Ethanol Policies and Welfare under the Pre-existing Fuel and Labor Taxes[1]

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Abstract

We develop a tractable general equilibrium model to analyze the welfare implications of a biofuel blend mandate and consumption subsidy in the presence of pre-existing labor and fuel taxes. We find empirically that the tax interaction and revenue recycling effects are significant relative to the overall costs of the policies and previous partial equilibrium studies. We find that removing the tax credit used in combination with a binding mandate – which mirrors the expiration of the U.S. blender's tax credit at the end of 2011 – yields a net welfare gain of only USD 9 million; this is significantly less than the welfare gain of USD 357 million attributable to fiscal interaction effects. This interesting result is due to the binding nature of the mandate. We find that the welfare cost of the blend mandate alone is USD 8.3 billion, which includes a tax interaction effect of USD 1.54 billion. We also find empirically that the tax credit is welfare superior to the mandate for a given level of ethanol consumption because the fuel tax is above the external costs of greenhouse gas emissions. This result is robust to the presence or absence of the labor tax.

Keywords: *biofuel policies, blend mandate, blender's tax credit, gasoline tax, greenhouse gas emissions, renewable fuel standard, second-best*

JEL Classification: D58, D62, H21, H23, Q42, Q58

Introduction

Biofuel blend mandates and consumption subsidies are used throughout the world. Although the U.S. ethanol blender's tax credit has expired, many other countries continue to employ tax-exemptions at the gasoline pump. In this paper,

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[1] Supplementary material to this article is available at:
< https://sites.google.com/site/dusandrabik83/Supplementarymaterial.pdf?attredirects=0&d=1>.

we quantify and compare the welfare costs and benefits of biofuel blend mandates, consumption subsidies, and their combination using a closed-economy, general equilibrium model focusing on the interactions of biofuel policies with the labor market and a fixed fuel tax.

A rich literature in public finance and environmental economics has shown that the interaction of environmental policies with the broader fiscal system can significantly affect welfare measures in the context of environmental externalities (e.g., Bovenberg and de Mooij, 1994; Parry, 1995; Goulder et al., 1999; Parry and Small, 2005; West and Williams, 2007). The fiscal interaction effect of an environmental policy consists of the “tax interaction effect” and the “revenue-recycling effect.”

The tax interaction effect arises when biofuel policies change the relative commodity prices (corn and fuel in our model) with respect to the price of labor which in turn affects demand for leisure, labor’s substitute. This first-order welfare effect due to a change in the labor tax base occurs because of the pre-existing distortion in the labor market (Browning, 1987; Parry, 1995). The revenue-recycling effect arises because biofuel policies affect government revenue from the fuel market, and fuel market revenue is a substitute for labor tax revenue. Assuming that the level of total government spending is held fixed, a biofuel policy which increases (decreases) government revenue from the fuel market will cause a decrease (increase) in the labor tax rate. The welfare effect of such a change in the labor tax is known as the “revenue-recycling effect” (Goulder, 1995).

If fiscal interaction effects are relatively large, research efforts which ignore them may overestimate the net benefits of the policies (if the fiscal interaction effects are negative), or underestimate the benefits (if the policies yield a “double dividend” – i.e., their net fiscal interaction effects are positive (Bento and Jacobsen, 2007; Parry and Bento, 2000)). This paper studies the importance of fiscal interaction effects for biofuel policies in the United States.

The supplementary material to this article is available at the website mentioned in footnote 1. There we provide details about the formulas for marginal welfare effects of biofuel policies, the numerical model, data and calibration, derivations of all formulas used in the paper, as well as more detailed tables with the results.

1. Related Literature

Previous research has shown that differences in environmental policies’ effects on government revenue can influence their welfare ordering (Goulder, Parry and Burtraw, 1997; Goulder et al., 1999). There are several inherent differences between biofuel blend mandates and consumption subsidies that make their fiscal interaction effects likely to differ. For example, although both the tax credit and mandate are revenue-requiring policies for a given level of ethanol (since fuel tax revenue declines with a mandate), the relative fiscal effects are *a priori* indeterminate. Fuel prices are always relatively higher under a mandate, and corn prices are the same for a given level of ethanol production, which implies that the mandate has a more costly tax interaction effect.

The majority of literature studying the welfare effects of biofuel policies has taken a partial equilibrium approach (Rajagopal et al., 2007; Khanna, Ando and Taheripour, 2008; de Gorter and Just, 2009b; Cui et al., 2011; Lapan and Moschini, 2012). Several partial equilibrium studies estimate optimal biofuel policies and find varying results, due largely to their inclusion of different externalities. For example, Khanna, Ando and Taheripour (2008) study a partial equilibrium model where vehicle-miles traveled (VMT) cause congestion and emissions externalities. They find that the first-best policy combination includes a negative ethanol subsidy – a USD 0.04 per gallon tax –since a positive ethanol subsidy decreases the price of the fuel blend and worsens the congestion externality. On the other hand, Vedenov and Wetzstein (2008) assume that ethanol consumption improves environmental quality and fuel security relative to gasoline; they find that the optimal ethanol subsidy is USD 0.22/gallon.

