Journal of Agricultural and Applied Economics, 42,1(February 2010):121–132

The Relative Impacts of U.S. Bio-Fuel Policies on Fuel-Energy Markets: A Comparative Static Analysis

C.S. Kim, Glenn Schaible, and Stan Daberkow

Rapidly declining gasoline prices from their record high during the summer of 2008, while ethanol prices remained relatively high, made it difficult for many bio-fuel policy modelers to fully explain the impacts of U.S. bio-fuel policies on fuel prices. Using profit-maximization models for blenders, refiners, and distillers, we conduct a comparative static analysis to measure the relative magnitudes of the impacts of tax credits and blending mandates on fuel-energy market equilibrium prices. Our results indicate that first, the prices of all fuels including conventional gasoline, ethanol, and blended gasoline decline as the bio-fuel tax credit increases, but they increase as the rate of the blending mandate increases. Second, the shadow value of a blending mandate represents the marginal rate of substitution between the marginal price change associated with a blending mandate and the marginal price change associated with a bio-fuel tax credit. Therefore, bio-fuel policies can affect the prices of all fuels including conventional gasoline, ethanol, and blended gasoline. Finally, ethanol imports are affected by domestic blender's market-power effects, more than by the import duty imposed to offset the tax credit associated with the use of imported ethanol in the blending process.

Key Words: bio-fuel tax credits, blended gasoline, blender's market power, mandated blending, tariff

JEL Classifications: Q11, Q21, Q42, Q48

Bio-fuel related policies, such as those specified in the American Jobs Creation Act (AJCA) of 2004, the Energy Policy Act of 2005, import tariffs,[1] and the Energy Independence and Security Act (EISA) of 2007 are, arguably, now much more influential policies affecting commodity and fuel-energy markets. Under the AJCA, the Federal ethanol tax incentive was set at \$0.51 (\$0.45 beginning in January 2009) per gallon of ethanol used for fuel, replacing the prior excise tax exemption

---

C.S. Kim, senior economist, Glenn Schaible and Stan Daberkow, agricultural economists, Economic Research Service, United States Department of Agriculture, Washington, DC.

The authors thank James Duffield at United States Department of Agriculture and the anonymous reviewers for their valued comments on the earlier drafts. The views expressed here are the authors' and do not necessarily represent the policies or views of United States Department of Agriculture.

[1] Established by the Omnibus Reconciliation Act of 1980 and amended by the Tax Reform Act of 1986 (Yacobucci, 2006).

with an excise tax credit (Koplow, 2006; Yacobucci and Schnepf, 2007). While the Energy Policy Act mandated a total renewable fuels requirement, allowing for ethanol and bio-diesel production substitution to meet the mandate, the EISA now mandates the volume of each bio-fuel separately. Blenders must now blend 10.5 billion gallons of ethanol in 2009, with the mandate rising to 15 billion gallons in 2015 and thereafter.[2]

Given the complexity and the magnitude of economic and environmental effects of U.S. bio-fuel policies, results from fuel-energy/commodity economic models have been increasingly relevant to economic and policy discussions (de Gorter and Just, 2009a,b; Du and Hayes, 2008; Schmitz, Moss, and Schmitz, 2007; Tyner and Taheripour, 2008; Vedenov and Wetzstein, 2007; Westhoff, 2008). However, the net effects on ethanol, conventional gasoline, and blended gasoline prices of both the bio-fuel tax credit under the AJCA and the blending mandate under the EISA have not been adequately discussed in the literature.[3] A major difficulty in analyzing bio-fuel policies is a lack of sufficient information on ethanol market prices. In addition, researchers have often assumed that ethanol price is largely determined by the conventional gasoline price, based on a high correlation coefficient between ethanol and conventional gasoline prices without any theoretical justification (de Gorter and Just, 2009a,b; Tyner and Taheripour, 2008). A correlation coefficient does not provide any information as to a cause and effect relationship. For instance, the correlation coefficient between monthly average ethanol and unleaded gasoline rack prices from January 2008–July 2009 (Free-on-Board [F.O.B.] Omaha, NE) is estimated to be 0.84, but Figure 1 does not reveal any cause and effect relationship between ethanol and conventional gasoline prices.

Ethanol, cherished for years by oil blenders as a cheap blending ingredient for motor fuel, has now become a burden for blenders, because ethanol price has remained stubbornly expensive compared with conventional gasoline, whose price crashed as the economic slowdown crimped demand in late 2008 (Gardner, 2008). Ethanol rack prices were lower than conventional gasoline rack prices before establishment of the EISA in December 2007. During the period of the “oxygenate season”[4] between October 2008 and April 2009, the average ethanol rack price (F.O.B. at Omaha, Nebraska) at $1.83 per gallon was higher than the average conventional gasoline rack price at $1.40 per gallon (see Figure 1). To evaluate the effects of U.S. bio-fuel policies on the prices of ethanol, conventional gasoline, and blended gasoline, recent market experience indicates a need for a more serious theoretical establishment of how ethanol price is determined. Assuming the issue away based on a correlation coefficient analysis between ethanol and conventional gasoline prices is inadequate.

While other researchers (for example, see Westhoff, 2008) often use spot-market ethanol prices, Hartwig (2006) points out that such prices reflect a very small number of short-term sales between refiners (and not between ethanol producers and refiners), and that these spot prices do not represent the average price that ethanol producers receive. Between 85 and 95% of ethanol in the United States is sold under longer-term contracts (6–12 months)

---

[2] In November 2008, the U.S. Environmental Protection Agency raised the amount of ethanol to be blended into gasoline in 2009 to 11.1 billion gallons (Gardner, 2008).

[3] Under the Energy Policy Act of 2005, the U.S. Environmental Protection Agency promulgates and enforces the regulations that ensure that gasoline sold in the United States contains a minimum volume of renewable fuel. The U.S. Environmental Protection Agency has set the 2008 Renewable Fuels Standard at 7.76% which is intended to lead to the use of 9 billion gallons of renewable fuel in 2008. Any organization that produces gasoline for use in the United States, including refiners, importers, and blenders, is considered an Obligated Party (OP). An OP is required to purchase enough renewable fuel to meet it’s Renewable Volume Obligation (RVO), which is based on its annual conventional gasoline volume. Any OP found liable for failure to meet its RVO is subject to civil penalties of up to $32,500 per day for each violation (U.S. Environmental Protection Agency, 2008).

