THE ECONOMICS OF A BLEND MANDATE FOR BIOFUELS

HARRY DE GORTER AND DAVID R. JUST

A biofuel blend mandate may increase or decrease consumer fuel prices with endogenous oil prices, depending on relative supply elasticities. Biofuel tax credits always reduce fuel prices. Tax credits result in lower fuel prices than under a mandate for the same level of biofuel production. If tax credits are implemented alongside mandates, then tax credits subsidize fuel consumption instead of biofuels. This contradicts energy policy goals by increasing oil dependency, CO$_2$ emissions, and traffic congestion, while providing little benefit to either corn or ethanol producers. These social costs will be substantial with tax credits costing taxpayers $28.7 billion annually by 2022.

Key words: biofuels, blend mandate, deadweight costs, environment, tax credit.

Worldwide, many governments now require that a minimum percentage of transportation fuels sold consist of biofuels. 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). But along with mandates, biofuel tax credits are also common worldwide. We define a biofuel tax credit as a reduction (or elimination) of the fuel tax charged on sales based on the biofuel content. A recent World Bank study finds that “among various support measures [for biofuels], fuel tax credits are most widely used” (Kojima, Mitchell, and Ward 2007, p. 54). The stated political objectives of biofuel mandates and tax credits are many. Among the most prominent are to reduce oil use, local air pollution, traffic congestion, and CO$_2$ emissions. As well, biofuel policies are often cited as means to improve farm incomes, reduce the tax costs of farm subsidies, and enhance rural development (Rajagopal and Zilberman 2007).

In the United States, the Energy Independence and Security Act (EISA 2007) established a new renewable fuel standard (RFS) that mandates the use of 36 billion gallons of biofuels annually by 2022. Of this mandate, 15 billion gallons must be corn-based ethanol. The previous RFS implemented in 2005 was never binding due to the combination of high oil prices and biofuel tax credits. State and local governments in the United States also impose mandates. These take several forms including biofuel consumption requirements for government fleet vehicles.

In addition to mandated use of biofuels, the EISA also calls for the continuation of existing biofuel subsidies in the form of federal tax credits. States also provide tax credits for ethanol use at an average rate of 6 cents per gallon.

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The authors gratefully acknowledge the detailed comments of three anonymous reviewers and Wally Thurman, which have improved this article immensely. However, any remaining errors are the authors. This research was supported by the Cornell University Agricultural Experiment Station federal formula funds, Project No. NYC-121438 received from Cooperative State Research, Education and Extension Service, U.S. Department of Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

1 Ethanol is a substitute for gasoline derived from petroleum. The term “fuel” in this article refers to the ethanol–gasoline or biodiesel–diesel mixture. For example, ethanol can be up to 10% of the fuel mixture in traditional combustion engines with virtually no modifications required.

2 In almost all countries except the United States, “tax credits” take the form of consumer excise tax exemptions at the pump (Jank et al. 2007). The taxpayer costs are in the form of revenue foregone. After 2004, U.S. blenders of oil-based gasoline with the biofuel receive a tax credit directly from the government. For the purpose of this article, the economic effects are identical and so we will refer to these as “tax credits” hereafter.

3 Perhaps the most important mandates historically were de facto or informal mandates through various environmental regulations including the implementation of the Clean Air Act in the 1990s or the recent implicit ban on the use of methyl tertiary butyl ether (MTBE) (Tyner 2007). MTBE had been a popular gasoline additive used as an oxygenator and to raise octane levels until it was discovered to cause groundwater contamination. With MTBE now banned in 25 states, and hundreds of lawsuits winding their way through the courts, fuel blenders were led to other alternatives. In smaller concentrations, ethanol can fill the role that MTBE once played. Thus, some commentators view ethanol as a complementary product to gasoline as an oxygenator and octane enhancer (Miranowski 2007). Thus, demand for ethanol was proportional to gasoline consumption, much like a blend mandate.
The estimated taxpayer cost of these tax credits for 2022 is $28.7 billion. The EISA mandates the use of 15 billion gallons of “conventional biofuels” (corn-based ethanol) and provides a tax credit of 45 cents per gallon of these fuels after January 2009, in addition to the existing state tax credits. The EISA mandate for “cellulosic advanced, noncellulosic advanced,” and “biomass-based diesel” totals 21 billion gallons and is to receive a tax credit of $1.00 per gallon.

The purpose of this article is to present a conceptual framework to analyze the economics of a blend mandate and derive the economic implications of combining a tax credit with the blend mandate. Although U.S. legislation calls for a minimum level of annual biofuel consumption (a “consumption mandate”), the mandate is implemented through the use of an annual minimum blending requirement called the renewable fuel standard (RFS), which is the ratio of ethanol to total fuel consumption that each fuel-producing firm must meet. The RFS is enforced by a trading credit scheme administered by the U.S. Environmental Protection Agency (EPA), tying together biofuel producers with refiners, exporters, and blenders of oil-based gasoline. Biofuel producers and importers generate renewable identification numbers (RINs) with each gallon of biofuel they produce. This RIN credit is transferred whenever the biofuel is sold to blenders or refiners. The RIN credit can be used by fuel blenders as evidence of compliance with the RFS. If the blend exceeds the RFS, then they can sell (i.e., trade) their excess RINs to other obligated parties who can now blend biofuels at a rate below the RFS (EPA 2008). The EPA therefore verifies the correct number of RINs for the total quantity of fuel blended.

