Which biofuel market does the ethanol tariff protect? Implications for social welfare and GHG emissions

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ABSTRACT

The ethanol tariff is one of the instruments used by the government to encourage domestic ethanol production. Existing literature analyzing the market and welfare effects of the US ethanol tariff has concluded that removing the tariff would increase social surplus and reduce greenhouse gas (GHG) emissions, due to the replacement of corn ethanol with lower cost and lower GHG intensive sugarcane ethanol. This paper re-examines these findings in the presence of a domestic cellulosic ethanol industry. The current RFS mandate requires 21 billion gallons of advanced biofuel, a portion of which could be met by any non-starch based biofuel that reduces emissions by at least 50% compared to an energy equivalent amount of gasoline. Sugarcane ethanol has been classified as an advanced biofuel, and competes for market share with domestic advanced biofuels such as cellulosic ethanol. In addition, it also competes with corn ethanol for market share in the non-advanced biofuel market. The dual market for sugarcane ethanol raises the question of which domestic biofuel market the tariff protects. Our results show that the effect of removing the tariff on social welfare and GHG emissions is ambiguous and depends on which biofuel market the tariff is protecting. If the tariff protects the corn ethanol market, its removal increases welfare and GHG emissions. However, if the tariff protects the cellulosic ethanol market, removing the tariff could increase emissions. Whether the tariff protects either the corn ethanol or cellulosic ethanol market, or both depends on the relative costs and supply elasticities of the three types of biofuel. In general, the removal of the tariff leads to an increase in social surplus, although in some cases, such as when the excess supply elasticity of sugarcane ethanol is not very elastic, net welfare could decrease when the tariff is removed. Removal of the tariff also reduces the share of domestically produced fuel, and this effect is greater when the tariff is protecting both the cellulosic and corn ethanol markets, i.e. the removal of the tariff causes a reduction in the production of both biofuels.

Keywords: biofuel, ethanol tariff, fuel externalities
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Motivations for biofuels include energy security, energy independence and climate change mitigation. To achieve these objectives, policy support in the form of mandates, subsidies and tariffs have been established, with the mandates and subsidies encouraging a shift towards cellulosic biofuels and the tariff limiting imports of sugarcane ethanol that could compete with corn ethanol or advanced biofuels. While these objectives are generally complementary, there could be some trade-offs between them. For example, the goal of energy independence that motivates greater domestic production of biofuels and limitation of imports through a tariff could also lead to reduced social surplus and increased emissions. We explore these trade-offs in biofuel policy objectives in the context of the existing renewable fuel standard (RFS) and ethanol tariff.

Existing literature analyzing the market and welfare effects of the US ethanol tariff have concluded that removing the tariff would increase social surplus and reduce GHG emissions, due to the replacement of corn ethanol with lower cost and lower GHG intensive sugarcane ethanol. This paper re-examines these findings in the presence of a domestic cellulosic ethanol industry.
The Energy Independence and Security Act (EISA) sets annual renewable fuel standard (RFS) consumption mandates beginning in 2008 that reaches 36 billion gallons by 2022. The use of corn ethanol has been capped at 15 billion gallons due to concerns about the effect of starch based ethanol production on food prices. “Advanced biofuels,” defined as those that decrease GHG emissions by more than 50% compared to gasoline make up the rest of the mandate, and within that category, 16 billion gallons have to come from cellulosic biofuels and 1 billion from biodiesel. The non-cellulosic and non-biodiesel portion of the mandate account for 4 billion gallons and this portion of the mandate could be supplied by sugarcane imports, which have been categorized as an advanced biofuel by the US Environmental Protection Agency (EPA) (EPA 2010). Depending on the cost of producing cellulosic ethanol in the next several years, sugarcane ethanol could be the primary source of non-cellulosic advanced biofuel. Sugarcane ethanol also competes with corn ethanol for market share in the traditional biofuels market.

Historically, the US has imported sugarcane ethanol primarily from Brazil and other countries that are part of the Carribean Basin Initiative (CBI). Sugarcane imports from Brazil are subject to an ad-valorem tariff of 2.5% and a secondary tariff of $0.54 per gallon while imports from CBI enter tariff-free. [1] Part of the tariff on Brazilian ethanol is meant to offset the $0.45 per gallon volumetric tax-credit given to blenders of ethanol, regardless of its source. However, given the lower tax credit, the net tariff has always been positive; in 2010 the net tariff was $0.3 per gallon. The existence of the tariff is viewed as a limiting factor in the expansion of imports from Brazil. If the advanced biofuel requirement of the RFS necessitates more imports of

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[1] Countries that have exported ethanol under the CBI tariff exemption include: Costa Rica, El Salvador, Jamaica, Trinidad and Tobago.

sugarcane ethanol, the US could be foregoing welfare gains by keeping the tariff in place. In addition to changes in social surplus, changes in imported quantities of sugarcane ethanol could also affect GHG emissions from fuel use. If sugarcane ethanol displaces corn ethanol, GHG emissions could decrease because sugarcane ethanol is 52% less GHG intensive than corn ethanol. On the other hand, if sugarcane imports replace domestic advanced biofuels from cellulosic ethanol, emissions could increase because cellulosic ethanol is 115% to 133% less GHG intensive than sugarcane ethanol.

The dual market for sugarcane ethanol raises the question of which biofuel market/s would be affected by increased ethanol imports and removal of the ethanol tariff. Whether imported ethanol would displace corn ethanol, or would be used primarily to fulfill the advanced biofuel requirement would have an impact on the share of domestic biofuel production, the welfare effect of the RFS, and GHG emissions of the resulting fuel mix.

In this study, we present a framework for identifying market conditions under which ethanol imports would affect both corn ethanol and advanced biofuel markets, or only the market for advanced biofuel. We quantify market and welfare effects, the share of domestic fuel production, and GHG emissions of the RFS mandate in 2022, with and without an ethanol tariff. Moreover, to account for uncertainty in future states of the biofuel market, as well as parameter assumptions, we provide a range of estimates for our results.

II. Review of Literature

Several studies have examined the market implication of removing the US ethanol tariff. Elobeid and Tokgoz (2008) examine the effect of the US ethanol tariff and tax credit on ethanol markets in the US and Brazil. They found that the tariff restricts ethanol imports from Brazil and that removing the tariff would significantly decrease domestic ethanol price in the US (by 14%) and more than double ethanol imports. Elobeid and Tokgoz (2008) assume that the price of Brazilian ethanol is lower than the US price and that importing sugarcane ethanol displaces corn ethanol. de Gorter and Just (2008) examine the impact of the tariff in the presence of a tax credit and mandate and concluded that without a binding mandate, the tariff has a significant impact on the world price of ethanol, but only has a small impact on domestic ethanol prices. However, with a binding mandate, imposing a tariff will lead to a greater increase in domestic ethanol prices, because the reduction in imports will have to be offset by increased domestic production in order to meet the mandate. The above studies consider corn and sugarcane ethanol markets, but not the market for advanced biofuels. Thompson et al. (2009) acknowledge that sugarcane ethanol may be used to fulfill the advanced biofuel mandate, and would be used first to fulfill the advanced biofuel requirement before it is used to replace domestically produced corn ethanol. In the presence of the RFS mandate, they show that the effect of the tariff depends on oil prices which determine whether or not the RFS mandate is binding. They find that the ethanol tariff has a modest impact on domestic ethanol production (and corn prices) when demand exceeds the mandate.

We extend the literature analyzing the market and welfare effect of the ethanol tariff to account for the presence of a domestic cellulosic biofuel industry and the dual market for sugarcane ethanol. Our representation of the biofuel market accounts for the cellulosic mandate which is a subset of the total advanced biofuel mandate, and the cap on traditional biofuel. Our model has some similar features to the model by Thompson et al. (2009) but instead of focusing on the impact of removing the tariff on the corn market, we focus on the social surplus and externality impacts. In addition, we explore the impact of technological improvements and learning on future costs of biofuels. We also model ethanol trade using a more recent data on quantities of ethanol traded and its price. Previous commentaries and studies such as Elobeid and Tokgoz and de Gorter and Just support the widely held belief that the US import tariff restricts ethanol trade and that removal of the tariff would displace corn ethanol with sugarcane ethanol. However, recent cost studies (Crago et al., 2010, Gallagher et al., 2006) and trade data (see Figure 1) show that sugarcane ethanol from Brazil could be more costly than corn ethanol even without the tariff. Figure 1 shows the trend in the cost of ethanol imports at the port versus US wholesale ethanol price. Before 2006, US ethanol wholesale prices were for most part higher than the cost of CBI or Brazilian imports (even with the tariff). In 2007 and 2009, US wholesale prices were higher than that of CBI imports, but not Brazilian imports without the tariff. Most recently in 2010, US domestic wholesale prices of ethanol are lower than either CBI or Brazilian imports even without the tariff that applies to Brazilian imports.

