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The Law of Unintended Consequences: How the U.S. Biofuel Tax Credit with a Mandate Subsidizes Oil Consumption and Has No Impact on Ethanol Consumption

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and

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Abstract

With a mandate, U.S. policy of ethanol tax credits designed to reduce oil consumption does the exact opposite. A tax credit is a direct *gasoline consumption subsidy* with no effect on the ethanol price and therefore does not help either corn or ethanol producers. To understand this, consider first the effects of each policy alone (a mandate and a tax credit). Although market prices for ethanol increase under each policy, consumer fuel prices always decline with a tax credit and increase with a mandate except when gasoline supply is less elastic than ethanol supply. To achieve a given ethanol price, the gasoline price is always higher with a mandate compared to a tax credit. A tax credit alone is an *ethanol consumption subsidy* but most of the benefits go to ethanol producers because ethanol is typically a small share of total fuel consumption. Fuel consumers benefit indirectly to the extent gasoline prices decline with increased ethanol production. With a tax credit or mandate, gasoline consumption declines but more so with a mandate (for a given ethanol price and production level).

However, a tax credit with a binding mandate always generates an increase in gasoline consumption, the extent to which depends on the type of mandate. If it is a blend mandate (as in most countries outside the United States), the tax credit acts as a *fuel consumption subsidy*. Ethanol producers only gain indirectly with the increased ethanol demand resulting from the increase in total fuel consumption. Most of the market effects are due to the mandate with the tax credit only exacerbating the ethanol price increase and causing an increase in the gasoline price but a decrease in the consumer fuel price. For a consumption mandate (as in the United States), the tax credit is even worse as it acts as a *gasoline consumption subsidy*. Market prices of ethanol do not change, even as the price paid by consumers for gasoline declines (while gasoline market prices rise). A tax credit is therefore a pure waste as it involves huge taxpayer costs while increasing greenhouse gas emissions, local pollution and traffic congestion, while at the same time providing no benefit to either corn or ethanol producers (or in promoting rural development) and fails to reduce the tax costs of farm subsidy programs but generates an increase in the oil price and hence wealth in Middle East countries. These social costs are huge because the new mandate calls for 36 bil. gallons by 2022, to cost over $28 bil. a year in taxpayer monies alone.

Even if the mandate is not binding initially, the elimination of the tax credit will cause the mandate to bind or the mandate can be increased so our results still hold.

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The Law of Unintended Consequences: How the U.S. Biofuel Tax Credit with a Mandate Subsidizes Oil Consumption and Has No Impact on Ethanol Consumption

1. Introduction

Important political, economic and environmental issues account for the increased focus worldwide on biofuel policies. Global climate change, local air pollution, increasing oil prices with dwindling reserves, political instability in oil-exporting countries and the desire for energy security have led to a number of different policies to encourage the production and use of biofuels as an alternative to fossil fuels (Kojima et al. 2007; UNCTAD 2006; Doornbosch and Steenblik 2007). In addition to reducing reliance on oil and oil imports and thereby diversifying energy sources, politicians also view policies that encourage the use and production of biofuels as a means to enhance farm incomes, reduce the tax costs of farm subsidy programs and promote rural development (Rajagopal and Zilberman 2007; Tyner 2007; Miranowski 2007). Given the plethora of public policy objectives, governments have therefore implemented a myriad of instrumentalities with biofuel consumption mandates and consumer excise-tax credits being the most prominent.[1] It is therefore important to understand the economic impacts of these policies, in view of biofuels as a rapidly expanding sector and an issue of global concern.

The purpose of this paper is to develop a general framework to evaluate the economic effects of a biofuel mandate and excise-tax credit, and the interaction effects when both are operating simultaneously.[2] It is difficult to ascertain which of these two policies are more important. A recent World Bank study finds that "among various support measures, fuel tax credits are most widely used" (Kojima et al. 2007, p. 54). A summary of biofuel policy interventions by de Gorter and Just (2007a) find that at least 65% of total world fuel consumption is affected by tax credits for biofuels. On the other hand, a recent FAO study concludes that "virtually all existing laws to promote…biofuels set blending requirements,

meaning the percentages of biofuels that should be mixed with conventional fuels" (Jull et al. 2007, p. 21). Rothkopf (2007) surveys 50 countries and reports that 27 countries have blend mandates established or under consideration.[3] However, new countries are announcing mandates on a regular basis while existing mandates are continually being expanded.[4] Nevertheless, most major economies including Brazil, China, EU, India and the United States have implemented both mandates and tax credits, so both policies are a priority for research (Jank et al. 2007; Steenblik 2007).[5]

The key issue is how each policy affects the ethanol (and hence corn) and gasoline sectors. To this end, we develop an analytical model that shows how the effects of a tax credit on biofuel producer and consumer fuel prices differ from that of a mandate.[6] Although producer biofuel prices increase regardless of the policy, consumer fuel prices always decline with a tax credit and can increase or decrease with a mandate, depending on the relative supply elasticity of oil *versus* biofuels. The gasoline price is always higher (and hence gasoline consumption lower) with a mandate compared to a tax credit that generates the same ethanol price. A tax credit is a *biofuel consumption subsidy* but because biofuels are a small share of total fuel consumption, the incidence of this subsidy is such that most of the benefits go to biofuel producers. Fuel consumers benefit indirectly to the extent gasoline prices decline with increased biofuel production.

However, a tax credit with a binding mandate always generates an increase in gasoline consumption, the extent to which depends on the type of mandate. If it is a blend mandate (as in most countries outside the United States), the tax credit acts as a *fuel consumption subsidy*. Ethanol producers gain only indirectly with the increased ethanol demand resulting from the increase in total fuel consumption. Most of the market effects are due to the mandate with the tax

credit only exacerbating the ethanol price increase and causing an increase in the gasoline price but a decrease in the consumer fuel price. For a consumption mandate (as in the United States), the tax credit is even worse as it acts as a *gasoline consumption subsidy*. Market prices of ethanol do not change, even as the price paid by consumers for gasoline declines (while gasoline market prices rise). A tax credit is therefore a pure waste as it involves huge taxpayer costs while increasing greenhouse gas emissions, local pollution and traffic congestion, while at the same time providing no benefit to either corn or ethanol producers (or in promoting rural development) and fails to reduce the tax costs of farm subsidy programs but generates an increase in the oil price and hence wealth in Middle East countries. These social costs are huge because the new biofuel mandate calls for 36 bil. gallons by 2022, to cost over $28 bil. a year in taxpayer monies alone.

To illustrate the complexity and importance of the interaction between biofuel mandates and tax credits, we empirically calibrate a stylized model of the U.S. ethanol market. On 19 December 2007, President Bush signed into law "the Energy Independence and Security Law" which established a mandate of 36 billion gallons of biofuels by 2022 and limiting corn-based ethanol to 15 billion gallons per year after 2015 (compared to production of 6 bil. gallons in 2006). The President's 2007 State of the Union address had called for 35 bil. gallons of renewable fuels by 2017 that was to reduce gasoline consumption by 20 percent and reduce imports of oil by 75 percent.[7] Meanwhile, there is a 51 cent a gallon tax credit for ethanol ($1 per gallon for biodiesel).[8] Our empirical results confirm the theoretical findings that when the blend mandate is binding, the tax credit has relatively small impacts. One empirical case where the mandate reduced consumer fuel prices was also found.

This paper is organized as follows. The next section develops a general theoretical model of mandates. Because governments choose mandates and tax credits simultaneously, Section 3 derives the important interaction effects compared to each policy alone. Section 4 presents a stylized empirical model of U.S. ethanol policies to illustrate the properties of the theory and highlight the importance of analyzing both policies simultaneously. We also use our model to explain why recent U.S. ethanol prices fell precipitously in the face of record oil prices. The last section provides some concluding remarks.

2. The Theory of Biofuel Mandates[9]

As a favor to the reader, we present a simplified model with an exogenous oil price,[10] no distinction between domestic and imported oil supply, and no imports of biofuels.[11] A complete exposition of the theory allowing for endogenous oil prices is given in the Appendix. Consider therefore a competitive market with a domestic supply curve for biofuels S_E and a supply curve for oil S_O in Figure 1. The domestic demand for liquid transportation fuel (the biofuel-gasoline mixture) is denoted by D_F. Biofuel and gasoline are therefore assumed to be perfect substitutes in consumption.[12] For ease of exposition, the intercept of the biofuel supply curve S_E is arbitrarily set to coincide with the price of oil.[13] Finally, we assume constant returns to scale in biofuel production.