Cui et al. (2011) analyze optimal biofuel policies in the presence of an emissions externality only and find that the optimal ethanol tax credit is USD 0.67 per gallon in 2009 (35 percent greater than its actual level of USD 0.49 per gallon) and that the optimal mandate yields even higher ethanol production than the optimal tax credit. Although our empirical model includes the same externality and is calibrated to 2009 U.S. data, we find the optimal tax credit or mandate to be zero. There are three main drivers of this difference. First, ethanol polices in the Cui et al. model derive additional benefits from the terms of trade effects in the oil and corn markets, which our closed economy model does not capture. Second, our ethanol policies have greater welfare costs because we interact them with a pre-existing labor tax and fixed government revenue requirement. Finally, the status quo ethanol policies in Cui et al. (2011) are associated with lower deadweight costs because of the absence – relative to our model – of rectangular deadweight costs.

Although the literature on fiscal interaction effects is extensive, few papers have measured the fiscal interaction effects of biofuel policies.[2] Crago and Khanna (2010) study the welfare effects of a carbon tax where a pre-existing ethanol subsidy and labor tax may be present; our approach here is to study the

[2] Studies that have analyzed the fiscal interaction effects of other agricultural policies include Parry (1999) and Taheripour, Khanna and Nelson (2008).

welfare effects of ethanol policies directly. Taheripour and Tyner (2012) analyze the welfare effects of an ethanol quantity mandate in an open economy general equilibrium framework using the GTAP-BIO-AEZ model; they model the mandate by imposing a combination of market incentives necessary to induce the mandated quantity of ethanol. We implement the blend mandate directly in our model – that is, we do not require any additional policies to generate the mandated ethanol consumption.

2. Analytical Model

The Representative Consumer

The representative consumer consumes fuel F, corn C, numeraire good x, and leisure N.[3] Leisure is assumed to be weakly separable from consumption of goods in utility. The consumer receives disutility σ (.) from an externality R associated with fuel consumption, whose nature is discussed further below. The externality is assumed to be separable from utility coming from the consumption goods and leisure; this assumption implies that the consumption-leisure trade-off is not affected by the level of environmental quality (Goulder et al., 1999). The utility function is given by

$$U = \varphi\big(u\left(F,\ C,\ x\right),\ N\big) - \sigma\left(R\right) \tag{1}$$

where φ (.) denotes utility from the consumption goods and leisure.

Production

Labor is the only factor of production, and the representative consumer's time endowment is $\bar{L}$. The consumer allocates his time between labor L and leisure N such that $L + N = \bar{L}$. Labor is used in the production of gasoline G, ethanol e, corn supply C^S, and the numeraire good. The quantities of labor used to produce each good are L_G, L_e, L_C, and L_x, respectively. The wage rate is denoted by w.

Gasoline and the numeraire are produced by constant returns-to-scale production technologies. We assume perfect competition in the production of both goods, so the prices of gasoline and the numeraire depend only on the wage rate. Corn is produced using labor according to a decreasing returns-to-scale technology f (.):

$$C^S = f\left(L_C\right) \tag{2}$$

[3] Fuel is a mixture of ethanol and gasoline. Because one gallon of ethanol has lower energy content than the same amount of gasoline, we measure fuel consumption in gasoline energy-equivalent gallons (GEEGs).

Profits from corn production are denoted by π_C and are returned lump-sum to the consumer.[4]

Ethanol quantity e is measured in physical gallons and produced from corn and labor according to a fixed coefficients production process:

$$e = \min\left\{e_C C^e,\ e_L L_e\right\} \tag{3}$$

C^e is the residual corn supply after corn consumption demand is met: $C^e \equiv C^S - C$; the parameter e_C denotes total gallons of ethanol produced from one bushel of corn, and e_L denotes gallons of ethanol produced per unit of time. When calibrating the model to observed data, we assume that the co-product from ethanol production (Dried Distillers Grains with Solubles) is a perfect substitute for corn.

The zero-profit condition for ethanol production determines the link between ethanol and corn prices, denoted by P_e and P_C, respectively:[5]

$$P_e = P_C / e_C + w / e_L \tag{4}$$

The link between the amount of labor and corn needed to produce e gallons of ethanol is obtained from cost minimization:

$$e = e_C C^e = e_C\left(C^S - C\right) = e_L L_e \tag{5}$$

The consumer buys a blend of gasoline and ethanol. We assume that the consumer values fuel for vehicle-miles traveled. Since one gallon of ethanol yields fewer miles than a gallon of gasoline, we let γ denote the ratio of miles traveled per gallon of ethanol and gasoline. Total fuel consumption measured in gasoline energy-equivalent gallons (GEEGs) is then given by $F = G + \gamma e$. Following de Gorter and Just (2008), we assume that $\gamma = 0.7$. Throughout our analysis, we use $E = \gamma e$ to denote ethanol measured in GEEGs. We assume that the fuel blend is produced by competitive blenders earning zero profits who face exogenous gasoline market price P_G and the ethanol market price $P_E = P_e/\gamma$, where P_E denotes the ethanol price in dollars per GEEG.

Externalities

Fuel consumption is assumed to produce only one externality, carbon dioxide (CO_2) emissions; we allow the emissions per consumed GEEG to differ between ethanol and gasoline.[6] We normalize the units of CO_2 emissions so the externality can be written as

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[4] Positive profits in corn production follow from our definition of the ethanol supply curve as the horizontal difference between the corn supply curve and the non-ethanol demand curve for corn. The positively sloped corn supply curve implies positive profits.

[5] The parameter e_C takes into account the effect of the ethanol co-product on the corn price.

$$R\left(G,\ E\right)=G+\xi E \tag{6}$$

where ξ denotes relative emissions of ethanol per GEEG.