Recent trade data also shows a sharp decline in imports from Brazil. Figure 2 shows the trend in US ethanol imports. Before 2004, imports of ethanol mostly came from CBI countries. It was not until 2004 that large amount of exports were sources from Brazil. The MTBE ban and the first RFS were enacted around 2005, which increased ethanol demand in the US, thus prompting significant imports of ethanol. However, domestic production capacity quickly scaled up, and by 2009 imports were down to pre-RFS1 levels, and in 2010 imports were less than 0.05% of total consumption. Imports from Brazil have declined significantly from its peak of 400 million in 2006 down to a negligible 78,6700 in 2010. CBI imports remained at a relatively steady level from 2005-2009 but also dropped significantly to 5 million in 2010. A large portion of ethanol from CBI is produced by importing hydrated ethanol from Brazil and dehydrating the ethanol in the CBI country – thus meeting the requirement of “substantial transformation” for tariff exemption. Thus, tighter supplies of ethanol from Brazil could also limit CBI imports.

Even if imports have decreased, the demand for imports notwithstanding higher prices suggest that the US still need these imports, most likely to augment the gap between domestic production and mandated quantities of advanced biofuels. Given the dependence of CBI exporters on Brazilian feedstock or hydrated ethanol, expansion of sugarcane ethanol production in the future would largely depend on the expansion of sugarcane and ethanol production in Brazil. However, recent price and trade data suggests that Brazil may not be able to meet the demand as easily as previously expected, or demand would be met but at a higher cost. If the tariff were to be removed to encourage more imports, the degree to which sugarcane imports could expand would depend on the elasticity of Brazil’s excess supply curve for sugarcane ethanol. In our analytical and numerical model, we explore the impact of different excess supply elasticities of Brazilian ethanol on the US market for fuel in 2022.

III. Analytical Model

We use an open market partial equilibrium model of the US fuel market, with gasoline and biofuel (corn, sugarcane and cellulosic ethanol) as fuel alternatives. We model gasoline and biofuel trade with the rest of the world. The equilibrium in the fuel market is denoted by:

$$D_F (P_F, t_F) = S_G^D(P_F) + S_G^M (P_F) + S_C (P_C,t_C) + S_{CL}(P_{CL}, t_{CL}) + S_B(P_S,t, t_C) + S_J (P_S,t,t_C) \quad (1)$$

where D_F is the total demand for fuel, S_G^D and S_G^M are supplies of domestic and imported gasoline, and S_C and S_{CL} are domestic supplies of corn and cellulosic ethanol. The last two terms in Equation (1) are supplies of imported ethanol from Brazil (S_B) and CBI countries (S_J). Quantities demanded and supplied are functions of prices and taxes, subsidies, or tariffs. The volumetric fuel tax is denoted by t_F, t is the import tariff, and t_C and t_{CL} are tax credits for traditional and cellulosic ethanol, respectively.

Because of the provisions of the RFS mandate, the following conditions also hold:

$$Q_B^{MAN} \leq S_C + S_{CL} + S_B + S_J$$

$$Q_A^{MAN \leq} S_{CL} + S_B + S_J \text{ if } Q_C^{CAP} = S_C \text{ or}$$

$$Q_A^{MAN \leq} S_{CL} + ((S_B + S_J) - (Q_C^{CAP} - S_C)) \text{ if } Q_C^{CAP} > S_C$$

$$Q_{CL}^{MAN \leq} S_{CL}$$

$$Q_C^{CAP} \geq S_C$$

where Q_B^{MAN} is the total biofuel mandate, Q_A^{MAN} is the advanced biofuel mandate, Q_{CL}^{MAN} is the cellulosic mandate, and Q_C^{CAP} is the maximum allowed quantity of starch based (i.e. corn) ethanol.

We assume that the ethanol and gasoline are perfect substitutes. Ultimately, the consumer buys fuel to produce miles. The consumer is indifferent about the type of fuel used to produce miles. However, the consumer is aware that a gallon of ethanol could only produce a fraction of the miles that could be produced from gasoline. Let λ be the ratio of the energy content of a gallon of ethanol and gasoline. The consumer is willing to pay an ethanol price (P_E) of at most (λP_G), where P_G is the price of gasoline. In addition, as noted by de Gorter and Just (2010) the consumer faces an additional penalty for purchasing ethanol because the fuel tax is levied on a per gallon basis. Thus, the consumer pays more tax per mile driven when they purchase ethanol. Using this representation, $P_E = \lambda P_G + (1 - \lambda) t_F$, and $P_F = P_G$ in equilibrium. Because the mandate is imposed on blenders (that is, they have to sell the mandated quantities at the pump), blenders bear the cost in the event that the producer price of ethanol is above the retail price of fuel.

Our interest is to examine the impact of removing the ethanol tariff in the presence of a mandate and a tax credit. The individual and combined effects of the mandate and the tax credit have been the subject of several previous studies (Ando *et al.* 2010;De Gorter and Just 2008;De Gorter and Just 2010). A comprehensive treatment of the interaction of these two policies, along with the tariff could be found in de Gorter and Just (2010). We devote the subsequent discussion on the primary focus of the paper, *viz,* the effect of the tariff.

Assume that the RFS is binding, and that the cost of cellulosic ethanol is high enough such that it is unlikely that it could be competitive with corn or sugarcane ethanol, for reasonable production levels. As shown in Figure 3, the producer price of cellulosic ethanol is P_{CL}, and the produced quantities are at Q_{CL}^{MAN}, equal to the cellulosic mandate. The production of corn ethanol is at the RFS cap (Q_C^{CAP}), and the producer price is P_C^{CAP}. On the right panel is ethanol trade with Brazil.[2] The excess demand curve is kinked because there is a fixed demand of $Q_B^T = Q_A^{MAN} - Q_{CL}^{MAN}$ which is the portion of the advanced biofuel mandate that could not be met by cellulosic ethanol production. If the US wants to fulfill the advanced biofuel requirement, it will import ethanol that would meet the remainder of the advanced biofuel mandate from Brazil, as long as its price is below P^{CL}. If in equilibrium, the price of sugarcane ethanol is lower than that of corn ethanol at the cap, additional ethanol will be imported in excess of Q_B^T. In this case, sugarcane ethanol is meeting the balance of the advanced biofuel requirement, while also competing for market share in the traditional biofuel category.

In the scenario depicted by Figure 3, removing the tariff reduces the price of imported sugarcane from P_{B1}^T to P_{B1}^{NT}. Since P_{B1}^{NT} is higher than P_C^{CAP}, removing the tariff has no impact on domestic biofuel production except to increase the price of sugarcane ethanol imports. Contrast this to Figure 4, which shows the case with a more elastic excess supply of sugarcane imports. In the initial equilibrium with the tariff, imported ethanol is at Q_B^T, while the price is P_{B2}^T. However, once the tariff is removed, the price of sugarcane ethanol drops to P_C^{NT}, which is lower than P_C^{CAP}. Without the tariff, sugarcane ethanol displaces corn ethanol and takes market share away from corn ethanol in the traditional biofuel market category.

Now, let’s proceed to the case in which cellulosic ethanol could be competitive with corn and sugarcane ethanol (either because corn and sugarcane ethanol is costly, or the cost of cellulosic ethanol production has gone down, or both). Figure 5 shows the supply curves of cellulosic, corn and sugarcane ethanol. The bold dotted line represents the advanced biofuel mandate. As mentioned earlier, a portion of the advanced biofuel mandate has to be met by cellulosic biofuel The bold, dashed line on the first panel represents the cellulosic ethanol mandate. To the left of M_{CEL}, production of cellulosic ethanol is fixed at that amount. To the right, production can exceed M_{CEL}, and is given by the cellulosic ethanol supply curve ($S_{CELLULOSIC}$). The middle panel shows the total domestic supply and demand curves of corn and advanced biofuel, where advanced biofuel refers to cellulosic production in excess of M_{CEL}.