Consider a mandatory biofuel blend where there must be a minimum share of biofuel α in all fuel sold, where $0 < \alpha < 1$. Because the cost of producing biofuels is higher than that for oil, biofuel and oil market prices diverge. Because no tax costs are involved with a mandate, the consumer has to pay the weighted average price of the biofuel and oil where the weights are formed by the required share of biofuels:

(1) $P_N = \alpha P_E + (1 - \alpha)P_O$

where P_N is the consumer weighted average price measured along D_F, P_E is the corresponding market supply price of the biofuel and P_O is the price of oil based fuel. The marginal cost of the mandated mixture is P_N as P_E is the marginal cost of biofuel and P_O is the marginal cost of gasoline. While D_F is a standard demand curve and S_E and S_O are standard supply curves, we now must solve for the market equilibrium prices P_E and P_N. This requires the derivation of a total fuel supply curve $S_F(P_N)$, made up of S_E and S_O. The mandate requires that

(2) $\alpha S_F(P_N) = S_E(P_E)$

(3) $(1-\alpha)S_F(P_N) = S_O$

Because equation (1) implies a one to one relationship between P_E and P_N, we can represent the biofuel supply curve S_E as a function of P_N. Solving for P_E from (1) and substituting into equation (2) allows for the supply curve for total fuel to thus be written as

(4) $$S_F(P_N) = \frac{1}{\alpha}S_E\left(\frac{1}{\alpha}P_N + \left(1-\frac{1}{\alpha}\right)P_O\right) = \frac{1}{\alpha}\widetilde{S}_E(P_N)$$

The equilibrium condition for P_N is defined by

(5) $S_F(P_N) = D_F(P_N)$

which solves for $C_F \equiv S_F(P_N^*)$, the equilibrium quantity of total fuel consumption. To derive the equilibrium P_E (as shown in Figure 1), a binding mandate imposes that the consumption of biofuels must equal $\alpha D_F(P_N)$ for any fuel price P_N. Thus, the price of biofuel is implicitly given by the equation

(6) $Q_E(P_E) = \alpha D_F(P_N)$

This means the intersection of P_N with the curve αD_F yields the quantity of biofuel Q_E while the intersection of Q_E with the biofuel supply curve S_E yields the equilibrium biofuel market price P_E (see Figure 1).[14]

As noted earlier, S_F yields the marginal cost of total fuel. The price of biofuel exceeds P_N by the marginal value of gasoline earned by the refiner in mixing an additional unit of biofuel: $P_E - P_N = [P_N - P_O](1-\alpha)/\alpha$ where $(1-\alpha)/\alpha$ is the ratio of gasoline to biofuel use. For example, if $\alpha = 0.5$, then $P_E - P_N = P_N - P_O$. An additional unit of the mandated fuel mixture increases marginal cost to the refiner by $\alpha P_E + P_O(1-\alpha)$. This represents the net supply relation S_F. The total subsidy to biofuel producers in Figure 1 is given by the area *abhi*. The extra amount consumers pay for oil is area *cfgh* that has to equal area *abcd*, the extra subsidy to biofuel producers above the consumer price of fuel. The mandate results in a deadweight cost of over-production (area *bhi*) and under-consumption (area *fmg*).

From Figure 1, it is necessarily the case that an increase in the blend requirement α results in a higher average consumer price for fuel P_N and therefore lower total fuel consumption. This is in sharp contrast to a fuel tax credit that will have no effect on fuel consumption with a fixed oil price (and increases fuel consumption if increased biofuel supply reduces the world oil price). With an endogenous oil price under a binding mandate, we also expect that an increase in the mandate requirement would again result in higher average consumer fuel prices. However, the model with endogenous oil prices derived in the Appendix shows that average consumer fuel prices can decline under special circumstances with an increase in the mandate requirement. The outcome depends on the relative value of the elasticity of supply between biofuel and gasoline:

$$(7) \qquad \frac{dP_N}{d\alpha} > 0 \text{ provided } \left(1+\frac{1}{\eta_O^S}\right)P_O < \left(1+\frac{1}{\eta_E^S}\right)P_E$$

where η_O^S and η_E^S are the elasticities of supply for oil and biofuel, respectively. An increase in the mandate requirement α can reduce the consumer price of fuel if the elasticity of biofuel supply is very large relative to that for gasoline and with lower prices of biofuel compared to the

price of oil. Interestingly, the empirical results to follow for U.S. ethanol finds one case where average consumer fuel prices would fall with an increase in the mandate, even though the ethanol price always rises. The intuition for this interesting comparative static result is as follows: an increase in α necessarily increases the price of ethanol. Hence, both elements of the first right hand term in equation (1) increase. Even though the price of ethanol increases, by mandate the consumption of ethanol necessarily rises. This means there is a drop in demand for gasoline and hence in the price of gasoline. Hence, both elements of the second right hand side term in equation (1) declines. This can overpower the increase in the first term such that the consumer price of fuel P_N declines. As shown in equation (7), the outcome depends on the relative supply elasticities and market prices. Inspection of equation (A.4) indicates that the size effect depends on the level of the elasticity of fuel demand and the mandate requirement α, but not the sign. A larger elasticity of fuel demand results in a smaller change in fuel price. A larger α will have a bigger or smaller impact on fuel prices, depending on the sign of equation (7).

Let us now consider the case where the mandate is replaced by an ethanol tax credit to achieve the same level of ethanol production Q_E in Figure 1. To take advantage of the government subsidy offered them, blenders of ethanol and gasoline will bid up the price of ethanol until it is above the market price of gasoline by the amount of the tax credit. If the price premium over gasoline were less than the tax credit, then blenders would be making windfall profits from the government subsidy by pocketing the difference. But competition among blenders will ensure that there will be no "free money left on the table," and the price of ethanol will therefore exceed that of gasoline by the full 51 cents per gallon tax credit. Gasoline consumption would remain at C_F^* in Figure 1, however, as the consumer price paid for fuel has not changed and remains at P_O.

Consumers of fuel pay only P_O (the difference made up by taxpayers). Ethanol production is now positive and with a fixed gasoline price, ethanol simply displaces gasoline consumption (consumers are unaffected but taxpayer transfers of area *abhi* in Figure 1 results in ethanol production of Q_E). Even if ethanol production lowers gasoline prices, the effect of the tax credit for ethanol is to increase the market price of ethanol relative to the price of gasoline by the tax credit. The only difference is the benefits of the tax credit are now shared between fuel consumers and ethanol producers while gasoline producers would now lose. Ethanol producers gain less than the tax credit, the extent to which depends on the effect of increased ethanol production in lowering gasoline prices.

A blend and consumption mandate compared

In most countries outside the United States, the biofuel policy objective is a percentage blend ratio α. Even though it is implemented like a blend mandate in the United States, the official U.S. policy is a consumption mandate: to achieve a specific level of annual biofuel consumption (from domestic and imported supplies). Concerns over energy security are reflected in this objective as are farm income goals.

To model a consumption mandate, consider an ethanol consumption mandate of the level $\bar{E}$. The consumer has to pay the weighted average price of ethanol and gasoline where the weights are formed by the required consumption of ethanol. The consumer price of fuel now becomes:

$$(1^*) \quad P_N = \left[P_E \bar{E} + P_O \left(C_F - \bar{E} \right) \right] \Big/ C_F$$

where $\bar{E}$ is the mandated level of ethanol consumption. The equilibrium in this case is more easily defined in terms of price as a function of quantity. The equilibrium will be given where

(5*) $$C_O + \bar{E} = D_F\left(P_N\right) = D_F\left(\left[P_E\bar{E} + S_O^{-1}\left(C_O\right)C_O\right]/C_F\right),$$

where C_O is the total amount of gasoline consumed in equilibrium. If the world price of gasoline is fixed so that supply is perfectly elastic, then (1*) defines a fuel supply function

(4*) $$S_F\left(P_F\right) = \frac{P_E - P_O}{P_N - P_O}\bar{E},$$

where $P_N \in \left(P_O, P_E\right]$, and fuel supply is declining in the price of fuel. In this case, the equilibrium will be as depicted in Figure 2.[15] The marginal cost and hence supply curve of the mandated mixture is S_F as P_E is the marginal cost of ethanol and P_O is the marginal cost of gasoline. The market equilibrium is determined by the intersection of S_F with the demand for fuel D_F that determines the weighted average price P_N and total fuel consumption C_F. The supply curve for fuel is flat at P_E until $\bar{E}$ is achieved; it is convex for all fuel consumption beyond $\bar{E}$ and is asymptotic to the perfectly elastic gasoline supply curve S_O.

3. The Economics of a Mandate and a Biofuel Tax Credit

Policy-makers are intent on using mandates and tax credits in concert. The market effects and incidence of introducing a consumption tax or subsidy with a binding mandate can be depicted as a shift in either the supply or demand curve. With a mandate already in place, Figure 3 depicts the effects of introducing a tax on fuel consumption as an upward shift in the supply of fuel S_F by the level of the tax t. This results in a higher consumer price P'_N (the increase depends on the level of t and the demand elasticity of fuel) and a lower biofuel market price P'_E (the extent to which depends on the mandated blend ratio α, demand elasticity of fuel and supply elasticity for the biofuel). Biofuel prices are lower because the demand for fuel (and hence biofuels) declines with a consumer fuel tax and so there is a move down the biofuel supply curve

(the latter determines the biofuel price). The price paid by consumers for biofuel increases to $P'_E + t$ which is greater than P_E, the price paid before the introduction of the fuel consumption tax. The extent of the price increase depends on the tax t, mandated blend ratio α, demand elasticity of fuel and supply elasticity for the biofuel. Total fuel consumption declines by more than the decline in biofuel production because αD_F is more inelastic than D_F.

We are now in a position to analyze the effects of a tax credit with a binding mandate in place. Instead of shifting the supply of fuel S_F up by the full amount t (as in Figure 3), a fuel tax with a tax credit for biofuels results in a shift down of S'_F by $\alpha \cdot t$ as shown in Figure 4. The tax credit generates a lower consumer fuel price P''_N and a higher biofuel market price P''_E. Biofuel prices are higher because total fuel consumption increases as the consumer price for biofuels declines sharply due to the tax credit from $P'_E + t$ in Figure 3 to P''_E in Figure 4. The supply price for biofuel is now equal to the demand price (unlike in Figure 3). With a binding mandate, the tax credit is a taxpayer financed *fuel consumption subsidy*. Compare this to the situation with a non-binding mandate where the tax credit (equal to the gasoline consumption tax t)[16] has no impact on the consumer price for fuel because it leads refiners and blenders to bid up the price of the biofuel from P_O to $P_O + t$.[17] The tax credit alone is a taxpayer financed *biofuel consumption subsidy* but because oil prices are fixed, the entire subsidy benefits biofuel producers.