[4] Many urban areas are forced by local and national clean air standards to blend ethanol with conventional gasoline during this season (Tiffany and Eidman, 2003).

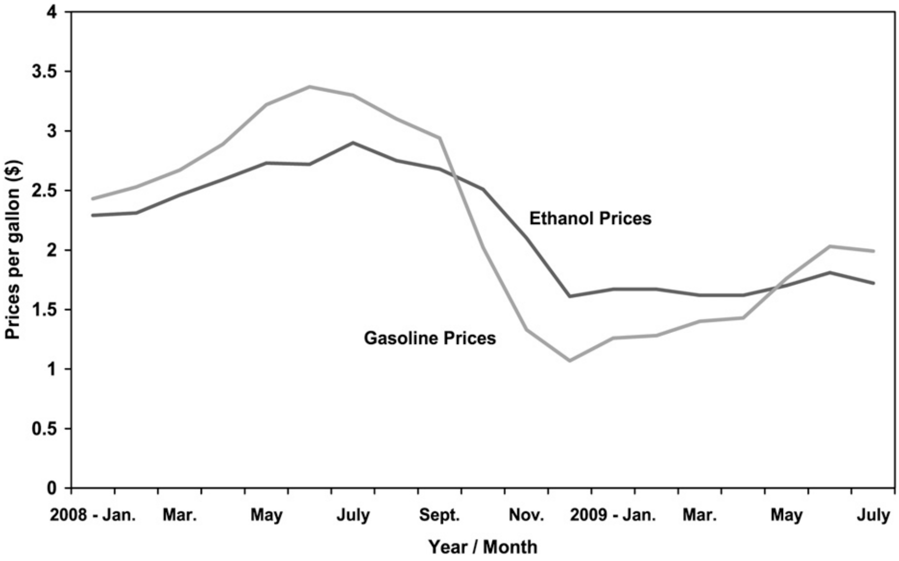

Figure 1. Monthly Average Ethanol and Unleaded Gasoline Rack Prices, Free-on-Board (F.O.B.) Omaha, NE (2008–July 2009)

negotiated between ethanol producers and oil refiners or gasoline blenders (Hartwig, 2006; Tiffany and Eidman, 2003). Furthermore, oil companies, or affiliates of oil companies, currently have a monopoly on blending fuel ethanol with conventional gasoline due to the lack of adequate fueling infrastructure (Donovan, 2009). In our research, therefore, ethanol price is assumed to be determined under contracts between distillers and blenders.[5] While the blenders pay the sum of the unit ethanol price and the tax credit to distillers (zFacts, 2008), they are also paid the tax credit by the government so that their net cost of ethanol is the contract ethanol price.

The price of blended gasoline also depends on whether ethanol and conventional gasoline production are independently determined, as implicitly assumed in recent studies (de Gorter and Just, 2009a; Du and Hayes, 2008; Schmitz, Moss, and Schmitz, 2007). When ethanol and conventional gasoline are assumed to be independent in production, but they are perfect substitutes in consumption, total blended gasoline supply would be obtained by adding the ethanol supply curve and the conventional gasoline supply curve. Then total blended gasoline supply would increase as ethanol production increases, and thereafter, have the effect of lowering its price. For this study, however, we consider conventional gasoline and ethanol as substitute goods in production and consumption, due to the blending requirement. Under our assumption, refiners reduce their supply of conventional gasoline,[6] when distillers increase ethanol production to meet the blending mandates. Therefore, the total supply of blended gasoline could be greater (less) than the conventional gasoline supply without the blending mandates, depending on whether the reduction in conventional gasoline production is less (greater) than the increase in ethanol production. We found that the impacts of changing the rate of the blending mandate on fuel prices are several times greater, as measured by the shadow value of the blending mandate, and in the opposite direction than the impacts associated with changing the bio-fuel tax credit.

---

[5] Due to the lack of facilities in ethanol transportation and fueling infrastructure, we assume that oil companies/blenders have market power in the ethanol market as described by Hartwig (2006).

[6] Meanwhile, Blanch (2008) and Lieberman (2008) discuss the effect of a reduction in capital investment on refinery facilities and how this will contribute to a reduction in gasoline production in the future.

Blenders are paid the tax credit for blending ethanol with conventional gasoline, whether ethanol is domestically-produced or imported. The United States produced more than 9.3 billion gallons of ethanol and also imported nearly 0.56 billion gallons of ethanol in 2008. The U.S. import tariff on ethanol includes two types of tariffs: first, a 2.5% *ad valorem* tax, and second, a $0.54 per gallon import duty. Caribbean and Central American countries enjoy import duty-free treatment under the Caribbean Basin Initiative tax legislation of 1984. Our results also indicate that the ethanol import price must equal the sum of the marginal factor cost of ethanol and the tax credit for domestically-produced ethanol, so that the insignificant level of ethanol imports are likely largely due to blender's market power effects, rather than the import duty imposed to offset the bio-fuel tax credit applied to imported ethanol from nonCaribbean countries.

For this study, our primary objective is to conduct a comparative static analysis to simultaneously evaluate the impacts of the bio-fuel tax credit under the AJCA and the blending mandate under the EISA on energy prices. Profit-maximization models are presented for blenders, refiners, and distillers, where blenders have a choice when generating blended gasoline supply between using domestically-produced ethanol and/or imported ethanol. To achieve our goal, this paper is organized as follows. The next section modifies the economic models by Kim, Schaible, and Daberkow (forthcoming) on the profit-maximizing behaviors of a blender, refiner, and distiller under established U.S. bio-fuel and trade policies to investigate how bio-fuel tax credits, tariffs, and the ethanol blending mandate affect the blender's choice between the use of domestically-produced and imported ethanol, and the production decisions of a refiner and a distiller. We demonstrate that the ethanol blending mandate reduces refiners' conventional gasoline production, while distillers increase ethanol production. The level of blended gasoline production would decline as refiners reduce conventional gasoline production and distillers increase mandated ethanol production. Section three then conducts a comparative static analysis to simultaneously evaluate the effects of bio-fuel policies on the fuel prices of conventional gasoline, ethanol, and blended gasoline. Finally, we present our conclusions.

