Welfare Implications of U.S. Ethanol and Motor Fuel Policies

Richard Shi
Advisor – Professor Malcolm Getz
Second Reader – Professor Robert Driskill
Economics Honors Thesis – Penultimate Draft
Spring 2013

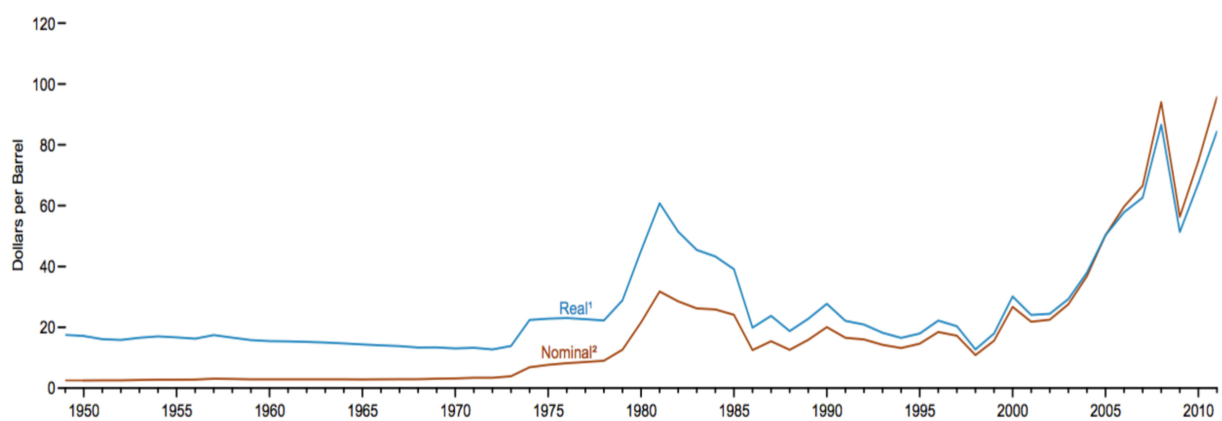
Introduction

Corn-based ethanol policies were first enacted by the United States in the 1970s mainly due to concerns about high and rising oil prices. The idea was that ethanol subsidies and/or ethanol mandates would increase production of ethanol, driving down its price, thus making it a more attractive substitute for gasoline produced from fossil fuel. Once consumers start switching from gasoline to ethanol, the demand for oil would fall, thus lowering oil prices. The oil shock of the 1970s was mainly caused by the unrest in Iran and the Middle East (i.e. large oil exporting countries). Furthermore, prices surged under the Carter Administration due to the OPEC cartel testing its ability to restrict oil supply. After these events, oil prices more or less stabilized in the following years.

Over the past decade, however, oil prices have been increasing steadily due to limited supply and the increasing demand of developing/industrializing countries such as China and India. This heightens the importance of lowering oil prices though fuel policies. Chart 1 below shows the changes in oil prices over the past six decades.[1]

Figure 5.18 Crude Oil Domestic First Purchase Prices

U.S. Average Prices, 1949-2011



[1] U.S. Energy Information Administration/Annual Energy Review 2011

In addition, oil's impact on pollution and the environment have prompted policymakers to advocate less consumption of oil overall and more consumption of alternative fuels such as corn based ethanol.

However, policymakers and economists questioned corn ethanol's benefit to the environment. Due to indirect land use, forests and pasture need to be converted to farmland for corn production. Clearing forests releases carbon. Another concern is the rise in the price of corn as food-items. The increased demand for corn drives the price of corn up. The increase in price is an indication of the long run elasticity of the supply of corn. A policy might not be desirable if it increases the price of food too much, especially in today's economic conditions. Others have pointed out that ethanol policies in the US tend to over-favor corn producers, a result of the intense lobbying by these producers. Inframarginal producers of corn earn deadweight gains in rents as the price of their land increases with the price of corn.

Because of these concerns, policymakers and economists have started to look into second-generation biofuel such as cellulosic ethanol as a possible source of alternative motor fuel to both corn-based ethanol and gasoline. Cellulosic ethanol is made from lignocellulose, a material found in much of the mass of plants. Popular cellulose materials that are used for ethanol production includes corn stover, switchgrass, and woodchips. Compared to corn-based ethanol (made from corn), these materials don't compete as much for additional land use. Much of the woodchips and corn stovers are byproducts that would otherwise be tossed away. Furthermore, compared to corn-based ethanol, the switchgrass that need to be cultivated for cellulosic ethanol reduce soil erosion, sequestrate more carbon in the soil, and require lower energy, water and agrochemical inputs per unit of biofuel produced. Therefore, they have potential to reduce more GHG emission than does corn-based ethanol. Also, most materials that are used to produce cellulosic ethanol are not edible, so it doesn't drive up food prices directly. However, the use of arable land can be diverted from growing food crops, thus increasing food prices indirectly.

Cellulosic ethanol has costs. One is its expensive production process. Improving technology may reduce the cost of producing cellulosic ethanol; but better research and development are still needed in this area.

Furthermore, both corn-based ethanol and cellulosic ethanol reduces the supply of the petroleum by-products that are produced when gasoline is made from oil. These by-products include aviation gasoline, kerosene-type jet fuel, kerosene, distillate fuel oil, and residual fuel oil. Thus, petroleum by-product prices may increase, another cost we must consider when thinking about switching from oil based gasoline to biofuels.

Given the rising costs of fossil fuel, it is important to find a suitable alternative energy source to invest in. This becomes even more significant if the country that first exploits it can gain a permanent advantage in international trade. However, choosing to invest in the wrong kind of alternative energy can be welfare harming. The purpose of this paper is to see that, given the benefits and costs of ethanol, how different ethanol policies impact social welfare, and what, if any, ethanol policy should be enacted.

