N is the number of lags included in the model. The results of the tests are presented in table 2 for $N = 1$, 2, and 4. The case of $N = 0$ corresponds to the model with no difference lags. The p-values used for significance testing are interpolated MacKinnon (1994) 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.

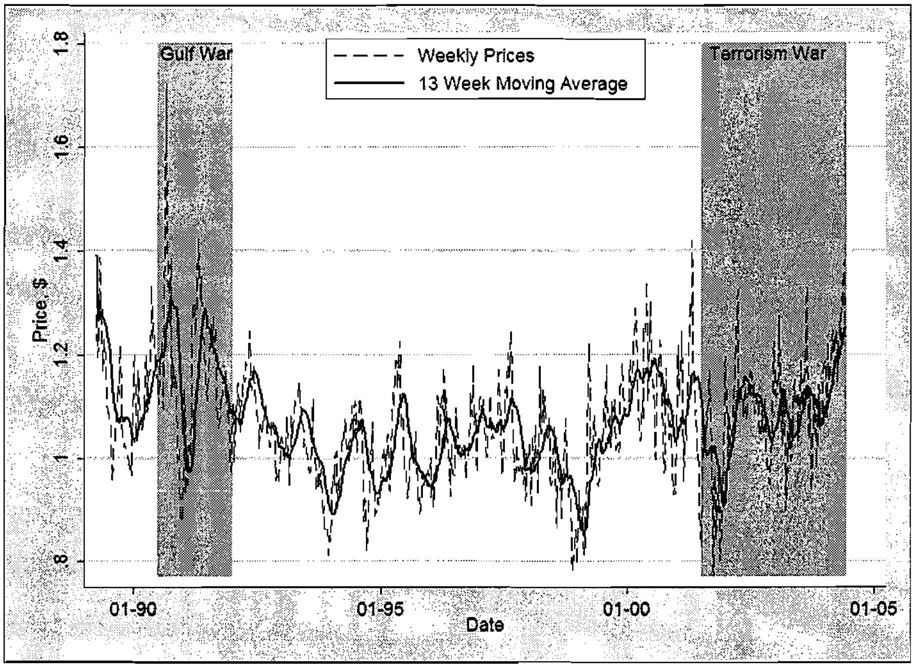

Figure 1. Conventional gasoline prices, Gulf Coast, 1989–2004 (in July 2004 $)

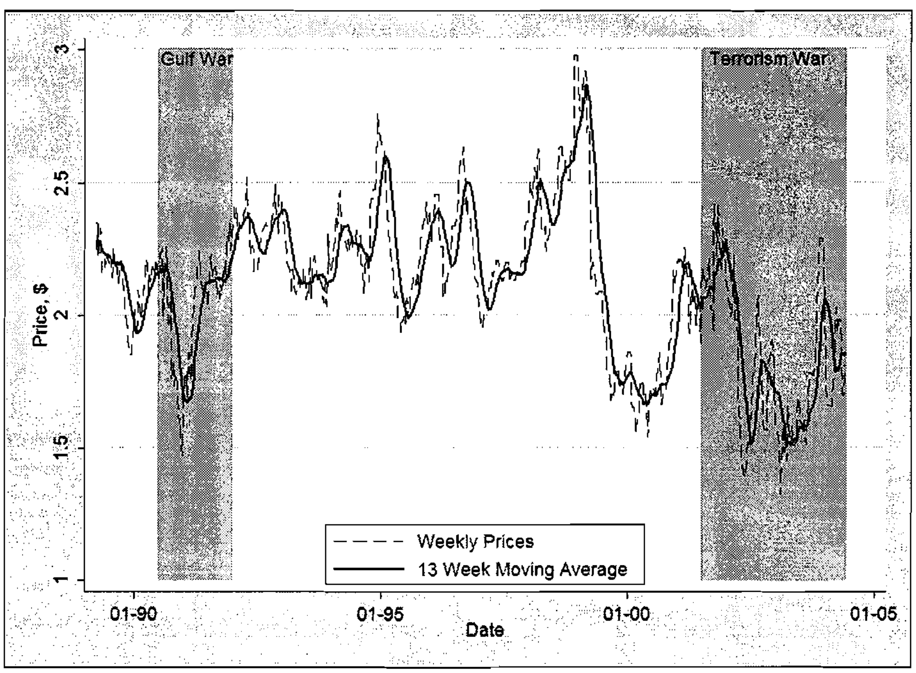

Figure 2. Ethanol prices, Gulf Coast, 1989–2004 (in July 2004 $)

Table 2. Results of Augmented Dickey-Fuller Unit-Root Test and AR(1) Parameters

	Number of Time Difference Lags							
	0		1		2		4	
Fuel	*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

Note: Coefficients for parameter υ are all significantly different from zero at the 0.001 level.

Estimation Procedures

The parameters of geometric Brownian motions (2) and (3), along with the correlation coefficients (ρ), have been estimated for the three fuel-price series: (*a*) full sample, (*b*) Gulf War subsample, and (*c*) Terrorism War subsample. Since the estimation procedure is identical for gasoline and ethanol blends, in the remainder of this section subscripts indicating types of fuel are omitted for the sake of brevity.