Impacts of a Tax Credit and a Blending Mandate on Fuel Production

Blended Gasoline Production

Most ethanol used for blending in the United States is domestically produced, but ethanol imports are increasing due to an expanded blending mandate. Blenders receive the tax credit for blending both domestically-produced and imported ethanol with conventional gasoline. The selection between domestically-produced and imported ethanol depends largely on the price blenders have to pay for ethanol. Blenders should be willing to pay up to $0.45 (January 2009) more per gallon for ethanol than the wholesale spot price per gallon of conventional gasoline, that is, an additional amount up to the amount of the ethanol tax credit (zFacts, 2008).[7]

The EISA of 2007 specifies the blending mandate of ethanol in absolute volumes. However, the U.S. Environmental Protection Agency has set the 2008 Renewable Fuels Standard at 7.76% which is intended to lead to the use of 9 billion gallons of renewable fuel in 2008 (U.S. Environmental Protection Agency, 2008). Therefore, for this study, we use the rate of the blending mandate instead of an absolute volume measure of the blending mandate. We first let blended gasoline production, which is equivalent to consumer demand for motor fuel, be represented by B_0 such that:

$$(1) \qquad B_0 = (1-\theta)G + \theta E, \quad 0 < \theta < 1,$$

where G is conventional gasoline in gallons, E is ethanol in gallons, which is the sum of domestically-produced ethanol (E_{do}) and imported ethanol (E_m), such that $E = E_{do} + \sum E_m^i$ where the superscript i represents the ith source of imported ethanol, and θ is the rate of the

---

[7] Even though the energy content of ethanol accounts for only 67 percent of the energy content for conventional gasoline, market ethanol prices reflect the volume of blended gasoline quantity purchased by consumers at the pump (and not its energy content).

blending mandate. To derive the optimum economic conditions for blenders, we now let the blender's profit to be maximized under a blending mandate and a bio-fuel tax credit be represented as follows:

$$\begin{aligned}\text{Max}\ \pi(B) = {} & P_B B(G, E(E_{do}, E_m)) \\ & - P_g G - [P_e E_{do} + \sum_i (P^i_m(1+\delta) \\ & - t_e + T^i_m)E^i_m] + \mu[B_0 - (1-\theta)G \\ & - \theta(E_{do} + \sum_i E^i_m)],\end{aligned} \tag{2}$$

where P_B is the price of blended gasoline per gallon, P_g is the price of conventional gasoline per gallon, P_e is the price of domestically-produced ethanol per gallon (without a tax credit), t_e is the unit tax credit on blending ethanol with conventional gasoline, P^i_m is an import price of ethanol from the *i*th country (Cost, Insurance and Freight [c.i.f.]), δ is the *ad valorem* tax per gallon of imported ethanol, $B(G, E(E_{do}, E_m))$ is blended gasoline, T^i_m is a tariff imposed on imported ethanol from the *i*th country (other than Caribbean and Central American countries), and the Lagrangian variable μ represents the shadow value of the blender's marginal profits of increasing blended gasoline production.

The necessary conditions for profit maximization in this market are represented in Appendix A. Equation (A1) states that at the optimum, conventional gasoline would be utilized for blending up to the point where the marginal value product of conventional gasoline equals the sum of its unit price and the shadow value of the blending mandate (weighted by its blending rate). Equation (A4) states that at the optimum, domestically-produced ethanol would be used up to the point where the marginal value product of domestically-produced ethanol equals the sum of the marginal factor cost associated with the use of domestically-produced ethanol and the shadow value of the blending mandate (weighted by its blending rate). Equation (A7) shows that at the optimum, the marginal value product of imported ethanol must equal the sum of its unit price, $[P^i_m(1+\delta) + T^i_m]$, less the tax credit and the shadow value of the blending mandate (weighted by its blending rate). Under the assumption that domestically-produced and imported ethanol are perfect substitutes for blending with conventional gasoline, an efficient selection between domestically-produced and imported ethanol at optimum is presented in Equation (3), which is obtained from Equations (A4) and (A7), as follows:

$$P_e(1+\varepsilon) + t_e = P^i_m(1+\delta) + T^i_m. \tag{3}$$

These results indicate that even though there are no contracts between domestic blenders and foreign ethanol exporters, the ethanol import price must equal the sum of the marginal factor cost of ethanol and the tax credit for domestically-produced ethanol. Therefore, these results demonstrate that market power effects are effectively transmitted to ethanol exporters.

Additionally, due to current U.S. energy policy, an import duty, T^i_m is imposed to offset the tax credit provided to blenders when they use imported ethanol. Therefore, the recently passed 2008 Farm Bill which lowered the tax credit for ethanol to $0.45 per gallon (since January 2009), while the import duty for sugar-based ethanol remains at $0.54 per gallon, would make imported ethanol relatively more expensive. Consequently, it is more likely that both domestic ethanol production and ethanol imports from Brazil would initially decline, while subsequently the demand for domestically-produced ethanol increases, consistent with the blender's need to meet the blending mandate, which then ultimately leads to a domestic ethanol price rise (this topic will be further discussed in the following section, Ethanol Production).