The third panel shows the excess supply of sugarcane ethanol from Brazil, as well as the excess demand of advanced and/or corn ethanol. Note that only US cellulosic production can meet the cellulosic ethanol mandate, which is why the excess demand is for advanced or corn

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[2] In the numerical simulation, we separate trade with CBI countries, and Brazil where only Brazilian imports are levied the tariff.

ethanol only. Note that in contrast to Figures 3 and 4, the excess demand curve has no vertical portion. This is due to the presence of a competitive cellulosic ethanol industry which could also supply advanced biofuel.

With the tariff in place, cellulosic ethanol production is at $Q_{CL}^{1} = M_{ADV}$, which means that it is meeting both the cellulosic mandate, as well as the total advanced biofuel mandate. Corn ethanol is also at its cap. If the tariff is removed, sugarcane ethanol displaces both cellulosic and corn ethanol, so that cellulosic ethanol decreases to just meeting the cellulosic ethanol mandate, and corn ethanol production falls below the cap.

Based on Figure 5, the tariff protects only the corn ethanol market if the equilibrium price (P^*) upon removal of the tariff is lower than the marginal cost of corn ethanol at the cap. i.e. $P^* < P_C^{CAP}$. The tariff protects only the cellulosic ethanol market if $P^* > P_C^{CAP}$ and $P^* < P_{CL}(Q_A^{MAN})$. Lastly, the tariff protects both corn and cellulosic ethanol market if $P^* < P_C^{CAP}$ and
$P_{CL}(Q_{CL}^{MAN}) < P^* < P_{CL}(Q_A^{MAN})$.

To see the effect of behavioral parameters such as supply elasticities on the likelihood that sugarcane imports will affect either or both the corn ethanol and advanced biofuel industry, we use the following notation:

$$S_C = (P_C)^{\gamma}$$
$$S_{CL} = (P_{CL})^{\alpha}$$
$$S_S = (P_S)^{\sigma}$$

where S_i and P_i, $i = C, S, CL$ are supply curves and prices for corn, sugarcane and cellulosic ethanol respectively, and γ, α and σ are supply elasticities. Imports of sugarcane ethanol classified as advanced biofuel are positive if the equilibrium price (P^*) is less than the marginal cost of cellulosic ethanol at the mandated advanced biofuel quantity. This means that at $P^* = P_{CL}(Q_A^{MAN})$, $S_S(P^*)$ is positive.

The following condition can also be expressed as:

$$S_S(P_{CL}(Q_A^{MAN})) > 0$$
$$(P_{CL}(Q_A^{MAN}))^{\sigma} > 0$$
$$((Q_A^{MAN})^{1/\alpha})^{\sigma} > \qquad (2)$$

Equation (2) implies that the likelihood of sugarcane ethanol affecting the advanced biofuel market is increased by (1) a greater sugarcane supply elasticity (2) a smaller cellulosic biofuel elasticity and (3) a greater mandated quantity of advanced biofuel.

Imports of sugarcane ethanol classified as traditional biofuel are positive if the equilibrium price is lower than the price of corn ethanol at the cap. This means that at $P^* =$

P_C^{CAP}, the supply of sugarcane ethanol after meeting the advanced biofuel requirement is positive. This condition can be expressed as:

$$\begin{aligned}
&S_S(P_C^{CAP}) - (Q_A^{MAN} - S_{CL}(P_C^{CAP})) > 0\\
&(P_C^{CAP})^{\sigma} - (Q_A^{MAN} - S_{CL}(P_C^{CAP})) > 0\\
&((Q_C^{CAP})^{1/\gamma})^{\sigma} - Q_A^{MAN} + ((Q_C^{CAP})^{1/\gamma})^{\alpha} > 0
\end{aligned} \tag{3}$$

Equation (3) implies that the likelihood of sugarcane ethanol affecting the corn ethanol market is increased by (1) a greater sugarcane supply elasticity (2) a greater cellulosic biofuel supply elasticity (3) a smaller corn ethanol supply elasticity, and (4) a smaller advanced biofuel mandate.

IV. Numerical Simulation

To assess the magnitude of the impact of the tariff along with other existing policies, we conduct a numerical simulation. Using 2009 data to calibrate the model, we project the situation in the US fuel market in 2022. The following scenarios are evaluated: No Policy, Mandate with tariff and tax credit for traditional and cellulosic biofuel, Mandate with tax credit for traditional and cellulosic biofuel (no tariff), and Mandate with tax credit for cellulosic biofuel (no tariff and traditional biofuel tax credit).

In defining supply elasticities, it is important to distinguish between short run and long run estimates. Because of our forward looking analysis, we use long run elasticities. The short production period and constant structural changes in the biofuel market have constrained rigorous econometric estimation of supply and demand elasticities for biofuel markets. Gallagher *et al.* (2003) reported a value of 1.5 for corn supply elasticity. More recently, Miranowski (2007) reported short-run elasticities of demand and supply to be -0.89 and 0.29 respectively. From this Gardner (2007) used a range of 1 to 5 for the long run supply elasticity. Following Gardner, we assume a long-run elasticity of 3 for corn and cellulosic ethanol, and perform sensitivity analysis using a range of 1 to 5. For the supply elasticity of imported sugarcane ethanol, Lee and Sumner (2010) estimate the short run elasticity to be 2.7. For the long run, we assume a value of 30 and test sensitivity using lower values of 3 and 10. For CBI countries, we assume that the excess supply elasticity is 3. CBI production is capacity constrained and relies mostly on Brazil for feedstock supply (Petrojam Ethanol 2007;Yacobucci 2008). Thus if the tariff were to be removed, most sugarcane imports is likely to come directly from Brazil.

About half of petroleum derived motor fuel consumed in the US is imported, while the rest is produced domestically (DOE 2010). Thus, we have two supply curves for gasoline: domestic and imported. For domestic gasoline supply, we use a long run elasticity of 0.4, based on estimates reported by Green and Ahmad (2005). Most recent estimates ranged from 0.2 to 0.6. The import supply elasticity of oil facing the US is determined both by the response of oil suppliers, and net importers of oil in the rest of the world (Leiby 2008). Leiby (2008) report that when the net effect of these two responses are taken into account, the import supply elasticity of oil lies between 4.3 to 18, with a 90% Confidence Interval and a mean of 8.9. Thus, we thus use a value of 9 for the supply elasticity of imported gasoline. For fuel demand elasticity, we use the estimate for gasoline demand of -0.4, with a range of -0.2 to -0.6 following previous literature (Greene and Ahmad 2005;Parry and Small 2005).

We also use 2009 market data to calibrate the model. Ethanol and gasoline prices are \$1.79 and \$1.76 per gallon (Omaha wholesale free-on-board average rack price) (NEB 2011). The cost of sugarcane ethanol from Brazil at the US port without tariff is \$1.8 per gallon, while for sugarcane ethanol from CBI countries, the cost is \$1.9 per gallon. A markup of \$0.30 per gallon and taxes of \$0.38 per gallon are added to get the retail prices of ethanol and gasoline. There is no reliable market data for the cost of cellulosic ethanol at the moment, since commercial production does not yet exist. Using the cost of feedstock from grasses and other cellulosic material, as well as projected processing costs, some studies have estimated the cost of producing cellulosic ethanol in 2022 (Khanna 2008;Chen 2011). We use a range of \$2-\$4 per gallon, with a central value of \$3 for the cost of cellulosic ethanol is 2022, assuming that production levels are in line with the mandate.

In 2009, 10.6 B gallons of ethanol was produced (RFA 2011). RFA also reports that total ethanol imports for the same year are 0.13 B gallons which brings total demand to 10.73 B gallons. According to the US ITC, of the 13 million in ethanol imports, 4 million were from Brazil, and the rest were from CBI countries, primarily Jamaica (USITC 2011). According to the Energy Information Administration, total gasoline consumed in 2009 was 125 B gallons (EIA 2011). The US Federal Highway Authority also reported that miles driven in 2009 was 3500 billion miles (FHA 2011).

In order to obtain estimates of the cost of fuel externalities, we assume that the marginal damage of a metric ton of carbon emission is \$25, based on Parry and Small (2005). We set emissions intensities for the different fuels based on several sources, including estimates used by the EPA in the RFS ruling. Emissions intensity of gasoline from “well to wheel” is 3.1 kg CO_2 per gallon or 93 kg CO_2 per MJ. For corn ethanol, the emissions intensity is 1.3 kg CO_2/gallon or 58 kg CO_2/MJ while for sugarcane ethanol, the value is 0.5 kg CO_2/gallon or 25 kg CO_2/MJ. For cellulosic ethanol, we use the average for miscanthus (-19.3 kg CO_2/MJ or -0.4kg CO_2/gal) and switchgrass (-8.7 kg CO_2/MJ or -0.2kg CO_2gal) (EPA 2010;Khanna *et al.* 2011). The emissions intensities above imply that for an equal energy content, corn ethanol emits about 37% less carbon than gasoline while sugarcane ethanol emits 73% less. Cellulosic ethanol reduces emissions by 109%.