But if a mandate is already binding, then introducing a tax credit benefits biofuel producers only indirectly through the increased demand for biofuel. Therefore, the increase in the price of biofuel due to a tax credit in this case is much lower than the case of a tax credit with no mandate. The intuition for this result is as follows. Under the mandate only, the consumer price of fuel is given by:

(1') $\quad P'_N = \alpha(P'_E + t) + (1 - \alpha)(P_O + t)$

where P'_E is the market (producer) price of ethanol (depicted in Figure 3 and again in Figure 4) while consumers pay $(P'_E + t)$ for ethanol. Under a tax credit with a binding mandate, the consumer price for fuel is given by:

(1") $P''_N = \alpha P''_E + (1 - \alpha)(P_O + t)$

where P''_E is less than P'_E but greater than $(P'_E + t)$, the price paid by consumers under the mandate. Because the second term in equations (1') and (1") are identical and α is fixed, it follows that $P''_N < P'_N$ and so fuel consumption increases. This means both ethanol and gasoline consumption rises but because α is relatively low, most of the fuel subsidy goes to gasoline. The ethanol price increases because as gasoline consumption rises, so too must ethanol consumption even though the price is higher because the blend mandate requires it. So ethanol prices increase even if the world price of oil is fixed. In this case, the tax credit causes a decrease in the price of gasoline paid by consumers (even with a fixed oil price) and so increases gasoline consumption. In contrast, a tax credit with no mandate had no effect on consumer gasoline prices (with a fixed market price) but reduced gasoline consumption. With a binding mandate, the tax credit is therefore a fuel consumption subsidy.

The relative change in ethanol *versus* fuel prices depends on relative elasticities. For example, if the slope of S_E was equal to that of αD_F (but of opposite sign) in Figure 4, then the increase in the biofuel market price equals the decrease in P_N. The more elastic S_E is, the lower the increase in the supply price of biofuel for a given change in P_N. The mathematical results for a change in the tax credit with endogenous oil prices are given in the Appendix. With a non-binding mandate, inspection of equation (A.5) shows that with a fixed oil price, the change in the biofuel price with respect to the tax credit is one: $dP_E/dt_c = 1$. If the mandate is binding (again holding the oil price fixed), then from equation (A.5):

$$\frac{dP_E}{dt_c} = \frac{1}{1-\left(\frac{1}{\alpha}\frac{\eta_E^S}{\eta_F^D}\frac{P_N}{P_E}\right)} < 1$$

Because α is low and η_F^D is expected to be less than η_E^S, then it follows that the effect of a tax credit on biofuel prices with a binding mandate is much lower than if the mandate was not binding. Results are modified with an endogenous oil price.

The likelihood the mandate is binding or not depends on the level of the tax credit itself. If a mandate is not binding initially, the elimination of the tax credit will in most cases cause the mandate to become binding. Because the tax credit prevented the mandate from binding, gasoline prices will be much lower than otherwise because a binding mandate with no tax credit results in higher gasoline prices than if the tax credit was the only policy. In other words, the correct counterfactual when assessing a tax credit is not current gasoline prices but the price that would otherwise occur if the tax credit was eliminated and the mandate became binding. Otherwise, the social costs of the tax credit are underestimated. So the results above still hold, the extent to which depends on how close ethanol production is with elimination of the tax credit and the mandate became binding to ethanol production with the tax credit.

The Case of a Consumption Mandate

Under a consumption mandate, the tax credit becomes a direct and full subsidy to gasoline consumption. In this case, the supply of fuel from equation (5*) can be written as

$$P_N = \left[\left(P_E - t_c\right)\bar{E} + P_O\left(C_F - \bar{E}\right)\right] / C_F ,$$

so that at the same level of fuel consumption, C_F, the tax credit lowers the fuel price by $t_c\bar{E}/C_F$. By reducing the cost of any given amount of fuel, the supply curve for fuel shifts down because

of the ethanol tax credit, increasing the equilibrium consumption of fuel (Figure 2). Because the amount of ethanol consumption is bound by the mandate, the increase in consumption of fuel to $C_F^{'}$ derives only from an increase in gasoline consumption. The tax credit creates a direct subsidy on gasoline, $t_c\bar{E}/C_F$, that decreases as more fuel is consumed. This is a more direct effect than under the blend mandate, as part of the ethanol tax credit under the blend mandate actually subsidizes ethanol consumption.

Consequently, the price paid by consumers for gasoline declines even more compared to a blend mandate, even as the price paid by consumers for gasoline declines (while gasoline market prices rise). A tax credit is therefore pure waste as it involves huge taxpayer costs while increasing greenhouse gas emissions, local pollution and traffic congestion, while at the same time providing no benefit to either corn or ethanol producers (or in promoting rural development) and fails to reduce the tax costs of farm subsidy programs but generates an increase in the oil price and hence wealth in Middle East countries. These social costs are huge because the new biofuel mandate calls for 36 bil. gallons by 2022, to cost over $28 bil. a year in taxpayer monies alone.

4. An Empirical Illustration: The Case of U.S. Ethanol

The historical relationship between ethanol and gasoline prices in the United States is described in detail in de Gorter and Just (2008). In many years, the implied price premium of ethanol over gasoline indicates that a mandate was in effect. Mandates have been implemented in many states and at the federal level but there may well have been a *de facto* mandate. Informal mandates through various environmental regulations including the implementation of the Clean Air Act in the 1990s or the recent *de facto* ban of MTBE may well have been important. This means ethanol is used in fixed proportions with gasoline. Some commentators view ethanol as a

complementary product to gasoline as an oxygenator and octane enhancer (Miranowski 2007; Taheripour and Tyner 2007) and model ethanol with a vertical demand curve. Ethanol demand is therefore proportional to gasoline consumption if used for its additive value and so should be modeled like a consumption blend mandate. As shown in Figure 1, if the demand for fuel is inelastic and the mandate α is low, then a vertical demand curve for ethanol may be a close approximation to reality.

If the price premium is above that of the tax credit, then most of the premium is due to the mandate (or the additive value of ethanol) and only a small part due to the tax credit. This follows from our previous theoretical result that when used in combination with a mandate, the effect of a tax credit in increasing the ethanol price is not equal to the tax credit and is not necessarily so even if the mandate is not binding. The implication is that the effects of each policy are not additive when used in combination. This is important to note because sometimes it is implied in the literature that the tax credit be added to the price premium (for example, to the "market price support" as described by Steenblik (2007) and Koplow (2007) or additive value, as in Tyner (2007)).

To illustrate the market effects of a combined blend mandate and tax credit, we calibrate a stylized supply-demand model of the U.S. corn-ethanol-gasoline market for 2006/07 and 2015/16 (the latter based on USDA and EIA projections for gasoline, ethanol and corn markets).[18] In the baseline, we assume the blend mandate is not binding in each of the two years so the tax credit determines the ethanol price premium. Because consumers at the gas pump have not distinguished ethanol from gasoline historically, we calibrate 2006/07 in nominal prices but adjust prices on the basis of its contribution to mileage for 2015/16. The purpose of this exercise is neither to judge what happened nor to predict what will happen. Rather, we want to illustrate

the implications of a tax credit with or without a binding mandate and the effect of a mandate without the tax credit.[19] To this end, we undertake three simulations:

(1) Mandate the baseline level of ethanol use plus 3 billion gallons

(2) Remove the tax credit when the mandate does not exist

(3) Remove the tax credit when the mandate is binding

Simulation (1) will show the impact of a blend mandate (analysis in Figure 1). Comparing simulations (2) and (3) will show how the effects of a tax credit are very different, depending on whether the blend mandate is binding (analysis in Figures 3 and 4) or does not exist.

The effects of a blend mandate are summarized in Table 1. The baseline in each of 2006/07 and 2015/16 is assumed to have a non-binding mandate. The observed price premium on the basis of its contribution to mileage in 2006/07 is ignored because we assume consumers do not distinguish between ethanol and gasoline at the gas pump.[20] In contrast, we assume there will be no price premium in 2015/16, not even on the basis of its contribution to mileage (price of ethanol in 2015/16 is assumed to be equal to 0.7125 times the price of gasoline plus the tax credit). Baseline ethanol consumption in 2015/16 is forecast by the USDA to be 12 billion gallons. Although current legislation calls for no more than 15 billion gallons of ethanol in 2015/16, an additional 3 billion gallons coincides with the goal for biofuels in the President's 2007 State of the Union address. Ethanol imports are assumed to be fixed.

The results in Table 1 illustrate the effects of a mandate as described in Figure 1 of the theory earlier. Columns [3] and [6] show the percentage change in key variables when imposing a mandate by increasing required ethanol consumption of an extra 3 billion gallons per year. Adding 3 billion gallons in 2006/07 represents a 50 percent increase in ethanol consumption. As expected, prices of corn and ethanol increase substantially while gasoline prices drop modestly.

Although we assume fairly inelastic domestic and import supply curves (with an elasticity of 0.2 and 2.63, respectively) with a weighted gasoline supply elasticity of 1.66, ethanol is such a small share of total production that gasoline (oil) prices do not react very much to a 50 percent increase in ethanol supplies. The overall effects in 2015/16 are somewhat more moderate in the corn market as ethanol is larger share of corn demand but more pronounced in the gasoline market as ethanol is expected to make up a larger share of fuel consumption.