The government sets the RFS blending requirement every year based on their expectation of total U.S. fuel consumption. If at the end of the year total fuel consumption differs from expectations, the RFS is adjusted for the following year to compensate for the over- or underprediction of total fuel consumption. The RFS, therefore, varies from year to year and is an endogenous function of the government’s expected gasoline consumption. Each firm must meet or exceed the blend requirement on each sale unless RINs are purchased from firms willing to exceed the requirement.

Because no taxpayers’ monies are involved with mandates, it is commonly assumed that consumers face higher gasoline prices to pay for the higher biofuel prices. We show that this is not always the case with endogenous oil prices. The mandate is shown to have an ambiguous effect on the consumer fuel price, which is calculated as a weighted average of the biofuel and oil-based gasoline or diesel prices. The market price for the biofuel increases with either a tax credit or a mandate by itself. Consumer fuel prices always decline with a tax credit by itself, but can either increase or decrease with a mandate by itself. The direction of the change in consumer prices when implementing a mandate depends on the relative supply elasticities of gasoline/diesel and the biofuel.

We also evaluate the effects of adding a tax credit to a binding blend mandate. While the tax credit in the absence of a mandate acts as a consumption subsidy for biofuels, the tax credit with a mandate becomes a consumption subsidy for fuel—both biofuel and oil-based fuel (gasoline or diesel). Adding a tax credit to a binding mandate, therefore, can offset benefits from reductions in gasoline/diesel consumption due to the mandate alone. As a result, oil prices rise as do CO₂ emissions, local pollution, and traffic congestion. At the same time little benefit is provided to producers of either the biofuel or the feedstock as biofuels are typically a small share of fuel consumption, resulting in the fuel consumption subsidy having a small impact on the biofuel market compared to a direct ethanol subsidy. In short, adding a tax credit to a binding mandate contradicts the stated goals of biofuel policies. For the same level of biofuel production (i.e., holding farm income constant), the government can achieve energy goals at a substantially lower cost by not using both policy instruments at the same time but relying on a mandate alone.

This article is organized as follows. The next section develops a conceptual model of a biofuel blend mandate. The third section derives the result that an increase in the blend mandate can have an ambiguous impact on the consumer price of fuel. The penultimate section derives the result that a tax credit, when implemented alongside a blend mandate, switches from being a consumption subsidy for the biofuel to a consumption subsidy for fuel. The last section provides some concluding remarks.

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4 The EPA can grant a cellulosic ethanol waiver if the production of cellulosic ethanol is projected to be less than the volume required by the law. Under such a scenario, the EPA is authorized to sell cellulosic RINs at the greater price of $0.25 per RIN, or $3.00 per RIN less the per gallon price of wholesale gasoline.
A Conceptual Framework to Analyze a Biofuel Mandate

We present a simplified model of biofuel mandates here. Within this simplified model, we assume an exogenous oil-based gasoline price, a single supply of gasoline curve (no distinction between domestic and imported gasoline supply), and no imports of biofuels. A complete exposition of the full theory—allowing for an endogenous oil (gasoline) price—is given in the appendix. To further simplify the analysis, we assume that fuel consists of only two products: ethanol and gasoline. The analysis in this article holds equally well for policies governing biodiesel and oil-based diesel.

Consider a competitive market with a domestic supply curve for ethanol $S_E$ and a supply curve for gasoline $S_G$ as in figure 1. The domestic demand for fuel (the ethanol–gasoline mixture) is denoted by $D_F$. Ethanol and gasoline are assumed to be perfect substitutes in consumption, as is arguably the case for blends containing less than 10% of ethanol in conventional engines and for blends containing up to 85% ethanol when used by flex cars. For ease of exposition, the intercept of the ethanol supply curve $S_E$ is arbitrarily set to coincide with the price of gasoline within this simplified example.

Consider a mandate where a minimum share of ethanol, $\alpha$, is required in all fuel sold, with $\alpha \in (0, 1)$. The mandate drives up the price of ethanol relative to equilibrium under no mandate, causing the market prices for ethanol and gasoline to diverge. In equilibrium, consumers must pay the marginal cost to the blender of producing a unit of fuel mixture. This marginal cost is given by the weighted average price of ethanol and gasoline where the weights are formed by the required share of ethanol under the mandate:

$$ P_F = \alpha P_E + (1 - \alpha) P_G $$

where $P_F$ is the weighted average consumer price, $P_E$ is the corresponding market supply price of ethanol, and $P_G$ is the price of gasoline. This constitutes the marginal cost of the mandated mixture because $P_E$ is the marginal cost of ethanol and $P_G$ is the marginal cost of gasoline to the blender. To find the market equilibrium prices $P_E$ and $P_F$, we must determine...
the market prices that cause total fuel supply to equal total fuel demand. This requires the derivation of a total fuel supply curve, $S_F(P_F)$, determined by the component supply curves $S_E$ and $S_G$. The mandate requires that

$$
(2) \quad \alpha S_F(P_F) = S_E(P_E)
$$

and

$$
(3) \quad (1 - \alpha) S_F(P_F) = S_G.
$$

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

$$
(4) \quad S_F(P_F) = \frac{1}{\alpha} S_E \left( \frac{1}{\alpha} P_F + \left( 1 - \frac{1}{\alpha} \right) P_G \right) = \frac{1}{\alpha} S_E(P_F).
$$

The equilibrium condition for $P_F$ is defined by

$$
(5) \quad S_F(P_F) = D_F(P_F)
$$

which solves for $Q_F \equiv S_F(P_F^*)$, 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 ethanol must equal $\alpha D_F(P_F)$ for any fuel price $P_F$. Thus, the price of ethanol is implicitly given by the equation

$$
(6) \quad S_E(P_E) = \alpha D_F(P_F).
$$

This means that evaluating the $\alpha D_F$ curve at price $P_F$ yields the quantity of ethanol $Q_E$. Evaluating the ethanol supply curve $S_E$ at the quantity $Q_E$ yields the equilibrium market price for ethanol $P_E$ (see figure 1).