Literature

Cui, Lapan, Mochini and Cooper (2011) conducted research on the impact of corn-ethanol and motor fuel policies by developing and using a welfare model for the aggregate U.S. economy. Their model assumes an economy with three commodities: corn, oil, and a numeraire good. There is also a processing sector that converts corn into ethanol, and another one that refines oil into gasoline and petroleum by-products. Using this model in conjunction with market equilibrium conditions, they then found the welfare gains/loss associated with various corn-ethanol and motor fuel policies when compare to the *laissez faire* market economy.[2]

Table 1: Welfare Effects of Alternative Corn-based Ethanol and Oil Policies (2005 Dollars)

	No Ethanol Policy	Status Quo	First Best	Optimal Tax and Subsidy	Optimal Subsidy	Optimal Mandate
Social Welfare ($billion)	0.5	6.7	11.5	9.9	7.5	8.2
Pollution effect ($billion)	1.4	1.0	2.6	2.6	0.8	1.1
Tax revenue ($billion)	49.7	47.6	78.5	108.5	43.0	53.6
Producer Surplus (P.S.) Oil supply ($billion)	-1.5	-3.4	25.8	-7.9	-4.3	-5.2
P.S. Corn Supply ($billion)	-8.8	7.4	7.0	15.2	16.0	18.4
Consumer Surplus (C.S.) Corn demand ($billion)	6.4	-4.9	-4.6	-9.6	-10.1	-11.5
C.S. Fuel demand ($billion)	-36.4	-18.7	-49.6	-48.3	-9.8	-14.3
C.S. Petroleum by-product ($billion)	-10.2	-22.3	-48.1	-50.5	-28.2	-33.9

The model found that, using 2005 data as baseline, 2005 *status quo* policies (which consists of a fuel tax of $0.39/gallon and a corn-ethanol subsidy of $0.45/gallon) increase welfare by $6.7 billion when compared to the *laissez faire* approach. The biggest welfare gains for the *status quo* approach came from tax revenues at $47.6 billion, while the biggest welfare loss came from

[2] Cui, Lapan, Moschini and Cooper (2011) defines the *laissez faire* market economy as the three-commodity economy without motor fuel taxes, corn-ethanol subsidies, or corn-ethanol mandates.

consumer surplus for both motor fuel demand and petroleum by-product demand at -\$18.7 billion and -\$22.3 billion dollars respectively. Cui, Lapan, Mochini and Cooper (2011) also determined the policies that need to be enacted in order to achieve optimal welfare gains. With a motor fuel tax of \$0.23/gallon, a corn-ethanol subsidy of \$0.11/gallons, an oil import tariff of \$17.53/barrel and a corn export tariff of \$1.26/bushel, they predict a welfare gain of \$11.5 billion when compared to the *laissez faire* approach. All of the prices discussed above are in 2005 dollars. Table 1 gives a summary of the welfare findings.

Cui, Lapan, Mochini and Cooper (2011) used exogenous research to determine the relative pollution efficiency of corn-based ethanol to gasoline. From Wang (2007), they set the carbon dioxide emission rate of gasoline at 11.29kg/gallon. They also set the carbon dioxide emission rate of corn ethanol at 8.42kg/GEEG[3] based on the research of Farrel et al. (2006). Thus, corn ethanol (when compared to gasoline) reduces carbon dioxide emissions by around 25.4% in Cui, Lapan, Mochini and Cooper (2011)'s model.

However, other researches question corn ethanol's benefit to the environment due to in indirect land use; forests and pasture need to be converted to farmland for additional corn production. According to a recent research by the U.S. Department of Energy (2012), corn-based ethanol (when compared to gasoline) only reduces carbon dioxide emissions by a modest 13%. The same research states that cellulosic ethanol (when compared to gasoline) can reduce carbon dioxide emissions by 86%.

---

[3] GEEG stands for gasoline energy equivalent gallons. Ethanol needs to be converted into GEEG from their natural gallons because of the differing heat content of corn ethanol, cellulosic ethanol, and gasoline.

Methodology

To analyze overall social welfare of various ethanol policies, I will be expanding the model developed by Cui, Lapan, Moschini and Cooper (2011). The main difference between this model and the one used by Cui, Lapan, Moschini and Cooper (2011) is that the demand/supply/environmental effects of cellulosic ethanol will be added to the model. This will take into account the vast potential benefits of cellulosic ethanol to the environment. I will also not consider eliminating the current \$0.39/gallon motor fuel tax as a viable policy option. The main purpose of the government in implementing this fuel tax is to generate revenue for highway/road construction and maintenance. It is unrealistic to take away this tax because roads and highways need to be maintained. Therefore I will include the \$0.39/gallon tax in every possible policy set for the model. Furthermore, I will use the U.S. Department of Energy (2012)'s research on carbon dioxide emissions of various ethanols to develop the model's relative pollution efficiency coefficients. Corn ethanol's environmental impact will thus be more harmful in this model than in Cui, Lapan, Moschini and Cooper (2011)'s. Additionally, in calculating welfare, welfare gains/loss of various policies will be determined by comparing results to the *status quo* market condition, rather than the *laissez faire* condition. This better highlights the impact on welfare due to a change away from current policies. Moreover, the model will be calibrated using exogenous data from the 2011 base year. A sensitivity analysis of exogenous parameters will also be conducted.

The model assumes an economy with four commodities: corn, oil, switch grass, and a numeraire good. Furthermore, there is a processing sector that converts corn into ethanol, another sector that converts switch grass to ethanol, and one more that refines oil into gasoline and other petroleum by-products. Assuming consumers have quasi-linear preferences, the following utility function can be developed:

$$U = y + \psi(D_f) + \varepsilon(D_c) + \theta(D_b) - \sigma(x_g + \lambda x_e + \mu x_p)$$

where y represents consumption valued in units of the numeraire good, D_f, D_c, D_b, represent consumption of fuel (which is made up of gasoline, corn-based ethanol and cellulosic ethanol), corn as food/feed, and petroleum by-products, respectively, and $\sigma(x_g + \lambda x_e + \mu x_p)$ represent the undesirable environmental pollution emission created by gasoline and ethanol. The parameters λ and μ reflects the relative pollution emissions of corn based ethanol and switch grass-based ethanol, respectively, when compared to the pollution effects of gasoline.