Interestingly, note that in 2006/07, the price of fuel for consumers declined with the imposition of the mandate (the shaded cell in Table 1). This is counter-intuitive but confirms the theoretical possibility with endogenous oil prices explained in the theory section earlier. Recall that the outcome depends critically on the relative supply elasticity of ethanol and gasoline. At low levels of ethanol to total corn use (as in 2006/07), the supply elasticity for ethanol is expected to be relatively high because the elasticity of ethanol supply η_E^S is defined as the weighted average of corn supply Q_C, domestic non-ethanol demand for corn C_C and corn export demand X_C:

$$\eta_E^S = \eta_C^S\left(\frac{Q_C}{Q_E}\right) - \eta_C^D\left(\frac{C_C}{Q_E}\right) - \eta_C^X\left(\frac{X_C}{Q_E}\right)$$

where η_C^S, η_C^D and η_C^X are the elasticities of corn supply, non-ethanol domestic corn demand and corn export demand, respectively, and Q_E is ethanol production. Because the production of ethanol is relatively low in 2006/07, the supply elasticity is high and so the outcome of a mandate resulting in lower consumer fuel prices is plausible. However, it is unlikely in general and the expected result is for a mandate to increase average consumer fuel prices and reduce fuel consumption (unlike a tax credit with a non-binding mandate that unequivocally increases total fuel consumption).

The results of simulation (2) where the tax credit is removed with a no mandate are given in Table 2. The shaded cell in Table 2 indicates ethanol production goes to zero in 2006, implying there is water in the tax credit. In other words, the price of corn less the tax credit ($1.43/ bushel) is less than the price of corn that otherwise would occur if no ethanol production existed (see de Gorter and Just 2008, 2007a for a complete explanation). As expected, sharp decreases in ethanol and corn prices occur with somewhat significant increases in gasoline prices. Corn and ethanol prices react more in 2015/16 than in 2006/07 because there is no water in the tax credit for 2015/16, prices are higher and ethanol use is a much higher share of total corn production.

These results contrast with those in Table 3 where the removal of the tax credit with a binding mandate has only a very small impact on the market (as the discussion of Figures 3 and 4 in the theory section indicated earlier). Hence, the tax credit does not benefit corn farmers in the United States very much when the mandate is binding. The tax credit for ethanol simply subsidizes fuel consumption and farmers benefit only indirectly and very little. Indeed, data in Table 3 indicates that the largest percentage change in any variable is that for the consumer price of fuel. This may have been an accurate depiction of the equilibrium in 2006/07 when the price premium was due to the *de facto* mandate due to environmental regulations or ethanol was valued for its use as an additive. In that case, the blend mandate model holds. But in 2015/16, the consumption mandate will likely be the appropriate 'what if' scenario. This will modify the results in Table 4. The ethanol price and production levels will not change, even if the oil price rises. In this case, a consumption mandate is a gasoline consumption subsidy only, having no impact on ethanol consumption or prices.

Explaining recent price trends

In the past few months, ethanol prices have plunged while oil prices reach recorded highs of $90 per barrel (Etter and Brat 2007). Our model can provide one possible explanation for this phenomenon. Environmental regulations including the implicit ban on MTBE or ethanol's additive value can be viewed as a *de facto* blend mandate for ethanol. As a result, there was a significant price premium for ethanol in recent years as predicted by our model in Figure 1. But a sharp increase in ethanol production capacity in the past year along with rising oil prices may have resulted in the mandate becoming non-binding in recent months with the price of ethanol now equal to the gasoline price plus the tax credit.

This can be shown in Figure 5 where the initial price premium is $P_E - (P_O + t)$. Rising oil prices along with increasing ethanol supply causes the fuel supply curve S_F to both shift up and pivot down to S'_F. The new equilibrium is at point a, where the new market price of ethanol P'_E equals the now lower consumer price P'_N $(= P'_O + t)$.[21] The demand curve for ethanol is kinked as given by the bold lines in Figure 5. The demand for ethanol αD_F is very steep when the mandate is binding, especially at very low levels of α (currently about 0.045 while Figure 5 shows α to equal 0.5) and an inelastic demand for fuel. Such a steep demand curve for ethanol when the mandate is binding in our model is consistent with the vertical demand curve depicted in Miranowski (2007). The recent precipitous decline in ethanol prices in the face of rising oil prices may be due to the increase in ethanol supply with a near vertical demand curve. But the environmental regulations for the use of ethanol are fulfilled when ethanol is about 4.5 percent of total fuel consumption (Gallagher 2006; Miranowski 2007). Hence, it could be that the implicit or *de facto* mandate (in terms of environmental regulations and/or additive value) is now no longer binding. This means the ethanol demand curve becomes very elastic (the analysis in

Figure 5 assumes oil prices are invariant to ethanol production; the reality is otherwise such that the demand curve is not flat but nonetheless very elastic).

5. Concluding Remarks

This paper develops a model to explain the effects of biofuel mandates and tax credits on gasoline and biofuel (agricultural) markets. On 19 December 2007, President Bush signed into law "The Energy Independence and Security Act of 2007," which established the largest increase in a biofuels mandate (known as the Renewable Fuels Standard, RFS) in history. The new RFS requires the use of at least 36 billion gallons of biofuels in 2022, a fivefold increase over current RFS levels. By 2022, biofuels could represent over 20% of U.S. automobile fuel consumption. Congress and the President argue that the RFS will diversify U.S. energy supplies and reduce dependence on foreign oil.

In analyzing mandates, we derive an important result: U.S. policy of ethanol tax credits designed to reduce oil consumption does (or will do) the exact opposite. With a mandate, the tax credit is a direct *gasoline consumption subsidy* with no effect on ethanol consumption or prices and therefore does not help either corn or ethanol producers. To explain this, we first consider the effects of each policy alone (a mandate and a tax credit). Although market prices for ethanol increase under each policy, consumer fuel prices always decline with a tax credit and increase with a mandate except when gasoline supply is less elastic than ethanol supply. The gasoline price is always higher with a mandate compared to a tax credit that generates the same ethanol price. This is because a mandate subsidizes ethanol production through an implicit tax on gasoline consumption. Consumers only see the blend price of the two fuels. A tax credit alone is an *ethanol consumption subsidy* but most of the benefits go to ethanol producers because ethanol is typically a small share of total fuel consumption. Fuel consumers benefit indirectly to the

extent gasoline prices decline with increased ethanol production. With a tax credit or mandate, gasoline consumption declines but more so with a mandate (for a given ethanol price and production level).

However, a tax credit with a binding mandate always generates an increase in gasoline consumption, the extent to which depends on the type of mandate. If it is a blend mandate (as in most countries outside the United States), the tax credit acts as a *fuel consumption subsidy*. Ethanol producers only gain indirectly with the increased ethanol demand resulting from the increase in total fuel consumption. Most of the market effects are due to the mandate with the tax credit only exacerbating the ethanol price increase and causing an increase in the gasoline price but a decrease in the consumer fuel price.

For a consumption mandate (as in the United States), the tax credit is even worse as it acts as a *gasoline consumption subsidy*. Market prices and consumption of ethanol do not change even as the price paid by consumers for gasoline declines (while gasoline market prices rise). A tax credit is therefore pure waste as it involves huge taxpayer costs while increasing greenhouse gas emissions, local pollution and traffic congestion, while at the same time providing no benefit to either corn or ethanol producers (or in promoting rural development) and fails to reduce the tax costs of farm subsidy programs but generates an increase in the oil price and hence wealth in Middle East countries. These social costs are huge because the new biofuel mandate calls for 36 bil. gallons by 2022, to cost over $28 bil. a year in taxpayer monies alone.

When used in combination with a mandate, the effects of a tax credit in increasing the ethanol price under a binding mandate is not equal to the tax credit and is not necessarily so even if the mandate is not binding. The implication is that the effects of each policy are not additive when used in combination.

To illustrate the complexity and importance of the interaction between mandates and tax credits, empirical analysis using a stylized model of the U.S. corn and gasoline markets confirms our theoretical findings, including one year where a mandate reduces fuel prices. Removing the tax credit when there is no mandate has huge impacts on the price of ethanol and hence corn but is moderated by the level of water in the tax credit for 2006/07 relative to the 2015/16 simulation. Imposing a mandate has the expected effect of increasing consumer fuel prices in 2015/16 but the mandates reduce consumer fuel prices in 2006/07 because of the relatively elastic supply of ethanol (and a relatively low elasticity of supply for oil in the United States).

Priorities for further research would be to extend the framework to evaluate the welfare economics of alternative policies. Although we showed that a mandate is welfare superior to consumption taxes or production subsidies only when the public policy objective is a percentage blend, the analysis should be extended to include multiple policy goals or multiple policy instruments beyond a mandate and tax credit. The model here allows one to calculate not only the deadweight loss triangles in production and consumption in the corn and oil markets, but also the rectangular deadweight costs due to water in the tax credit or mandate and the terms of trade improvements in the import of oil and export of corn (de Gorter and Just 2007a; 2008). The model lends itself to analyzing the effects of farm subsidy programs (de Gorter and Just 2007a).

The model is also well suited to form a basis for evaluating the social benefits of the tax credit *versus* the mandate in reducing local pollution, greenhouse gas emissions and oil dependency, and the social costs in adding to traffic congestion, accidents and other negative externalities arising from more fuel consumption (Parry et al. 2007). Hence, the model can be extended to assess the efficacy of alternative policies like a gasoline tax in achieving multiple policy goals.

