Journal of Agricultural and Applied Economics, 32,2(August 2000):373–381

Biodiesel as a Substitute for Petroleum Diesel in a Stochastic Environment

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ABSTRACT

The objective of the research presented in this paper is the development of a stochastic adoption threshold. The option pricing approach for modeling investment under uncertainty is extended for the case of comparing two stochastic input prices associated with inputs that are perfect substitutes in a production process. Based on this methodology, a threshold decision rule influenced by the drift and volatility of these two input prices is developed. Theoretical results establish an empirical link for measuring the tradeoff of a relatively more expensive input (biodiesel) with lower price drift and volatility compared with a lower but more volatile priced input (petroleum diesel).

Key Words: *Option pricing, production, renewable fuels, technology adoption under uncertainty.*

Biodiesel is a renewable diesel-fuel substitute with the advantages of reducing dependence on foreign petroleum, mitigating greenhouse gas emissions, and improving urban air quality. As estimated by Sheehan *et al.* (1998), biodiesel has the potential of reducing CO_2, particulate matter, carbon monoxide, and sulfur oxide emissions by 78, 32, 35, and 8 percent respectively. With these advantages, biodiesel has the potential of supplanting petroleum diesel as an engine fuel. This is true not only for pure 100 percent biodiesel fuel, called *neat biodiesel,* but is also true for what are called *blend biodiesel fuels.* For economic and engine-compatibility reasons, blend biodiesel is a mix (blend) of biodiesel with petroleum diesel. Generally this blend is 20 percent biodiesel and 80 percent petroleum diesel (B-20) (Brown). Such substitution is consistent with Federal regulatory policies resulting from the implementation of the Clean Air Act Amendments of 1990 which promote cleaner fuels and the Energy Policy Act (EPACT) of 1992 which encourage the use of alternative fuels as a means of reducing petroleum imports.

Recently, new legislation designed for encouraging biodiesel development has intensified interest in biodiesel. The Energy Conservation Reauthorization Act of 1998 emended EPACT allowing government motor fleets, who are required to purchase alternative fueled vehicles, to earn biodiesel fuel use credits. For meeting EPACT requirements, the U.S. Department of Energy is allowing government fleets the option of using 450 gallons of biodiesel per year in lieu of purchasing an alternative fueled vehicle such as vehicles operated with natural gas, ethanol, or electricity. The new rule also allows fleet operators to use

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This paper is a winner of the SAEA Outstanding Graduate Paper Award.

biodiesel blends containing at least B-20, and operators can distribute the 450-gallon requirement over their motor fleet, which reduces the biodiesel fuel cost-per-vehicle significantly. In addition, diesel engines require little modification to operate on B-20. Thus, biodiesel may be attractive to some fleet operators because it can increase their purchasing flexibility while meeting EPACT requirements.

The current fuel choice, petroleum diesel, has an associated relatively low price of $0.64 per gallon compared with an estimated biodiesel price of around $2.60 per gallon.[1] On a B-20 basis the price estimate is $1.03. Neoclassical principles assert that if two inputs (fuels) are perfect substitutes in production, the first-order condition of least-cost production reduces to a simple comparison of input costs. Thus, without considering the positive externalities associated with biodiesel, agents would not substitute biodiesel for petroleum diesel until there is a reversal in the price of the fuels they are facing. Neo-classical theory would indicate that agents who are not internalizing the positive externalities of biodiesel would require a subsidy in the amount of the price differentials. However, in the presence of stochastic fuel prices, petroleum diesel may not yield over time the least-cost production scenario. A comparison of the stochastic price processes associated with biodiesel and petroleum diesel fuels is required for determining this least-cost production. A decision rule based on their stochastic processes can then be developed and applied.

