TRANSITION TO A BIO ECONOMY

Environmental and Rural Development Impacts

Proceedings of the October 15 and 16, 2008 Conference,
St. Louis, Missouri

Editor
Madhu Khanna
Department of Agricultural and Consumer Economics
Energy Biosciences Institute
University of Illinois at Urbana-Champaign

The conference was a collaboration of Farm Foundation, USDA Office of Energy Policy and New Uses, USDA Economic Research Service, USDA Rural Development, USDA Natural Resources Conservation Service, and the U.S. Forest Service.

The Impact of Ethanol Policy on Social Welfare and GHG Emissions

Christine Lasco and Madhu Khanna[1]

Abstract: We develop a stylized model of fuel markets in an open economy to analyze the impact of ethanol policy on social welfare and greenhouse gas (GHG) emissions. The policies considered here include the $0.51 per gallon blender's subsidy for ethanol and the import tariff of $0.54 per gallon on sugarcane ethanol. Our analysis shows that the combined subsidy and tariff policy decreases welfare by about $3.6 billion relative to a non intervention policy. Furthermore, there are no GHG mitigation benefits since GHG emissions show a slight increase (0.08%) when both policies are in place.

Concerns about energy security and climate change have led to the rapid increase in demand for alternative fuels, particularly ethanol which uses corn as feedstock. The growth of the ethanol industry in the US not only impacts agriculture and energy markets but also environmental quality, primarily through its impact on greenhouse gas emissions from the use of fuel. Policies that regulate the ethanol market have direct implications for social welfare and GHG emissions. Energy policy in the US supports the domestic production of ethanol through several policies including mandates on the use of renewable fuels, a subsidy for blending ethanol with gasoline and a tariff on ethanol imports, notably from Brazil which produces ethanol from sugarcane at a lower marginal cost.

The purpose of this paper is to examine the effects of the $0.51 subsidy on blending ethanol and the $0.54 tariff on imported ethanol on social welfare and GHG emissions. Life-Cycle Analysis (LCA) is a useful tool for measuring GHG emissions from the production and use of different fuel types. We use estimates of GHG emissions of gasoline, corn ethanol and sugarcane ethanol from various LCA studies and use these to differentiate the environmental impact of each fuel type.

Other studies have analyzed the effect of existing biofuel policies on fuel prices, quantities consumed, and social welfare. Gallagher et al. (2003) used a partial equilibrium simulation model to analyze the implication of the national MTBE ban and the implementation of a renewable fuel standard (RFS) on demand for ethanol. They found that the MTBE ban increases the share of ethanol in the additives market, and implementing an RFS with the MTBE ban further increases demand for ethanol. Both policies lead to losses in social surplus, but also improve air quality by decreasing air pollutants. De Gorter and Just (2007a, b) analyzed the implications of the ethanol tax credit and import tariff with and without a binding ethanol mandate for prices and quantities consumed of domestic and imported ethanol and gasoline. They show that under a non-binding mandate, the tax credit for ethanol is a subsidy to producers and that removal of the import tariff would increase imports by 94%. Elobeid and Tokgoz (2006) analyzed the effects of trade liberalization and removal of the tax credit for the prices and quantities of domestic and imported ethanol. Results show that the removal of trade distortions

[1] PhD Candidate and Professor, respectively, at the Department of Agricultural and Consumer Economics, University of Illinois Urbana-Champaign. Please send correspondence to Christine Lasco (mlasco2@illinois.edu).

and the tax credit decreases US ethanol price and increases the world price relative to non-intervention. This leads to a doubling of imports, all of which come from Brazil.

Our paper differs from the existing literature analyzing the impacts of ethanol policy in several important aspects. First, we specify a constant elasticity of substitution production function for miles driven from which ethanol and gasoline demands are derived. Most studies have assumed that ethanol and gasoline are either perfect substitutes (De Gorter and Just, 2007, 2008) or have dominant complementarity (Elobeid and Tokgoz, 2008). The prevailing market condition has features of both substitutability and complementarity. When used as an additive and in E10 fuels, ethanol and gasoline are complements. However, with the advent of E85, ethanol is potentially becoming a substitute for gasoline. Since it is too constraining to impose perfect substitutability or complementarity for gasoline and ethanol, we model gasoline and ethanol as imperfect substitutes with a low elasticity of substitution that recognizes that there are costs and constraints to substituting one fuel for the other. The framework developed here allows us to analyze the effects of changing this elasticity on the market impacts of ethanol policies.