Government

The government employs a volumetric fuel tax t, a proportional tax on labor earnings t_L, and either a volumetric ethanol blender's tax credit t_c and/or an ethanol blend mandate θ which dictates the minimum share of ethanol (in energy terms) in the fuel (ethanol and gasoline) blend. Profits from corn production are not taxed. Real government revenue Γ is a fixed lump-sum transfer to consumers, and the government's budget is balanced and satisfies

$$\Gamma = t_L wL + t\left(G+e\right) - t_c e \tag{7}$$

The first term on the right-hand side of equation (7) represents government receipts from taxing labor; the second term denotes tax revenues from fuel consumption; the final term denotes expenditures on the tax credit. To hold the real lump-sum transfer Γ fixed, the labor tax is adjusted in response to biofuel policy changes (i.e., when either the tax credit or the mandate is changed and ethanol consumption, labor supply, and other variables in the model respond, the new labor tax is the one which generates the original government transfer). The fuel tax is assumed to be held constant.

Equilibrium

The assumption of perfect substitutability between gasoline and ethanol (on a miles-traveled basis) implies the following relationship between prices if the tax credit is the binding biofuel policy (de Gorter and Just, 2009a; Cui et al., 2011; Lapan and Moschini, 2012):

$$P_F = P_G + t = P_E + t/\gamma - t_c/\gamma \tag{8t}$$

Recall that the volume of one GEEG of ethanol is more than one gallon; since the fuel tax and ethanol tax credit are both volumetric, adjusting them by γ converts them to dollars per GEEG units.

In the situation when the blend mandate θ (in energy terms) determines the ethanol price, the fuel price paid by consumers is a weighted average of the ethanol price and gasoline price:

[6] Other externalities associated with fuel consumption, such as traffic congestion or motor vehicle accidents, arise from vehicle-miles traveled (VMT) rather than fuel combustion. If ethanol is measured in GEEG, its VMT externalities do not differ from those of gasoline. In our model, the only potential benefit from ethanol relative to gasoline is reducing emissions. In our numerical model, we find that an extremely high marginal external cost of carbon would make the optimal ethanol policies positive.

$$P_F = \theta\left(P_E + t/\gamma - t_c/\gamma\right) + \left(1-\theta\right)\left(P_G + t\right) \tag{8m}$$

A key difference between the binding tax credit and the binding blend mandate model is how the corn price is determined. With a tax credit, corn prices are directly linked to the gasoline price. Combining equations (4) and (8t) and invoking $P_e = \gamma P_E$, we see that the tax credit directly affects the corn price:

$$P_C = e_C\left[\gamma P_G - \left(1-\gamma\right)t + t_c\right] - e_C w/e_L \tag{9}$$

With a binding mandate, corn-market clearing determines the corn price P_C, where the corn output supply function, denoted by $g(P_C)$ in equation (10), equals the sum of consumer demand for corn and the corn required for ethanol production (where ethanol production, in turn, depends on fuel demand):[7]

$$g\left(P_C\right) = \theta F\left(P_C, \cdot\right)/\gamma e_C + C\left(P_C, \cdot\right) \tag{10}$$

Note that with either policy in place, corn production profits can be expressed as a function of the corn price and the wage rate:

$$\pi_C = P_C g\left(P_C\right) - f^{-1}\left(g\left(P_C\right)\right)w \equiv \pi_C\left(P_C, w\right) \tag{11}$$

where f^{-1} denotes the inverse of the corn supply function defined by equation (2).

We close the model by specifying the labor market clearing condition,

$$L_G + L_x + L_C + L_e = L \tag{12}$$

and the representative consumer's budget constraint,

$$P_F F + P_C C + P_x x + \omega N = \omega\overline{L} + \Gamma + \pi_C \tag{13}$$

Consumer wealth, on the right-hand side of equation (13), includes (*i*) the after-tax value of the labor endowment, where $\omega \equiv (1 - t_L)w$, (*ii*) the government transfer, and (*iii*) profits from corn production; all three terms are exogenous from the perspective of the consumer.

3. Results

Using the calibrated model (see supplementary materials), we first determine the optimal blender's tax credit and mandate (individually) by maximizing social welfare (i.e., the representative consumer's utility). Unlike other studies (e.g.,

[7] For simplicity, in the fuel demand and corn demand functions ($F(P_C,\cdot)$ and $C(P_C,\cdot)$, respectively) in equation (10), we use dots to denote all arguments besides the corn price. See supplementary material for further detail.

Khanna, Ando and Taheripour, 2008; Cui et al., 2011), we find that both policies are zero at the optimum. The most important factor contributing to this result is the presence of 'water' in the status quo ethanol policy price premium and associated rectangular deadweight costs (RDC).[8]

To discuss the concept of 'water,' three ethanol prices must be considered: the observed ethanol price P_E, the 'no policy' ethanol price P_E^* that would prevail in the absence of any biofuel policies, and the 'no ethanol' price P_{NE} that is the intercept of the ethanol supply curve. With the status quo ethanol policies, the observed ethanol price in our model is P_E = USD 2.56 per GEEG. The 'no policy' ethanol price P_E^* = USD 1.55 per GEEG is determined by equation (8t) with a zero tax credit; since ethanol and gasoline are perfect substitutes, their prices must be the same after adjusting for the volumetric fuel tax. Hence, the ethanol policy price premium, defined as the difference between the observed ethanol price and its 'no policy' counterpart, is equal to USD 2.56 – USD 1.55 = USD 1.01 per GEEG. The price premium is also equal to the marginal deadweight loss of the final unit E of ethanol produced – the consumer could have this unit of fuel for P_E^* but instead pays P_E for it.