Previous evaluation of alternative fuels in general, and biodiesel in particular, generally do not take this stochastic nature of fuel prices into consideration. For example, Griffin, *et al.* (1985) analyzed the impact of substituting plant oils for petroleum diesel using nonstochastic prices and did not find biodiesel competitive with petroleum diesel. As a case study, Brown (1997) observed the Transportation Department of Chillicothe, Ohio in 1994 switching to a 30 percent biodiesel blend for its cleaner burning, better odor properties, and a small increase in miles per gallon, only to revert back to petroleum diesel two years later due to the higher biodiesel cost. Similarly, Ahouissoussi and Wetzstein (1997) and Tollefson (1993) found biodiesel was the least-cost per compliance mile for alternative fuels with the potential of satisfying Federal regulatory policies; however, biodiesel would require tax incentives or subsidies to become viable with petroleum diesel.

Such evaluations ignore the stochastic nature of fuel prices. Edmond (1994) reports on the fluctuation in biodiesel prices particularly following the Midwest floods in early 1990s, and past oil disruptions, such as the 1973–1974 period, have caused prices in general and petroleum diesel prices in particular to vary considerably. A decision rule explicitly incorporating this stochastic nature of fuel prices will provide an improved comparison of these alternative fuels. The stochastic nature of fuel prices implies an adoption rule based on the expected future prices of the fuels. For example, if the expected price of biodiesel relative to petroleum diesel is declining and the volatility in biodiesel prices is lower than for petroleum diesel then it may be profitable to adopt biodiesel prior to its price declining to the point of matching petroleum-diesel price. Some threshold above the petroleum-diesel price would instead trigger adoption.

The objective of the research presented in this paper is the development of such a stochastic adoption threshold. The option pricing approach for modeling investment under uncertainty is extended for the case of comparing two stochastic input prices associated with inputs that are perfect substitutes in a production process. Based on this methodology, a threshold decision rule influenced by the drift and volatility of these two input prices is developed. Theoretical results establish an empirical link for measuring the tradeoff of a relatively more expensive input (biodiesel) with lower price drift and volatility compared with a lower but more volatile priced input (petroleum diesel).

[1] Currently there are not enough observations on biodiesel sales for determining an average market price. The estimated market price used in this paper is based on average soybean oil prices and other biodiesel production costs.

Decision Threshold

Following closely the Dixit and Pindyck (1994) approach for real option pricing, the stochastic nature of fuel choice arises from fluctuations over time in the price for biodiesel, B, and petroleum diesel, D, fuels. For analysis purposes, the biodiesel term B represents both neat biodiesel and blend biodiesel. Such uncertainty may be represented by geometric Brownian motion processes

(1) $dB = \alpha_B B dt + \sigma_B B dz_B$ and

(2) $dD = \alpha_D D dt + \sigma_D D dz_D$,

where dB and dD represent the change in the prices of biodiesel and petroleum diesel, respectively, α is the rate of change or drift rate, σ is the standard deviation (volatility), and the subscripts B and D denote parameters associated with biodiesel and petroleum diesel, respectively. The increment of a Wiener process is dz, with $E(dz_B^2) = E(dz_D^2) = dt$ and $E(dz_B, dz_D) = \rho dt$, where ρ denotes the correlation coefficient between B and D.

Taking the expected value of (1) and (2) and solving the differential equations for the current prices $B(0) = B_0$ and $D(0) = D_0$ yields

(3) $E[B(t)] = B_0 e^{\alpha_B t}$ and $E[D(t)] = D_0 e^{\alpha_D t}$.

Given these price processes, assume the objective of an agent, for example a bus transportation authority, is to minimize cost subject to maintaining some level of utility (service quality). Such an agent, when considering switching fuels, is interested in maximizing the cost saving from switching. This is a stochastic optimal-stopping problem, where a threshold value for the price of biodiesel, B*, is determined. The problem is to determine when to exercise the option of switching to biodiesel, and the decision rule is to adopt biodiesel if $B \leq B^*$; otherwise do not exercise the option and continue using petroleum diesel.