Conventional Gasoline Production

Since the Renewable Fuel Standard under the Energy Policy Act of 2005 redefined ethanol as a renewable fuel and the Energy Independence and Security Act of 2007 mandated bio-fuel production levels, the introduction of ethanol into the U.S. fuel market has undoubtedly had an effect on domestic blended gasoline prices. Accordingly, several studies have recently reported that the tax credit and mandated ethanol production increases the domestic fuel supply, leading to a reduction in the price of gasoline at the pump (Blanch, 2008; Cooper, 2008; de

Gorter and Just, 2009b; Du and Hayes, 2008; Schmitz, Moss, and Schmitz, 2007). Blanch (2008) referenced a Merrill Lynch study indicating that conventional gasoline prices would be 15% higher without mandated ethanol production. Du and Hayes (2008) reported that the growth in ethanol production has caused retail blended gasoline prices to be \$0.29 to \$0.40 per gallon lower than they would otherwise have been. Schmitz, Moss, and Schmitz (2007) reported that the increase in ethanol production lowers the price of gasoline by 4.3–6.0 cents per gallon, depending upon the relative size of the elasticity of demand for gasoline. The Renewable Fuels Association (2008a) summarized the impacts of ethanol on gasoline prices, claiming an ethanol savings ranging between \$0.20 and \$0.50 per gallon of gasoline.

These authors implicitly assumed that ethanol and conventional gasoline are substitute goods for consumers, but that they are produced independently by distillers and refiners. However, we assume that conventional gasoline and ethanol are substitute goods in production due to the blending mandate,[8] and therefore, a mandate to blend ethanol with conventional gasoline may have a negative impact on conventional gasoline production by refiners, while it has a positive impact on ethanol production by distillers, as long as ethanol production is less than the blending mandate, as illustrated below.

A refiners' profit to be maximized under a blending mandate is represented by:

$$\text{Max } \pi(G) = P_g G - C(G) + \lambda\,[B_0 - (1-\theta)G - \theta E]. \tag{4}$$

Part of the necessary conditions for profit-maximization in this market are represented as follows:

$$P_g \le \left(\frac{\partial C(G)}{\partial G}\right) + \lambda(1-\theta), \tag{5}$$

$$B_0 = (1-\theta)G + \theta E, \text{ and } \lambda \underset{>}{\overset{<}{=}} 0. \tag{6}$$

The Lagrangian variable λ represents the shadow value of the refiners' marginal profits of increasing conventional gasoline production associated with an increase in blended gasoline production. Since the output price must be greater than or equal to its marginal cost at market equilibrium in the short-run, based on Equation (5), the shadow value λ must be positive. Therefore, Equation (5) indicates that refiners produce conventional gasoline up to the level where the unit price of conventional gasoline equals the sum of the marginal costs of producing conventional gasoline and the shadow value of a blending mandate (weighted by its blending rate).

The impacts of a blending mandate on the marginal costs of conventional gasoline production can be obtained from Equation (5) at the optimum as follows:

$$\frac{\partial\left(\frac{\partial C(G)}{\partial G}\right)}{\partial \theta} = \lambda > 0, \tag{7}$$

which implies that the marginal costs of producing conventional gasoline increases as the rate of the blending mandate increases, so that the refiner's conventional gasoline supply curve shifts to the left, and therefore, refiners reduce conventional gasoline production.

Ethanol Production

Similarly, the impacts of a blending mandate on ethanol supply can be evaluated by maximizing the distiller's profit function, specified as follows:

$$Max\ \pi(E_{do}) = (P_e + t_e)E_{do} - C(E_{do}) + w\,[B_0 - (1-\theta)G - \theta E], \tag{8}$$

where, $E = E_{do} + \sum E^i_m$ and w is a Lagrangian multiplier. While a blender utilizes ethanol up to the point where the marginal value product of domestically-produced ethanol equals the sum of the marginal factor cost of ethanol and the shadow value of the blending mandate, a distiller is paid the sum of the unit cost of ethanol and the tax credit from the blender, where the blender is paid the tax credit from the government. The essential part of the necessary conditions for optimum for this analysis is represented as follows:

---

[8] When blended gasoline production is equivalent to consumer demand for motor fuel, raising the rate of the blending mandate implies that conventional gasoline and ethanol are substitute goods.

$$(9)\qquad (P_e + t_e) \leq \left(\frac{\partial C(E_{do})}{\partial E_{do}}\right) + w\theta.$$

Therefore, Equation (9) indicates that at the optimum, distillers produce ethanol up to the level where the sum of the ethanol price per unit and the bio-fuel tax credit equals the sum of the marginal costs of producing ethanol and the shadow value of a blending mandate. The impact of a blending mandate on the marginal costs of ethanol production is derived from Equation (9) at optimum as follows:

$$(10)\qquad \frac{\partial\left(\dfrac{\partial C(E_{do})}{\partial E_{do}}\right)}{\partial\theta} = -w < 0,$$

which implies that the marginal costs of producing ethanol decline as the rate of the blending mandate increases so that the ethanol supply curve shifts to the right.

Current energy data illustrates these points, by showing that as ethanol production has increased, crude oil use as an input at U.S.-based refineries has been declining since 2004, as shown in Figure 2. While ethanol production has increased by 2.63 billion gallons during the 2004–2007 period, conventional gasoline production has declined by 2.58 billion gallons during the same period.[9] Therefore, there is no evidence that a blended gasoline price would be higher without mandated ethanol production.

So, these results tell us that the impact of a blending mandate on the equilibrium price and quantity of blended fuel depends on the relative magnitudes between: (1) the reduced conventional gasoline production as a result of the blending mandate to blenders; (2) the increase in ethanol production as a result of the bio-fuel tax credit and the blending mandate; and (3) the price elasticity of consumer demand for motor fuel. An equilibrium price of blended gasoline could be higher when the reduction in the conventional gasoline supply resulting from the mandated blending requirement is greater than the increase in ethanol production (as discussed in the following section).