Secondly, in measuring welfare impacts, we take into account environmental damages associated with the production and use of fuels. Although some studies (Gallagher et al., 2003) report impacts on environmental quality, the social costs of these impacts have not been incorporated into welfare measurement. There are a few studies that have addressed this issue. Vedenov and Wetzstein (2008) derive the optimal ethanol subsidy taking into account policy impacts on energy security and GHG emissions. Khanna et al. (2008) also looked at the effect of the ethanol subsidy considering its environmental impacts. Our study extends the analysis in the studies mentioned above by examining the effect of the ethanol subsidy as well as the tariff on imported ethanol. We differentiate between ethanol from Brazil and the US based on their environmental impacts and analyze the impact of trade restrictions on welfare and GHG emissions.

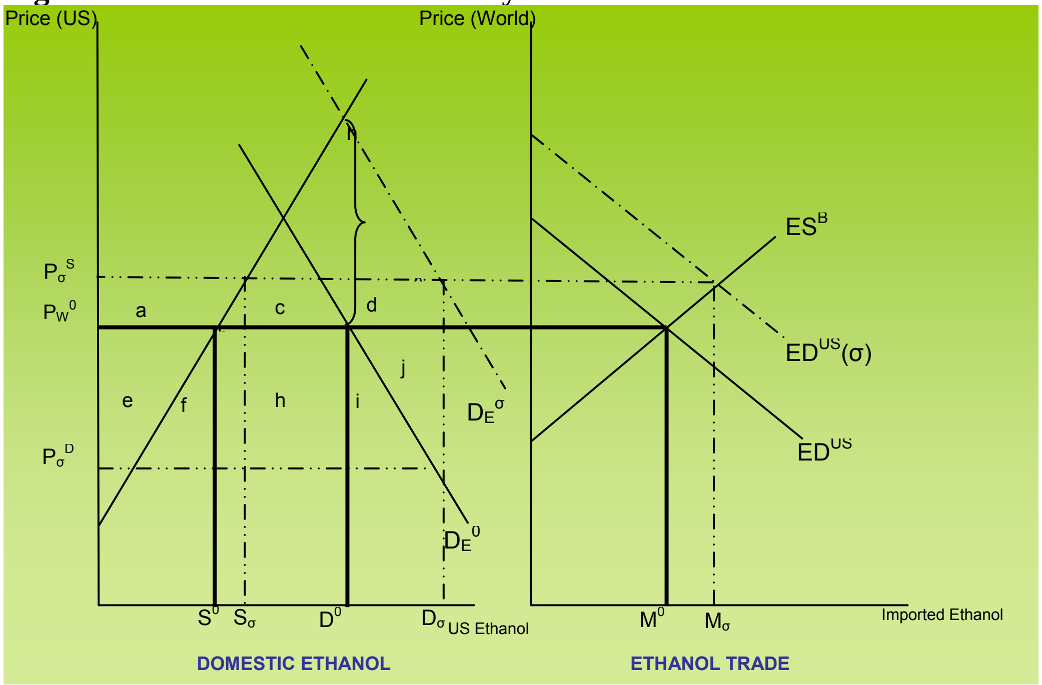
2. Theoretical Framework

In this section we discuss the welfare and GHG emissions effects of a subsidy, a tariff and a combined subsidy and tariff, which is the status quo policy relative to non intervention. We illustrate the deadweight loss associated with policy intervention, starting with the effect of a subsidy which is shown in Figure 1. To keep the discussion tractable, we exclude welfare loss from increased GHG emissions, as well as welfare changes in the gasoline and miles markets.