Assuming the fuels are perfect substitutes, the expected present value, V, of switching from petroleum diesel to biodiesel at the current prices is

(4) $$V = E \int_0^T e^{-rt}[D(t) - B(t)]\, dt,$$

where E is the expectation operator, r is the continuous discount rate, and T is the life of the engine. This discounted present value is the difference in fuel costs over the life of the engine, given all other costs associated with engine operation remain the same across the two alternative fuels and the ending salvage value is not affected by fuel choice. Substituting (3) into (4) yields

$$V = \int_0^T e^{-rt}[D_0 e^{\alpha_D t} - B_0 e^{\alpha_B t}]\, dt.$$

Following Dixit and Pindyck, the option value of adopting biodiesel, F(V), at time S is

(5) $$F(V) = \int_S^{T+S} e^{-rt}[D_0 e^{\alpha_D t} - B_0 e^{\alpha_B t}]\, dt,$$

Performing the integration

(6) $$F(V) = \frac{D[e^{T(\alpha_D - r)} - 1]}{\alpha_D - r} - \frac{B[e^{T(\alpha_B - r)} - 1]}{\alpha_B - r}.$$

This option to adopt biodiesel has no returns until at the time of adoption, so the only return from holding the option to adopt is its expected capital appreciation, E(dF). The Bellman equation for the determination of the optimal threshold B* is equating this expected capital appreciation to the expected return on adopting biodiesel

(7) $rFdt = E(dF)$

As indicated by Dixit and Pindyck (1994), expanding dF using Ito's Lemma results in

(8) $$dF = F_B dB + F_D dD + 1/2(F_{BB} dB^2 + 2F_{BD} dB dD + F_{DD} dD^2),$$

where the subscripts indicate partial derivatives. Substituting (1) and (2) into (8) and dividing through by dt yields

(9) $$E(dF) = \alpha_B B F_B + \alpha_D D F_D + 1/2(F_{BB}\sigma_B^2 B^2 + 2F_{BD}\rho\sigma_B\sigma_D BD + F_{DD}\sigma_D^2 D^2),$$

where $E(dz_B) = E(dz_D) = 0$ and ρ is the correlation coefficient between the prices of biodiesel and petroleum diesel. Substituting (9) into (7) the Bellman equation can now be stated as

(10) $$\alpha_B B F_B + \alpha_D D F_D + 1/2(F_{BB}\sigma_B^2 B^2 + 2F_{BD}\rho\sigma_B\sigma_D BD + F_{DD}\sigma_D^2 D^2) - rF = 0.$$

Equation (10) is a second-order partial differential equation with B and D as independent variables. As addressed by Dixit and Pindyck (1994), the solution to (10) is possible by considering the homogeneity of the value function. The option function is homogeneous of degree one in B and D, so multiplying both prices B and D by a positive constant increases the option function but does not change the ratio of B to D, $b = B/D$. The optimal solution depends only on the price ratio, b. Specifically

$$F(\lambda B, \lambda D) = \lambda F,$$

where $\lambda > 0$. Letting $\lambda = 1/D$

(11) $$F(B, D) = DF(\lambda B, \lambda D) = Df(B/D) = Df(b).$$

Differentiating (11) with respect to B and D yields

$$F_B = f'(b), \qquad F_D = f(b) - bf'(b),$$

$$F_{BB} = f''(b)/D, \qquad F_{DD} = b^2 f''(b)/D,$$

$$F_{BD} = -f''(b)b/D.$$

Substituting these partial differentiations into (10) and rearranging terms

(12) $$1/2(\sigma_B^2 - 2\rho\sigma_B\sigma_D + \sigma_D^2)b^2 f'' + (\alpha_B - \alpha_D)bf' + (\alpha_D - r)f = 0.$$

Equation (12) is a second-order linear homogeneous equation with a solution

(13) $$f(b) = A_1 b^{\beta_1} + A_2 b^{\beta_2},$$

where

(14) $$A_1 < 0, \qquad A_2 = 0, \qquad \beta_1 > 1, \qquad \beta_2 < 0,$$

which are dependent on the parameters α_B, α_D, ρ, σ_B, α_D, and r. The conditions on A_1 and A_2 are determined by considering the prospect of exercising the option when b is large. With a relatively large b, the possibility of B declining to the exercise threshold B* is rather remote, so the option value, f(b), should be small. Thus, as $b \to \infty$, $f(b) \to -\infty$. This condition holds given (14). Thus, (13) reduces to

(15) $$f(b) = A_1 b^{\beta_1}.$$

Parameter β_1 is the root of the quadratic equation (12). Taking the first and second derivative of (15) with respect to β_1 and substituting the results into (12) yields