Comparative Static Analyses

This section analyzes the economic impacts of selected changes in U.S. bio-fuel policies and blenders' market power on fuel prices. It conducts a comparative static analysis on fuel prices for blended gasoline, conventional gasoline, and ethanol using the parameter, ε, which represents the blender's market power effects, and two bio-fuel policy variables, t_e and θ. The analysis requires a few initial steps in developing a matrix of derivative results. We begin by inserting the refiner's optimum condition for conventional gasoline production from Equation (5) into the blender's optimum condition of conventional gasoline use for blended gasoline production in Equation (A1) (from Appendix A), which results in the following relationship (hereafter, arguments for blended gasoline production, *B,* are omitted):

$$(11)\qquad P_B\left(\frac{\partial B}{\partial G}\right) = P_g\left(1 + \frac{\mu}{\lambda}\right) - \left(\frac{\partial C(G)}{\partial G}\right)\left(\frac{\mu}{\lambda}\right).$$

Similarly, inserting the distiller's optimum condition for ethanol production from Equation (9) into the blender's optimum condition of ethanol use for blended gasoline production in Equation (A4) (from Appendix A) results in the following:

$$(12)\qquad \begin{aligned} P_B\left(\frac{\partial B}{\partial E_{do}}\right) &= P_e\left(1 + \varepsilon + \frac{\mu}{w}\right) + t_e\left(\frac{\mu}{w}\right) \\ &\quad - \left(\frac{\partial C(E_{do})}{\partial E_{do}}\right)\left(\frac{\mu}{w}\right). \end{aligned}$$

Finally, the blender's optimum use of imported ethanol for blended gasoline production in Equation (A7) (from Appendix A) is rewritten as follows:

$$(13)\qquad P_B\left(\frac{\partial B}{\partial E^i_m}\right) = [P^i_m(1 + \delta) - t_e + T^i_m] + \theta\mu.$$

Then, total differentiation of Equations (11) through (13), reflecting price effect relationships for blended and conventional gasoline and ethanol, can be compactly presented in matrix form as follows:

---

[9] Approximately 19.6 gallons of motor gasoline are produced from one barrel of crude oil (Energy Information Administration, 2008).

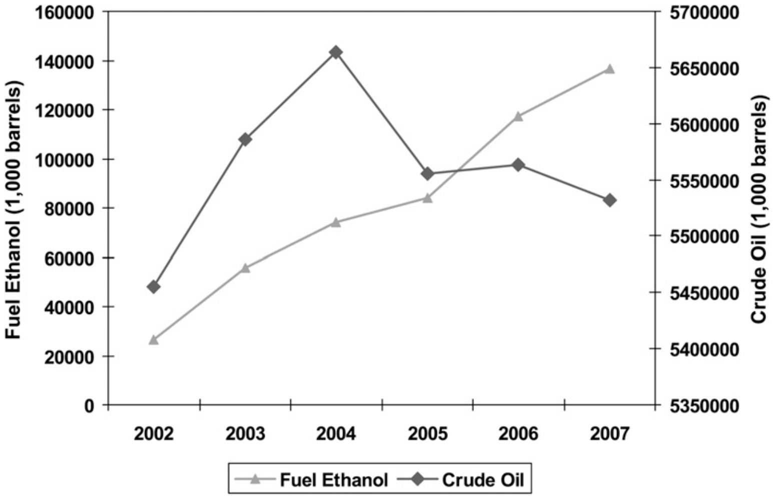

Figure 2. Refinery and Blender Net Inputs of Crude Oil and Fuel Ethanol (Source: Energy Information Agency, U.S. Department of Energy, Internet site: http://tonto.eia.doe.gov/dnav/pet/pet_pnp_input_dc_nus_mbbl_m.htm (Accessed July 28, 2008)

$$\text{(14)} \qquad \begin{bmatrix} dP_B \\ dP_g \\ dP_e \end{bmatrix} = \frac{1}{D} \begin{pmatrix} B_{11} & B_{12} & B_{13} \\ B_{21} & B_{22} & B_{23} \\ B_{31} & B_{32} & B_{33} \end{pmatrix} \begin{bmatrix} d\varepsilon \\ dt_e \\ d\theta \end{bmatrix},$$

where $D = \left(1 + \frac{\mu}{\lambda}\right)\left(1 + \varepsilon + \frac{\mu}{w}\right)\left(\frac{\partial B}{\partial E_m^i}\right) > 0$. All elements B_{ij} (i, j = 1, 2, 3) are presented in Appendix B, while the comparative static results that follow from Equation (14) are presented in Appendix C.

Equations (B1) through (B3) in Appendix B, respectively, describe the effects of increasing the blender's market power on the prices of blended gasoline, conventional gasoline, and ethanol. Equations (B1) and (B2) explain that blended gasoline and conventional gasoline prices are independent of the blender's market power effects. Equation (B3) shows that ethanol price would decline as blender's market power increases.

Equations (B4) through (B6) in Appendix B, respectively, explain the effects of changing the bio-fuel tax credit on blended gasoline, conventional gasoline, and ethanol prices. Without the blending mandate, ethanol and conventional gasoline could be independently produced, but they are considered to be perfect substitutes in consumption, so that blended gasoline supply would increase, and therefore, have the effect of lowering its price as shown in Equation (B12). This result, without a blending mandate, is consistent with other recent studies (de Gorter and Just, 2009a; Du and Hayes, 2008; Schmitz, Moss, and Schmitz, 2007). As the blended gasoline price declines, the conventional gasoline price also declines (along the conventional gasoline supply curve).

Using Equation (B6), the result in Matrix Element (B32) (from Appendix B) can be rewritten as follows:

$$\text{(15)} \quad \frac{\partial P_e}{\partial t_e} = -\frac{C_{32}}{D} = -\frac{\left[\left(\frac{u}{w}\right)\left(\frac{\partial B}{\partial E_m^i}\right) + \left(\frac{\partial B}{\partial E_{do}}\right)\right]}{\left[\left(1 + \varepsilon + \frac{u}{w}\right)\left(\frac{\partial B}{\partial E_m^i}\right)\right]} < 0,$$

which says that ethanol price declines as the bio-fuel tax credit increases. The effects of increasing the bio-fuel tax credit on ethanol price can be further investigated by rewriting Equation (3) as follows:

$$\text{(16)} \qquad P_e = \frac{[P_m^i(1 + \delta) - t_e + T_m^i]}{(1 + \varepsilon)}.$$

Equation (16) describes that the ethanol price could decline as much as the tax credit increase (discounted by the price flexibility of ethanol supply), but by not as much as the increase in the bio-fuel tax credit (due to the blender's market power effect). As an example, these results imply that as the tax credit is reduced by 6¢ (from \$0.51 per gallon of ethanol to \$0.45 under the

2008 Farm Bill), then the ethanol price would be expected to rise by less than 6¢ due to the blender's market power effect.