According to Ito's lemma, the logarithm of a price variable following the geometric Brownian motion is described by the Brownian motion process:

$$dp = \left(\mu - \tfrac{1}{2}\sigma^2\right)dt + \sigma dz = \alpha dt + \sigma dz. \quad (12)$$

The respective maximum-likelihood estimators for the drift (α) and volatility (σ) in (12) are:

$$\hat{\alpha} = \frac{1}{n}\sum_{t=1}^{n} r_t,$$

$$\hat{\sigma}^2 = \frac{1}{n}\sum_{t=1}^{n} (r_t - \hat{\alpha})^2,$$

where $r_t = \Delta p_t / p_t$ is the first difference of the logarithm of corresponding real price at time t, and n is the number of observations (Campbell, Lo, and MacKinlay, 1997, p. 363). The volatility estimator can then be used directly for estimating volatilities of the geometric Brownian motions (2) and (3), while the corresponding drifts (μ) can be estimated as:

$$\hat{\mu} = \hat{\alpha} + \tfrac{1}{2}\hat{\sigma}^2.$$

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 41.8%. At the same time, the respective drift and volatility of ethanol were only 1.5% and 25.2% per year. The correlation between the ethanol and gasoline prices in the full sample was 0.284, suggesting combinations of ethanol and gasoline would have lower volatility due to a portfolio effect.

Table 3. Estimated Parameters of Geometric Brownian Motion

Fuel	Sample[a]	Drift (μ)	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
Ethanol	Full	0.015	0.252	0.284
	Gulf War	0.095	0.300	0.579
	Terrorism War	0.051	0.364	0.281

[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.

The ethanol blends contain either an 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, due to low correlation between the ethanol and conventional gasoline, both the drift and volatility of the blends decline relative to conventional gasoline even with a small addition of ethanol. 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 more stable 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 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 subsample yields the largest increases in drift, whereas the Gulf War period represents the period of 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 reflects 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 was not observed in the Terrorism War subsample, perhaps due to continuing duration of military conflicts. More recent data reflecting dramatic increases in oil and gasoline prices in the second half of 2004, and especially during 2005, would probably manifest such a pattern more profoundly.

Table 4. Switching Threshold Prices for Ethanol Blends

		Discount Rate				
		6%			8%	10%
Ethanol Fuels	Sample[a]	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
		— *Average Price 2001–2004 = $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
		— *Average Price 2001–2004 = $1.205* —				

Note: Prices are normalized to July 2004 dollars.
[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.

The estimated parameters of the price processes were used to calculate the switching thresholds (11) 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 in table 4, the optimal thresholds increase in length of the time horizon and decrease in the discount rate. The intuition behind these results follows from interpretation of equation (7). Recall that the switching threshold is determined as a price which equates the total expected return from the switch and the expected capital appreciation. Further, from (6), higher thresholds result in lower expected return from the switch and vice versa. Longer time horizons increase the expected returns so that the switch is economically optimal even at higher prices of the alternative fuels. On the other hand, higher discount rates result in higher capital appreciation, which can be matched by the expected returns only when the switch occurs at relatively low prices of alternative fuel.

The thresholds for E15 are uniformly higher than the thresholds for E10, which is consistent with the fact 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.

The main result of the analysis is that the average ethanol blend prices are below the switching threshold for every scenario across all the sample periods, even without taking into account the 5.2¢ 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 this does not decrease efficiency of the vehicle. Furthermore, the increased drift and volatility of gasoline prices in recent years make such a switch even more attractive and economically justified.

This result differs directly from the findings of Tareen, Wetzstein, and Duffield (2000) for biodiesel, who determined that the price trigger for adopting biodiesel was above the current market price for biodiesel. Thus, in contrast to biodiesel, ethanol blended fuels are currently price-competitive, which at least partially explains the substantial recent growth in this industry. The continuing hunger for oil by developed countries, the marked increase in oil consumption by 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. Consequently, this competitive price advantage of ethanol blends is likely to continue into the future.

While wholesale purchasers of fuel can hedge their exposure to fuel price volatility by using market-traded instruments (e.g., options and other derivatives), such an approach involves transaction costs and additional expenses associated with development and implementation of hedging strategies. Alternative fuels, on the other hand, provide a low-cost natural hedging capacity due to a portfolio effect.

Policy Implications and Concluding Remarks

The macroeconomic stumbles from petroleum price volatility are of major concern, particularly since the energy crisis of 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, the Energy Policy Act of 1992, and most recently the Domenici-Barton Energy Policy Act of 2005.

Alternative fuels such as ethanol blends exhibit lower price volatility than conventional gasoline due to the portfolio effect. This analysis has demonstrated that this lower price volatility of alternative fuels, combined with increasing levels and volatility of prices of conventional gasoline, should result in market conditions receptive to government incentives geared toward widespread adoption of renewable fuels. The results also emphasize the importance of taking into account the portfolio effect, as the impact of government incentives may be underestimated if the portfolio effect is ignored. The average conventional gasoline price for the Terrorism War subperiod (2001–2004) is $1.096 (table 1). Comparing this to the average price of E10 ($1.169) or E15 ($1.205) over the same period (table 4), one would conclude incorrectly (given these alternative fuel prices are higher than conventional gasoline prices) that additional subsidies may be warranted to facilitate adoption.

Hence, a major implication of this analysis is that policy makers 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 price of gasoline of $1.096 and the E10 average price of $1.169, i.e., $0.073. In contrast, the benefit to agents 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, more widespread adoption of ethanol blends 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 conventional and alternative fuels. Combining the macroeconomic stability benefits with the environmental benefits of ethanol blends could increase their value considerably.

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