Regardless of the value of $\alpha$, the total increase in revenue to ethanol producers due to the mandate is given by $P_E \times Q_E$, or area $abQEO$ in figure 1. This increase in revenue is derived directly from an increase in consumer expenditure under the mandate and must thus be equal to area $dfgi$ minus $gmQ_F^*Q_F$. Gasoline producers are left with revenue of $P_G \times (Q_F - Q_E)$, or area $hgQ_FQ_E$ in figure 1. Total revenue to fuel producers is thus $abQEO$ plus $hgQ_FQ_E$, while total expenditures on fuel is area $dfQ_FO$. Thus area $cfgh$, the added expenditures on gasoline above cost, must equal area $abcd$, the extra transfer to ethanol producers above the consumer price of fuel.

The increase in quasi rents to ethanol producers is given by area $abi$. Deadweight costs of overproduction are therefore given by area $bhi$. The total loss to fuel consumers is area $dfmi$, resulting in a deadweight cost of under-consumption given by area $fmgh$. Fuel demand in the United States is characteristically inelastic. Alternatively, if we model the fuel demand as perfectly inelastic (so that both the $D_F$ and $\alpha D_F$ curves are vertical), then the mandate will have no impact on fuel consumption, but each gallon of ethanol will exactly displace one gallon of gasoline consumption. With a less elastic demand curve, consumption of fuel will decline less under an ethanol mandate. Alternatively, the less elastic demand curve will cause a greater increase in ethanol consumption and a greater decrease in gasoline consumption under a blend mandate.

Let us now consider the case where the mandate is replaced by an ethanol tax credit designed to achieve the same level of ethanol production $Q_E$ in figure 1. This will require a tax credit equal to $P_E - P_G$. To take advantage of the government subsidy offered to 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 positive 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 value of the tax credit. Fuel consumption will remain at $Q_F^*$ in figure 1, as the consumer price paid for fuel has not changed and remains at $P_G$. Gasoline consumption will decrease by $Q_E$.

Consumers of fuel pay only $P_G$, with the difference in cost of ethanol made up by taxpayers. Ethanol production is now positive, and with a fixed gasoline price, ethanol simply displaces gasoline consumption. Consumers in this case are unaffected, but taxpayer transfers of area $abhi$ in figure 1 result in ethanol production of $Q_E$. Even in the more general case with endogenous gasoline prices, so that 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 amount of the tax credit. In analyzing either the tax credit or an equivalent mandate, the primary difference in the general

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The text is a detailed economic analysis of the impact of a blend mandate for biofuels, specifically ethanol, on the market for fuel. It covers the derivation of supply curves, equilibrium conditions, and the effects of mandates and tax credits on fuel prices and consumption. The analysis includes graphical representations and mathematical equations to illustrate the economic relationships. The text is comprehensive, providing a deep understanding of the economic impacts of biofuel mandates and tax credits in the context of the United States fuel market.
The case of endogenous gasoline prices is that the benefits of the tax credit are now shared between fuel consumers and ethanol producers, while gasoline producers lose.

Returning to the simplistic model in figure 1 where we assume the supply curve for gasoline is flat, the transfer to ethanol producers resulting from a mandate is completely financed by an implicit consumer tax on gasoline. For the same level of ethanol production, this necessarily implies gasoline consumption is lower with a mandate compared to a tax credit. With a tax credit only, there is no effect on total fuel consumption with a fixed gasoline price. Total fuel consumption remains at \( Q_F^* \) and gasoline consumption declines by \( Q_F \). But with a mandate, total fuel consumption declines compared to a tax credit, necessarily resulting in a lower level of gasoline consumption by the amount of \( Q_F^* - Q_F \) in figure 1. Gasoline consumption may generate additional negative externalities (relative to ethanol) in the form of direct CO2 emissions, local pollution, traffic congestion, and “energy insecurity.” It is generally regarded that fuel taxes are suboptimal in the United States (Parry and Small 2005), making a mandate, which generates higher fuel prices relative to a tax credit, an attractive alternative to a tax credit in achieving the same level of ethanol production.

The Impact of an Increase in the Blend Mandate on Consumer Fuel Prices with the Full Model

While the simple model in the previous section provides some intuition, the full model—including endogenous gasoline prices—is needed to analyze the potential impacts of a tax credit and a mandate. The equilibrium may now be represented as

\[
\frac{dP_F}{d\alpha} = \frac{(P_G - P_E) - \left( \frac{P_E}{\eta_E} - \frac{P_G}{\eta_G} \right)}{\frac{P_E}{\eta_E} \left( \frac{\eta_E^D}{P_F} - \frac{\eta_S^S}{P_E} \right) + (1 - \alpha) \left( \frac{\eta_E^D}{P_F} \frac{P_G}{\eta_G} \right)} > 0
\]

if the price weighted elasticity of gasoline supply is relatively larger than the price weighted elasticity of ethanol supply (defined as \( (1 + 1/\eta_E^G)P_G < (1 + 1/\eta_E^E)P_E \), where \( \eta_S^S, \eta_E^S, \) and \( \eta_E^D \) are the elasticities of supply for gasoline and ethanol and the elasticity of demand for fuel, respectively).