Subsidy

A subsidy benefits consumers through decreased prices and benefits ethanol producers by decreasing the marginal cost of ethanol production. However, this is at the expense of government expenditures. In Figure 1, the domestic ethanol market is on the left panel and ethanol trade with Brazil (representing all foreign produced ethanol) is on the right panel. We assume that world excess demand for ethanol is the excess demand of the US. In the non-intervention scenario, ethanol price in the domestic and world market is P_W^0. Domestic supply is S_0, demand is D_0 and imports are M_0. Suppose the government provides a subsidy of σ per gallon of ethanol consumed. Initially, this would shift the domestic demand to the right by the size of the subsidy. This decreases the consumer price to (P_σ^D) and increases the producer price to (P_σ^S), with the difference in P_σ^D and P_σ^S being σ. The shift in the demand curve also shifts the excess

Figure 1. Welfare effect of a subsidy



demand curve to $ED^{US}_{(\sigma)}$ although the vertical rise of ED^{US} is less than σ because the increase in ethanol price also increases domestic production. The shift in excess demand increases ethanol price in the world market to P_σ^S which increases imports to M_σ. This implies that importers are also benefited by the domestic subsidy.

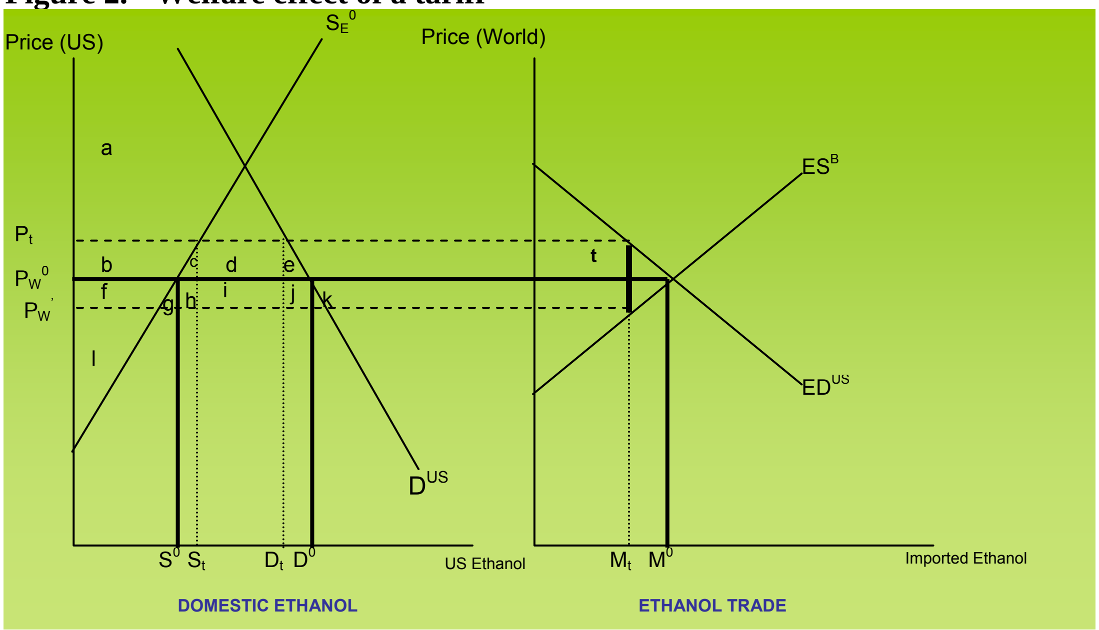
The welfare effect of a subsidy is clearly negative. Consumers gain area (e + f + g + h + i) and producers gain area a. However, the government incurs a cost of area (a + b + c + d + e + f + g + h + i + j) to subsidize all ethanol consumption leading to a net welfare loss of (b + c + d + j). Area b is the loss in social welfare due to the distortion caused by the increase in domestic production at a marginal cost that is higher than the world price P_W^0. Area (c + d) is the loss in social welfare for the US due to subsidy payments on the imported quantity of ethanol M_σ and area j is the loss in social welfare due to a distortion caused by the increase in consumption as the subsidy causes the domestic price to fall below the non-intervention level.

The subsidy makes ethanol relatively cheaper than gasoline, which induces substitution of ethanol for gasoline. Since ethanol is less GHG intensive than gasoline, this substitution of ethanol for gasoline could reduce carbon emissions. However the subsidy also lowers fuel prices which could lead to higher miles consumption, thereby increasing GHG emissions through higher fuel consumption. Thus, the net effect on emissions is unclear since disutility from increased consumption of miles may or may not offset benefits from reduced carbon emissions (see Khanna, et al., 2008; Vedenov and Wetzstein, 2008).