A. Results

A.1 Market Effects

Table 1 shows the simulation results using central estimates for model parameters, with varying costs of cellulosic ethanol and learning rate for corn ethanol production. In 2022, with the mandate, tax credits, and tariff in place, and cost of cellulosic ethanol production at $3, domestic production of corn and cellulosic ethanol are at the mandated levels. Imports of sugarcane ethanol are at 3.81 billion, while imports from CBI countries are 19 million. Imports fill the gap between the total advanced biofuel mandate, and cellulosic ethanol production. With the removal of the tariff, sugarcane ethanol displaces domestic corn ethanol, which decreases 37% to 9.43 billion gallons. Some CBI imports are displaced as well. Since sugarcane ethanol cannot meet the cellulosic mandate, cellulosic production stays at 16 billion. Removing the non-cellulosic ethanol subsidy does not change the mix of fuels in the market but primarily affects government revenue and welfare of blenders who receive the subsidy.

Assuming that cellulosic ethanol is less costly to produce ($2 per gallon at 16 billion gallons), with the tariff in place, the production of cellulosic ethanol is above the mandated level of cellulosic ethanol, at 18.57 billion gallons. Sugarcane ethanol imports total 1.43 billion gallons. However, once the tariff is removed, sugarcane ethanol displaces cellulosic ethanol in the advanced biofuel market, and also displaces domestic corn ethanol production. Cellulosic biofuel production goes down by 14%, while corn ethanol production goes down by 37%. Once the subsidy to corn and sugarcane ethanol is removed, cellulosic ethanol takes market share from both biofuels, increasing in production to 18.43 billion gallons, while corn and sugarcane ethanol production decreases to 9.18 and 7.29 billion gallons, respectively.

The last set of results show the case with cellulosic ethanol still at $2 per gallon, but the production cost of corn ethanol decreases by 30%. Several studies have shown that the production of biofuel has shown declining costs, as producers gain experience in production. Hettinga et al. (2009), study the evolution of corn ethanol production costs and concluded that from the early-1980 to 2005, production costs have decline by 60%. They estimate that in 2020, corn ethanol production cost could further decrease by 28-44% due solely to technical learning. We assume a cost reduction of 30% for corn ethanol. In this case, removing the tariff only causes displacement of cellulosic ethanol while corn ethanol production stays at its cap of 15 billion gallons. Removing the tax credit along with the tariff does not change the relative competitiveness of corn and sugarcane ethanol. However, without the tax credit, cellulosic ethanol is more competitive with sugarcane ethanol, thus is it able to take market share away from sugarcane ethanol.

A.2 Welfare Impacts

The welfare changes due to the removal of the tariff accrue to ethanol producers, blenders and the government. Fuel consumers are not impacted by the removal of the tariff because the retail price of gasoline does not change due to the assumption that the biofuel mandate is binding.

The removal of the tariff decreases the domestic price of ethanol, with blenders who purchase ethanol being the main beneficiary of the price decrease. In the scenario with no corn ethanol cost reduction and $3 cellulosic ethanol, blender surplus increases by 7.5 billion with the removal of the tariff, relative to the scenario with mandate, subsidies and tariff. However this welfare gain is more than offset when the non-cellulosic tax credit is removed as well, because the wholesale price of ethanol increases. With the removal of the tariff, ethanol producer surplus declines due to the decrease in market share. This loss is further increased if the tax credit is also removed. Welfare loss is greatest in the case with low cost ($2 per gallon) cellulosic ethanol because removing the tariff and tax credit also leads to cellulosic ethanol taking some market share.

When the cost of cellulosic ethanol is uncompetitive with sugarcane and/or corn ethanol, as is the case when the cost of production is $3, removing the tariff has no welfare effect on cellulosic ethanol producers since their production in all scenarios is equal to the mandated quantity. However, when cellulosic ethanol is competitive with sugarcane ethanol, the tariff serves to "protect" the cellulosic ethanol market. Thus, removing the tariff reduces welfare of cellulosic ethanol producers. On the other hand, this loss is mitigated if the tax credit for traditional biofuels is removed as well, since the tax credit increases the competitiveness of corn and sugarcane ethanol with cellulosic ethanol.

The change in government revenue with the removal of the tariff depends on which domestic ethanol market the tariff is protecting. If the cellulosic industry is uncompetitive with the sugarcane ethanol industry, government revenue decreases with the removal of the tariff (due to lower tariff revenues). Government revenues increase with the removal of the tariff and subsidy because the government's expenditures on the subsidy decrease. However, when the cellulosic industry is competitive with the sugarcane ethanol industry, government revenues increase with the removal of the tariff, because sugarcane ethanol replaces cellulosic ethanol. When this replacement occurs, the government does not have to subsidize cellulosic ethanol production above the mandate. Since the cellulosic ethanol subsidy is higher than the tariff per gallon ethanol, government revenue increases.

In general, domestic welfare increases with the removal of the tariff. However, the removal of the subsidy for corn and sugarcane ethanol could reduce the welfare gains from removing the tariff. This occurs when the removal of the subsidy for traditional biofuels leads to an increase in cellulosic ethanol production. Welfare decreases, relative to the case when only the tariff is removed because the reduction in deadweight loss from the subsidy for traditional biofuels is offset by the increase in deadweight loss from the provision of cellulosic ethanol subsidy, which is greater than the tariff and tax credit. Thus, from a purely social surplus perspective, it may not be beneficial to remove both the tariff and tax credit if a cellulosic subsidy is also in place.

In terms of greenhouse gas emissions, the direction of the change is ambiguous when the tariff (and tax credit) is removed. When removing the tariff leads to sugarcane ethanol displacing mostly corn ethanol, as is the case when cellulosic ethanol is uncompetitive with other biofuels, greenhouse gas emissions decrease. On the other hand, when cellulosic ethanol competes with sugarcane ethanol in the advanced biofuel market, and removing the tariff causes cellulosic ethanol to be displaced by sugarcane ethanol, greenhouse gas emissions increase.

The scenario with the mandate, subsidy, and tax credit yields the highest share of domestic fuel production. Removing the tariff leads to the lowest share of domestic fuel production. The effect of removing the tariff on fuel security is relatively large (5% decrease from 60% to 55%) in the case where sugarcane ethanol displaces both corn and cellulosic ethanol. In the case with a reduction in cost of corn ethanol production, the share of domestic fuel production is fairly high in all policy scenarios, ranging from 58% to 60% because sugarcane ethanol does not displace corn ethanol in any of the policy scenarios. On the other hand, emission levels are also relatively high, compared to the case when corn ethanol has no learning advantage. This is because corn ethanol is more GHG intensive than sugarcane ethanol, so the lack of market displacement of corn ethanol with the removal of the tariff limits the emissions reduction that could be achieved.

B. Sensitivity Analysis

Tables 3 – 8 show selected results from the sensitivity analysis. The simulations show results assuming central parameter values for those parameters not being varied, and cellulosic ethanol production cost of $3 per gallon. Table 3 shows that if the excess supply elasticity of Brazilian sugarcane ethanol is lower (3 or 10), removing the tariff does not affect corn ethanol production. If the elasticity is 3, cellulosic ethanol production is above the mandate, with and without the tariff. When the elasticity is 10, removing the tariff decreases cellulosic ethanol production to the mandated level. This is in contrast to the central case, where removing the tariff does not impact cellulosic ethanol (which stays at 16 billion gallons), while removing the tariff decreases corn ethanol production.

If the cost of cellulosic ethanol is $2/gallon, and sugarcane ethanol excess supply elasticity is either 3 or 10, removing the tariff will not impact corn ethanol production, and will have little impact on cellulosic ethanol production. The welfare effects are also minimal. With cellulosic ethanol cost at $3, a low elasticity of sugarcane ethanol leads to an overall loss in domestic welfare when the tariff is removed (Table 4). This is different from the result of other scenarios, where the removal of the tariff almost always leads to a welfare gain. When the tariff is removed, there is a slight decrease in the production of cellulosic ethanol which leads to a decrease in producer surplus. Government revenues also decrease due to the loss in the tariff revenue. However, because prices of advanced biofuel remain high (over $3) and do not drop with the removal of the tariff , blenders’ gain from the removal of the tariff in minimal, causing an overall loss in welfare.