The derivation of result 1 can be found in the appendix. Interestingly, with an endogenous gasoline price under a blend mandate, an increase in the blend mandate requirement would not necessarily result in higher average consumer fuel prices. The model with endogenous gasoline prices shows that the consumer fuel price can decline with an increase in the mandate requirement. The outcome depends on the relative value of the elasticity of supply between ethanol and gasoline. An increase in the mandate requirement \( \alpha \) can reduce the consumer price of fuel if the elasticity of ethanol supply is very large relative to that for gasoline and with a lower gap in prices between ethanol and gasoline.

The intuition for result 1 is as follows: an increase in \( \alpha \) necessarily increases the price of ethanol as more ethanol must be consumed. Hence, both elements of the first right-hand side term in equation (7) increase. The rise in ethanol consumption leads to a drop in demand for gasoline and hence in the price of gasoline. Therefore, both elements of the second right-hand side term in equation (7) decline. This decline can overpower the increase in the first term such that the consumer price of fuel \( P_F \) declines. Result 1 states that the outcome depends on the relative supply elasticities and market prices. Inspection of equation (A.4) in the appendix indicates that the magnitude of the price change depends not only on the relationship listed in result 1, but also on the level of the elasticity of fuel demand and the mandate requirement \( \alpha \). A larger elasticity of fuel demand results in a smaller derivative of the fuel price with respect to \( \alpha \). Thus, in a relatively non-price-responsive setting, such as in the United States, we might expect relatively larger fuel price responses to increases in biofuel mandates. A larger \( \alpha \) will increase the size...
Table 1. Estimated Impact of Mandate on Fuel Prices and Subsidy Share of Tax Credit

<table>
<thead>
<tr>
<th>Year</th>
<th>Ethanol Share of Fuel Consumption</th>
<th>Supply Elasticities</th>
<th>Prices</th>
<th>Δ in Fuel Price</th>
<th>Gasoline Subsidy Share</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Ethanol</td>
<td>Gasoline</td>
<td>Ethanol</td>
<td>Gasoline</td>
</tr>
<tr>
<td>2001–2002</td>
<td>0.015</td>
<td>13.6</td>
<td>1.68</td>
<td>1.59</td>
<td>0.95</td>
</tr>
<tr>
<td>2002–2003</td>
<td>0.021</td>
<td>9.3</td>
<td>1.66</td>
<td>1.13</td>
<td>0.76</td>
</tr>
<tr>
<td>2003–2004</td>
<td>0.025</td>
<td>8.6</td>
<td>1.72</td>
<td>1.25</td>
<td>0.96</td>
</tr>
<tr>
<td>2004–2005</td>
<td>0.029</td>
<td>8.6</td>
<td>1.77</td>
<td>1.60</td>
<td>1.13</td>
</tr>
<tr>
<td>2005–2006</td>
<td>0.038</td>
<td>6.9</td>
<td>1.82</td>
<td>1.62</td>
<td>1.49</td>
</tr>
<tr>
<td>2006–2007</td>
<td>0.048</td>
<td>5.1</td>
<td>1.82</td>
<td>2.61</td>
<td>1.99</td>
</tr>
<tr>
<td>2008–2009</td>
<td>0.070</td>
<td>3.1</td>
<td>1.81</td>
<td>2.40</td>
<td>3.00</td>
</tr>
<tr>
<td>2015–2016</td>
<td>0.105</td>
<td>2.2</td>
<td>1.81</td>
<td>2.43</td>
<td>3.18</td>
</tr>
</tbody>
</table>

Asterisk (*) denotes forecast. Δ, change; α, ethanol share.

Source: Calculated.

of the fuel price change, but the sign of the price change will be dictated by the relationship in result 1.

To empirically assess the impact of a hypothetical mandate in the U.S. ethanol market on fuel prices, table 1 provides estimates of the required parameters to determine the sign of result 1. A key factor determining the outcome is the elasticity of the ethanol supply curve relative to that of the supply curve for gasoline. The supply curve for ethanol is defined as the horizontal difference between the supply of corn and the demand for nonethanol corn (de Gorter and Just 2009). Thus, the elasticity of ethanol supply is given by

\[ \eta_{SE} = \frac{\eta_{SC} S_C - \eta_{SNE} S_{NE}}{S_E}, \]

where \( \eta_{SC} \) is the supply elasticity for corn, \( \eta_{SNE} \) is the demand elasticity for nonethanol corn (domestic and export sales), \( S_C \) is the production of corn, \( S_E \) is the corn used as an input to ethanol production, and \( S_{NE} \) is corn used for nonethanol purposes. The elasticities assumed in the U.S. corn market are as follows: 0.2, −0.2, and −1.0 for supply, nonethanol domestic demand, and export demand, respectively. Using observed or forecast quantities for various years and the assumed parameter values, table 1 summarizes the simulated supply elasticity for ethanol and gasoline by year. Because ethanol was a small share of corn production in the early part of this decade (given in the first column in table 1), the supply elasticities are high relative to gasoline supply elasticities. The assumed elasticities for gasoline are 0.2, −0.2, and 2.63 for domestic supply, domestic demand, and import supply, respectively. The import supply elasticity is derived similarly to that of ethanol supply, where an OPEC supply elasticity of 0.71 is assumed, 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). The second to last column in table 1 gives the sign for result 1. Historically, the marginal effect of the mandate was to reduce fuel prices except for in 2003–2004 and 2006–2007. However, we expect in the future that the marginal effect of a mandate would increase fuel prices as the supply elasticity of ethanol declines with corn for ethanol, becoming an increasing share of total corn production.