From this utility function, and taking into account the processing sectors of corn, switch grass and oil, the following welfare function can be derived:

$$\begin{aligned} W = \{I - C(Q_c) - \Omega(S_o) - \Lambda(S_d) - w_e x_e - w_g x_g - w_p x_p - [p_o^w \bar{S}_o - p_c^w \bar{D}_c]\} \\ + [\psi(x_g + x_e + x_p) + \varepsilon(D_c) + \theta(D_b)] - \sigma(x_g + \lambda x_e + \mu x_p) \end{aligned}$$

The term in {.} represents the utility gained from consumption of the numeraire good. *I* is aggregate income, $C(Q_c)$ is cost of aggregate corn output, $\Omega(S_o)$ is cost of domestic oil production, $\Lambda(S_d)$ is cost of domestic switch grass production. $w_e x_e, w_g x_g, w_p x_p$ are cost of other inputs used in fuel production through the various processing sectors, with x_e, x_g, x_p representing aggregate output of corn-based ethanol, gasoline, and cellulosic ethanol, respectively. $[p_o^w \bar{S}_o - p_c^w \bar{D}_c]$ is the value of net imports of oil and corn. The term in [.] in the second line measures consumer utility gained from fuel, corn as food, and petroleum by-product. The last term measures the cost of pollution from the use and production of motor fuel.

There are two ways to solve for welfare gains and loss given various sets of motor fuel and ethanol policies. One way is to solve for the market equilibrium values of the various variables in the welfare function above. Plug in the values and solve for welfare. Then determine welfare changes of policies by comparing it to the *status quo* condition's welfare.

The second way is to first develop the supply and demand functions (given a set of policies) for the markets of the non-numeraire commodities in the model, namely domestic oil supply, net import oil supply, petroleum-by-product demand, gasoline supply, corn-based ethanol supply, cellulosic ethanol supply, fuel demand, corn supply, domestic corn as food/feed demand, and net export corn demand. With these supply and demand functions, we can then solve for the equilibrium values of the following commodity market equilibrium conditions:

Corn Market Equilibrium: $S_C(p_C) = D_C(p_C) + \overline{D}_C(p_C) + \dfrac{X_e}{a}$

Fuel Market Equilibrium: $D_f(p_f) = \beta\{S_o(p_o) + \overline{S}_o(p_o^w)\} + x_e + x_p$

Petroleum By-product Equilibrium: $D_b(p_b) = \beta_2\{S_o(p_o) + \overline{S}_o(p_o^w)\}$

In the corn market equilibrium, $S_C(p_C)$ is corn supply, $D_C(p_C)$ is domestic corn demand as food/feed, $\overline{D}_c(p_c^w)$ is net export corn demand, X_e is the natural gallons of corn-based ethanol consumed, and a is the number of natural gallons of corn ethanol produced from one bushel of corn. In the fuel market equilibrium, $D_f(p_f)$ is fuel demand, β is the gasoline production coefficient (number of gallons of gasoline produced from one barrel of oil), $S_o(p_o)$ is domestic oil supply, $\overline{S}_o(p_o^w)$ is net import oil supply, x_e is the GEEG of corn-based ethanol supplied, and x_p is the GEEG of cellulosic ethanol supplied. In the petroleum by-product equilibrium, $D_b(p_b)$ is petroleum demand and β_2 is the petroleum production coefficient. These equilibrium values can then be used in conjunction with the supply/demand functions to calculate changes in producer surplus, consumer surplus, tax revenue, subsidy spending, and pollution costs when compared to the *status quo* condition. Changes in welfare can then be determined.

Equilibrium Values

Of the two different approaches in calculating welfare, this paper will use the latter one.

Baseline Data

In order to determine welfare changes under the second approach, it is necessary to develop the supply and demand functions, given a specific set of policies, of the different commodity markets. To do so, a set of baseline prices and quantities of the markets must first be gathered. This paper uses 2011 baseline equilibrium values. All prices are in 2011 dollars. Table 2 shows each of the exogenous baseline equilibrium variables (not all the equilibrium values we need, those will be derived later), its symbol, its value, and its source.

Table 2. Exogenous 2011 Baseline Values

Variable	Symbol	Value	Source
Ethanol Price ($/natural gallon)	p_E	2.70	Official Nebraska Gov. Website (2012)
Petroleum By-product Price ($/GEEG)	p_b	3.00	U.S. EIA (2012)
U.S. Oil Price ($/barrel)	p_o	100.74	U.S. EIA (2012)
Oil Import Price ($/barrel)	p_o^w	100.74	No Tariff. Same as P_o
U.S. Corn Price ($/bushel)	p_c	5.98	USDA Feed Grains Data (2012)
Corn Export Price ($/bushel)	p_c^w	5.98	No Tariff. Same as P_c
Fuel Demand (billions natural gallons)	X_f	139.7625	U.S. EIA (2012)
Corn ethanol quantity (Billion gallons)	X_e	13.9420	U.S. EIA (2012)
Cellulosic Ethanol Q (Billion gallons)	X_p	0.0066	U.S. EPA Renewable Fuel Standards (2011)
Domestic Oil Supply (Billions Barrels)	$S_o(p_o)$	2.0601	U.S. EIA (2012)
Net Import Oil Supply (Billions Barrels)	$\bar{S}_o(p_o^w)$	3.1091	U.S. EIA (2012)
Total Corn Supply (Billions Bushels)	$S_c(p_c)$	12.36	USDA Feed Grains Data (2012)
Net Export Corn D (Billions Bushels)	$\bar{D}_c(p_c^w)$	1.76	USDA Feed Grains Data (2012)

In order to derive the baseline equilibrium prices for fuel, gasoline, and cellulosic ethanol from the price of corn-based ethanol (measured in GEEG), the following price relationships need to be utilized:

$$p_e$$

$$p_f = p_e + \frac{t}{r} - \frac{b}{r}$$

$$p_g = p_e + \frac{t}{r} - \frac{b}{r} - t$$

$$p_p = p_e + \frac{t}{r} - \frac{b}{r} - \frac{t}{\pi} + \frac{c}{\pi}$$

Where p_e is the price of corn ethanol measured in \$/GEEG, p_f is the price of fuel in \$/GEEG, p_g is the price of gasoline in \$/GEEG, p_p is the price of cellulosic ethanol in \$/GEEG, t is the fuel tax in \$/natural gallon, b is corn ethanol subsidy in \$/natural gallon, c is cellulosic ethanol subsidy in \$/natural gallon, r is the corn ethanol energy equivalent coefficient, and π is the cellulosic ethanol energy equivalent coefficient. Thus we need to find the exogenous values of t, b, c, r, π. We also need to find a in order to find the amount of corn used in ethanol production. The values of these exogenous parameters, as well as the derived baseline prices and other derived baseline values can be found in Table 3.[4]