Equations (C13) through (C33) (from Appendix C), respectively, describe the effects of changing the rate of the blending mandate on blended gasoline, conventional gasoline, and ethanol prices. Equation (C23) explains that the conventional gasoline price would rise as the rate of the blending mandate increases. For a given consumer demand, as the rate of the blending mandate increases, the blender's demand for conventional gasoline declines, but the marginal costs of the refiner's conventional gasoline production increase so that the conventional gasoline supply curve shifts to the left, which leads to an increase in the conventional gasoline price.

We demonstrated in Equation (10) that marginal production costs of domestically-produced ethanol decline as the rate of the blending mandate increases, so that the ethanol supply curve shifts to the right which leads to a lowering of the ethanol price. However, an increase in the rate of the blending mandate increases the ethanol demand for blending, and as a result, the ethanol price rises along the distiller's ethanol supply curve. Therefore, the result in Equation (C33) states that an increase in the ethanol price resulting from an increasing ethanol demand to meet the blending mandate is greater than the reduction of the ethanol price resulting from declining marginal ethanol production costs. Therefore, these results explain that ethanol price would increase as the rate of the blending mandate increases.

Equation (C13) explains that the blended gasoline price would rise as the rate of the blending mandate increases. Since blenders produce blended gasoline with conventional gasoline and ethanol, and the prices of both fuels rise as the rate of the blending mandate increases, the blended gasoline price must rise.

Relative Impacts of a Tax Credit versus a Blending Mandate on Fuel Prices

Comparative static analyses presented in Equations (C12) through (C32) (from Appendix C) show that fuel prices decline as the bio-fuel tax credit increases, but increase as the rate of the blending mandate increases. To compare the relative impacts of a tax credit and a blending mandate on fuel prices, the following Equations (17–1) through (17–3) are obtained from equations (B4) through (B9) in Appendix B.

$$\text{(17-1)}\quad \frac{\partial P_B}{\partial \theta} = -\mu\left(\frac{\partial P_B}{\partial t_e}\right).$$

$$\text{(17-2)}\quad \frac{\partial P_g}{\partial \theta} = -\mu\left(\frac{\partial P_g}{\partial t_e}\right).$$

$$\text{(17-3)}\quad \frac{\partial P_e}{\partial \theta} = -\mu\left[\left(\frac{\partial P_e}{\partial t_e}\right) + \left(1 + \frac{\mu}{\lambda}\right)\left(\frac{\mu}{w}\right)\left(\frac{\partial B}{\partial E_m^i}\right)\right].$$

Equations (17–1) and (17–2) show that the impacts of changing the rate of the blending mandate on blended gasoline and conventional gasoline prices, respectively, are multiple times greater than the price effect associated with changing the bio-fuel tax credit. Meanwhile, using Equations (17–1) through (17–3), the Lagrangian multiplier μ can be rewritten as follows:

$$\text{(18)}\quad \mu = -\frac{\left(\frac{\partial P_B}{\partial \theta}\right)}{\left(\frac{\partial P_B}{\partial t_e}\right)} = -\frac{\left(\frac{\partial P_g}{\partial \theta}\right)}{\left(\frac{\partial P_g}{\partial t_e}\right)} = -\frac{\left(\frac{\partial P_e}{\partial \theta}\right)}{\left[\left(\frac{\partial P_e}{\partial t_e}\right) + \left(1 + \frac{\mu}{\lambda}\right)\left(\frac{\mu}{w}\right)\left(\frac{\partial B}{\partial E_m^i}\right)\right]}.$$

Equation (18) shows that the shadow values associated with the blending mandate represents the marginal rate of substitution of the blending mandate for the tax credit, which is the ratio of the marginal fuel prices for a blending mandate and a tax credit. This ratio effectively measures the comparative-static effect of the blending mandate requirement on the optimal value of the blender's objective function presented in Equation (2).

In summary, as demonstrated in Equations (C12) through (C33) in Appendix C, fuel prices would decline as the tax credit increases, while they would rise as the blending mandate increases. The optimum level of the tax credit can be derived from Equations (12) and (13) as follows:

$$\text{(19)}\quad t_e = \frac{1}{\theta\left(\frac{\mu}{w}\right)}\left\{\theta P_B\left(\frac{\partial B}{\partial E_{do}}\right) - P_e\left(1 + \varepsilon + \frac{\mu}{w}\right) + \left(\frac{\partial C(E_{do})}{\partial E_{do}}\right)\left(\frac{\mu}{w}\right) - \theta^2\right\}.$$

As the blending mandate increases, the optimal level of the tax credit must also increase in order to maintain the optimum level of social economic benefits associated with the mandate and tax credit levels prior to their increase. Since blenders must blend 10.5 billion gallons of ethanol in 2009, with the mandate rising to 15 billion gallons in 2015 and thereafter (under the EISA), and since the tax credit was lowered to $0.45 beginning in January 2009 under the AJCA, inflationary pressures mount on the prices of all fuels including conventional gasoline, ethanol, and blended gasoline.

Conclusions

Newly enacted bio-fuel related programs, especially as established by the AJCA of 2004 and the EISA of 2007 are, arguably, now much more influential policies affecting fuel prices. From an economic analysis perspective, the introduction of these programs has created numerous complexities in modeling the adjustment process for both blended gasoline and ethanol prices. Therefore, we integrate a refiner's profit function associated with conventional gasoline production, a distiller's profit function associated with ethanol production, and a blender's profit function associated with blended gasoline production to evaluate within a comparative static analysis the effects of tax credits, blending mandates, and blender's market power on equilibrium market prices for blended gasoline, conventional gasoline, and ethanol.