The Economics of a Mandate and a Tax Credit Combined

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 the demand curve. With a mandate already in place, figure 2 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 \( P_F' \). Prior to the fuel tax, the consumer and market price for ethanol is \( P_E \). Instituting the fuel tax raises the consumer price of ethanol to \( P_E' + t \) and lowers the market price of ethanol to \( P_E' \). The extent of the ethanol price changes will depend on the mandated blend ratio \( \alpha \), the demand elasticity of fuel, and the supply elasticity for ethanol. Ethanol prices are lower because the demand for fuel (and hence ethanol) declines with a consumer fuel tax, and so there is a move down the ethanol supply curve leading to a lower market price. Total fuel consumption declines

\[^{8}\text{This is also true in the general case of endogenous gasoline prices—see the appendix.}\]
by more than the decline in ethanol production. To see this, note that $\alpha D_F$ and $D_F$ yield the demand for ethanol and total fuel, respectively, for any given price of fuel $P_F$. Because $\alpha D_F$ has by definition a more negative slope than $D_F$, any increase in the price of fuel will result in a larger decrease in fuel consumption than ethanol consumption. If fuel demand is perfectly inelastic, then total fuel consumption, ethanol consumption, and the market price of ethanol and gasoline are unaffected by the tax, but fuel prices increase by the amount of the tax.

We are now in a position to analyze the effects of a tax credit with a binding mandate in place. While a fuel tax of amount $t$ shifts the supply of fuel $S_F$ up by the full amount $t$ (as in figure 2), a tax credit on ethanol only applies to the proportion of fuel that derives from biological sources. By mandate, this proportion is $\alpha$. Thus, a tax credit of amount $t$ for ethanol results in a shift down of $S_F'$ by $\alpha t$ as shown in figure 3. The tax credit hence generates a lower consumer fuel price $P'_F$ where the new fuel supply curve intersects the fuel demand curve. The lower price for fuel expands fuel consumption from $Q'_F$ to $Q''_F$. The greater consumption of fuel together with the mandate forces an increase in the market price for ethanol, $P''_E$, in order to encourage higher production. The consumer price for ethanol declines sharply due to the tax credit from $P'_E + t$ (shown in figure 2) to $P''_E$ in figure 3. The market price for ethanol is now equal to the consumer price (unlike in figure 2).

**Result 2:** With a binding mandate in place, increasing the tax credit on ethanol increases both the consumption of ethanol and the consumption of gasoline.

For a full derivation of result 2 for the general model of endogenous gasoline prices, see the appendix. With a binding mandate, the tax credit is a taxpayer’s financed fuel consumption subsidy. Compare this to the situation with a nonbinding mandate where the tax credit has no impact on the consumer price for fuel. Because we assume ethanol and gasoline are perfect substitutes, when there is no binding mandate, blenders will continue to bid up the price of ethanol until the input cost for ethanol is equal to that of gasoline. This will raise the price of ethanol from $P_G$ to $P_G + t$.\(^9\)

The tax credit alone is a taxpayer’s financed ethanol consumption subsidy. If gasoline prices are fixed, the entire subsidy benefits ethanol producers. Alternatively, with an upward sloping supply of gasoline, consumers may also benefit as ethanol consumption displaces gasoline consumption, resulting in lower gasoline prices.

\(^9\) For a generalization where the tax credit does not equal to the tax, see de Gorter and Just (2008).

\(^{10}\) A nonbinding mandate in figure 3 implies the $P_F$ under a mandate only would be less than $P_G + t$. 

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**Figure 2. The economics of a blend mandate with a fuel tax**
If a mandate is already binding, then introducing a tax credit benefits ethanol producers, but only indirectly. In this scenario, ethanol producers benefit through the increased demand for ethanol. The tax credit shifts the total fuel supply down (as in figure 3), lowering the price of fuel by an amount less than $\alpha_t$. Only the mandated percentage of this increased production is in the form of increased ethanol production, with the rest coming from an increase in gasoline production. Therefore, the increase in the price of ethanol due to a tax credit in this case is much lower than in the case of a tax credit with no mandate.

The intuition for this result is as follows. Under the mandate and fuel tax only, the consumer price of fuel is given by

$$P'_F = \alpha(P'_E + t) + (1 - \alpha)(P_G + t)$$

where $P'_E$ is the market (producer) price of ethanol (depicted in figure 2) while consumers pay $(P'_E + t)$ for ethanol. Under a tax credit with a binding mandate, the consumer price for fuel is given by (as depicted in figure 3)

$$P''_F = \alpha P''_E + (1 - \alpha)(P_G + t)$$

where $P''_E$ is less than $P'_E$ but greater than $(P'_E + t)$, the price paid by consumers under the mandate. If gasoline prices are fixed, the second terms in equations (10) and (11) are identical. Thus for a fixed $\alpha$, it follows that $P''_E < P'_E$ and so fuel consumption increases. This means both ethanol and gasoline consumption rise. Total fuel price is the only signal transmitted to consumers; hence, a lower fuel price will increase consumption of all fuels. If $\alpha$ is relatively low, most of the subsidy on fuel consumption due to the ethanol tax credit goes to gasoline.

In this case, the tax credit causes a decrease in the price of gasoline paid by consumers (even with a fixed market price for gasoline) and so increases gasoline consumption. In contrast, a tax credit with no mandate has no effect on consumer gasoline prices (with a fixed market price for gasoline) but reduces gasoline consumption. With a binding mandate, the tax credit is therefore a fuel consumption subsidy.