Without ethanol policies, the volume of ethanol production depends only on the relative prices of gasoline and corn (in GEEG units). If the corn price is low enough relative to the gasoline price, then ethanol production will occur even without biofuel policies. For ethanol production to take place without biofuel policies, the intercept of the ethanol supply curve must be below the gasoline price inclusive of the fuel tax. If this is not the case, no ethanol will be produced and there is 'water' in the ethanol price premium, where 'water' is the part of the ethanol price premium range that is above the 'no policy' ethanol price yet below the intercept of the ethanol supply curve (de Gorter and Just, 2008; Drabik, 2011).

The critical element is P_{NE}, the intercept of the ethanol supply curve. The supply curve intercept reflects ethanol producers' competition with corn consumers for the corn supply. At any corn market price, the amount of corn used for ethanol is equal to the difference between corn supply and consumer corn demand. Thus, we can think of the intercept of the ethanol supply curve as the equilibrium corn price that would arise if no ethanol were produced (after a unit adjustment from bushels to GEEGs).

In our model, we obtain P_{NE} = USD 2.07 per GEEG. The difference between P_{NE} and P_E^* is the 'water' in the policies: USD 2.07 – USD 1.55 = USD 0.52 per GEEG.[9] Our finding that $P_{NE} > P_E^*$ means that there would be no ethanol

[8] An explanation of 'water' in the biofuel policy price premium and related concepts can be found in greater detail in Drabik (2011).

production in the status quo without biofuel policies; every bushel of corn produced has greater value to the consumer in the form of corn than in the form of ethanol. The total rectangular deadweight cost (RDC) associated with the status quo ethanol production is equal to 'water' multiplied by the amount of ethanol produced. We find that the RDC is equal to roughly USD 4 billion (= USD 0.52 per GEEG x 7.73 billion GEEGs).[10] This significant deadweight loss is a central reason why the optimal policies are found to be zero in our model – it is very inefficient to produce ethanol from corn when its substitute, gasoline, is much less costly.[11]

To measure the welfare effects of the biofuel policies, we analyze three policy simulations: the status quo scenario (i.e., a binding blend mandate coupled with a tax credit); a scenario where the blend mandate is held at its status quo level but the tax credit is removed (the removal of the tax credit in this scenario mimics the policy change that occurred in January 2012 when the U.S. ethanol blender's tax credit expired but the corn ethanol mandate under the Renewable Fuel Standard remained in place); and a scenario with no ethanol policies. The results of these policy simulations are shown in Table A2 of the supplementary materials.

Welfare Effects of the Tax Credit with a Binding Mandate

In the status quo scenario, ethanol production is determined by a binding blend mandate of 5.88 percent combined with a blender's tax credit of USD 0.498 per gallon. Table 1 decomposes the total welfare change from the tax credit removal into the four components: the primary distortion effect, tax interaction effect, revenue recycling effect, and externality effect. The welfare effects presented in Table 1 correspond to a policy change from the status quo to the "tax credit removed" scenario in Table A2.

The primary distortion effect of removing the tax credit is estimated to be a loss of USD 328 million. To better understand this effect's origin, consider Figure 1 where P_G denotes the gasoline price and $P_G + t$ is the consumer price of fuel with no biofuel policy. The Harberger deadweight loss triangle associated with the fuel tax t is area *abc*. When a tax credit t_c and a fuel tax t are combined

[9] Our estimate of 'water' in the biofuel policy price premium is similar to the partial equilibrium estimate of USD 0.76 per GEEG reported by Drabik (2011). That our estimate of water is lower than that in Drabik (2011) is consistent with the empirical observation that general equilibrium effects tend to be smaller relative to those obtained from a partial equilibrium analysis.

[10] 7.73 billion GEEGs correspond to 11.038 billion gallons of ethanol in the first column in Table A2 in the supplementary materials.

[11] In contrast, Cui et al. (2011) find that there would be ethanol production even in the absence of the mandate and tax credit in 2009. This difference arises because they calibrate their model to a binding tax credit; this necessitates adjusting the observed gasoline price up by USD 0.32 per gallon and results in no 'water' in the policies. Moreover, their model's linear supply and demand curves (in contrast to our non-linear ones) make the presence of 'water' less likely.

with the blend mandate θ, the fuel price increases to $P_F(\theta, t_c, t)$, making the implicit tax[12] on fuel equal to the distance *ed* with a corresponding distortion equal to the area *dbe*.

Table 1

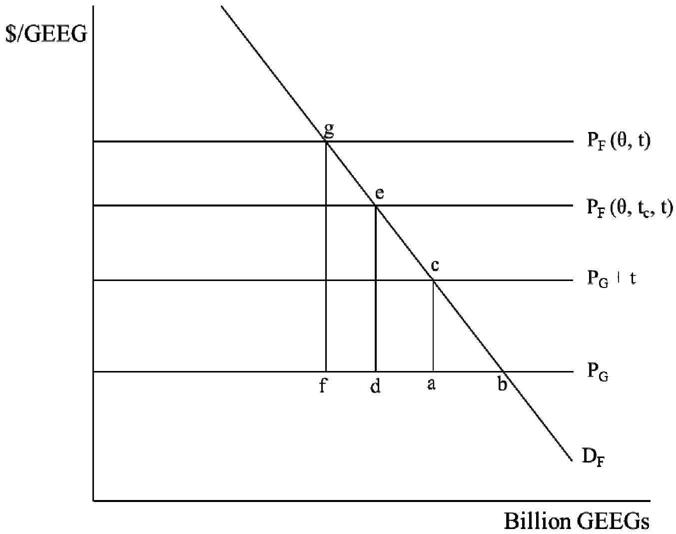
Welfare Effects of Removing the Tax Credit but Keeping the Mandate

Welfare Component	Welfare Change (USD billion)
Primary Distortion	–0,328
Tax Interaction Effect	–0,063
Revenue Recycling Effect	0,360
Externality Effect	0,040
Total Change in Welfare	0,009

Source: Calculated.