Results indicate that first, the prices of all fuels including conventional gasoline, ethanol, and blended gasoline would decline as a bio-fuel tax credit increases, but they increase as the rate of a blending mandate increases, other things being equal. Second, the shadow value of a blending mandate represents the marginal rate of substitution between the marginal price change associated with a blending mandate and the marginal price change associated with a tax credit. Therefore, these results imply that a blending mandate is a more (less) effective policy tool when the marginal rate of substitution between the blending mandate and the tax credit is greater (smaller).

As the rate of the blending requirement increases, the marginal costs of producing conventional gasoline increase so that the conventional gasoline supply curve shifts to the left, leading to a higher gasoline price. Previous studies implicitly assumed that conventional gasoline and ethanol are independent goods in production, so that blended gasoline supply would increase and its price per gallon would decline as a result of a blending mandate. However, our model posits that refiners reduce conventional gasoline production due to the shadow value associated with the blending mandate. The Energy Information Administration (2008) data lends support to our position by showing that refinery net inputs of crude oil (for conventional gasoline production) have been declining since 2004. This data illustrates that conventional gasoline production declined by 2.58 billion gallons between 2004 and 2007, while ethanol production increased by 2.63 billion gallons during the same period. These results cast doubt on the suggestion that an increase in ethanol production lowers the price of blended gasoline by 20–50 cents per gallon.

As the blending mandate increases, the optimal level of tax credits must also increase in order to maintain the social economic benefits associated with the level of the bio-fuel policy instruments prior to their increase. Since blenders must blend 10.5 billion gallons of ethanol in 2009, with the mandate rising to 15 billion gallons in 2015 and thereafter (under the EISA), and since the tax credit was lowered to $0.45 beginning in January 2009 under the AJCA, the prices of all fuels including conventional gasoline, ethanol, and blended gasoline are expected to rise.

Finally, we show that blender' decisions between using domestically-produced and/or imported ethanol to blend with conventional gasoline depend largely on the level of their own market power, as well as the level of bio-fuel specific tax credits, *ad valorem* taxes, and secondary tariffs. With the 2008 Farm Act lowering the tax credit for ethanol to $0.45 per gallon, beginning in January 2009, and with the import duty for sugar-based ethanol remaining at $0.54 per gallon, the price of imported ethanol would likely be affected. However, due to the reduced tax credit and an increasing blending mandate, pressure builds on all fuel prices, including those for conventional gasoline, ethanol, and blended gasoline, to rise until equilibrium conditions again hold. Consequently, our results suggest that ethanol imports from Brazil would likely not be affected significantly. However, our results also tell us that the unit price of blended gasoline would likely increase, and therefore, consumer demand for blended gasoline would likely decline.

[Received March 2009; Accepted September 2009.]

References

Blanch, F. "As Biofuels Catch On, Next Task Is to Deal With Environmental, Economic Impact." *Wall Street Journal*, March 24, 2008.

Cooper, M. Consumer Federation of America. "Slashing Ethanol Production would Raise Gasoline Prices Consumer Group Warns EPA." Internet site: http://blog.foodpricetruth.org/?p=108 (Accessed August 7, 2008).

de Gorter, H., and D. Just. "The Economics of A Blended Mandate for Biofuels." *American Journal of Agricultural Economics* 91,3(2009a): 738–50.

de Gorter, H., and D. Just. "The Welfare Economics of a Biofuel Tax Credit and the Interaction Effects with Price Contingent Farm Subsidies." *American Journal of Agricultural Economics* 91,2(2009b):477–88.

Donovan, B.J. "Independent U.S. Ethanol Producers will Not Survive as Price Takers." News Blaze. Internet site: http://newsblaze.com/story/20090807091234zzzz.nb/topstory.html (Accessed August 20, 2009).

Du, X., and D.J. Hayes. "The Impact of Ethanol Production on U.S. and Regional Gasoline Prices and on the Profitability of the U.S. Oil Refinery Industry." Center for Agricultural and Rural Development, Iowa State University. Selected paper presented at the Agricultural and Applied Economics Association meetings, Orlando, FL, July 27–29, 2008.

Energy Information Administration. U.S. Department of Energy, "Energy Kid's Page." Internet site: www.eia.doe.gov/kids/energyfacts/sources/non-renewable/oil.html (Accessed February 21, 2008).

Gardner, T. "High Ethanol Price to Test, Not Break, U.S. Mandate." *Reuters*, David Gregorio, ed. Internet site: http://www.reuters.com/article/idUSTRE4B18DT20081202 (Accessed December 2, 2008).

Hartwig, M. "Just the Facts: Ethanol Markets." Renewable Fuels Association, June 26, 2006. Internet site: http://www.ethanolrfa.org/objects/documents/746/justthefacts-Markets.pdf.

Kim, C.S., G. Schaible, and S. Daberkow "Modelling the Effects of U.S. Bio-fuel Policies on Commodity and Energy Markets." *The Economic Impact of Public Support to Agriculture: An International Perspective*, Chapter 10. New York: Springer. April/May 2010.

Koplow, D. *Biofuels-At What Cost? Government Support for Ethanol and Biodiesel in the United States*. Cambridge, MA: Earth Track, Inc., 2006.

Lieberman, B. The Heritage Foundation, "Time for Second Thoughts on the Ethanol Mandate." WebMemo, No. 1879. Internet site: http://www.heritage.org/Research/EnergyandEnvironment/wm1879.cfm (Accessed April 2, 2008).

Renewable Fuels Association. *Estimating the Impact of Increased Ethanol Production on U.S. Household Spending*. Internet site: http://www.ethanolrfa.org/documents/EthanolandHouseholdSpending_000.pdf (Accessed 2008a).

Schmitz, A., C.B. Moss, and T.G. Schmitz. "Ethanol: No Free Lunch." *Journal of Agricultural & Food Industrial Organization*, Vol. 5, Article 3, 2007. Internet site: http://www.bepress.com/jafio/vol5/iss2/art3.