(16) $$1/2(\sigma_B^2 - 2\rho\sigma_B\sigma_D + \sigma_D^2)\beta_1(\beta_1 - 1) + (\alpha_B - \alpha_D)\beta_1 + (\alpha_D - r) = 0.$$

The positive root of (16) is then

$$\beta_1 = 1/2 - (\alpha_B - \alpha_D) + \{[(\alpha_B - \alpha_D)/\sigma^2]^2 + [2r - \alpha_D)/\sigma^2]\}^{1/2} > 1,$$

where $\sigma^2 = (\sigma_D^2 - 2\rho\sigma_B\sigma_D + \sigma_D^2)$ and the sign is determined by the condition of $r > \alpha_B$.

The remaining conditions are the following boundary conditions

(17) $$f(b) = F/D = \frac{[e^{T(\alpha_D - r)} - 1]}{\alpha_D - r} - \frac{b[e^{T(\alpha_B - r)} - 1]}{\alpha_B - r},$$

called the value-matching condition, where the last equality is based on (6), and the smooth-pasting condition

(18) $$f'(b) = -\frac{[e^{T(\alpha_B - r)} - 1]}{\alpha_B - r}.$$

Equating (15) and (17) and taking the derivative of (15) and setting the derivative equal to (18) yields two independent equations for determining the optimal values of b and A

$$f(b) = A_1 b^{\beta_1} = \frac{[e^{T(\alpha_D - r)} - 1]}{\alpha_D - r} - \frac{b[e^{T(\alpha_B - r)} - 1]}{\alpha_B - r},$$

$$f'(b) = \beta_1 A_1 b^{\beta_1 - 1} = -\frac{[e^{T(\alpha_B - r)} - 1]}{\alpha_B - r}.$$

Solving these equations yield the optimal or threshold value

$$(19) \quad b^* = \frac{\beta_1}{\beta_1 - 1} \frac{[e^{T(\alpha_D - r)} - 1](\alpha_B - r)}{[e^{T(\alpha_B - r)} - 1](\alpha_D - r)},$$

$$B^* = \frac{\beta_1}{\beta_1 - 1} \frac{[e^{T(\alpha_D - r)} - 1](\alpha_B - r)}{[e^{T(\alpha_B - r)} - 1](\alpha_D - r)} D \geq D.$$

Thus, the decision rule for switching to biodiesel is when its price, B, is less than the threshold value B*. If $\alpha_B = \alpha_D$ and $\sigma_B = \sigma_D$, then (19) reduces down to B* = D which is the traditional nonstochastic criterion for switching fuels. When $\alpha_B < \alpha_D$, with $\sigma_B = \sigma_D$, B* > D, indicating the threshold for switching to biodiesel becomes less restrictive. The threshold is now higher so the price does not have to decline as far before biodiesel is adopted. The effect of σ_B and σ_D on B* is indeterminate. An increase in σ_B or σ_D may increase or decrease B* depending on the magnitude of their ratio and on the sign of ρ.

Application

Generally, the cost of engines, fuel system costs, miles between rebuilds, and engine rebuild costs are the same for biodiesel versus petroleum-diesel fueled engines. This equivalence greatly simplifies the analysis and allows a direct comparison of stochastic fuel prices. For such a comparison, monthly data on fuel prices or costs, covering years 1972 through 1997, were available from U.S. Department of Agriculture (USDA) and U.S. Department of Energy (DOE) publications. Price data for petroleum diesel (#2 diesel fuel) are refiner prices of petroleum diesel at the wholesale level (cents per gallon exclusive of taxes) as reported in issues of DOE's Energy Information Administration, Monthly Energy Review. For biodiesel prices, unfortunately, such price data is not readily available on the market, so no market price series exists. Thus, biodiesel prices are determined by transforming soybean-oil price data following the procedure outlined by Withers and Noordam (1996). Soybean prices account for approximately 75 percent of soydiesel costs, and soydiesel is the major type of biodiesel fuel currently produced in the U.S. The soybean-oil price data are reported in issues of the USDA's Economic Research Service publication, *Oil Crops Situation and Outlook Yearbook.* In these publications soybean-oil prices are reported as soybean-oil price, crude, tanks FOB Decatur in cents per pound exclusive of taxes. For determining biodiesel prices, soybean-oil prices were first converted from pounds to gallons by multiplying the data by 7.7, since a gallon of crude soybean oil weighs 7.7 pounds. Soybean-oil price data in gallons was then converted to biodiesel price data. This requires accounting for a transesterfication cost of $0.58 per gallon in addition to overhead costs of $0.33 per gallon. The net glycerine and meal value of this process is $0.39 per gallon which yields a net increase of $0.52 in biodiesel costs over soybean-oil prices. This adjustment in soybean-oil price of $0.52 yields the biodiesel price in cents per gallon.