Table 3. Exogenous Parameters and Derived 2011 Baseline Values

Parameter/Variable	Symbol	Value	Source/Explanation
Fuel Tax ($/natural gallon)	t	0.39	Cui, Lapan, Mochini and Cooper (2011)
Corn Ethanol Subsidy ($/gallon)	b	0.45	U.S. EPA Renewable Fuel Standards (2011)
Cellulosic Ethanol Subsidy ($/gallon)	c	1.01	U.S. EPA Renewable Fuel Standards (2011)
Corn E energy equivalent coefficient (GEEG/gallon)	r	0.69	National Renewable Energy Lab (2008)
Cellulose E energy equivalent coefficient (GEEG/gallon)	π	0.63	EPA renewable fuel standard (2011), National Renewable Energy Lab (2008)

[4] Beta and Beta2 are derived parameters of the model. They are also included in Table 3

Parameter/Variable	Symbol	Value	Source/Explanation
Ethanol produced from 1 corn bushel (gallon/bushel)	a	2.80	Eidman (2007)
Corn Ethanol Price ($/GEEG)	p_e	3.92	$\frac{p_E}{r}$
Fuel Price ($/GEEG)	p_f	3.83	$p_e + \frac{t}{r} - \frac{b}{r}$
Gasoline Price ($/GEEG)	p_g	3.44	$p_e + \frac{t}{r} - \frac{b}{r} - t$
Cellulosic Ethanol Price ($/GEEG)	p_p	4.82	$p_e + \frac{t}{r} - \frac{b}{r} - \frac{t}{\pi} + \frac{c}{\pi}$
Gas quantity (billions GEEG)	x_g	125.8139	$X_f - X_e - X_p$
Corn ethanol quantity (Billions GEEG)	x_e	9.62	$X_e * r$
Cellulosic ethanol Q (billions GEEG)	x_p	0.00414	$X_p * \pi$
Fuel Demand Q (billions GEEG)	x_f	135.43	$x_g + x_e + x_p$
Total Oil Supply (billions barrels)	x_o	5.1692	$S_o(p_o) + \bar{S}_o(p_o^w)$
Corn used for Ethanol Production (billions bushels)	$\frac{X_e}{a}$	4.98	$\frac{X_e}{a}$
Corn Demand as Food (billions bushels)	$D_c(p_c)$	5.62	$S_c(p_c) - \bar{D}_c(p_c^w) - \frac{X_e}{a}$
Gas production coeff. (GEEG/barrel)	β	24.34	$\frac{x_g}{x_o}$
Petroleum by-p. production coeff. (GEEG/barrel)	β_2	20.39	EIA: $42 * 1.065 - \beta$ or $\frac{x_b}{x_o}$
Petroleum by-product Q (billions GEEG)	x_b	109.07	$x_o * \beta$

All the baseline equilibrium values are determined. We can now derive baseline supply and demand function using these values along with exogenous demand/supply elasticities. Table 4 shows these elasticities.

Table 4 Exogenous Elasticities

Elasticity	Symbol	Value	Source
Domestic oil supply	ε_o	0.20	de Gorter and Just (2009)
Foreign oil supply	$\bar{\varepsilon}_o$	3.00	de Gorter and Just (2009)
Domestic corn supply	ε_c	0.30	Cui et al. (2011)
Corn ethanol supply	ε_e	5.01	Cui, Lapan, Moschini and Cooper (2011)
Cellulosic E supply	ε_p	5.01	Assumed the same as ε_e

Elasticity	Symbol	Value	Source
Gasoline supply	ε_g	1.61	Cui, Lapan, Moschini and Cooper (2011)
Foreign corn demand	$\overline{\eta}_c$	-1.50	Food and Agricultural Policy Research Institute (2004)
domestic corn demand	η_c	-0.20	de Gorter and Just (2009b)
Fuel demand	η_f	-0.50	Cui, Lapan, Moschini and Cooper (2011)
Petroleum by-product demand	η_b	-0.50	Cui, Lapan, Moschini and Cooper (2011)

Baseline Supply and Demand Functions

To derive the baseline supply and demand functions, let us first turn to the following general elasticity equation:

$$\eta = \frac{dQ}{dP} * \frac{P}{Q}$$

where η is elasticity, P is equilibrium price, Q is equilibrium quantity and $\frac{dQ}{dP}$ is the change in quantity with respect to the change in price. This equation can be rearranged as:

$$\eta \frac{dP}{P} = \frac{dQ}{Q}$$

Integrating both sides then gives us:

$$C\eta \ln(P) = \ln(Q)$$

where C is a constant resulting from the integration. Finally, we can express this equation as either a general demand or a general supply function in the form:

$$e^{C} P^{\eta} = Q$$

With our baseline equilibrium values and elasticities, we can solve for the constant of the baseline curves. The derived baseline supply and demand functions are as follow[5]:

Fuel Demand: $D_f = e^{5.58} P_f^{-0.5}$

[5] The functions dealing with different types of fuel are all measured in $ and billions GEEG

Domestic Oil Supply: $S_o = e^{-0.1998} P_o^{0.2}$

Foreign Oil Supply: $\overline{S}_o = e^{-12.703} P_o^{w\,3}$

Domestic Corn Supply: $S_c = e^{1.9779} P_o^{0.3}$

Domestic Corn Demand: $D_c = e^{2.084} P_c^{-0.2}$

Foreign Corn Demand: $\overline{D}_c = e^{3.248} P_c^{w\,-1.5}$

Petroleum by-product Demand: $D_b = e^{5.207} P_b^{-0.5}$

Corn Ethanol Supply: $S_e = e^{-4.58} P_e^{5.01}$

Cellulosic Ethanol Supply: $S_p = e^{-13.37} P_p^{5.01}$

Gasoline Supply: $S_g = e^{2.8457} P_g^{1.61}$

Deriving Market Equilibrium Values for Other Possible Policy Options

In deriving the market equilibrium values of other possible policy sets, the supply and demand functions for the new policy set must first be re-calibrated to account for changes in taxes and subsidies. If additional fuel taxes are implemented, the fuel demand curve must shift down by the amount of the additional tax to account for the decrease in demand. Likewise, if subsidies to either corn ethanol or cellulosic ethanol change, its supply curve must shift up or down depending on the policy. The corn ethanol supply curve must shift by $\tilde{b} = \frac{b}{r} - \frac{(1-r)t}{r}$ from its zero subsidy supply curve, and the cellulosic ethanol supply curve must shift by $\tilde{c} = \frac{c}{\pi} - \frac{(1-\pi)t}{\pi}$ from its zero subsidy supply curve. This is so because b and c are measured in \$/natural gallons. They must be changed to \$/GEEG to be consistent with supply functions. b and c are thus changed to $\frac{b}{r}$ and $\frac{c}{\pi}$, respectively. In addition, when taxes are implemented on fuel demand, the fuel demand curve shift by t \$/GEEG to be consistent with the function. However, by definition of an all-encompassing motor fuel tax, corn ethanol and cellulosic ethanol are suppose to be taxed by t \$/natural gallon. Therefore,

$-\frac{(1-r)t}{r}$ is added to the corn ethanol supply curve shift, and $-\frac{(1-\pi)t}{\pi}$ is added to the cellulosic ethanol supply curve shift.