In terms of externality impacts, a lower elasticity of sugarcane ethanol leads to an increase in GHG emissions when the tariff is removed. This is because removing the tariff causes sugarcane ethanol to displace only cellulosic ethanol, thus leading to greater emissions. In addition, lower sugarcane ethanol elasticities also lead to a greater overall share of domestic fuel production, and a smaller impact of removing the tariff on the share of domestically produced fuel.

Tables 5 and 6 show market and welfare changes when the supply elasticity of cellulosic ethanol is varied. With a cellulosic ethanol price of $3, differences in the supply elasticity of cellulosic ethanol do not affect the market outcome of removing the tariff since cellulosic ethanol production remains at 16 billion gallon in all scenarios. If cellulosic ethanol is priced at $2, and cellulosic ethanol is less elastic, the imports displaced by cellulosic ethanol when the tariff is removed is smaller. Because of the steeper supply curve, the loss of cellulosic ethanol producers is greater with a lower elasticity when the tariff is removed, although the change in quantity produced with and without the tariff is smaller. Blenders gain more because of the greater reduction in prices. In addition government revenues also decrease because of the reduction in tariff revenue. Total domestic welfare gain from the removal of the tariff is lower. On the other hand, if cellulosic ethanol supply is more elastic, there is greater displacement of cellulosic ethanol (and corn ethanol) when the tariff is removed. However, because the supply curve is flatter, the welfare loss is smaller. In contrast to the less elastic case, government revenue increases with the removal of the tariff because there is a greater decrease in expenditures for subsidizing cellulosic ethanol. Domestic net welfare gain is larger.

Table 7 and 8 show the market and welfare changes when the supply elasticity of corn ethanol is varied. Similar the case of cellulosic ethanol, a greater supply elasticity of corn ethanol leads to a greater reduction in corn ethanol production with the removal of the tariff, and a greater increase in sugarcane ethanol imports. Welfare loss for corn ethanol producers and the government is smaller when the supply elasticity is flatter. However, a flatter corn ethanol supply curve also means that blenders' gain from the reduction in price is lower. Thus, there is no clear trend in the change in net domestic surplus. The greatest reduction in GHG emissions is achieved when corn ethanol is most elastic, because larger amounts of corn ethanol are displaced by sugarcane ethanol. However, this also leads to the largest drop in the share of domestically produced fuel.

V. Conclusions

This study has demonstrated that in the presence of nested mandates, and different types of biofuel, the market and welfare impact of removing the tariff is ambiguous. Generally, removing the tariff in the presence of a mandate leads to increased welfare, as the price of biofuels decreases. An exception is the case when the excess supply elasticity of sugarcane ethanol is not very elastic. In this case, removing the tariff increases the demand for cellulosic ethanol, which is costly and highly subsidized, thus leading to a net welfare loss.

Depending on the relative cost of biofuels, the tariff could be protecting different biofuel markets. When the cost of cellulosic ethanol is high and not competitive with sugarcane ethanol, the tariff has no impact cellulosic ethanol production; it only protects the corn ethanol industry. However, when the cost of cellulosic ethanol is low and competitive with sugarcane ethanol, the tariff also serves to protect the cellulosic ethanol industry.

Removing the tariff either maintains or decreases the share of domestically produced fuels. On the other hand, depending on which market the tariff protects, GHG emissions could increase or decrease. When the tariff is only protecting the corn ethanol market, GHG emissions decrease with the removal of the tariff. Conversely, when the tariff is only protecting the advanced biofuel market, GHG emissions increase with the removal of the tariff. When the tariff is protecting both the advanced and corn ethanol industry, the effect of removing the tariff on GHG emissions is ambiguous and would depend on the relative emissions intensities, as well as the quantity of traditional and advanced biofuel displaced by sugarcane ethanol.

The results in this paper show that in terms of biofuel policy objectives, removing the tariff may not advance all of the goals of biofuel policy. Generally removing the tariff increases social surplus. However, it decreases the share of domestic fuel production and the effect on GHG emissions is ambiguous. Thus, if the government wants to increase energy security by increasing the share of domestic fuel production through protecting domestic industries with a tariff, it has to trade-off this benefit for lower social welfare and possibly higher emissions level. It may be impossible for one policy intervention to advance all the goals of bioenergy policy. However, a clear understanding of what goals are achieved by a particular policy intervention brings us one step closer to designing a set bioenergy policies that achieves their stated objectives.

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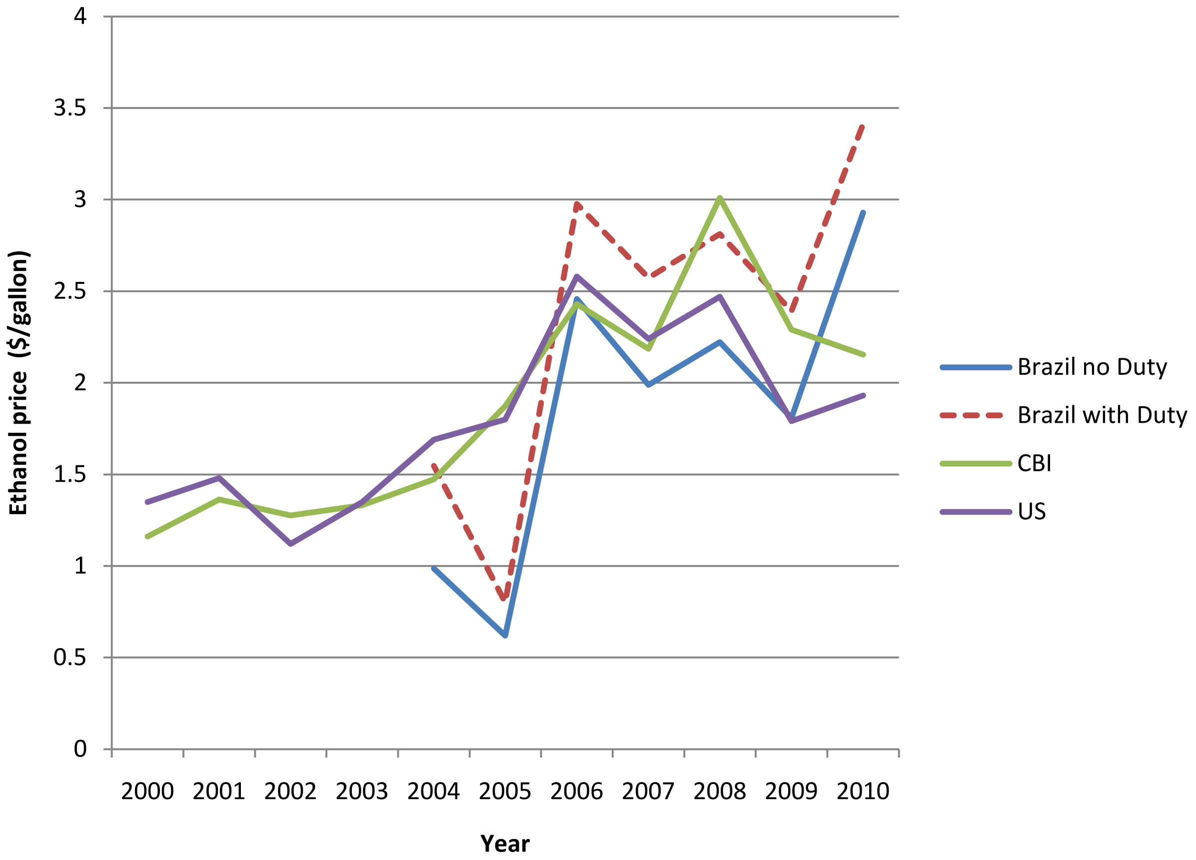