In terms of fuel efficiency, a direct comparison of biodiesel prices with petroleum-diesel prices requires the biodiesel prices be adjusted for fuel efficiency differences. Biodiesel blend fuels compared with #2 diesel fuel are 0.9916, 0.9766, 0.9297, and 0.8887 efficient for 20 percent, 35 percent, 60 percent, and 100 percent biodiesel blends, respectively (Ahouissoussi and Wetzstein). No fuel efficiency differences between a 10 percent biodiesel blend and petroleum diesel are assumed. The biodiesel prices are weighted by these efficiency parameters for direct fuel price comparisons.

Based on these fuel-price series, the drift, α, and volatility, σ, of biodiesel and petroleum-diesel fuels along with the correlation coefficients, ρ, between biodiesel fuels and petroleum diesel prices were computed using the method outlined by Hull (1997). The drift and

Table 1. Threshold Prices for Biodiesel and Petroleum Diesel Price Series from 1972 to 1997

Parameter	Petroleum Diesel	Percent Biodiesel Blend				
		100 Percent	60 Percent	35 Percent	20 Percent	10 Percent
Coefficient						
Drift	0.0058	0.0019	0.0022	0.0027	0.0033	0.0041
Volatility	0.0684	0.0640	0.0573	0.0517	0.0494	0.0518
Correlation, ρ	1	−0.0115	0.1444	0.3726	0.6289	0.8537
Price (dollars)						
Threshold[a]		0.88	0.85	0.81	0.77	0.72
Biodiesel		2.61	1.82	1.33	1.03	0.84
Biodiesel/Threshold		2.98	2.15	1.65	1.34	1.17

[a] Threshold price is based on a petroleum diesel price of $0.64, a discount rate of 5 percent, and terminal time of 30 years.

volatility parameters of a Brownian motion are based on a continuous time observation. Empirically, however, we are limited to examining data that has been recorded in discrete time intervals. Drift and volatility of petroleum diesel price, observed on a monthly basis, may be estimated by first logging the data series and then taking the expected value and the standard deviation, respectively, of the first differenced series. The correlation coefficients were calculated as the correlation between the first difference in logged biodiesel price and first difference in logged petroleum-diesel price.

Results

Incorporating the drift, volatility, and correlation coefficients into (19), from the time series data on estimated biodiesel and petroleum-diesel prices, the threshold prices B^* are calculated. These threshold prices are determined by comparing alternative blends of biodiesel with petroleum diesel. Table 1 lists these thresholds along with drift, volatility, and correlation coefficients for the whole time series, 1972–1997. Results for this time interval, along with the other two intervals investigated (Tables 2 and 3), are based on an average 1997 price of #2 petroleum diesel of $0.64 and neat biodiesel price of $2.61. These results also assume a discount rate, r, of 5 percent and terminal life for the refueling infrastructure, T, of 30 years.