After recalibrating the supply and demand functions[6], we want to then calculate the equilibrium prices of the various different types of fuel, i.e. p_e, p_f, p_g, p_p. To do this, take the fuel market equilibrium condition: $D_f(p_f) = \beta\{S_o(p_o) = \bar{S}_o(p_o^w)\} + x_e + x_p$. Since $\beta = \frac{x_g}{x_o}$, and since there is no oil tariffs implemented (except in the optimal welfare condition – we will use a different approach then), we can rewrite the market equilibrium condition above as:

$$D_f(p_f) = x_g + x_e + x_p \text{ or } D_f(p_f) = S_g(p_g) + S_e(p_e) + S_p(p_p)$$

Next, we must determine the price relationship of the different types of fuels based on the set of policy that we're interested in. We can then substitute all the different prices for functions of p_e in the above fuel market equilibrium condition. After solving for p_e, we can use it to solve for p_f, p_g, p_p. These prices, along with the re-calibrated supply/demand functions, can then be used to solve for x_g, x_p, x_e.

With x_g, we can solve for x_o by using the equation $\beta = \frac{x_g}{x_o}$. We can then turn to the oil equilibrium market where $x_o = S_o(p_o) + \bar{S}_o(p_o^w)$, and solve for p_o and p_o^w.

Then, turning to the petroleum by-product market condition where $D_b(p_b) = \beta_2\{S_o(p_o) + \bar{S}_o(p_o^w)\}$, we can solve for x_b, which equals $D_b(p_b)$, and then for p_b.

[6] Only fuel demand, corn ethanol supply and cellulosic ethanol supply are re-calibrated for all instances expect the optimal welfare condition. As discussed later, the optimal welfare condition calls for both oil import tariff as well as corn export tariff. The oil and corn market conditions will change as a result.

Finally, we can turn to the corn market where $S_C(p_C) = D_C(p_C) + \overline{D}_C(p_c^w) + \frac{X_e}{a}$. Knowing $\frac{x_e}{a}$, we can find the new p_c and p_c^w (because the two are equal – there are no tariffs on corn exports yet). $S_c, D_c, \overline{D}_c$ can then be derived.

Deriving the Optimal Welfare Policy

To derive the equilibrium values of the optimal welfare ethanol policy for the 2011 base year, we have to first determine what the optimal policy should be.

Recall the welfare function developed in the beginning of this paper:

$$W = \{I - C(Q_c) - \Omega(S_o) - \Lambda(S_d) - w_e x_e - w_g x_g - w_p x_p - [p_o^w \overline{S}_o - p_c^w \overline{D}_c]\} \\ + [\psi(x_g + x_e + x_p) + \varepsilon(D_c) + \theta(D_b)] - \sigma(x_g + \lambda x_e + \mu x_p)$$

Take the derivative of this function and rearrange the terms to yield the following equation:

$$dW = (\delta' - C')dD_c + ([\phi' - \lambda\sigma'] - [w_e + (C'/a)])dx_e + ([\phi' - \mu\sigma'] - [w_p + (S'/z)])dx_p + ([\phi' + (\beta_2/\beta)n' - \sigma'] - [w_g + (\Omega'/\beta)])dx_g \\ + (\Omega' - [p_o^w + \overline{S}_o(dp_o^w/d\overline{S}_o)])\overline{S}_o' dp_o^w + ([p_c^w + \overline{D}_c(dp_c^w/d\overline{D}_c)] - C')\overline{D}_c' dp_c^w$$

In order to maximize welfare, dW must equal zero. There are six terms in the equation above. Thus each term need to equal zero.

The first term is given by $(\delta' - C')dD_c$, where δ' is marginal utility gained from corn as food consumption and C' is the marginal cost of corn production. Left on its own, the market will produce where $\delta' = C'$. Thus, term 1 equals zero.

Let's now jump to the fourth term. Term 4 is given by $\left(\left[\phi' + \left(\beta_2/\beta\right)n' - \sigma'\right] - \left[w_g + \left(\Omega'/\beta\right)\right]\right)dx_g$, where $\left[\phi' + \left(\beta_2/\beta\right)n' - \sigma'\right]$ is the marginal utility gained from gasoline and petroleum by-product minus the marginal cost of pollution, and $\left[w_g + \left(\Omega'/\beta\right)\right]$ is the marginal cost of producing gasoline and petroleum by-product. When left on its own, the market will produce where $\phi' + \left({\beta_2}/{\beta}\right) n' = w_g + \left({\Omega'}/{\beta}\right)$ because markets don't consider the cost of pollution – it is an externality. Thus, optimal policy must add a cost of σ' in the form of a carbon tax to gasoline.

Terms two and three deals with the two ethanol markets. The terms are given as $([\phi' - \lambda\sigma'] - [w_e + ({C'}/{a})])dx_e$ and $([\phi' - \mu\sigma'] - [w_p + ({S'}/{z})])dx_p$. Like the gasoline market, the two ethanol markets will disregard the cost of pollution (externality) when determining how much to consume. Therefore, to optimize welfare, a carbon tax of $t_e = \lambda\sigma'$ need to be added to the cost of corn ethanol, and a carbon tax of $t_p = \mu\sigma'$ need to be added to the cost of cellulosic ethanol.