Figure 1: The Economics of a Biofuel Blend Mandate

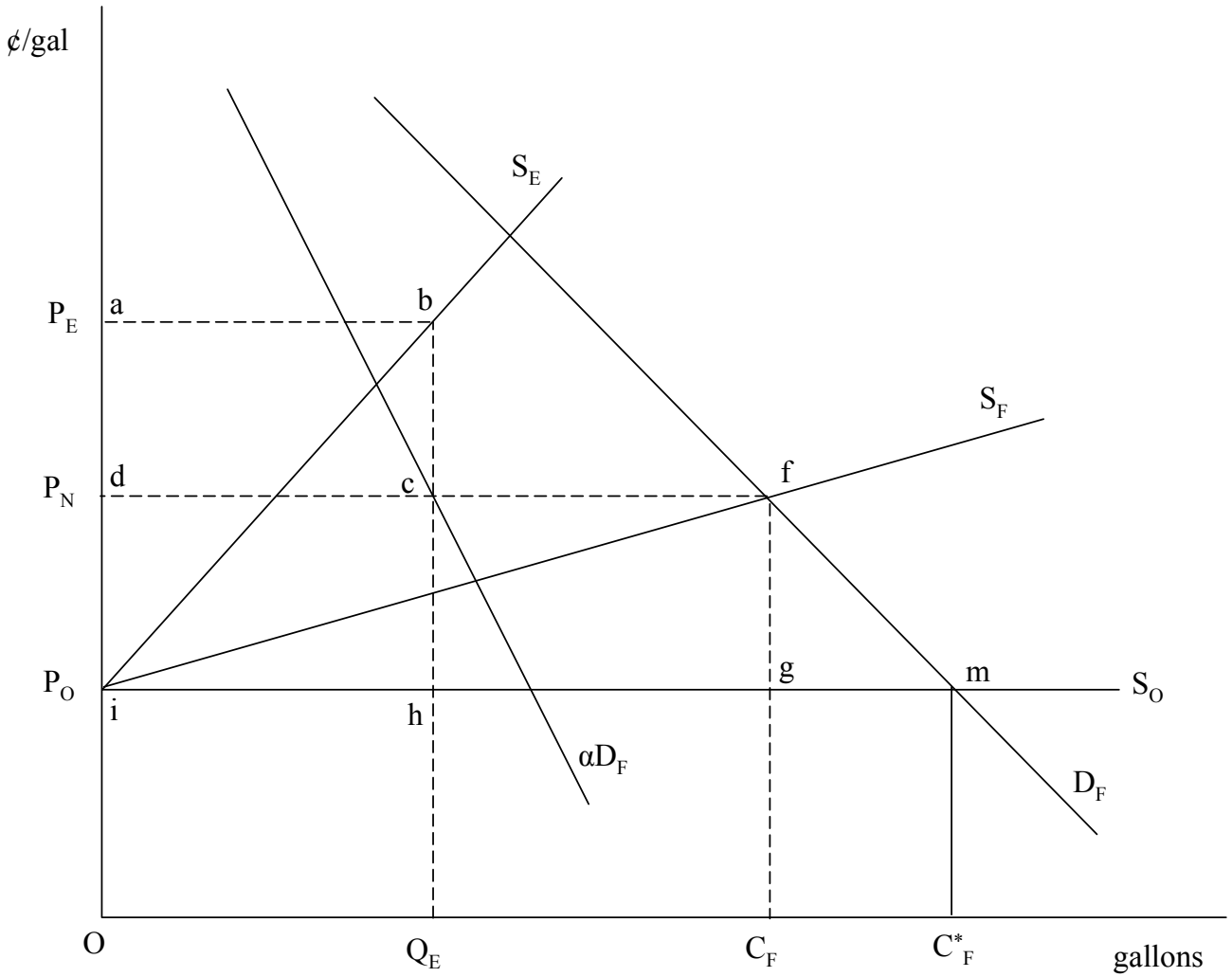

Figure 2: The Economics of a Consumption Mandate

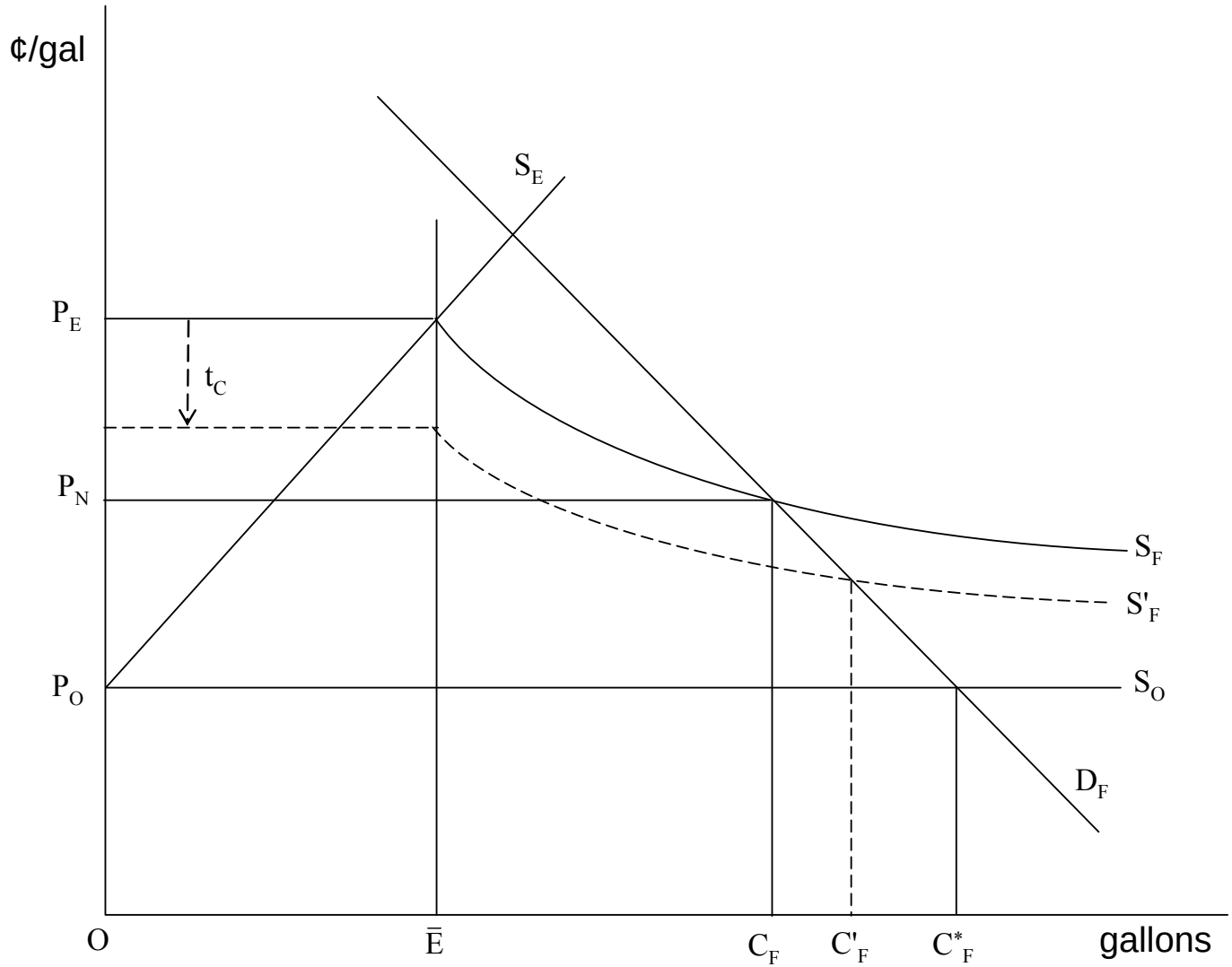

Figure 3: The Economics of a Biofuel Mandate with a Fuel Tax

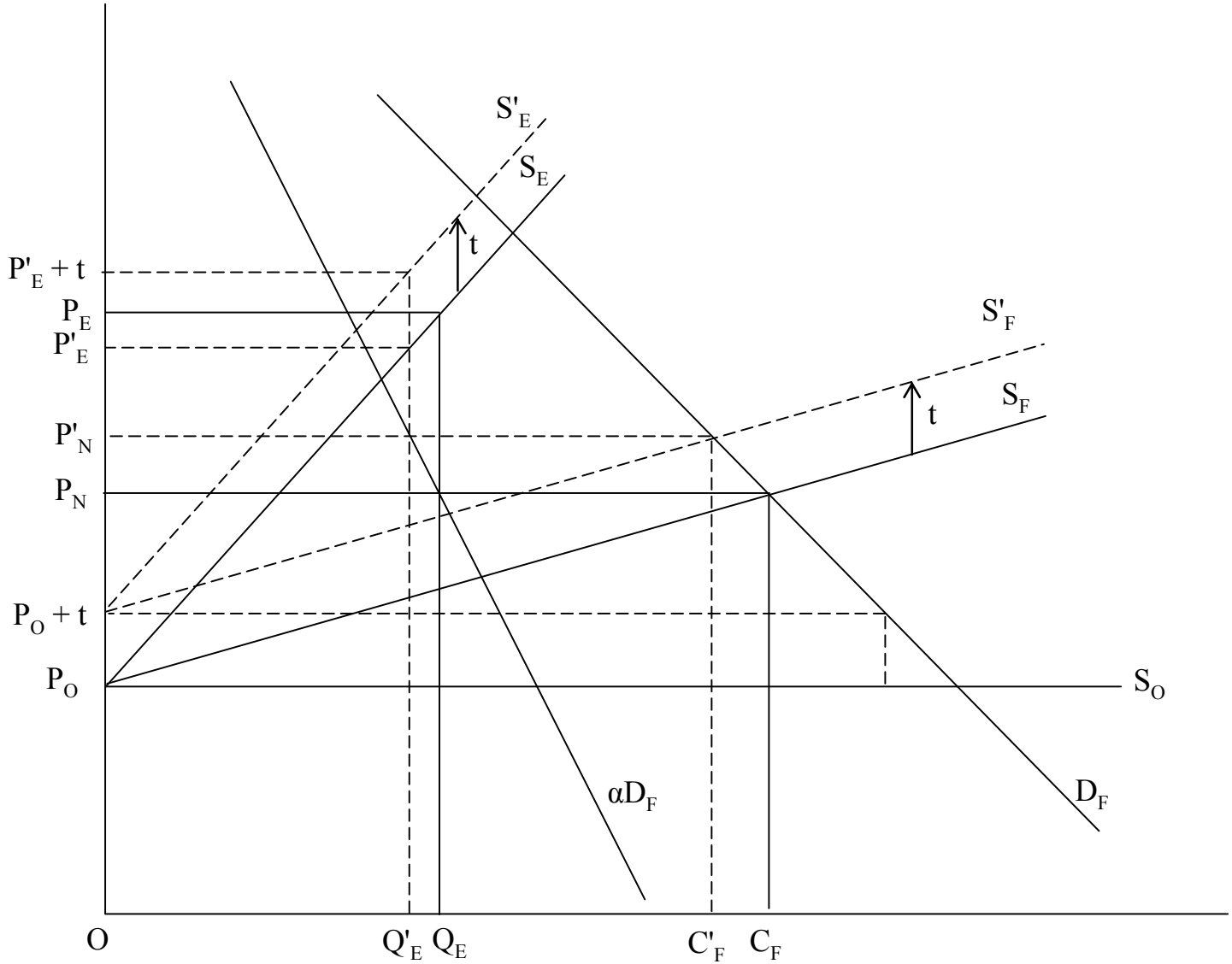

Figure 4: The Economics of a Blend Mandate with a Tax Credit

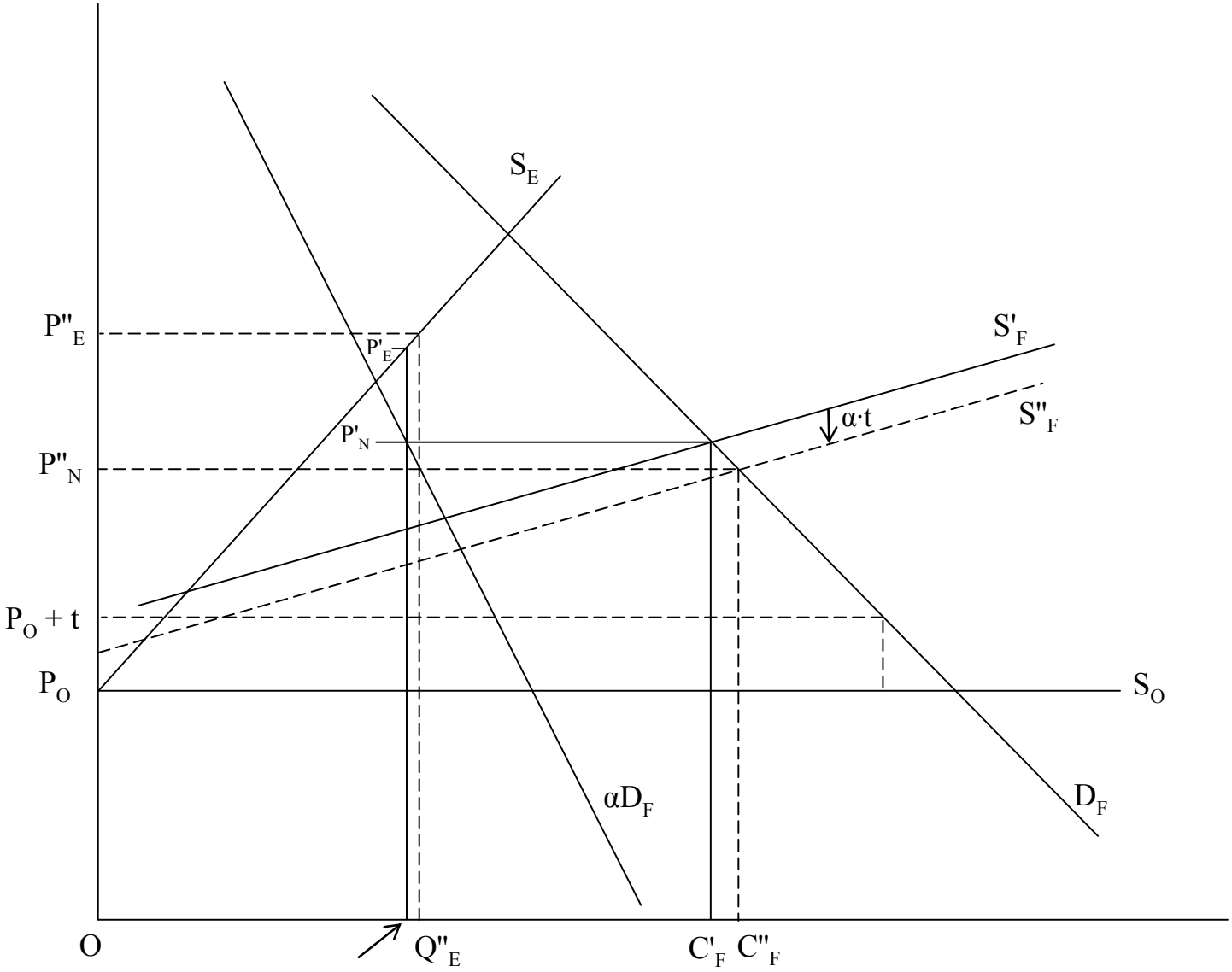

Figure 5: The Effect of Increasing Ethanol Supplies and Oil Prices

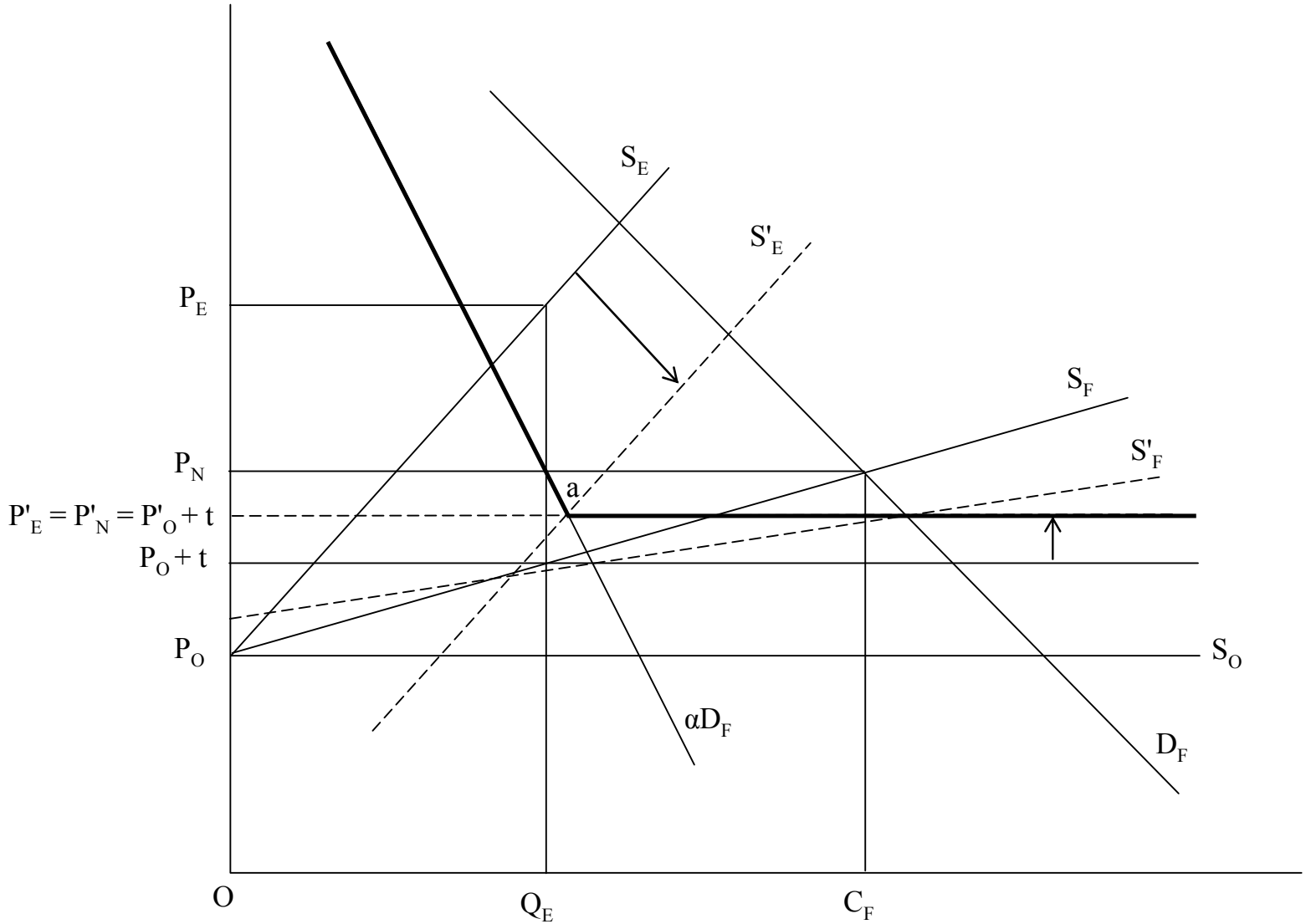

Table 1: Effects of Mandate

	2006			2015		
	Baseline	**add 3 bil gals (α times 1.5)**	**Effect of Mandate**	**Baseline[1]**	**add 3 bil gals (α times 1.5)**	**Effect of Mandate**
	[1]	[2]	[3]	[4]	[5]	[6]
Price						
Ethanol ($/gal.)	2.32	2.51	8.0%	2.43	2.61	7.3%
Gasoline ($/gal.)	1.81	1.78	-1.4%	3.18	3.12	-1.7%
Corn ($/bu)	3.03	3.55	17.2%	3.35	3.85	14.9%
Corn						
Production	10,535	11,224	6.5%	12,450	13,164	5.7%
Ethanol use	2,150	3,345	55.6%	4,300	5,463	27.1%
Fuel						
Ethanol	6,673	10,019	50.1%	13,346	16,603	24.4%
Gasoline	135,727	132,519	-2.4%	144,006	139,998	-2.8%
Price	2.32	2.31	-0.48%	3.58	3.67	2.4%
Consumption						
Nominal	142,400	142,538	0.10%	157,352	156,601	-0.5%
BTU basis	140,482	139,657	-0.59%	153,515	151,827	-1.1%
Blend %	4.69%	7.03%	50%	8.48%	10.60%	25%

[*] Baseline is non-binding mandate.