**Result 3**: If no mandate binds and the elasticity of gasoline supply is infinite, the response of ethanol prices to an increase in the tax credit follows $dP_E/dt_c = 1$. Thus, the price of ethanol increases by the amount of the tax credit.

**Result 4**: Under a binding mandate with exogenous oil prices, the response of ethanol prices to an increase in the tax credit follows $dP_E/dt_c = 1/(1 - \eta_P P_F / \alpha d_P P_E)$ and must be greater than zero and less than 1. Thus, the price of ethanol increases by less than the amount of the tax credit.

The derivation of results 3 and 4 can be found in the appendix. Result 3 shows that if the mandate binds, the full tax credit...
acts as a subsidy for ethanol consumption—presumably as intended. Alternatively, result 4 shows that if the blend mandate binds, only a portion of the subsidy impacts ethanol production. Further, the formula shows that as $\alpha$ increases, the price response for ethanol will be larger. If $\alpha$ is relatively small, as it is in the United States, the subsidy to ethanol consumption will be only a small portion of the tax credit. Because $\alpha$ is low and $\eta^D_S$ is expected to be less than $\eta^D_G$, then it follows that the effect of a tax credit on ethanol prices with a binding mandate is much lower than if the mandate was not binding. Under perfectly inelastic demand for fuel, the quantities and market prices of gasoline and ethanol do not change as a result of the tax credit; rather the tax credit is simply a transfer of money to the consumer.

Result 5: Under a binding mandate, the rise in gasoline prices relative to the rise in ethanol prices resulting from a tax credit is
\[
\frac{dP_G}{d\tau} = \frac{\eta^D_G}{\eta^D_E} P_G / P_E.
\]
The transfer from the tax credit to gasoline producers relative to ethanol producers is thus
\[
\frac{dP_G}{d\tau} S_G / (dP_E/d\tau) S_E = (1 - \alpha) \eta^S_G P_G / \alpha \eta^S_E P_E.
\]

Result 5 shows that the subsidy effect on gasoline depends on the elasticity of supply of gasoline relative to ethanol. The final column of table 1 shows that, even with a value for $\alpha$ of over 0.10 in 2015–2016, the share of subsidy going to gasoline is around 0.97. Given that $\alpha$ is relatively low, the change in price for gasoline need not be very high for the transfer of wealth to gasoline producers to be larger than the transfer to ethanol producers. For example, using the prices and simulated elasticities in table 1, $\alpha$ would only need to be less than 0.52 for gasoline’s subsidy share to be larger than that for ethanol.

The social costs of having a tax credit when a mandate could have generated the same level of ethanol consumption can be substantial. The projected tax costs of $28.7 billion by 2022 will not directly affect ethanol production if the mandate is binding. The taxpayers’ costs will subsidize gasoline consumption as well as ethanol consumption (according to result 2). In addition to the excess burden of taxation, market prices of gasoline increase, reducing the terms of trade in oil imports, while the lower consumer price paid for gasoline and the resulting increase in gasoline consumption increases the social costs from CO2 emissions, local air pollution, and traffic congestion. Ethanol producers and corn farmers are only affected indirectly. To the extent the fuel consumption subsidy translates into higher ethanol prices, ethanol producers will benefit but producers will also face higher input costs as energy is a large share of corn production costs.

The likelihood that the mandate is binding or not depends on the level of the tax credit itself. What if the tax credit is binding and the mandate is dormant? The hypothetical ethanol price premium over gasoline with a mandate alone would be lower than the current tax credit. In this case, the ethanol price premium that otherwise would occur with a mandate only represents the subsidy on gasoline consumption due to the tax credit because the tax credit is not allowing the mandate to bind. Furthermore, one can easily increase the mandate to generate the same desired level of ethanol consumption as the tax credit would be currently generating. In this way, one obtains the same level of ethanol consumption but with no taxpayers’ costs. Using a mandate alone has an additional advantage: for the same level of ethanol consumption, a mandate generates a higher consumer price paid for gasoline relative to a tax credit and so further enhances energy and environmental policy goals. This is particularly relevant for the United States where the gasoline tax is deemed suboptimal (Parry and Small 2005).

Concluding Remarks

Governments worldwide are implementing biofuel mandates and tax credits in conjunction. We outline a basic economic model of a blend mandate and show what happens if a tax credit is added to the mandate. With a fixed gasoline price, we show how mandates increase consumer prices of gasoline to finance the transfer to ethanol producers. This necessarily results in lower fuel consumption compared to a tax credit that generates an equivalent level of ethanol consumption. With endogenous gasoline prices, however, it is possible for the consumer fuel price to decline under a mandate, depending on the

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11 Because the tax credit is preventing the mandate from binding, gasoline prices are 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.
relative supply elasticities of ethanol and gasoline. The higher ethanol price in this case is financed by the lower price, facing gasoline producers.

If a biofuel tax credit is implemented alongside an ethanol blend mandate, then the effects of the tax credit are reversed. Instead of subsidizing ethanol consumption, the tax credit subsidizes fuel consumption. Because in most countries the share of ethanol in total fuel consumption is fairly low, most of the ethanol tax credit subsidizes gasoline consumption. This has important policy implications because now the tax credit is working against the energy goals of biofuel policy by increasing CO2 emissions, local pollution, and traffic congestion-related externalities. At the same time, the United States as a large importer of oil is reducing its terms of trade in oil imports. By transferring more wealth overseas, the United States is thereby reducing “energy security.” These social costs may be substantial because the new biofuel mandate calls for 36 billion gallons by 2022, to cost over $28 billion a year in taxpayers’ monies for the tax credits alone. Furthermore, little benefit is realized by either corn or ethanol producers because most of the ethanol tax credit is subsidizing gasoline consumption under a blend mandate. This means the biofuel tax credit contributes little in achieving other farm goals of biofuel policies like promoting rural development or reducing the tax costs of farm subsidy programs.