Figure 1

The Primary Distortion Effects in the Fuel Market



Source: Authors.

Because a mandate *per se* works as an implicit fuel tax (de Gorter and Just, 2010b; Lapan and Moschini, 2012), before being removed the tax credit was suppressing the full effect of the implicit tax by lowering the price of the fuel blend.[13] The elimination of the tax credit increases the fuel price to $P_F(\theta, t)$, and

[12] Distance *ed* is the total implicit tax because it combines both the explicit fuel tax *t* and the implicit taxation effect of a blend mandate.

[13] de Gorter and Just (2009a) show that the tax credit in combination with a binding mandate acts as a fuel consumption subsidy. Similarly, Drabik (2011) and Lapan and Moschini (2012) show that for a given blend mandate, an increase in the blender's tax credit decreases the fuel price, but increases the gasoline price.

the distortion in the fuel market is the area *fbg*. The trapezoid *fdeg* then represents the primary distortion effect of removing the blender's tax credit.[14]

The fuel price increase lowers the real wage and causes the consumer to substitute leisure for consumption goods, thus shifting the labor supply curve to the left.[15] The contraction of the labor tax base results in a welfare loss due to the tax interaction effect of USD 63 million.

When the blender's tax credit is abandoned, the government revenue from the fuel tax decreases by USD 349 million (see Table A2). However, the government saves USD 5.5 billion by no longer having to pay for the tax credit, so the overall revenue from the fuel market increases by USD 5.15 billion. This additional revenue is "recycled" – the labor tax rate can be reduced while the real government transfer is held constant. The revenue-recycling effect of alleviating the pre-existing distortion in the labor market yields a benefit of USD 360 million.

The last welfare component in Table 1 is the positive externality effect of USD 40 million. This benefit is due to a decrease in fuel consumption of 710 million gallons (Table A2), caused by the elimination of the tax credit. It should be noted that the externality effect related to CO_2 emissions is the smallest (in absolute) value among all effects in Table 1.

In total, we estimate that removing the tax credit improves social welfare by USD 9 million. This result is consistent with earlier findings from partial equilibrium models (e.g., de Gorter and Just, 2010b), although the magnitude of the total welfare effect is perhaps smaller than a partial equilibrium model would predict. The welfare improvement is rather small because the tax credit's removal causes a significant increase in the primary distortion in the fuel market.

The main result from Table 1 is that the removal of the tax credit (while keeping the mandate) costs USD 63 million (the tax interaction effect) but there is a much bigger welfare gain due to the revenue recycling effect of USD 360 million. This means the *net* fiscal interaction welfare effect is large compared to the total welfare gains and is approximately equal to the welfare loss of the primary distortion effects.

In standard models of environmental taxation, the revenue recycling effect exceeds the tax interaction effect if the taxed good is a relatively weak substitute for leisure (Parry, 1995). Our nested-CES functional form imposes that all goods are equal (and hence all average) substitutes for leisure, so our finding that the revenue recycling effect exceeds the tax interaction effect in magnitude is

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[14] The tax credit does not cause any primary distortion in the corn market because corn is not taxed in our model.

[15] Although the corn price decreases by USD 0.007 per bushel, this effect is more than offset by an increase in the fuel price by USD 0.041per GEEG such that the overall price index rises from 1 to 1.001.

perhaps surprising. However, since the tax credit was imposed on top of a binding mandate in this model (in a departure from the standard model), the relative size of the two fiscal interaction effects was *a priori* indeterminate.

To further analyze the role of the fiscal interaction effects in the welfare change due to the tax credit removal, we set the labor tax to zero (thus eliminating the fiscal interaction effects) and recalculate the primary distortion and externality effects. The primary distortion and externality effects are similar to those reported in Table 1 – a loss of USD 355 million and a gain of USD 44 million, respectively (further results of simulation available from authors by request). Owing to the absence of the fiscal interaction effects, however, the elimination of the tax credit results in a welfare loss of USD 311 million. This indicates that when the labor tax cannot be adjusted in response to a change in the net fuel tax revenue and when the real government transfer is not held constant, adding a tax credit to a binding mandate may indeed be welfare improving. In this case, the welfare improvement occurs only due to higher fuel tax revenue which is transferred lump sum to the representative consumer.[16] Because the ethanol price is determined by the mandate, the addition of the tax credit has only a marginal effect on ethanol consumption, and (mostly) gasoline consumption is subsidized instead. This gives rise to higher fuel tax revenues.

Welfare Effects of Blend Mandate Removal

We now quantify how welfare would change if the status quo blend mandate were removed, with no tax credit in place. This is the welfare effect of a change from the second scenario in Table A2 (*Tax Credit Removed*) to the third scenario (*No Ethanol Policy*). We anticipate that removing the mandate will cause welfare gains since we find that the optimal blend mandate is zero. Table 2 presents our estimates of the total welfare effect as well as its components. The last row of Table 2 does indeed confirm that overall welfare improves by USD 8.28 billion when the mandate is removed.