Figure 1. Ethanol domestic wholesale price and cost at port

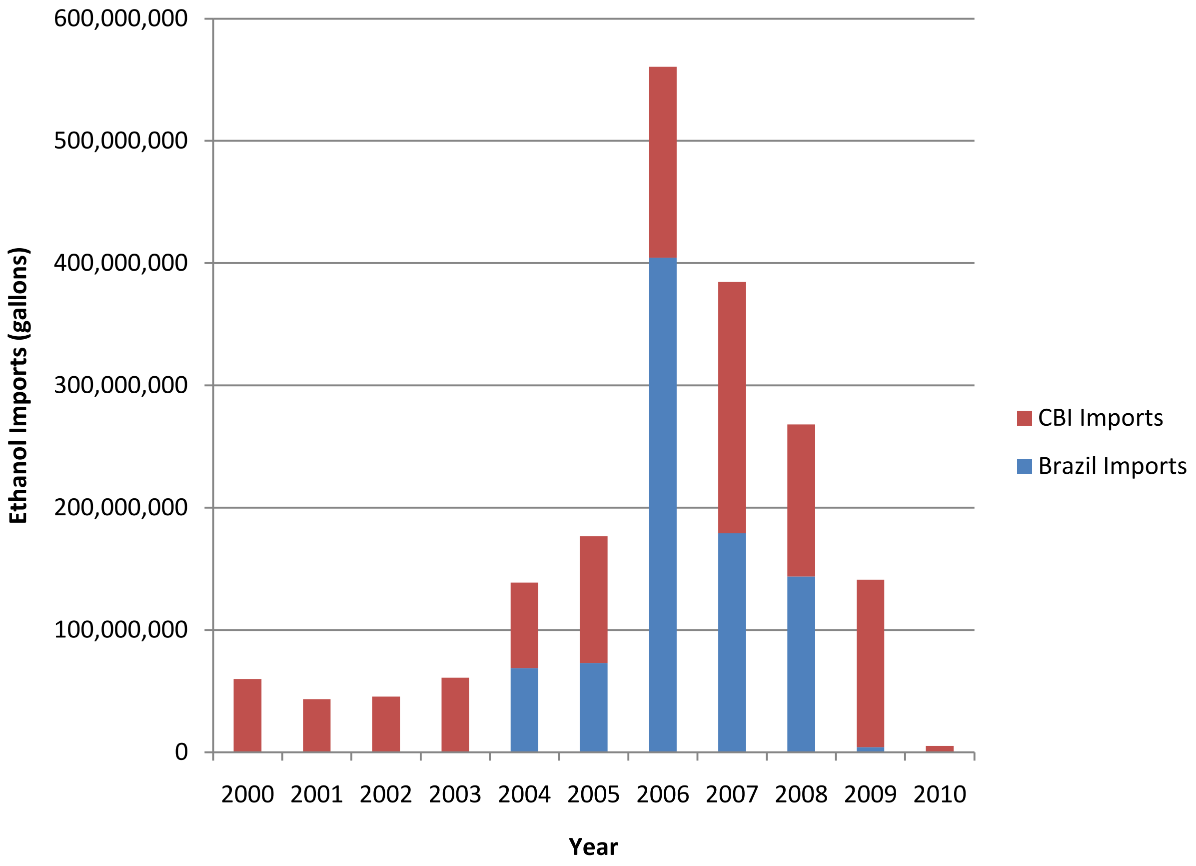

Figure 2. Ethanol Imports

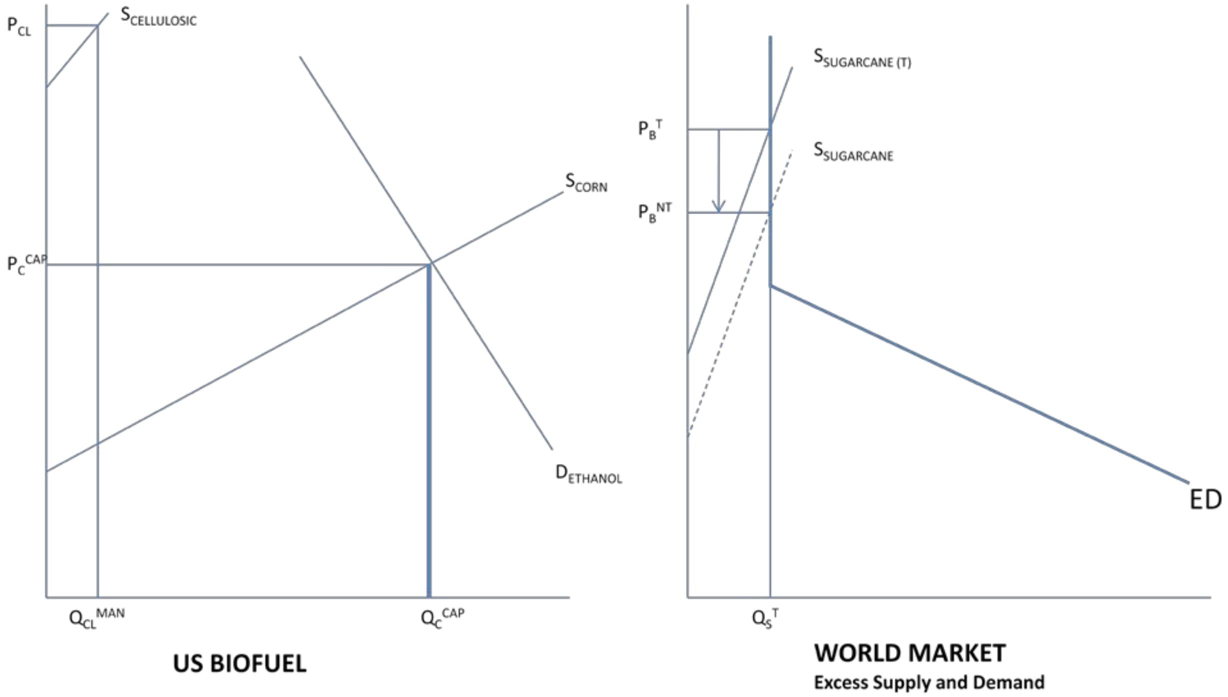

Figure 3. Domestic and world ethanol market

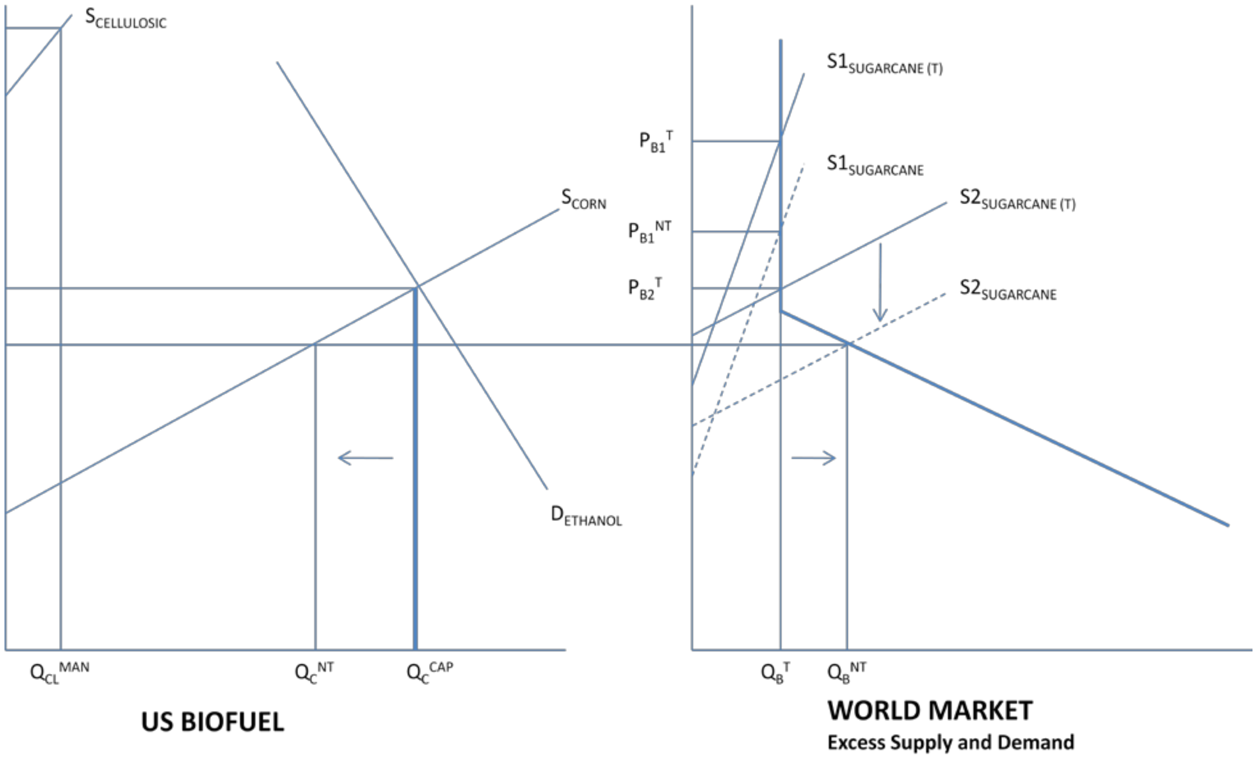

Figure 4. Effect of sugarcane supply elasticity on market outcome of removing tariff