A policy implication is that it may be desirable to have only one policy instrument to achieve the desired level of biofuel consumption. The question arises as to which policy to choose. A mandate has two advantages over a tax credit. First, tax credits involve taxpayers’ costs and the marginal excess burden of taxation associated with it. Second, the price of gasoline is higher under a mandate that at least partially offsets the suboptimal gasoline tax in the United States (Parry and Small 2005). Regardless, eliminating one of the two policies involves only a modest change in biofuel policy while dramatically improving policy achievements. This has implications for other government policies as well. For example, twenty-four states in the United States have renewable portfolio standards that require electricity providers to obtain a minimum percentage of their power from renewable energy resources. Together these states account for more than half of the electricity sales in the United States (DOE 2008). Meanwhile, both state governments and the federal government provide a potpourri of tax credits for wind and solar power and other renewable energy used in electricity production.

Priorities for future research should include relaxing some of the simplifying assumptions of the model, especially constant returns to scale in biofuel production and perfect competition. There are some recent indications of increasing returns to scale in ethanol production in the United States. If this is the case, the industry may see significant cost economies in expanding production facilities, reducing the marginal cost of transforming corn to ethanol. The result of such cost economies will be a long-run downward shift in the ethanol supply curve—making ethanol potentially more practical and putting downward pressure on the deadweight costs associated with ethanol policies. Despite cost economies, given current yield levels and land use, it seems likely that ethanol producers would run into significant market diseconomies in using corn as an input. Clearly we are running out of prime corn land to which production can expand. In this case, while the supply curve may shift down, the supply curve itself may become more elastic, potentially putting upward pressure on fuel prices and the deadweight costs of biofuel policies.

[Received February 2008; accepted January 2009.]

References


Appendix

While the simplified model presented in the body of the article is instructive, endogenous oil prices can add some richness to the results. This model requires three equilibrium conditions. Let \( P_F \) be the price of fuel mixture, \( P_E \) the price of the biofuel, \( P_G \) the price of oil-based gasoline, \( t \) the consumption tax on fuel, \( t_c \) the volume-based tax credit on biofuels, and \( \alpha \) be the proportion of fuel required to be from biofuels. Further, let \( S_E(P_E) \) be the excess supply of the biofuel, \( S_G(P_G) \) be the supply of gasoline and \( D_F(P_F) \) be the demand for the fuel mixture. The equilibrium conditions can then be written as

\[
\begin{align*}
\text{(A.1)} & \quad P_F = \alpha(P_E + t_c) + (1 - \alpha)(P_G + t) \\
\text{(A.2)} & \quad D_F(P_F) = S_G(P_G) + S_E(P_E) \\
\text{(A.3)} & \quad \alpha D_F(P_F) = S_E(P_E).
\end{align*}
\]

Equation (A.1) contains the price relationship between ethanol, gasoline, and fuel mixture, requiring that fuel retailers charge marginal cost for the fuel mixture. Equation (A.2) describes the market-clearing condition, and equation (A.3) describes the constraint imposed by the mandate. To extend the model to include imports of oil (gasoline), a supply curve for imported oil (gasoline) would need to be added to equation (A.2). Doing so, however, does not substantially change the following analysis.

Results 1 through 5 can be obtained by totally differentiating equations (A.1)–(A.3) in order to derive the comparative static changes in prices resulting from changes in the mandate or tax credit. Totally differentiating obtains

\[
\begin{pmatrix}
1 & -\alpha & -(1 - \alpha) \\
D_F' & -S_E' & -S_G' \\
\alpha D_F' & -S_E' & 0 \\
\end{pmatrix}
\begin{pmatrix}
dP_F \\ dP_E \\ dP_G \\
\end{pmatrix}
\begin{pmatrix}
D_F - P_E + t_c \\
0 \\
0 \\
\end{pmatrix}
\begin{pmatrix}
\alpha \\
-1 \\
0 \\
\end{pmatrix}
\begin{pmatrix}
d\alpha \\ dt_c \\ dt \\
\end{pmatrix}
= \begin{pmatrix}
0 \\
0 \\
0 \\
\end{pmatrix}
\]

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

\[
\frac{dP_F}{d\alpha} = -\frac{P_G - P_E + t_c}{D_F} \begin{pmatrix}
-\alpha & -(1 - \alpha) \\
0 & -S_E' \\
0 & -S_G' \\
\end{pmatrix}
= \frac{(P_G - P_E + t_c)S_E' S_G - D_F(\alpha S_G' - (1 - \alpha)S_E')}{S_G'[\alpha^2 D_F' - S_E'] + (\alpha - 1)^2 S_E' D_F'}
\]
or

\[ dP_E \quad \frac{dP_E}{d\alpha} = \left( P_G - P_E + \epsilon_c \right) - \frac{P_E - P_G}{\eta_E} < 0 \]

or

\[ (A.4) \quad \frac{dP_E}{d\alpha} = \frac{P_G - P_E + \epsilon_c}{\eta_E} \left[ \frac{\eta_E}{P_F} \left[ \frac{\eta_E}{P_F} - \frac{\eta_E}{P_F} \right] + (1 - \alpha) \frac{\eta_E}{P_F} \frac{P_E}{P_G} - \frac{P_E}{\eta_E} \frac{P_E}{\eta_E} \right] < 0 \]

where \( \eta_E \) represents the elasticity of relation \( i \) (either supply or demand) with respect to the price of product \( j \) (either biofuel, gasoline, or fuel mixture).