T a b l e 2

Welfare Effects of Removing the Mandate after Tax Credit is Removed

Welfare Component	**Welfare Change (USD billion)**
Primary Distortion	6,974
Tax Interaction Effect	1,544
Revenue Recycling Effect	–0,063
Externality Effect	–0,173
Total Change in Welfare	8,282

Source: Calculated.

[16] This is analogous to Cui et al. (2011) where the status quo versus a tax credit results in significant welfare gains due to increased tax revenues.

The primary distortion effect is the most significant component (about 85 percent) of the total welfare change. This reflects in large part the elimination of the RDC due to 'water' in the ethanol price premium (USD 4 billion). Welfare gains also arise because eliminating the mandate decreases both price and quantity distortions. The fuel price decreases from USD 2.31 per GEEG to USD 2.25 per GEEG, and the amount of fuel consumed increases by 1.10 billion GEEGs (Table A2). In Figure 1, this is depicted as the transition from area *gfb* to area *abc*, yielding a reduction in the distortion equal to the difference between the two triangles, i.e., area *gfac*.

The decreases in the fuel and corn prices after the mandate is removed increase the real wage; this shifts the labor supply curve to the right, as depicted in panel (a) of Figure 2.[17] Keeping the labor tax rate at its original level t_L^0, rectangle *lopm* represents the tax interaction effect (due to an expansion of the tax base) that we estimate to be USD 1.54 billion (17 percent of the total welfare change).

Although the quantity of fuel in energy terms increases, its volume measured in gallons actually decreases (Table A2). This happens because in the absence of the mandate, no ethanol is consumed and the fuel consists exclusively of gasoline. Because gasoline has less volume than the energy-equivalent amount of ethanol, the total volume of fuel decreases. This decrease results in a reduction in the fuel tax revenue because the fuel tax is levied on a volumetric basis. In order to be able to depict this situation in panel (b) of Figure 2, we have to convert the volumetric fuel tax into its energy-equivalent. Denoting t_F as the common energy-based fuel tax (when ethanol is present), it has to satisfy $t_F F = (t/\gamma)E + tG$, from which $t_F = \theta(t/\gamma) + (1-\theta)t$.

The initial fuel tax revenue in panel (b) of Figure 2 corresponds to the rectangle *abcd*. When the mandate is removed, the consumer price of fuel falls to $P_G + t$, earning tax revenue of area *efgh*, which is empirically found to be smaller than area *abcd*. The loss of fuel tax revenue must be compensated by increasing the labor tax to keep the real government transfer constant. This is depicted in panel (a) of Figure 2, where the theoretical increase[18] in the labor tax corresponds to a lower after-tax wage $w - t_L^1$. This yields labor tax revenue equal to area *qrsn* which must be larger than the original revenue of *klmn*. The positive difference

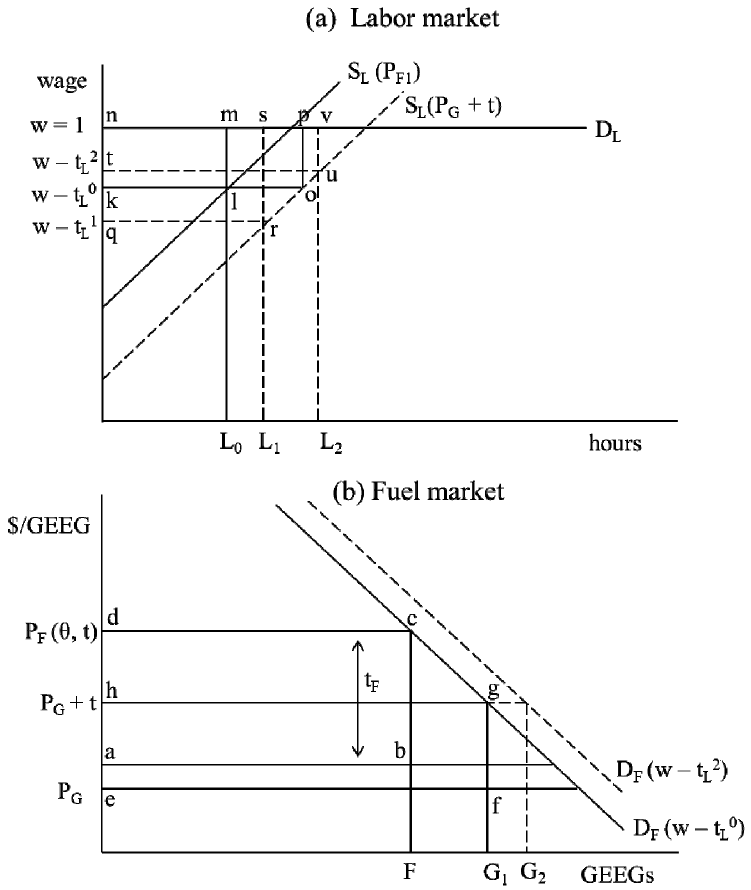
[17] $S_L(P_{F1})$ denotes the labor supply curve when the price of fuel is P_{F1} (i.e., with the mandate alone), and $S_L(P_G + t)$ denotes the labor supply curve after the mandate has been abandoned. Demand for labor is assumed to be perfectly elastic in Figure 2.