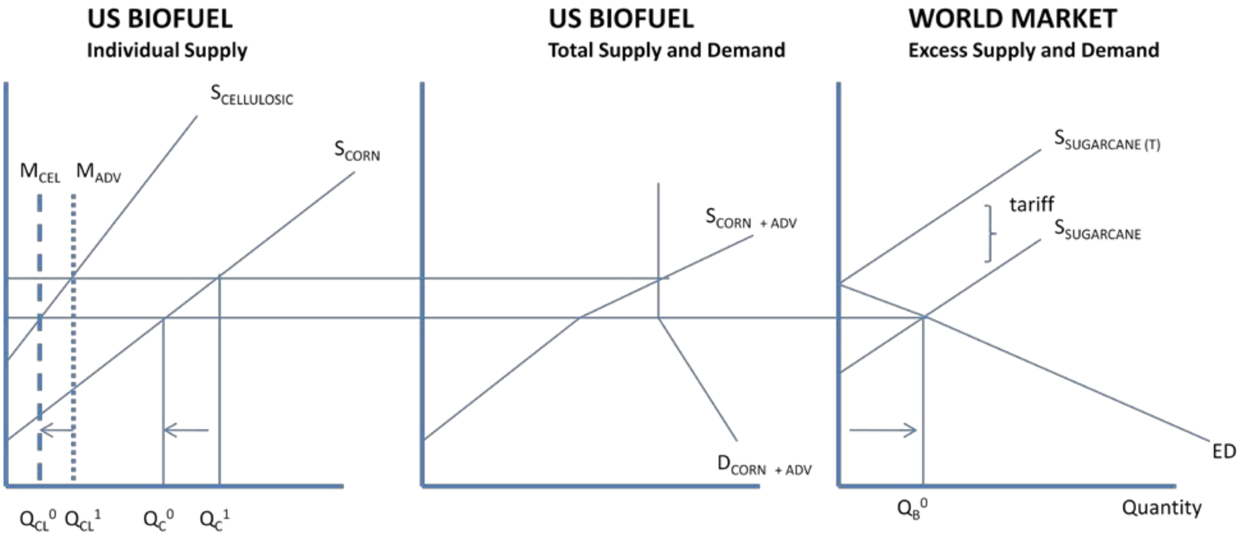

Figure 5. Domestic and world ethanol market with a competitive cellulosic industry

Table 1. Market Effects of Removing Tariff and Traditional Biofuel Tax Credit

Assumptions	**Cellulosic Cost at 16 B: \$3 Corn ethanol cost reduction: 0%**			**Cellulosic Cost at 16 B: \$2 Corn ethanol cost reduction: 0%**			**Cellulosic Cost at 16 B: \$2 Corn ethanol cost reduction: 30%**		
Policies	**MAN** t_C, t_{CL} **t**	**MAN** t_C, t_{CL}	**MAN** t_{CL}	**MAN** t_C, t_{CL} **t**	**MAN** t_C, t_{CL}	**MAN** t_{CL}	**MAN** t_C, t_{CL} **t**	**MAN** t_C, t_{CL}	**MAN** t_{CL}
Prices (\$)*									
Corn Ethanol	2.08	1.71	2.16	2.08	1.71	2.14	1.47	1.47	1.92
Imported Ethanol	2.23	1.71	2.16	2.15	1.71	2.14	2.15	1.65	2.07
Cellulosic Ethanol	3	3	3	2.15	2	2.14	2.15	2	2.07
Gasoline	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
Fuel (Retail)	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44
Quantities (billion gallons)									
Ethanol Demand	35	35	35	35	35	35	35	35	35
Corn Ethanol	15	9.43	9.43	15	9.43	9.18	15	15	15
Imported Ethanol (Brazil)	3.81	9.47	9.47	1.26	9.47	7.29	1.26	3.91	2.69
Imported Ethanol (CBI)	0.19	0.1	0.1	0.17	0.1	0.1	0.17	0.09	0.09
Cellulosic Ethanol	16	16	16	18.57	16	18.43	18.57	16	17.23
Gasoline Demand	125.92	125.92	125.92	125.92	125.92	125.92	125.92	125.92	125.92
Domestic Gasoline Supply	62.54	62.54	62.54	62.54	62.54	62.54	62.54	62.54	62.54
Gasoline Imports	63.38	63.38	63.38	63.38	63.38	63.38	63.38	63.38	63.38
Externalities									
GHG Emissions (B kg CO_2)	1477.6	1462.8	1462.8	1469.6	1462.8	1454.6	1469.6	1477.6	1473.8
Share of Domestic Fuel Production	0.58	0.55	0.55	0.60	0.55	0.56	0.60	0.58	0.59

*All prices are wholesale blender prices, except for fuel.

Table 2. Welfare Effects of Removing Tariff and Traditional Biofuel Tax Credit (B US$)

Assumptions	**Cellulosic Cost at 16 B: $3 Corn ethanol cost reduction: 0%**			**Cellulosic Cost at 16 B: $3 Corn ethanol cost reduction: 0%**			**Cellulosic Cost at 16 B: $2 Corn ethanol cost reduction: 30%**		
Policies	**MAN** **t_C, t_{CL}** **t**	**MAN** **t_C, t_{CL}**	**MAN** **t_{CL}**	**MAN** **t_C, t_{CL}** **t**	**MAN** **t_C, t_{CL}**	**MAN** **t_{CL}**	**MAN** **t_C, t_{CL}** **t**	**MAN** **t_C, t_{CL}**	**MAN** **t_{CL}**
Corn Ethanol Producer Surplus		-4.37	-4.37		-4.37	-4.55		0.00	0.00
Cellulosic Ethanol Producer Surplus		0.00	0.00		-2.64	-0.15		-2.64	-1.40
Blender Surplus		7.50	-1.05		8.90	-0.87		3.56	-5.19
Government Revenue		-2.21	6.34		0.69	6.80		0.69	8.01
Net Domestic Welfare Change		0.91	0.91		2.57	1.23		1.60	1.43

Table 3. Sensitivity analysis: effect of sugarcane ethanol elasticity on market impacts

Assumptions	**Sugarcane ethanol elasticity = 3**			**Sugarcane ethanol elasticity = 10**			**Sugarcane ethanol elasticity = 30**		
Policies	**MAN** **t_C, t_{CL}** **t**	**MAN** **t_C, t_{CL}**	**MAN** **t_{CL}**	**MAN** **t_C, t_{CL}** **t**	**MAN** **t_C, t_{CL}**	**MAN** **t_{CL}**	**MAN** **t_C, t_{CL}** **t**	**MAN** **t_C, t_{CL}**	**MAN** **t_{CL}**
Prices ($)*									
Corn Ethanol	2.08	2.08	2.53	2.08	2.08	2.53	2.08	1.71	2.16
Imported Ethanol	3.27	3.27	3.28	3.16	2.85	3.13	2.23	1.71	2.16
Cellulosic Ethanol	3.27	3.27	3.28	3.16	3	3.13	3	3	3
Gasoline	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
Fuel (Retail)	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44
Quantities (billion gallons)									
Ethanol Demand	35	35	35	35	35	35	35	35	35
Corn Ethanol	15	15	15	15	15	15	15	9.43	9.43
Imported Ethanol (Brazil)	0.03	0.04	0.03	1.55	3.65	2.12	3.81	9.47	9.47
Imported Ethanol (CBI)	0.5	0.5	0.34	0.46	0.35	0.3	0.19	0.1	0.1
Cellulosic Ethanol	19.47	19.46	19.63	18	16	17.58	16	16	16
Gasoline Demand	125.92	125.92	125.92	125.92	125.92	125.92	125.92	125.92	125.92
Domestic Gasoline Supply	62.54	62.54	62.54	62.54	62.54	62.54	62.54	62.54	62.54
Gasoline Imports	63.38	63.38	63.38	63.38	63.38	63.38	63.38	63.38	63.38
Externalities									
GHG Emissions (B kg CO_2)	1466.8	1466.8	1466.3	1471.4	1477.6	1472.7	1477.6	1462.8	1462.8
Share of Domestic Fuel Production	0.60	0.60	0.60	0.59	0.58	0.59	0.58	0.55	0.55

*All prices are wholesale blender prices, except for fuel.