[1] USDA baseline forecasts for 2015 can be found at http://www.ers.usda/Briefing?Baseline/crops.htm#box2 accessed 5 October 2007.

EIA forecasts are at http://www.eia.doe.gov/oiaf/aeo/index.html last accessed 5 October 2007.

Table 2: Effect of Removing Tax Credit for Ethanol (mandate not binding in baseline)

	2006			2015		
	Baseline[1]	No tax credit	% change	Baseline	No tax credit	% change
Price						
Ethanol ($/gal.)	2.32	2.06	-11.3%	2.43	2.01	-17.6%
Gasoline ($/gal.)	1.81	1.85	2.4%	3.18	3.30	3.9%
Corn ($/bu)	3.03	2.29	-24.3%	3.35	2.15	-35.8%
Corn						
Production	10,535	9,425	-10.5%	12,450	10,429	-16.2%
Ethanol use*	2,150	0	-100.0%	4,300	5,439	26.5%
Fuel						
Ethanol	6,673	653	-90.2%	13,346	2,711	-79.7%
Gasoline	135,727	141,220	4.0%	144,006	153,604	6.7%
Price	2.32	2.36	1.9%	3.58	3.70	3.4%
Consumption						
Nominal	142,400	141,873	-0.4%	157,352	156,314	-0.7%
BTU	140,482	141,685	0.9%	153,515	155,535	1.3%

[1] The baseline assumes a non-binding mandate.

* Because of water in the tax credit, ethanol production is zero when the tax credit reaches 0.2036 cents per gallon.

Table 3: Effects of Removing Tax Credit (Mandate binding)

	2006			2015		
	Baseline[1]	Remove tax credit	% change	Baseline	Remove tax credit	% change
Price						
Ethanol ($/gal.)	2.51	2.50	-0.07%	2.61	2.61	-0.15%
Gasoline ($/gal.)	1.78	1.78	-0.17%	3.12	3.12	-0.25%
Corn ($/bu)	3.55	3.55	-0.1%	3.85	3.84	-0.3%
Corn						
Production	11,224	11,218	-0.05%	13,164	13,149	-0.11%
Ethanol use	3,345	3,335	-0.3%	5,463	5,439	-0.4%
Fuel						
Ethanol	10,019	9,991	-0.3%	16,603	16,536	-0.4%
Gasoline	132,519	132,145	-0.28%	139,998	139,436	-0.40%
Price	2.31	2.34	1.42%	3.67	3.74	2.0%
Consumption						
Nominal	142,538	142,136	-0.28%	156,601	155,973	-0.40%
BTU basis	139,657	139,263	-0.28%	151,827	151,219	-0.40%
Blend %	7.03%	7.03%	0%	10.60%	10.60%	0%

[1] The baseline assumes a binding mandate.

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Appendix

While the simplified model presented in the body of the paper is instructive, endogenous oil prices can add some richness to the results. This model requires three equilibrium conditions. Let P_N be the price of fuel mixture, P_E the price of biofuel, P_O the price of oil based fuels, t the consumption tax on fuel, t_c the volume based tax credit on biofuels, and α be the proportion of fuel required to be from biofuels. Further, let $S_E\left(P_E\right)$ be the excess supply of ethanol, $S_O\left(P_O\right)$ be the supply of oil based fuels and $D_F\left(P_N\right)$ be the demand for fuel mixture. The equilibrium conditions can then be written as

(A.1) $$P_N = \alpha\left(P_E + t - t_c\right) + \left(1-\alpha\right)\left(P_O + t\right),$$

(A.2) $$D_F\left(P_N\right) = S_O\left(P_O\right) + S_E\left(P_E\right),$$

(A.3) $$\alpha D_F\left(P_N\right) = S_E\left(P_E\right).$$

Equation (1) contains the price relationship between biofuel, oil and fuel mixture, requiring that fuel retailers charge marginal cost for fuel mixture. Equation (2) describes the market clearing condition, and (3) describes the constraint imposed by the mandate. If we wished to examine the model with imports of oil, we would need to add an additional supply curve for imported oil to equation (2). Doing so, however, does not substantially change the following analysis.

By totally differentiating (1) to (3) we can examine the comparative static changes in prices resulting from changes in the mandate or tax credit. Totally differentiating obtains

$$\begin{bmatrix} 1 & -\alpha & -\left(1-\alpha\right) \\ D_F' & -S_E' & -S_O' \\ \alpha D_F' & -S_E' & 0 \end{bmatrix} \begin{bmatrix} dP_N \\ dP_E \\ dP_g \end{bmatrix} + \begin{bmatrix} P_g - P_E + t_c & \alpha \\ 0 & 0 \\ D_F & 0 \end{bmatrix} \begin{bmatrix} d\alpha \\ dt_c \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \end{bmatrix}$$

With both a mandate and a tax credit, the change in the price of fuel for a change in the mandate can be written as

$$\frac{dP_N}{d\alpha} = -\frac{\begin{vmatrix} P_O - P_E + t_c & -\alpha & -(1-\alpha) \\ 0 & -S_E' & -S_o' \\ D_F & -S_E' & 0 \end{vmatrix}}{|H|} = \frac{(P_O - P_E + t_c) S_E' S_o' - C_F \left(\alpha S_o' - (1-\alpha) S_E'\right)}{S_o' \left[\alpha^2 D_F' - S_E'\right] + (\alpha - 1)^2 S_E' D_F'},$$

or,

$$\frac{dP_N}{d\alpha} = \frac{(P_O - P_E + t_c) - \left(\frac{P_E}{\eta_E^S} - \frac{P_O}{\eta_O^S}\right)}{\frac{P_E}{\eta_E^S}\left[\alpha \frac{\eta_F^D}{P_F} - \frac{\eta_E^S}{P_E}\right] + (1-\alpha)\frac{\eta_F^D}{P_F}\frac{P_O}{\eta_O^S}},$$

where η_j^i represents the elasticity of relation *i* (either supply or demand) for product *j* (either biofuel, oil or fuel mixture).

The denominator is always negative, hence, P_N increases with a mandate when

$$(P_O - P_E + t_c) - \left(\frac{P_E}{\eta_E^S} - \frac{P_O}{\eta_O^S}\right) < 0,$$

or,

(A.4) $$\left(1 + \frac{1}{\eta_O^S}\right) P_O < \left(1 + \frac{1}{\eta_E^S}\right) P_E - t_c.$$

Thus, the fuel price is more likely to increase with a mandate as the oil supply becomes more elastic relative to the ethanol supply.

With both a mandate and a tax credit, the change in the ethanol price given a change in the tax credit can be written as

$$\frac{dP_E}{dt_c} = -\frac{\begin{vmatrix} 1 & \alpha & -(1-\alpha) \\ D_F' & 0 & -S_g' \\ \alpha D_F' & 0 & 0 \end{vmatrix}}{|H|} = \frac{\alpha^2 D_F' S_g'}{S_g'\left[\alpha^2 D_F' - S_E'\right] + (\alpha-1)^2 S_E' D_F'} > 0,$$

or,

(A.5)
$$\frac{dP_E}{dt_c} = \frac{\alpha \frac{\eta_F^D}{P_N}\frac{\eta_O^S}{P_O}}{\frac{\eta_O^S}{P_O}\left[\alpha \frac{\eta_F^D}{P_N} - \frac{\eta_E^S}{P_E}\right] + (1-\alpha)\frac{\eta_E^S}{P_E}\frac{\eta_F^D}{P_N}} > 0.$$

Note that as the elasticity of supply for oil goes to infinity, the value of this derivative will converge to something less than one. Thus, the mandate mitigates the effects of the tax credit.