Taheripour, F., and W. Tyner. "Ethanol Subsidies, Who Gets the Benefits?" Bio-Fuels, Food and Feed Tradeoffs Conference, St. Louis, MO, April 12–13, 2007.

Tiffany, D.G., and V.R. Eidman. "Factors Associated with Success of Fuel Ethanol Producers." Staff Paper PO3-7. Department of Applied Economics, University of Minnesota, 2003.

Tyner, W.E., and F. Taheripour. "Policy Options for Integrated Energy and Agricultural Markets." *Review of Agricultural Economics* 30(2008):387–96.

U.S. Environmental Protection Agency. Internet site: http://www.epa.gov/otaq/renewablefuels/#regulations (Accessed November 28, 2008).

Vedenov, D., and M. Wetgstein. "Toward an Optimal U.S. Ethanol Fuel Subsidy." *Energy Economics* 30,5(2008):2073–90.

Westhoff, P. "The Energy Independence and Security Act of 2007: Preliminary Evaluation of Selected Provisions," Congressional Staff Report, FAPRI-MU #01-08, Food and Agricultural Policy Research Institute, University of Missouri, 2008.

Yacobucci, B.D. "Biofuels Incentives: A Summary of Federal Programs." CRS Report for Congress, Congressional Research Service, July 25, 2006.

Yacobucci, B.D., and R. Schnepf. "Ethanol and Biofuels: Agriculture, Infrastructure, and Market Constraints Related to Expanded Production." CRS Report for Congress, Congressional Research Service, 2007.

zFacts. *The Wholesale Price of Ethanol*. Internet site: http://zfacts.com/p/438.html (Accessed September 24, 2008).

Appendix A

$$\text{(A1)}\quad P_B\left(\frac{\partial B(G, E_{do}, E_m)}{\partial G}\right) \le P_g + (1-\theta)\mu$$

$$\text{(A2)}\quad P_B\left(\frac{\partial B(G, E_{do}, E_m)}{\partial G}\right) G = P_g G + G(1-\theta)\mu$$

$$\text{(A3)}\quad G \ge 0$$

$$\text{(A4)}\quad P_B\left(\frac{\partial B(G, E_{do}, E_m)}{\partial E_{do}}\right) \le P_e(1+\varepsilon) + \theta\mu,$$

where $\varepsilon = \left(\frac{\partial P_e}{\partial E_{do}}\right)\left(\frac{E_{do}}{P_e}\right)$ is the supply flexibility of domestically-produced ethanol.

$$\text{(A5)}\quad P_B\left(\frac{\partial B(G, E_{do}, E_m)}{\partial E_{do}}\right) E_{do} = P_e(1+\varepsilon)E_{do} + \theta\mu E_{do}$$

$$\text{(A6)}\quad E_{do} \ge 0$$

$$\text{(A7)}\quad P_B\left(\frac{\partial B(G, E_{do}, E_m)}{\partial E^i_m}\right) \le [P^i_m(1+\delta) - t_e + T^i_m] + \theta\mu$$

$$\text{(A8)}\quad P_B\left(\frac{\partial B(G, E_{do}, E_m)}{\partial E^i_m}\right) E^i_m = E^i_m[P^i_m(1+\delta) - t_e + T^i_m] + \theta\mu E^i_m$$

$$\text{(A9)}\quad E^i_m \ge 0$$

$$\text{(A10)}\quad B_0 = (1-\theta)G + \theta(E_{do} + \Sigma E^i_m)$$

$$\text{(A11)}\quad \mu[B_0 - (1-\theta)G - \theta(E_{do} + \Sigma E^i_m)] = 0$$

$$\text{(A12)}\quad \mu \lesseqgtr 0$$

Appendix B

$$\text{(B1)}\quad \text{B11} = 0$$

$$\text{(B2)}\quad \text{B21} = 0$$

$$\text{(B3)}\quad \text{B31} = -\left(1+\frac{\mu}{\lambda}\right)\left(\frac{\partial B}{\partial E^i_m}\right)P_e$$

$$\text{(B4)}\quad \text{B12} = -\left(1+\frac{\mu}{\lambda}\right)\left(1+\varepsilon+\frac{\mu}{w}\right)$$

$$\text{(B5)}\quad \text{B22} = -\left(1+\varepsilon+\frac{\mu}{w}\right)\left(\frac{\partial B}{\partial G}\right)$$

$$\text{(B6)}\quad \text{B32} = -\left(1+\frac{\mu}{\lambda}\right)\left[\left(\frac{\mu}{w}\right)\left(\frac{\partial B}{\partial E^i_m}\right) + \left(\frac{\partial B}{\partial E_{do}}\right)\right]$$

$$\text{(B7)}\quad \text{B13} = \mu\left(1+\frac{\mu}{\lambda}\right)\left(1+\varepsilon+\frac{\mu}{w}\right)$$

$$\text{(B8)}\quad \text{B23} = \mu\left(1+\varepsilon+\frac{\mu}{w}\right)\left(\frac{\partial B}{\partial G}\right)$$

$$\text{(B9)}\quad \text{B33} = \mu\left(1+\frac{\mu}{\lambda}\right)\left(\frac{\partial B}{\partial E_{do}}\right)$$

Appendix C

$$\text{(C11)}\ \frac{\partial P_B}{\partial \varepsilon} = 0,\qquad \text{(C21)}\ \frac{\partial P_g}{\partial \varepsilon} = 0,\qquad \text{(C31)}\ \frac{\partial P_e}{\partial \varepsilon} < 0,$$

$$\text{(C12)}\ \frac{\partial P_B}{\partial t_e} < 0,\qquad \text{(C22)}\ \frac{\partial P_g}{\partial t_e} < 0,\qquad \text{(C32)}\ \frac{\partial P_e}{\partial t_e} < 0,$$

$$\text{(C13)}\ \frac{\partial P_B}{\partial \theta} > 0,\qquad \text{(C23)}\ \frac{\partial P_g}{\partial \theta} > 0,\qquad \text{(C33)}\ \frac{\partial P_e}{\partial \theta} > 0$$