The denominator is always negative; hence, \( P_E \) increases with a mandate when

\[ (P_G - P_E + \epsilon_c) - \frac{P_E - P_G}{\eta_E} < 0 \]

or

\[ (A.5) \quad \left( 1 + \frac{1}{\eta_E} \right) P_G < \left( 1 + \frac{1}{\eta_E} \right) P_E - \epsilon_c. \]

The price of fuel will decrease otherwise, leading to result 1. Thus, the fuel price is more likely to increase with a mandate as the gasoline (oil) supply becomes more elastic relative to the biofuel supply.

Increasing the tax with a binding mandate results in

\[ dP_F \quad \frac{dP_F}{dt} = \frac{P_G - P_E + \epsilon_c}{\eta_E} \left[ \frac{\eta_E}{P_F} \left[ \frac{\eta_E}{P_F} - \frac{\eta_E}{P_F} \right] + (1 - \alpha) \frac{\eta_E}{P_F} \frac{P_E}{P_G} - \frac{P_E}{\eta_E} \frac{P_E}{\eta_E} \right] > 0 \]

or

\[ \left| \begin{array}{ccc} -1 & -\alpha & -(1 - \alpha) \\ 0 & -S_E & -S_G \\ 0 & -S_E & 0 \end{array} \right| \]

\[ \frac{dP_F}{dt} = -\frac{S_E S_G}{S_G \left[ \alpha^2 D_F' - S_E \right] + (\alpha - 1)^2 S_E D_F'} > 0 \]

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

\[ dP_E \quad \frac{dP_E}{dt} = \frac{P_G - P_E}{\eta_E} \left[ \frac{\eta_E}{P_F} \left[ \frac{\eta_E}{P_F} - \frac{\eta_E}{P_F} \right] + (1 - \alpha) \frac{\eta_E}{P_F} \frac{P_E}{P_G} - \frac{P_E}{\eta_E} \frac{P_E}{\eta_E} \right] > 0. \]

Thus, the quantity of ethanol consumed increases with the tax credit as noted in result 2. Note that, as the elasticity of supply for oil (gasoline) goes to infinity, the value of this derivative will converge to something less than one.

\[ \lim_{\eta_E \to \infty} \frac{dP_E}{dt} = \frac{1}{1 - \frac{\eta_E}{\eta_E} \frac{P_E}{P_G}} < 1. \]

Thus, the mandate mitigates the effects of the tax credit.

Finally, the change in gasoline prices is given by

\[ \left( \begin{array}{ccc} 1 & -\alpha & \alpha \\ D_F' & -S_E & 0 \\ 0 & -S_E' & 0 \end{array} \right) \]

\[ \frac{dP_G}{dt} = \frac{\alpha \eta_E \eta_E}{P_P \left[ \eta_E \eta_E - \frac{\eta_E}{P_F} \right] + (1 - \alpha) \eta_E \eta_E} > 0. \]

or

\[ (A.7) \quad \frac{dP_G}{dt} = \frac{\alpha \eta_E \eta_E}{P_P \left[ \eta_E \eta_E - \frac{\eta_E}{P_F} \right] + (1 - \alpha) \eta_E \eta_E} > 0. \]

Thus, the quantity of gasoline consumed also increases as noted in result 2.

Without the mandate the equilibrium is given by

\[ P_E - \epsilon_c - P_G = 0 \]

\[ D_F(P_G + \epsilon_c) - S_G(P_G) - S_E(P_E) = 0 \]

Totally differentiating obtains

\[ \left[ \begin{array}{ccc} 1 & -1 & \alpha \\ -S_G & D_F' & -S_G \end{array} \right] \frac{dP_E}{dt} + \left[ \begin{array}{c} -1 \\ 0 \end{array} \right] dt_c = \left[ \begin{array}{c} 0 \\ 0 \end{array} \right]. \]

This results in the comparative static

\[ \frac{dP_E}{dt} = \frac{\alpha D_F' - S_G}{|H|} > 0. \]
or

\[ \frac{dP_E}{dt_c} = \frac{\eta_P^D D_F - \eta_P^S S_G}{\eta_P^D P_F - \eta_P^S P_G} > 0. \]

Note that, as the elasticity of supply for gasoline goes to infinity, the derivative becomes one, thus providing results 3 and 4. Thus, the tax credit would result in a direct and equivalent increase in the price of the biofuel. Thus, the change in the price of the biofuel will be greater under no mandate if

\[ \frac{\eta_P^D D_F - \eta_P^S S_G}{\eta_P^D P_F - \eta_P^S P_G} - \frac{\eta_P^S S_E - \eta_P^E S_G}{\eta_P^S P_E - \eta_P^E P_G} < 0. \]

This simplifies to

\[ (1 - \alpha) P_E \eta_P^E (P_E \eta_P^G - \eta_P^D P_G)^2 \]

\[ - \eta_P^D P_G P_E + \eta_P^S P_F P_E (1 - \alpha) + \eta_P^S P_F P_G \alpha \]

\[ - \alpha \eta_P^G P_E + \eta_P^S \eta_P^D P_F - (1 - \alpha) \eta_P^S \eta_P^E P_G > 0. \]

which must always hold.