From our exogenous parameters, we know the marginal cost of pollution for gasoline: σ'=\$0.226/gallon. Thus, to account for this externality cost of gas, a fuel tax, t, of \$0.226/gallon can be implemented on the motor fuel market. This fuel tax (measured in \$/natural gallons) would then mean a \$0.33/GEEG tax on corn ethanol and a \$0.36/GEEG tax on cellulosic ethanol. However, using the optimization conditions developed earlier for terms two and three, corn ethanol is only suppose to receive a carbon tax of $t_e = \$0.20/GEEG$ and cellulosic ethanol is only suppose to receive a carbon tax of $t_p = \$0.032/GEEG$. Therefore, a subsidy of \$0.13/GEEG needs to be given to corn ethanol and a subsidy of \$0.34/GEEG needs to be given to cellulosic ethanol. The subsidies in \$/natural gallons would then be $b = \$0.09/gallon$ and $c = \$0.21/gallon$.

Now consider the fifth term. Term 5 is given as $(\Omega' - \left[p_o^w + \overline{S}_o\left({dp_o^w}/{d\overline{S}_o}\right)\right])\overline{S}_o' dp_o^w$, where Ω' is the marginal utility gained from oil consumption and $p_o^w + \overline{S}_o\left({dp_o^w}/{d\overline{S}_o}\right)$ is the marginal cost of importing oil. Left on its own, the market will consume where $\Omega' = p_o^w$. However, the market failed to account for the United States being a big country. That means U.S. demand can affect world oil prices. The more the U.S. consumes imported oil, the higher the world oil price will be. Thus, to account for this externality and optimize welfare, an oil import tariff of $\tau_o = \overline{S}_o(dp_o^w / d\overline{S}_o)$ must be implement. Using both the Foreign Oil Supply and Domestic Oil Supply functions, we can find the optimal oil tariff in terms of domestic price: $\tau_o = \frac{P_o}{4}$

Term 6 is very similar to term 5. Term 6 is the corn export market: $(\left[p_c^w + \overline{D}_c\left(dp_c^w / d\overline{D}_c\right)\right] - C')\overline{D}_c' dp_c^w$. Left alone, the market will produce where $p_c^w = C'$. Thus the optimal welfare condition requires a corn export tariff of $\tau_c = -[\overline{D}_c(dp_c^w / d\overline{D}_c)]$. Using both the Foreign Corn Demand as well as the Domestic Corn Demand as Food functions, we can find the optimal corn tariff in terms of domestic price: $\tau_c = 2P_c$

The actual numerical values of optimal τ_o and τ_c will be determined along with the rest of the equilibrium values for the optimal condition in the next section.

Deriving Equilibrium Values for the Optimal Welfare Condition

Before we go any further, it is important to note that the optimal welfare policy we just came up with is not very viable. This is so because the presence of tariffs. In order to keep in line with international trading regulations, as well as to prevent trading retaliations from foreign countries, the United States cannot issue oil import tariffs. Furthermore, export tariffs are off the table as well since the United States Constitution does not allow them. Nonetheless, it is important to examine the optimal welfare condition as a benchmark for more feasible policy sets.

In deriving the equilibrium values for the optimal condition, we first need to adjust the fuel demand curve, corn ethanol supply curve, and cellulosic ethanol supply curve given the new fuel taxes and subsidies associated with the optimal condition. Doing so yields:

Fuel Demand:	$D_f = e^{5.58}(P_f - 0.164)^{-0.5}$
Corn Ethanol Supply:	$S_e = e^{-4.58}(P_e - 0.4485)^{5.01}$
Cellulosic Ethanol Supply:	$S_p = e^{-13.37}(P_p - 1.173)^{5.01}$

Next, we turn to the fuel market. The fuel market equilibrium is given as: $D_f = \beta\{S_o(p_o) + \bar{S}_o(p_o^w)\} + x_e + x_p$. We can write $S_o(p_o) + \bar{S}_o(p_o^w)$ in terms of p_o and τ_o, with $\tau_o = \frac{P_o}{4}$. Next we turn to the oil refinement market price relationship: $\beta P_g + B_2 P_b = P_o + \beta w_g$. Using this in conjunction with the Petroleum by-Product equilibrium market where $D_b(p_b) = \beta_2\{S_o(p_o) + \bar{S}_o(p_o^w)\}$, we can express P_g in terms of P_o. Once we have that, we can express P_f, P_e, P_p in terms of P_o as well. These relationships and the fuel market equilibrium condition allow us to solve for P_o, P_f, P_e, P_g, P_p, and τ_o. These values can then be used to solve for all other equilibrium values, besides that of the corn market, by using the same steps as those used to derive the status quo equilibrium values.

For the corn market, we look at the equilibrium condition: $S_c(p_c) = D_c(p_c) + \overline{D}_c(p_c^w) + \frac{x_e}{a}$. We can express this equation in p_c and τ_c, where $\tau_c = 2P_c$. Once p_c is determined, the rest of the equilibrium values for the corn market can be derived.

Equilibrium Values: Results

All the results for the equilibrium values of different policy sets are given in Table 5. Since I am including the \$0.39/gallon tax in every possible policy set for the model (with the exception of the *Optimal Condition*), the *No Ethanol Policy* condition can be viewed as the *Laissez Faire* condition.

Table 5. Equilibrium Market Values for Different Policy Sets

	No Ethanol Policy	No Corn Ethanol Policy	No Cellulosic E Policy	Status Quo	Optimal
Fuel tax ($/Gallon)	0.39	0.39	0.39	0.39	0.226
Ethanol Subsidy ($/gallon)	0	0	0.45	0.45	0.09
Cellulosic E Subsidy ($/gallon)	0	1.01	0	1.01	0.21
Oil Tariff ($/barrel)	0	0	0	0	32.19
Corn Tariff (S/barrel)	0	0	0	0	8.86
Fuel Price ($/GEEG)	3.93	3.93	3.83	3.83	4.54
Gasoline Price ($/GEEG)	3.54	3.54	3.44	3.44	4.31
Cellulosic E Prices ($/GEEG)	3.31	4.91	3.21	4.82	4.52
Ethanol Price ($/GEEG)	3.36	3.36	3.92	3.92	4.34
Ethanol Price ($/gallon)	2.32	2.32	2.7	2.7	2.99
Petroleum by-product P($/GEEG)	2.74	2.74	3	3	3.35
U.S. Oil Price ($/barrel)	103.15	103.15	100.74	100.74	128.74
Oil import Price	103.15	103.15	100.74	100.74	96.55
U.S. Corn Price ($/bushel)	3.76	3.76	5.98	5.98	4.43
Corn Export Price	3.76	3.76	5.98	5.98	13.29
Gasoline Quantity (Billion GEEG)	131.65	131.65	125.81	125.81	119
Ethanol Quantity (Billion GEEG)	2.0642	2.0642	9.62	9.62	9.277
Cellulosic E Quantity (Billion GEEG)	0.0000421	0.00481	0.00003224	0.00414018	0.000664
Petroleum by-product Q (B GEEG)	110.285	110.285	105.4	105.4	99.74
Oil domestic supply (Billion Barrels)	2.0699	2.0699	2.0601	2.0601	2.16
Net oil Import (billion Barrels)	3.3386	3.3386	3.1091	3.1091	2.737
Corn Production (billion Bushels)	10.75	10.75	12.36	12.36	11.296
Corn Demand as Food (B Bushels)	6.17	6.17	5.62	5.62	5.97
Net Corn export (Billion Bushels)	3.53	3.53	1.76	1.76	0.53
Corn used for Ethanol (B Bushels)	1.0683	1.0683	4.98	4.98	4.95