[18] This increase is only theoretical because it corresponds to the revenue recycling effect that occurs simultaneously with the tax interaction effect. As a result, in simulations we only observe the net fiscal interaction effect.

between these two areas offsets the revenue loss in the fuel market. This increased distortion in the labor market results in the revenue recycling effect of – USD 63 million.

Figure 2

Fiscal Interaction Effects of Removing a Blend Mandate



Source: Authors.

The observed change in the labor tax rate reflects both fiscal interaction effects – the tax interaction effect decreases it through the expanded labor tax base and the revenue recycling effect increases it through the lost fuel tax revenue – and the general equilibrium effects of fuel and corn demand shifts, so its overall direction depends on these magnitudes. Empirically, we find that removing the mandate causes the labor tax rate to decrease from 0.3996 to 0.3983. In panel (a), this is depicted as an increase of the after-tax wage: from $w - t_L^0$ to $w - t_L^2$.[19] The final labor tax revenue is represented by area *tuvn*. Note also that because the real wage rate increases, the demand for fuel (and corn for non-ethanol use) increases, which is depicted by the demand curve $D_F(w - t_L^2)$ in panel (b).

Eliminating the mandate yields a welfare loss of USD 173 million from the externality effect. The welfare loss arises from two sources: the share of the dirtier fuel (gasoline) in the blend increases, and fuel demand increases due to the fuel price decrease. Again, the magnitude of the externality effect is significantly smaller than the primary distortion effect.

The main result from Table 2 is that the tax interaction effect of removing the mandate results in a welfare gain of USD 1.54 billion which is partially offset by a welfare loss of USD 63 million due to the revenue recycling effect. This means the *net* fiscal interaction welfare effect is again significant in magnitude, although the magnitude is not large relative to the primary distortion or the total welfare gain. The net welfare gain associated with the elimination of the blend mandate is largely due to elimination of primary distortions, including the RDC of USD 4 billion.

Welfare Comparison of a Tax Credit and a Mandate

This section is motivated by a recent literature which shows that in a partial equilibrium framework an optimal biofuel mandate is welfare superior to an optimal tax credit not only with a suboptimal fuel tax (de Gorter and Just, 2010b) but also without it (Lapan and Moschini, 2012). Because in our model both optimal policies are zero, we do not perform a general equilibrium welfare comparison analogous to the above studies. Instead, we fix the blend mandate at its status quo level (5.88 percent) and calculate a tax credit that by itself would generate an equivalent quantity of ethanol. We then compare the welfare effects of removing each policy. To see how the fuel and labor taxes affect the welfare outcome, we consider three cases summarized in the rows of Table 3: (*i*) both taxes exist, (*ii*) fuel tax only and (*iii*) labor tax only.

Table 3

Welfare Effects of Removing Status Quo Mandate vs. an Equivalent Tax Credit

Pre-Existing Distortion Scenario	**Welfare change (USD billion)**	
	Mandate	*Tax credit*
Fuel tax and labor tax	7,096	6,607
Fuel tax*	6,296	5,693
Labor tax	7,227	7,269

Note: * The value of the government transfer is allowed to freely adjust in these simulations.

Source: Calculated.

[19] Table A2 shows that revenue from both taxes (fuel and labor) are decreased by the mandate's removal. This (perhaps surprising) result arises since the price level in the economy also decreases. As previously noted, real government revenue is constant across scenarios.

Consider first the case where both the fuel and labor taxes are present, and the ethanol quantity under the mandate and tax credit alone is 10.98 billion gallons (see Table A3 in supplementary materials). When either policy is eliminated, ethanol production falls to zero because the existing 'water' prevents any ethanol production without a biofuel policy. Although the decrease in ethanol production is the same for both policies (10.98 billion gallons), the removal of the mandate yields a greater total welfare gain (USD 7.096 billion) than the removal of the tax credit (USD 6.607 billion). Alternatively, these welfare changes can be interpreted as follows: the introduction of a biofuel mandate reduces welfare by USD 7.1 billion, while the introduction of the same quantity of ethanol through a tax credit reduces welfare by only USD 6.6 billion. This implies the tax credit is welfare superior to the mandate. But this result needs to be interpreted cautiously.

Because we do not compare optimal policy levels, our finding does not violate the theoretical conclusion of Lapan and Moschini (2012) about the superiority of the mandate. But even when the tax credit and the mandate are compared for the same level of ethanol production, de Gorter and Just (2010b) show theoretically that the mandate welfare dominates the tax credit and more so if both policies are coupled with a suboptimal fuel tax. However, the results presented in the first row of Table 3 are clearly not in line with this prediction.

The explanation is quite simple and intuitive: our fuel tax of USD 0.49/gallon is not literally *suboptimal* (i.e., less than the external cost of the externality of USD 0.06/gallon reported in Table A1), but it is *suboptimal* in the sense that it is higher than the marginal external cost.[20] Because the mandate by itself acts as an implicit tax on fuel consumption (in the form of a higher fuel price), the addition of a suboptimal fuel tax makes it even more distortionary. On the other hand, because the tax credit lowers the fuel price, it works in the opposite direction and brings the effective fuel tax closer to its optimal level. This explanation also holds for the case when only the fuel tax is present, as seen in the second row of Table 3.

However, with only the labor tax in place in the third row of Table 3, the mandate becomes superior to a tax credit in the absence of the fuel tax. This is consistent with the explanation above as well as the prediction of de Gorter and Just (2010b) because the (zero) fuel tax is suboptimal. In this scenario, when the mandate implicitly taxes gasoline consumption to pay for higher ethanol prices, it is beneficially compensating for the suboptimal fuel tax.