Without the mandate the equilibrium is given by

$$P_E - t_c - P_O = 0$$

$$D_F(P_O + t) - S_O(P_O) - S_E(P_E) = 0,$$

Totally differentiating obtains

$$\begin{bmatrix} 1 & -1 \\ -S_O' & D_F' - S_O' \end{bmatrix}\begin{bmatrix} dP_E \\ dP_O \end{bmatrix} + \begin{bmatrix} -1 \\ 0 \end{bmatrix} dt_c = \begin{bmatrix} 0 \\ 0 \end{bmatrix}.$$

This results in the comparative static

$$\frac{dP_E}{dt_c} = -\frac{\begin{vmatrix} -1 & -1 \\ 0 & D_F' - S_O' \end{vmatrix}}{|H|} = \frac{D_F' - S_O'}{D_F' - S_O' - S_E'} > 0,$$

or,

(A.6)
$$\frac{dP_E}{dt_c} = \frac{\eta_F^D \frac{D_F}{P_N} - \eta_O^S \frac{S_O}{P_O}}{\eta_F^D \frac{D_F}{P_N} - \eta_O^S \frac{S_O}{P_O} - \eta_E^S \frac{S_E}{P_E}} > 0$$

Note that as the elasticity of supply for oil goes to infinity, the derivative becomes one. Thus the tax credit would result in a direct and equivalent increase in the price of ethanol. Thus, the change in the price of ethanol will be greater under no mandate if

$$\frac{\eta_F^D \frac{D_F}{P_N} - \eta_O^S \frac{S_O}{P_O}}{\eta_F^D \frac{D_F}{P_N} - \eta_O^S \frac{S_O}{P_O} - \eta_E^S \frac{S_E}{P_E}} < \frac{\alpha \frac{\eta_F^D}{P_N} \frac{\eta_O^S}{P_O}}{\frac{\eta_O^S}{P_O}\left[\alpha \frac{\eta_F^D}{P_N} - \frac{\eta_E^S}{P_E}\right] + (1-\alpha)\frac{\eta_E^S}{P_E}\frac{\eta_F^D}{P_N}},$$

This simplifies to

$$\frac{(1-\alpha) P_E \eta_E^S \left(P_N \eta_O^S - \eta_F^D P_O\right)^2}{\left(-\eta_F^D P_O P_E + \eta_O^S P_N P_E (1-\alpha) + \eta_E^S P_N P_O \alpha\right)\left(-\alpha \eta_O^S \eta_F^D P_E + \eta_O^S \eta_E^S P_N - (1-\alpha)\eta_E^S \eta_F^D P_O\right)} > 0,$$

which must always hold.

Endnotes

[1] There are several other important categories of biofuel policies that are not analyzed in this paper including import tariffs, production subsidies (e.g., grants, loan guarantees and tax related incentives), subsidies for R&D of new production technologies, subsidies for feedstocks and downstream subsidies for new vehicles and infrastructure. There are also a host of related policies that indirectly affect the impact of biofuel mandates and tax credits. For example, in the United States, high domestic prices for sugar due to import quotas not only affects the relative profitability of using corn in ethanol production but also diverts corn into sweetener use. Similarly, subsidies for other crops that compete with corn for land in the production of biofuels or are substitutes in demand for biofuels impact the outcome as well.

[2] For a comprehensive model of tax credits (and the interaction effects with price contingent farm subsidies), see de Gorter and Just (2007a).

[3] Rothkopf's (2007) study is incomplete because it omits other countries with mandates while several countries have meanwhile announced new mandates or changes therein.

[4] For example, in practically every newsletter in 2007, F.O. Lichts reports country plans for a new or revised mandate (http://www.agra-net.com/portal/home.jsp?pagetitle=showad&pubId=ag072). See also Biopact http://biopact.com/ and Biofuels Digest http://biofuelsdigest.com/blog2/category/policy/ for a regular update on new policy initiatives on biofuel mandates and tax credits.

[5] Note that the U.S. federal mandate is a quantity or market share of biofuels consumption, rather than a mandatory blending requirement per se as in most other countries. However, the U.S. implements the program as a blend requirement and individual states have their own blending mandates. For example, California, Minnesota, and Iowa have a 10, 20 and 25 percent ethanol mandate, respectively (Doornbosch and Steenblik 2007; Kojima et al. 2007; Jull et al. 2007). Furthermore, many U.S. states have their own tax credits. For example, Koplow (2007) reports 8 states with tax credits. However, this data is already out of date as more states have added tax credits in the meantime. See sources in footnote 4.

[6] Ethanol is a substitute for gasoline derived from petroleum. The term "fuel" in this paper refers to the ethanol/gasoline or biodiesel/diesel mixture. Ethanol can be up to 10 percent of the fuel mixture in traditional combustion engines with virtually no modifications required.

[7] Biofuels are to be 15 bil. gallons of the 35 bil. gallon renewable fuel target.

[8] As noted in de Gorter and Just (2008), the national average tax credit is 56.9¢/gal if individual state credits are also added in but we ignore this in this paper.

[9] The literature to date on the welfare economics of biofuel mandates and tax credits is sparse. Unlike in this paper, no study analyzes both policies simultaneously. Runge (2002) does not present a formal model in estimating the increased cost to consumers of a biodiesel mandate but Althoff, Ehmke and Gray (2003) analyze the latter as a leftward shift in the soybean supply curve. Schmitz et al. (2003) model Brazil's ethanol mandate as an outward shift in the sugar demand curve while Gardner (2003) models the U.S. ethanol mandate as a fixed quantity of demand for corn while separately depicting the ethanol tax credit as an ethanol production subsidy. Saitone et al. (2007) follow Gardner's (2003) approach in modeling the effects of the U.S. ethanol tax credit but in an imperfect market setting. Extending Gardner's (2003) model, Taheripour and Tyner (2007) evaluate the distribution of benefits from the tax credit between refiners, ethanol producers, corn farmers and landowners, while modeling the mandate as a vertical supply curve for ethanol.

[10] Because U.S. ethanol production in 2006 is estimated to be 0.211 percent of world petroleum consumption, a fixed oil price in the theoretical analysis is a plausible assumption. However, most of the results derived in this section are unaffected by an endogenous oil price. A full derivation of the model with an endogenous oil price is given in the Appendix. Endogenous oil prices are however modeled in the empirical section to follow.

[11] International trade in biofuels has been small, mostly because of high tariffs (Howse et al.; 2006; Kojima et al. 2007). Ethanol imports are a small part of biofuel consumption in the United States. Except for recent episodes of very high U.S. ethanol prices, most imports into the United States normally come through a preferential trading arrangement with Caribbean countries and are limited by an import quota. The tariff was implemented to offset the benefit exporters would otherwise obtain from the higher price of ethanol induced by the tax credit. We ignore imports here only to make the analysis in this paper more tractable while at the same time not affecting the main conclusions. For a specific analysis of import tariffs and the interaction effects with mandates and tax credits, see de Gorter and Just (2007b).

[12] A gallon of ethanol has approximately 2/3rds the energy of a gallon of gasoline but only about a 28.75 percent reduction in mileage. Up to now, U.S. consumers have not distinguished between gasoline and ethanol at the gas pump. This will change in the future however, like it is today in Brazil. Hence, the model would need to be adjusted to allow for consumers purchasing ethanol on the basis of its contribution to mileage and hence adjust the appropriate variables by 0.7125.

[13] Assuming the intercept of S_E is at P_O ensures there is no "water" in the tax credit – the latter has full impact on the supply of ethanol. At historical oil prices, however, the intercept of the ethanol supply curve exceeded the price of oil - see de Gorter and Just (2008; 2007a). The implication is there exists rectangular deadweight costs, an issue we return to in the empirical section later.

[14] A biofuel blend mandate is similar to a proportional import quota except the market equilibrium is determined by a fraction of demand and not of supply (McCulloch and Johnson 1973).

[15] A biofuel consumption mandate is similar to blend pricing with U.S. dairy policy except the equilibrium is determined by the intersection of average revenue and the demand curve and not the supply curve (Ippolito and Masson 1978).

[16] For a generalization where the tax credit does not equal to the tax, see de Gorter and Just (2008).

[17] A non-binding mandate in Figure 4 implies the P_N under a mandate only would be less than $P_O + t$.

[18] The elasticities assumed in the U.S. corn market are as follows: 0.2, -0.2 and -1.0 for supply, non-ethanol domestic demand and export demand, respectively. The export demand elasticity for corn was derived from the standard formulas:

$$\eta_C^{X_1} = \eta_M^{ED}\left(\frac{M}{X_1}\right) - \eta_X^{ES}\left(\frac{X_2}{X_1}\right) \; where \quad \eta_M^{ED} = \eta_M^{D}\left(\frac{C}{M}\right) - \eta_M^{S}\left(\frac{Q}{M}\right) \; and \quad \eta_X^{ES} = \eta_X^{S}\left(\frac{Q}{X}\right) - \eta_X^{D}\left(\frac{C}{X}\right)$$

The assumed elasticities for gasoline were 0.2, -0.2 and 2.63 for domestic supply, domestic demand and import supply, respectively. The import supply elasticity for gasoline is derived using the negative of the above formula for export demand facing U.S. corn. The import supply elasticity of 2.63 corresponds to an OPEC supply elasticity of 0.71, in the range of Leiby (2007) while we use the excess demand of other oil importers excluding the United States to be -0.86 as in Leiby (2007).

[19] The biofuel mandate was binding in Brazil in the past and will be in countries like the EU and Japan were ambitious mandates will not be filled in foreseeable future from domestic biofuel supplies. Elimination of import tariffs and substantially improved export supply conditions will be needed before mandates are non-binding in these countries.

[20] We also re-calibrated 2006 on a BTU basis, thereby speculating that the price premium was in fact due to mandates. Eliminating the tax credit under this baseline scenario generated results similar to that for 2006 under simulation (3) and so is not presented in Table 3. One could interpret the U.S. ethanol market facing a binding mandate for several years in the past, given the fuel additives mandated by environmental regulations under Clean Air Act of the 1990s, and again with the recent *de facto* ban of MTBE, not to mention various state mandates

(including public vehicles requiring biofuels), the federal Renewable Fuel Standard, city mandates (e.g., Portland), and the like.

[21] The price of fuel is shown to decline but could increase, depending on the relative shift in S_E and P_O.

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