Conclusions from Equilibrium Values

One of the most noticeable features of the above results is that almost all the prices listed under all the different sets of policy options (with the exception of cellulosic ethanol) have increased tremendously from their 2005 values determined by Cui, Lapan, Moschini and Cooper (2011). For instances, the *status quo* fuel prices went from $2.50/GEEG in Cui, Lapan, Moschini and Cooper (2011)'s 2005 baseline values to $3.83/GEEG in this model's 2011 baseline price. Likewise, oil prices increased from $61.0/gallon to $100.74/gallon, corn ethanol prices went from $1.79/gallon to $2.7/gallon, and corn prices went from $3.74/bushel to $5.98/bushel. The increase in oil prices, and hence the increase in gasoline and petroleum by-product prices, can be attributed to the ever-increasing world demand for oil. A cause for the increase in corn prices, and hence the increase in corn-based ethanol prices, is the drought experienced by U.S. corn producers over the past two years, resulting in a supply shock of corn.

The increase in oil prices lead one to believe that corn-based ethanol subsidies will be more important because it decreases the domestic demand for oil, thus lowering its price. On the other hand, the increase in corn prices lead one to believe that corn-based ethanol subsidies will be more harmful to welfare because it increases the demand for corn used in ethanol production, thus further driving up corn's price.

Looking purely at the oil sector from this paper's model, the price of oil only increased approximately $2.41/barrel (from $100.74/barrel to $103.15/barrel) when the 2011 baseline corn ethanol subsidy is eliminated. Thus, the increase in gasoline prices and motor fuel prices were also small at $0.10/GEEG. This leads me to believe that eliminating the 2011 *status quo* corn-based ethanol subsidy will not cause major welfare loss fuel demand consumer surplus. Furthermore, due to the increase demand and consumption of oil (since there is very little corn ethanol fuel substitute), the supply of petroleum by-product also increases. This increase in supply drives down the price of petroleum by-products, increasing consumer surplus, and hence welfare, in that sector.

However, if we focus on the corn sector from this paper's model, we can see that corn prices decrease significantly when the 2011 baseline corn ethanol subsidy is eliminated. Corn prices drop from $5.98/bushel to $3.76/bushel. This may greatly increase the consumer surplus of corn as food/feed. But at the same time, producer surplus of corn may decrease. Even so, I still predict that eliminating the 2011 *status quo* corn ethanol subsidy will cause significant welfare gains.

It is hard to see the welfare effects of eliminating the 2011 baseline cellulosic ethanol subsidy. Taking the subsidy away does not seem to effect oil or fuel prices. Given the minuscule amount consumed, the producer surplus of cellulosic ethanol and the revenue spent on subsidies appear to be very insignificant as well. Only 0.0066 billion natural gallons of cellulosic ethanol have been produced in the 2011. That's a far cry even from the 0.0171 billion natural gallons of cellulosic ethanol that the EPA originally mandated. The technology needed for viable commercial production is still not yet available, even with big government subsidies. Thus, I predict there to be a relatively small and insignificant change in welfare if cellulosic ethanol is eliminated.

Regarding the optimal policy set, I expect the huge rise in fuel prices (from $3.92/GEEG to $4.54/GEEG), domestic oil prices ($100.74/barrel to $128.74/barrel) and petroleum by-product prices ($3/GEEG to $3.35/GEEG) to decrease consumer surplus for fuel demand and petroleum by-product, as well as increase producer surplus for domestic oil supply, when compared to the status quo condition. The decrease in corn prices and the decrease in corn export will probably mean an increase in consumer surplus for corn as food, as well as a decrease in producer surplus for corn. The biggest change in welfare, however, will most likely occur in the increase in tariff revenue ($32.19/barrel), as well as the decrease in fuel tax revenue. Fuel tax revenue will suffer due to the decrease in both the tax amount ($0.226/gallon from $0.39/gallon), as well as the consumption of fuel (from 135.434 Billion GEEG to 128.277 Billion GEEG).[7]

[7] Note: It may be puzzling that the fuel tax is lower in the optimal condition than it is in the status quo state. However, a lot of what the fuel tax is meant to do (drive down fuel consumption, reduce pollution, and even maintain highways) is covered in large part by the oil import tariff.

Welfare Gains/Loss

The goal of this section is to calculate welfare changes of different policy sets when compared to the current, 2011 baseline policies. To do so, domestic oil supply producer surplus (P.S.), cellulosic ethanol supply P.S., fuel demand consumer surplus (C.S.), petroleum by-product C.S., corn supply P.S., corn as food/feed demand C.S., motor fuel tax revenue, subsidy spending and pollution effects must first be determined for the 2011 *status quo* conditions.[8]

Consider the motor fuel equilibrium market under the 2011 baseline conditions. We can derive fuel demand C.S. by finding the area above the consumer price (2011 baseline fuel price) and below the *status quo* demand curve. To do so, we integrate the Fuel Demand function and subtract out the rectangular area beneath the consumer price. We can also derive the tax revenue gains by multiplying the GEEGs of fuel consumed by t.[9]

From the oil equilibrium market, we can derive the 2011 baseline domestic oil P.S. by finding the area below the domestic price of oil and above the domestic oil supply curve using the same kind of integration method as before.