[20] Like us, Cui et al. (2011) also consider only one externality – carbon (CO_2) emissions. They assume marginal emissions damage of USD 20 per tCO_2. Parry, Walls and Harington (2007) assume the marginal external damage due to carbon emissions to be USD 25 per tCO_2, which corresponds to USD 0.06 per gallon. Therefore, the marginal emissions damage of USD 20 per tCO_2 in Cui et al. (2011) translates into USD 0.048 per gallon which is less than the fuel tax of USD 0.39 per gallon they use. Hence, their fuel tax is suboptimal.

To test the impact of the rectangular deadweight costs on the results in Table 3, we artificially increase the gasoline price (to USD 2.41 per gallon) such that 'water' in the ethanol price premium is eliminated. The welfare gains from removing the policies given this assumption are reported in Table 4. The welfare gains are significantly smaller than their counterparts in Table 3, largely because the rectangular deadweight cost of USD 4 billion is now absent. However, the results in Table 4 are qualitatively unchanged from Table 3, so we conclude that the presence of 'water' has no qualitative impact on the welfare superiority of a tax credit over a mandate (for the same ethanol production) under a suboptimal fuel tax.

Table 4

Welfare Effects of Removing Status Quo Mandate vs. an Equivalent Tax Credit: the "No Water" Case

Pre-Existing Distortion Scenario	Welfare change (USD billion)	
	Mandate	*Tax credit*
Fuel tax and labor tax	1,507	1,381
Fuel tax*	0,506	0,300
Labor tax	1,035	1,045

Note: * The value of the government transfer is allowed to freely adjust in these simulations.

Source: Calculated.

The central message of the analysis above is that in countries which have a suboptimal fuel tax, like Great Britain (Parry and Small, 2005), a tax credit will be welfare-superior to a mandate when comparison is made for the same ethanol production.

Conclusions

Although several earlier works have studied the welfare effects of the U.S. biofuel policies (a tax credit and blend mandate), the analyses have primarily used a partial equilibrium framework and thus failed to capture the policies' general equilibrium fiscal interaction effects. In this paper, we build a tractable general equilibrium model of the U.S. economy to analyze the welfare effects of a change in (or a complete removal of) the U.S. biofuel policies. The fiscal interaction effects are found by assuming that the government keeps the real transfer to consumers fixed and adjusts the labor tax whenever a change in a biofuel policy occurs. This enables us to study two interactions of biofuel policies with the broader fiscal system.

First, the tax interaction effect arises when the price of corn and/or fuel increases (decreases) as a result of a biofuel policy change, making the real wage decrease (increase) and thus contracting (expanding) the labor supply curve. The ensuing loss (gain) in labor tax revenue – holding the labor tax constant – represents the tax interaction effect. Second, a change in the biofuel policy affects government fuel tax receipts. If the biofuel policy change yields greater (less) fuel tax revenue, this additional revenue is used to reduce (increase) the pre-existing labor tax to keep the real transfer to the consumer fixed; depending on the change in the labor tax, the pre-existing distortion in the labor market can either increase or decrease. The direction of the net fiscal interaction effect depends on the direction and magnitude of its tax interaction and revenue recycling components.

To mirror the recent expiration of the U.S. corn-ethanol tax credit, we simulate the welfare effects of removing the tax credit, keeping the blend mandate unchanged. Eliminating the tax credit yields a small total welfare gain of USD 9 billion, but the fiscal interaction effects are more pronounced. Because the fuel price increases when the tax credit is removed, the tax interaction effect is estimated to be a loss of USD 63 million. But because the fiscal savings due to the absence of the tax credit can be used to reduce the labor tax, the revenue recycling effect of this policy change is a welfare gain of USD 360 billion. This implies that the *net* fiscal interaction welfare effect is large compared to the total welfare change, and it is approximately equal to the welfare loss of the primary distortion effect. The magnitude of the CO_2-related externality effect is significantly smaller than the primary distortion effect which is in line with the findings of Cui et al. (2011).

Motivated by our finding that the optimal mandate (or tax credit) is zero, we analyze the welfare effects of eliminating the status quo mandate. We indeed find that the blend mandate is not optimal as its abandonment results in a total welfare gain of more than USD 8 billion. Significant welfare gains come from the elimination of the rectangular deadweight costs (estimated to be USD 4 billion), as well as from a positive tax interaction effect of USD 1.54 billion. However, the welfare gains from the tax interaction effect are partially offset by a loss of USD 63 million due to the revenue recycling effect. In sum, the *net* fiscal interaction welfare effect of removing the mandate is significant in magnitude, although the magnitude is smaller relative to the primary distortion or total welfare gain.

For the same ethanol production, a blender’s tax credit is empirically found to be welfare superior to a mandate. This ordering is found to hold regardless of the presence of ‘water’ in the ethanol price premium (i.e., the gap between the free-market ethanol price and the intercept of the ethanol supply curve). This is a novel result, since previous literature has concluded that, given the same ethanol production, a mandate always welfare dominates the tax credit. The suboptimality of the fuel tax in our model reflects the exclusion of vehicle-miles-traveled externalities such as traffic accidents or congestion. The implication of our results is that the biofuel mandate is likely to be inferior to a blender's tax credit (or a tax exemption) in countries that have a suboptimal fuel tax, such as the United Kingdom (Parry and Small, 2005).

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