As indicated in Table 1, both drift and volatility are lower for biodiesel compared with petroleum diesel. As the percent of biodiesel declines in fuel blends, the drift coefficient ap-

Table 2. Threshold Prices for Biodiesel and Petroleum Diesel Prices Series from 1993 to 1997

Parameter	Petroleum Diesel	Percent Biodiesel Blend				
		100 Percent	60 Percent	35 Percent	20 Percent	10 Percent
Coefficient						
Drift	−0.00027	0.0026	0.0022	0.0017	0.0012	0.0007
Volatility	0.0492	0.0435	0.0368	0.0312	0.0301	0.0394
Correlation, ρ	1	−0.1770	0.0127	0.3315	0.6890	0.9187
Price (dollars)						
Threshold[a]		0.80	0.78	0.75	0.72	0.69
Biodiesel		2.61	1.82	0.33	1.03	0.84
Biodiesel/Threshold		3.25	2.34	1.78	1.44	1.22

[a] Threshold price is based on a petroleum diesel price of $0.64, a discount rate of 5 percent, and terminal time of 30 years.

Table 3. Threshold Prices for Biodiesel and Petroleum Diesel Prices Series from 1973 to 1974

Parameter	Petroleum Diesel	Percent Biodiesel Blend				
		100 Percent	60 Percent	35 Percent	20 Percent	10 Percent
Coefficient						
Drift	0.0434	0.0417	0.0418	0.0419	0.0421	0.0424
Volatility	0.1559	0.1237	0.1145	0.1048	0.0990	0.1035
Correlation, ρ	1	−0.1399	−0.0178	0.1834	0.4607	0.7989
Price (dollars)						
Threshold[a]		2.83	2.56	2.21	1.83	1.39
Biodiesel		2.61	1.82	1.33	1.03	0.84
Biodiesel/Threshold		0.92	0.71	0.60	0.56	0.60

[a] Threshold price is based on a petroleum diesel price of $0.64, a discount rate of 5 percent, and terminal time of 30 years.

proaches petroleum-diesel drift. This occurs given petroleum-diesel prices are weighed more as the percent of biodiesel declines in the fuel blends. In contrast, the volatility coefficient declines as the percent of biodiesel decreases from 100 percent to 20 percent biodiesel and increases with a 10 percent blend. This is the standard result in portfolio theory, where the variance of a portfolio for some given combination of two assets will be less than their individual variance if $\rho \neq 1$. The correlation between petroleum diesel and 100 percent biodiesel is negative; however, as the percent of biodiesel declines in the fuel blends, the correlation increases.

These changes in the drift, volatility, and correlation coefficients directly affect the biodiesel-price thresholds, B^*. The threshold of $0.88 for 100 percent biodiesel is larger than the petroleum-diesel price of $0.64, indicating the price of biodiesel does not have to match the petroleum-diesel price before it is feasible to switch. At the 1997 average biodiesel price of $2.61, switching is not feasible even with $B^* > D$. This biodiesel price is almost 200 percent higher than the threshold.

As Table 1 indicates, the biodiesel-blend price declines as the percent of biodiesel decreases, given the price of petroleum diesel, $0.64, is less than the biodiesel price of $2.61. The threshold price also declines as the percent of biodiesel decreases; however, as indicated by the price ratios of biodiesel to the threshold, this decline in threshold price is less than the biodiesel price decline. The cause of this disparity is the portfolio effect associated with the volatility coefficient. Given the decrease in volatility as the percent of biodiesel declines from 100 percent to 20 percent biodiesel, the threshold price does not experience a proportional decline with the biodiesel-blend price. Thus, at a 20 percent blend of biodiesel with petroleum diesel, the blend price of $1.03 is only 34 percent higher than the threshold price of $0.77, which is in contrast with the almost 200 percent differential associated with 100 percent biodiesel.

This reduction in the price ratio of biodiesel to the threshold is rather robust. For example, consider the price series for biodiesel and petroleum diesel covering the period from 1993 to 1997. As indicated in Table 2, the drift coefficient for petroleum diesel is negative compared with a positive drift for biodiesel, whereas the volatility for petroleum diesel is larger than for biodiesel. This results in corresponding lower threshold prices, B^*, compared with the whole time series, Table 1. However, the price ratio of biodiesel to the threshold still declines as the percent of biodiesel blend decreases.