Tariff

The tariff drives a wedge between the excess supply curve of Brazil (ES^B) and the excess demand curve of the US (ED^{US}) (Figure 2). This restricts imports and supports domestic ethanol production by increasing the domestic price of ethanol. Since the US is assumed to be a large buyer in the ethanol market it faces an upward sloping excess supply curve of Brazil. The tariff lowers the world price of ethanol to P_W' and raises domestic price of ethanol in the US to P_t. Domestic supply increases to S_t but imports (M_t) and overall demand (D_t) decrease. The welfare effect of this tariff is ambiguous since the tariff lowers the world price of ethanol. The improvement in terms of trade for the US creates welfare gains that offset some of the loss in welfare caused by the tariff-induced increase in domestic price and loss in domestic consumer surplus. Consumers lose area (b+c+d+e) due to the price increase while producers gain area b. The government gets tax revenues equal to (d+i) which means that net welfare is positive if i−c−e > 0 and negative otherwise.

Figure 2. Welfare effect of a tariff

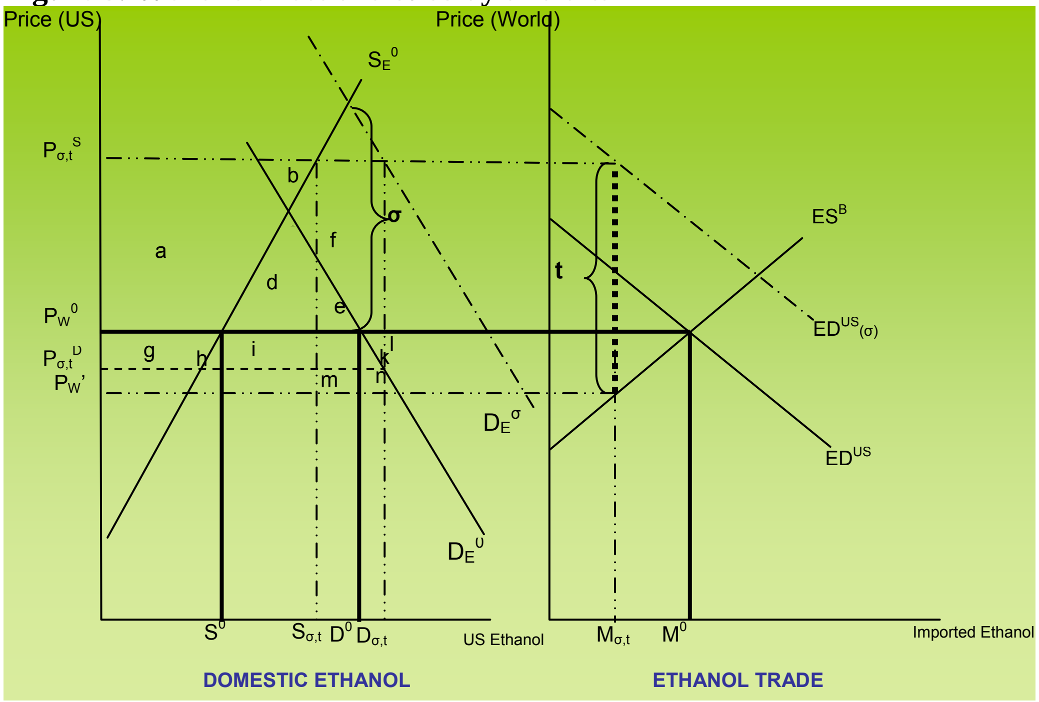


The tariff biases consumption against imported sugarcane ethanol in favor of domestic corn ethanol and gasoline which are both more carbon intensive. Furthermore, the tariff increases overall ethanol price which leads to more gasoline consumption. These two effects increase GHG emissions relative to the non intervention level as well as relative to the case where there is only a subsidy. Since a tariff could increase overall fuel price it could also lead to less miles consumption and therefore less demand for fuels. Thus, the net environmental impact of a tariff is ambiguous since it is not clear whether reduced emissions from lower miles consumption will offset increased GHG emissions from the substitution of gasoline for ethanol.