Table 4. Sensitivity analysis: effect of sugarcane ethanol elasticity on welfare impacts

Assumptions	**Sugarcane ethanol elasticity = 3**			**Sugarcane ethanol elasticity = 10**			**Sugarcane ethanol elasticity = 30**		
Policies	**MAN** $\mathbf{t_C, t_{CL}}$ **t**	**MAN** $\mathbf{t_C, t_{CL}}$	**MAN** $\mathbf{t_{CL}}$	**MAN** $\mathbf{t_C, t_{CL}}$ **t**	**MAN** $\mathbf{t_C, t_{CL}}$	**MAN** $\mathbf{t_{CL}}$	**MAN** $\mathbf{t_C, t_{CL}}$ **t**	**MAN** $\mathbf{t_C, t_{CL}}$	**MAN** $\mathbf{t_{CL}}$
Corn Ethanol Producer Surplus		0.00	0.00		0.00	0.00		-4.37	-4.37
Cellulosic Ethanol Producer Surplus		-0.024	0.219		-2.72	-0.58		0.00	0.00
Blender Surplus		0.025	-6.973		3.50	-6.10		7.50	-1.05
Government Revenue		-0.006	6.819		0.20	7.17		-2.21	6.34
Net Domestic Welfare Change		-0.005	0.063		0.98	0.49		0.91	0.91

Table 5. Sensitivity analysis: effect of cellulosic ethanol elasticity on market impacts

Assumptions	**Cellulosic ethanol elasticity = 1**			**Cellulosic ethanol elasticity = 3**			**Cellulosic ethanol elasticity = 5**		
Policies	**MAN** **t_C, t_{CL}** **t**	**MAN** **t_C, t_{CL}**	**MAN** **t_{CL}**	**MAN** **t_C, t_{CL}** **t**	**MAN** **t_C, t_{CL}**	**MAN** **t_{CL}**	**MAN** **t_C, t_{CL}** **t**	**MAN** **t_C, t_{CL}**	**MAN** **t_{CL}**
Prices ($)*									
Corn Ethanol	2.08	1.71	2.16	2.08	1.71	2.16	2.08	1.71	2.16
Imported Ethanol	2.23	1.71	2.16	2.23	1.71	2.16	2.23	1.71	2.16
Cellulosic Ethanol	3	3	3	3	3	3	3	3	3
Gasoline	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
Fuel (Retail)	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44
Quantities (billion gallons)									
Ethanol Demand	35	35	35	35	35	35	35	35	35
Corn Ethanol	15	9.43	9.43	15	9.43	9.43	15	9.43	9.43
Imported Ethanol (Brazil)	3.81	9.47	9.47	3.81	9.47	9.47	3.81	9.47	9.47
Imported Ethanol (CBI)	0.19	0.1	0.1	0.19	0.1	0.1	0.19	0.1	0.1
Cellulosic Ethanol	16	16	16	16	16	16	16	16	16
Gasoline Demand	125.92	125.92	125.92	125.92	125.92	125.92	125.92	125.92	125.92
Domestic Gasoline Supply	62.54	62.54	62.54	62.54	62.54	62.54	62.54	62.54	62.54
Gasoline Imports	63.38	63.38	63.38	63.38	63.38	63.38	63.38	63.38	63.38
Externalities									
GHG Emissions (B kg CO_2)	1477.6	1462.8	1462.8	1477.6	1462.8	1462.8	1477.6	1462.8	1462.8
Share of Domestic Fuel Production	0.58	0.55	0.55	0.58	0.55	0.55	0.58	0.55	0.55

*All prices are wholesale blender prices, except for fuel.

Table 6. Sensitivity analysis: effect of cellulosic ethanol elasticity on welfare impacts

Assumptions	**Cellulosic ethanol elasticity = 1**			**Cellulosic ethanol elasticity = 3**			**Cellulosic ethanol elasticity = 5**		
Policies	**MAN** t_C, t_{CL} **t**	**MAN** t_C, t_{CL}	**MAN** t_{CL}	**MAN** t_C, t_{CL} **t**	**MAN** t_C, t_{CL}	**MAN** t_{CL}	**MAN** t_C, t_{CL} **t**	**MAN** t_C, t_{CL}	**MAN** t_{CL}
Corn Ethanol Producer Surplus		-4.374	-4.374		-4.37	-4.37		-4.37	-4.37
Cellulosic Ethanol Producer Surplus		0.00	0.00		0.00	0.00		0.00	0.00
Blender Surplus		7.497	-1.053		7.50	-1.05		7.50	-1.05
Government Revenue		-2.212	6.338		-2.21	6.34		-2.21	6.34
Net Domestic Welfare Change		0.911	0.911		0.91	0.91		0.91	0.91

Table 7. Sensitivity analysis: effect of corn ethanol elasticity on market impacts

Assumptions	**Corn ethanol elasticity = 1**			**Corn ethanol elasticity = 3**			**Corn ethanol elasticity = 5**		
Policies	**MAN** t_C, t_{CL} **t**	**MAN** t_C, t_{CL}	**MAN** t_{CL}	**MAN** t_C, t_{CL} **t**	**MAN** t_C, t_{CL}	**MAN** t_{CL}	**MAN** t_C, t_{CL} **t**	**MAN** t_C, t_{CL}	**MAN** t_{CL}
Prices ($)*									
Corn Ethanol	2.26	1.71	2.16	2.08	1.71	2.16	1.96	1.72	2.17
Imported Ethanol	2.26	1.71	2.16	2.23	1.71	2.16	2.23	1.72	2.17
Cellulosic Ethanol	3	3	3	3	3	3	3	3	3
Gasoline	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76	1.76
Fuel (Retail)	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44	2.44
Quantities (billion gallons)									
Ethanol Demand	35	35	35	35	35	35	35	35	35
Corn Ethanol	12.77	10.17	10.17	15	9.43	9.43	15	8.81	8.81
Imported Ethanol (Brazil)	6.03	8.74	8.74	3.81	9.47	9.47	3.81	10.09	10.09
Imported Ethanol (CBI)	0.19	0.1	0.1	0.19	0.1	0.1	0.19	0.1	0.1
Cellulosic Ethanol	16	16	16	16	16	16	16	16	16
Gasoline Demand	125.92	125.92	125.92	125.92	125.92	125.92	125.92	125.92	125.92
Domestic Gasoline Supply	62.54	62.54	62.54	62.54	62.54	62.54	62.54	62.54	62.54
Gasoline Imports	63.38	63.38	63.38	63.38	63.38	63.38	63.38	63.38	63.38
Externalities									
GHG Emissions (B kg CO_2)	1471.7	1464.8	1464.8	1477.6	1462.8	1462.8	1477.6	1461.2	1461.2
Share of Domestic Fuel Production	0.57	0.55	0.55	0.58	0.55	0.55	0.58	0.54	0.54

*All prices are wholesale blender prices, except for fuel.

Table 8. Sensitivity analysis: effect of corn ethanol elasticity on welfare impacts

Assumptions	**Corn ethanol elasticity = 1**			**Corn ethanol elasticity = 3**			**Corn ethanol elasticity = 5**		
Policies	**MAN** $\mathbf{t_C, t_{CL}}$ **t**	**MAN** $\mathbf{t_C, t_{CL}}$	**MAN** $\mathbf{t_{CL}}$	**MAN** $\mathbf{t_C, t_{CL}}$ **t**	**MAN** $\mathbf{t_C, t_{CL}}$	**MAN** $\mathbf{t_{CL}}$	**MAN** $\mathbf{t_C, t_{CL}}$ **t**	**MAN** $\mathbf{t_C, t_{CL}}$	**MAN** $\mathbf{t_{CL}}$
Corn Ethanol Producer Surplus		-6.35	-6.35		-4.37	-4.37		-2.85	-2.85
Cellulosic Ethanol Producer Surplus		0.00	0.00		0.00	0.00		0.00	0.00
Blender Surplus		10.52	1.97		7.50	-1.05		5.70	-2.85
Government Revenue		-3.50	5.05		-2.21	6.34		-2.21	6.34
Net Domestic Welfare Change		0.67	0.67		0.91	0.91		0.64	0.64