This wedge between the biodiesel price and the threshold is breachable. For example, in Table 1 for a 20 percent biodiesel blend, there is only a $0.24 difference between the blend price of $1.03 and the threshold price of $0.77. This difference is breachable under a number of possible scenarios. Examples are further biodiesel industry development, including increased production resulting in economies of size, translating into biodiesel price reductions, or environmental benefits generating a subsidy for biodiesel or imposition of a tax on petroleum diesel. For example, Van dyne, *et al.* (1996) determined biodiesel is competitive with petroleum diesel when produced in a community-based plant. Alternatively, a prolonged disruption in petroleum-diesel supply, yielding both an increase in price drift and volatility, can enhance the feasibility of biodiesel.

This latter scenario may be investigated by considering the effect on the price drift and volatility of petroleum diesel and biodiesel during the 1973–1974 oil embargo. Assuming a worse-case scenario where such a disruption is chronic over the entire planning horizon of 30 years, Table 3 lists the threshold prices. Price drift and volatility for both petroleum diesel and biodiesel are higher compared with the whole price series in Table 1. The thresholds based on these coefficients are considerably higher and now rise above the biodiesel prices. Even with 100 percent biodiesel, it is now feasible to switch from petroleum diesel to biodiesel.

Policy Implications

Uncertain oil supply and price volatility are major concerns in this country since the energy crisis of the 1970s. In response to these concerns, Congress enacted the EPACT to help develop alternative fuels from domestic sources and reduce our dependence on foreign petroleum. When judging the success of EPACT, analysts tend to focus on increases in alternative fuel consumption and sales of alternative fueled vehicles. However, the effect of the program on price volatility has generally been ignored. Results from this study indicate even small influxes of alternative fuels, such as biodiesel blends, can have a significant effect on price volatility. This suggests the potential benefits of EPACT and other alternative fuel programs have been underestimated.

Policymakers should consider price volatility effects when determining appropriate spending levels for alternative fuel programs. For example, the value of reducing price volatility from using B-20 is $0.13 per gallon. This value can be used to help estimate the cost and benefits of tax credits and other economic incentives that may be needed to stimulate biodiesel demand in government fleet markets and other programs designed for promoting alternative fuel development.

In addition to energy security benefits, biodiesel may help the United States achieve its air quality goals and reduce greenhouse gasses. Future research is required for estimating the value of these environmental benefits in order to make accurate cost comparisons between biodiesel and petroleum diesel. Also, it would be useful for policy formulation to determine if low blends of biodiesel, such as B-20, could have significant effects on mitigating air pollution and global warming. Combining the environmental and energy security benefits of biodiesel could increase its value considerably. In order to exploit the full value of biodiesel, government programs could be designed to simultaneously capture its environmental value and energy security benefits. For example, using biodiesel in government vehicles operating in national parks could help reduce air pollution in recreational areas and at the same time help fleet operators meet their EPACT requirements. Further research is required on alternative fuels programs which simultaneously provide both energy security and environmental benefits.

Conclusion

As early as the first half of the 19^{th} century Von Thuenen was collecting evidence from his farm in Germany suggesting the ability of one input to compensate for another was significant. Based on his observation, Von Thuenen postulated on what came to be known as *the principle of substitutability.* This principle states it is possible to produce a constant output with a variety of input combinations.

Neo-classical economics refined this principle, yielding the first-order condition of least-cost production for a constant output. If the inputs are perfect substitutes, this first-order condition reduces to a simple comparison of input costs. Whichever input is associated with a lower cost will be employed. As demonstrated in this paper, the presence of stochastic input prices may not yield over time this least-cost production scenario. A comparison of the stochastic processes of the input prices over time is required for determining least-cost production. Such a comparison can yield a threshold price above the current input price and trigger switching inputs prior to the competing input price matching the current price.

The results of comparing alternative fuels indicate this threshold price can be considerably above the current price. For example, results considering the popular B-20 blend indicate a threshold price of $0.77 compared with a current petroleum-diesel price of $0.64. This is over a 20 percent increase in the trigger price for biodiesel becoming competitive.

The analysis of stochastic fuel prices can be extended to other alternative fuels. However, in contrast to biodiesel, these fuels generally require modification in engines and fuel systems, alternative infrastructures for fuel delivery, and differences in engine performance resulting in different engine maintenance and rebuilding intervals and costs. Accounting for these differences would require a modification in the development of the price thresholds.

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