Status Quo

Current US policy gives a subsidy for blending ethanol with gasoline regardless of whether the ethanol is produced domestically or imported. However, a larger tariff is also imposed on sugarcane ethanol to keep foreign producers from benefiting from the subsidy. This lowers the marginal cost of corn ethanol while increasing the marginal cost of sugarcane ethanol. In Figure 3, with both a tariff and a subsidy in place, domestic demand and excess demand both shift to the right (D_E^{σ} and $ED^{US}_{(\sigma)}$ respectively), but there is a wedge the size of the tariff between $ED^{US}_{(\sigma)}$ and ES^B. Depending on the magnitude of the tariff and subsidy the resulting demand price in the US could be higher or lower than the non-intervention price (P_W^0). As shown, $P_{\sigma t}^D$, the domestic market price after a subsidy and tariff, is lower than P_W^0. Domestic producers receive $P_{\sigma t}^D + \sigma$ or $P_{\sigma t}^S$. This leads to an increase in domestic ethanol production from S^0 to $S_{\sigma ,t}$, and an increase in ethanol demand to $D_{\sigma ,t}$. Because of the tariff, ethanol exporters receive only P_W' which decreases imports to ($M_{\sigma t}$).

Figure 3. Welfare effect of a subsidy and a tariff



We find that the welfare effect of a tariff and a subsidy in the US market is ambiguous. Consumers gain (g + h + i + j + k) and producers gain (a + b), respectively, from the price change while the government spends (a + b + c + d + e + f + g + h + i + j + k + l) on subsidies and gets a tariff revenue of (e + f + j + k + l + m + n). The net social surplus effect is positive if (j + k + l + m + n) −(d + c) > 0 and negative otherwise. For ethanol importers, the subsidy received (f + e) is less than tariff payments, which implies that the status quo policy is welfare decreasing to ethanol exporters. In the case where the non intervention price is lower than the domestic price with subsidy and tariff, this ambiguity in welfare effect remains, although as a result of the subsidy and tariff, consumers will lose from the price increase and producers will have greater gains in producer surplus. In terms of GHG emissions, the combined subsidy and tariff induces substitution towards corn ethanol away from gasoline and sugarcane ethanol. Since gasoline emits more GHG while sugarcane ethanol emits less GHG, the overall impact of the substitution effect is unclear. Depending on the overall effect on fuel prices, there could be an increase or decrease in miles consumption which will determine the impact on the total demand for fuels (and hence GHG emissions).

Since the welfare impacts of a subsidy and tariff are ambiguous, we use numerical simulation to quantify price, quantity, and welfare measures associated with the status quo and non-intervention, taking into account resulting changes in corn, gasoline and miles markets and the cost of changes in GHG emissions.

3. Empirical Model

We develop an empirical model to measure social welfare and environmental quality under non-intervention and status-quo. In non intervention, there are no tariffs or subsidies. In the Status Quo scenario, there is a $0.51 subsidy for blending ethanol with gasoline and a $0.54 tariff on imported ethanol.

In our analytical framework, we assume that consumers derive benefits from the consumption of miles and disutility from aggregate greenhouse gas emissions through its impact on air quality and global warming. The markets in our model are those for corn, domestic ethanol, imported ethanol, refined gasoline and miles. We include the corn market to account for the effects of changing feedstock price on ethanol supply, although we limit our welfare measurement in the miles and fuels markets. We use a constant elasticity of substitution (CES) production function for miles with gasoline and ethanol being imperfect substitutes but domestically produced ethanol and imported ethanol being perfect substitutes. The elasticity of substitution is set to 2 and the share and scale parameters are calibrated using 2006 market data. The level of GHG emissions is modeled as an additive function of marginal carbon emissions of each fuel multiplied by the level of use. Each unit of GHG emission has some cost which is parameterized using estimates from the literature. The miles supply function and the demands for domestic ethanol and gasoline are derived within the model. Imported ethanol demand is defined as the net demand in the domestic market. The rest of the supply and demand curves are assumed to have constant elasticity forms and are parameterized based on estimates available in the recent literature in this area and market data. We derive remaining unknown parameters by calibrating our model to data on relevant prices, quantities and elasticities.

Data and Parameters

We use elasticity estimates found in the literature. For corn supply, Lee and Helmberger (1985) estimated the supply price elasticity to be 0.25. Gallagher (2003) reported ethanol supply elasticity to be 1.5 while wholesale gasoline supply elasticity is 10. For the supply elasticity of imported ethanol, we use 2.7 as reported by De Gorter and Just (2007b). Corn demand elasticity is assumed to be -0.17, which is from the USDA elasticities database. The demand elasticity for miles is -0.40 (Parry and Small, 2005; Vedenov and Wetzstein, 2008).

Market data in 2006 is used to calibrate the model. The price of corn is $3 per bushel which is the weighted average farm price reported by the USDA (2008). Ethanol and gasoline prices are \$2.6 and \$1.9 per gallon respectively (Omaha wholesale free-on-board average rack price, Nebraska Ethanol Board (2007)). We add a markup of \$0.30 per gallon and taxes of \$0.38 per gallon to get the retail prices of ethanol and gasoline.

In 2006, 12.5 B bushels of corn were produced, 17% (2.1 B bushels) of which went into the production of 4.9 B gallons of ethanol (RFA, 2007; USDA, 2008). RFA also reports that total ethanol imports for the same year are 0.65 B gallons which brings total demand to 5.5 B gallons. According to the Department of Energy (2007), total gasoline input to motor fuels production was 112 B gallons. The US Federal Highway Authority (2007) also reported that miles driven in 2006 was 2966 B miles. To parameterize the environmental disutility functions, we set the marginal damage of a metric ton of carbon (mt C) emissions to be \$25 based on Parry and Small (2005). Emissions intensity from "well-to-wheel" of gasoline is 3.2 kg C per gallon, while for corn the value is 1.7 kg C/gallon (Farrell et al., 2006). Macedo et al. (2008) report that "seed to factory gate" emissions of sugarcane ethanol are 0.44 kg C per gallon. Based on this, we assume that transportation adds 0.16 kg C per gallon which gives sugarcane ethanol a "well-to-wheel" emissions intensity of 0.60 kg C/gallon. These intensities imply that for equal energy content, the use of corn ethanol emits 18% less carbon than gasoline while sugarcane ethanol emits 67% less.

4. Results

Table 1 summarizes the results of our numerical simulation. The deadweight loss associated with the subsidy and tariff compared to non-intervention is \$3.6 billion. The deadweight loss associated with the combined subsidy and tariff is \$3.2 billion, while the cost of increased GHG emissions is \$450 million.

The combined effect of the subsidy and the tariff lowers fuel prices by 0.34% and 3% for gasoline and ethanol respectively. Because of decreased fuel prices, driving miles become less expensive, thus increasing miles consumption in the status quo by 0.19% from 2960 to 2966 B miles. Most of the increase in fuel use comes from ethanol rather than gasoline. Ethanol demand increases by 6% while gasoline demand decreases by 0.09%. Most of the increase in demand is met by domestic production which increases by 9% while imports are reduced by 11%.

GHG emissions are higher in the status quo by 0.08% relative to non-intervention. Even though ethanol has increased its fuel share (by 1%), the increase in driving brought about by lower fuel prices increases overall fuel use. Thus, the benefits of reduced GHG emissions due to the substitution of corn ethanol for gasoline appear to be more than offset by increased GHG emissions that results from the rise in miles and fuels consumption, as well as the decrease in the use of sugarcane ethanol.

We conducted sensitivity analysis to key parameter assumptions and found that the elasticity of substitution (φ) between ethanol and gasoline in the miles production function affected the magnitude of responses in the ethanol market. A high elasticity of substitution implies that the cost of substituting one fuel for the other is low, while a low elasticity of substitution implies a higher cost. Thus, given a policy change that decreases the price of ethanol, the increase in ethanol demand will be greater if the elasticity of substitution is high. On the other hand, the response in the ethanol market is constrained if the elasticity of substitution is low. When we set φ = 10, ethanol demand increased by 8% from non intervention to the status quo, while when φ = 0.1, the increase in demand is only 1%. Despite the varying impacts in the ethanol market, however, the impact on gasoline and miles markets, as well as on the overall welfare outcome, is modest. The primary reason for this is that ethanol has a small share in fuel consumption such that a change in the ethanol market may not greatly affect the market for gasoline and miles.

Table 1. Welfare, price and quantity for alternative policies

	Unit	Non Intervention	Status Quo
Welfare Change	B$		-3.6
Quantity			
Miles	B miles	2960	2966
			(0.19)
Gasoline	B gallons	112.1	112
			(-0.09)
Ethanol			
Domestic Supply	B gallons	4.5	4.9
			(9)
Imports	B gallons	0.73	0.65
			(-11)
Total Demand	B gallons	5.2	5.5
			(6)
GHG Emissions	B mT C	0.37	0.37
			(0.08)
Consumer Price			
Ethanol	$/ gallon	2.8	2.7
			(-3)
Gasoline	$/ gallon	2.6	2.6
			(-0.34)

Note: Numbers in parentheses are % change from Non Intervention to Status Quo.

5. Conclusions

Our findings show that a combined subsidy and tariff increases ethanol demand and domestic production, while restricting the ethanol imports from Brazil. Energy security and climate change mitigation have been cited as reasons for the current ethanol policy which uses both the subsidy and the tariff. Our study shows that this causes deadweight loss in the economy and does not help mitigate climate change, since GHG emissions are increased, relative to non intervention. Thus, a serious reconsideration of current policy is warranted if the goal of ethanol policy is to increase welfare and environmental quality.

References

De Gorter, H., and D. Just, 2007. "The Economics of a Biofuel Consumption Mandate and Excise-Tax Exemption: An Empirical Example of US Ethanol Policy." Working Paper, Department of Applied Economics and Management, Cornell University.

—2008 "The Economics of the U.S. Ethanol Import Tariff with a Blend Mandate and Tax Credit" *Journal of Agricultural & Food Industrial Organization*, 6(2), December.

Department of Energy, 2007. Department of energy webpage. Website accessed July 2007. http://www.eia.doe.gov/emeu/mer/petro.html

Elobeid, A., and S. Tokgoz. 2008. "Removing distortions in the US ethanol market: What does it imply for the United States and Brazil?" *American Journal of Agricultural Economics* 90: 918-932

Farrell, A., R. Plevin, B. Turner, A. Jones, M. O'Hare, and D. Kammen, 2006. "Ethanol Can Contribute to Energy and Environmental Goals." *Science* 311:506-08.

Federal Highway Authority. 2008. Highway Statistics 2006. Website accessed July 2007. http://www.fhwa.dot.gov/policy/ohpi/qftravel.cfm.

Gallagher, P., H. Shapouri, J. Price, G. Schamel, and H. Brubaker, 2003. "Some long-run effects of growing markets and renewable fuel standards on additives markets and the US ethanol industry." *Journal of Policy Modeling* 25 (6-7): 585–608.

Lee, D., and P. Helmberger, 1985. "Estimating Supply Response in the Presence of Farm Programs." *American Journal of Agricultural Economics* 67 (2): 193–203.

Macedo, I. C., J. E. Seabra, and J. E. Silva, 2008. "Green house gases emissions in the production and use of ethanol from sugarcane in Brazil: The 2005/2006 averages and prediction for 2020." *Biomass and Bioenergy* 32: 582–595.

Nebraska Ethanol Board. Ethanol and Unleaded Gasoline Average Rack Prices. Website accessed July 2007. http://www.neo.state.ne.us/statshtml/66.html

Parry, I., and K. Small. 2005. "Does Britain or the United States Have the Right Gasoline Tax?" *American Economic Review* 95 (4), 1276–1289.

RFA, 2007. Renewable Fuels Association Ethanol Industry Overview. Website accessed July 2007. URL http://www.ethanolrfa.org

USDA, 2008. USDA Feed Grains Database. Website accessed July 2007. http://www.ers.usda.gov/Data/FeedGrains/

Vedenov, D., and M. Wetzstein. 2008. "Toward an Optimal US Ethanol Fuel Subsidy." *Energy Economics* 30:2073–2090.