Moving on to the corn equilibrium market for the *status quo* condition, we can determine the corn supply P.S. by finding the area below the domestic price of corn and above the corn supply curve. We can derive the corn as food/feed demand C.S. by finding the area below the domestic corn as food/feed demand curve and above the price of corn. In addition, we can

---

[8] The P.S. and C.S. listed cover all the surplus changes in the model's economy sans the numeraire good. In the model, the only purpose of switch grass is for cellulosic ethanol production. Thus, P.S. switch grass supply is covered by P.S. cellulosic ethanol supply, and C.S. switch grass demand is just C.S. cellulosic ethanol demand, which is in turn included under C.S. fuel demand.

[9] This explanation will be much better understood with the aid of a graph depicting the fuel market equilibrium for the 2011 baseline condition. The same applies for the rest of the explanation in this section. In fact, I hand-drew graphs to help me solve for P.S., C.S., tax revenue, etc. Unfortunately, I have not yet developed these graphs digitally. One of my next steps is to incorporate them digitally into this paper.

derive the amount spent on corn ethanol subsidy by multiplying the natural gallons of corn-based ethanol consumed by b.

Cellulosic ethanol P.S., petroleum by-product C.S., and cellulosic ethanol subsidy spending can be derived in similar fashion.

To solve for the pollution damages of the baseline conditions, plug the equilibrium values into the following equation:

$$\text{Carbon damage measured in dollars} = \sigma(x_g + \lambda x_e + \mu x_p)$$

in which σ is the marginal emission damage of gasoline measured in \$/GEEG, λ is the relative pollution efficiency of corn-based ethanol, and μ is the relative pollution efficiency of cellulosic ethanol. σ, λ, μ are exogenous parameters:

$\bar{\sigma}'(.) = \$.226$/gallon	source: Wang (2007), Stern (2007), National Highway Traffic Safety Administration (2009)
$\lambda = .87$	source:Wang (2007), U.S. Department of Engery
μ=.14	source: Wang (2007), U.S. Department of Energy

Using the techniques described above, solve for C.S., P.S., tax revenue, subsidy spending, and pollution damage for the other policy sets. The tariff revenues can also be calculated for the optimal condition set. This is achieved similar to the way we derived fuel tax and subsidy spending. Next, subtract each category by its counterpart in the *status quo* condition. Sum up all the changes in C.S., P.S., tax revenue, subsidy spending, tariff revenue and pollution damage for a specific policy condition. The resulting value is the change in welfare from the 2011 baseline condition.

Welfare Results: Table 6. Welfare Changes from 2011 Baseline, *Status Quo* Conditions

($billions)	No Ethanol Policy	No Corn Ethanol Policy	No Cellulosic E Policy	Optimal
P.S. Oil domestic supply	4.885	4.885	0	59.087
P.S. Corn supply	-25.75	-25.75	0	-18.36
P.S. Cellulosic E supply	-0.00323	0	-0.00323	-0.002897
C.S. Corn as food demand	13.41	13.41	0	9.163
C.S. Fuel demand	-13.36	-13.36	0	-70.947
C.S. Petroleum by-P demand	27.77	27.77	0	-35.523
Fuel Tax Revenue	-0.67	-0.67	0	-24.16
Subsidy Spending	4.9344	4.9344	0.00667	0.2293
Oil Tariff Revenue	0	0	0	88.104
Corn Tariff Revenue	0	0	0	4.7
Pollution Effect	0.168	0.168	0	1.6
Social Welfare Gain	**11.38417**	**11.3874**	**0.00344**	**13.890403**

Conclusion from Welfare Results

From Table 6, it's clear that eliminating current corn-based ethanol subsidies is very beneficial (approximately $11.4 billion in welfare gains). As predicted, the gain in C.S. of corn as food/feed is significant at positive $13.41 billion. This is just enough to cover the loss in C.S. of motor fuel, which measures -$-13.36 billion.

However, the loss in P.S. of corn supply is surprising. The $25.75 billion loss in P.S. is the largest loss in welfare for the no corn ethanol policy set. One reason why this may have occurred is corn ethanol's huge impact on corn prices. Without subsidies, corn-based ethanol production becomes hard to sustain due to its cost, and thus it decrease dramatically. Corn demand thus falls, sharply decreasing corn price. With the sharp drop in price, corn producers significantly shrink their supply, causing the huge loss in P.S. of corn supply.

Also surprising is the size of the gain in C.S. of petroleum by-product (about $28 billion). It was predicted that C.S. of petroleum by-product would increase. The absence of corn-based ethanol as motor fuel will push the economy to consume more gasoline, and thus more oil. The increase in oil increases the supply of petroleum by-products, which in turn drives down its price, allowing consumers to consume more of the good at its lower price.

The gains in P.S. of domestic oil supply and in government subsidy spending are also significant, at about $4.89 billion and $4.93 billion, respectively. The loss in fuel tax revenue ($0.67 billion) is mainly due to the decrease in fuel consumption.

Finally, the pollution effect of eliminating corn ethanol subsidies is a positive welfare gain. This is not too surprising considering corn-based ethanol drives up overall motor fuel consumption. Plus, in this model, the pollution damage caused by a unit of corn-based ethanol is only slightly better than the damage caused by the same unit of gasoline.

Eliminating current cellulosic ethanol policy yields a positive welfare gain, albeit a small one. Taking away the subsidy given to cellulosic ethanol producers greatly decrease cellulosic ethanol production. Thus, P.S. of cellulosic ethanol will fall (-$0.00323). But the gains in government saving will have a bigger positive impact on welfare. However, there are still too little information/technology from the cellulosic ethanol sector to give a good analysis on the biofuel's potential benefits to the economy.

Turning to the optimal policy set as a comparison, we see that the total welfare gain is at $13.89 billion, about one and a half billion dollars more than the next best policy set listed on the table. As expected, consumer surplus for fuel and petroleum by-product decreased significantly, at -$70.947 Billion and -$35.523 Billion, respectively. At the same time, producer surplus for domestic oil increased tremendously (about $59 Billion). This is due to the sharp increase in oil/fuel prices, as well as in the decrease in oil imports caused by the oil tariff. The changes in surplus in the corn market for the optimal condition are also as expected. The increase in C.S.

for corn as food and the decrease in P.S. for corn supply are both due in part to the corn export tariff.

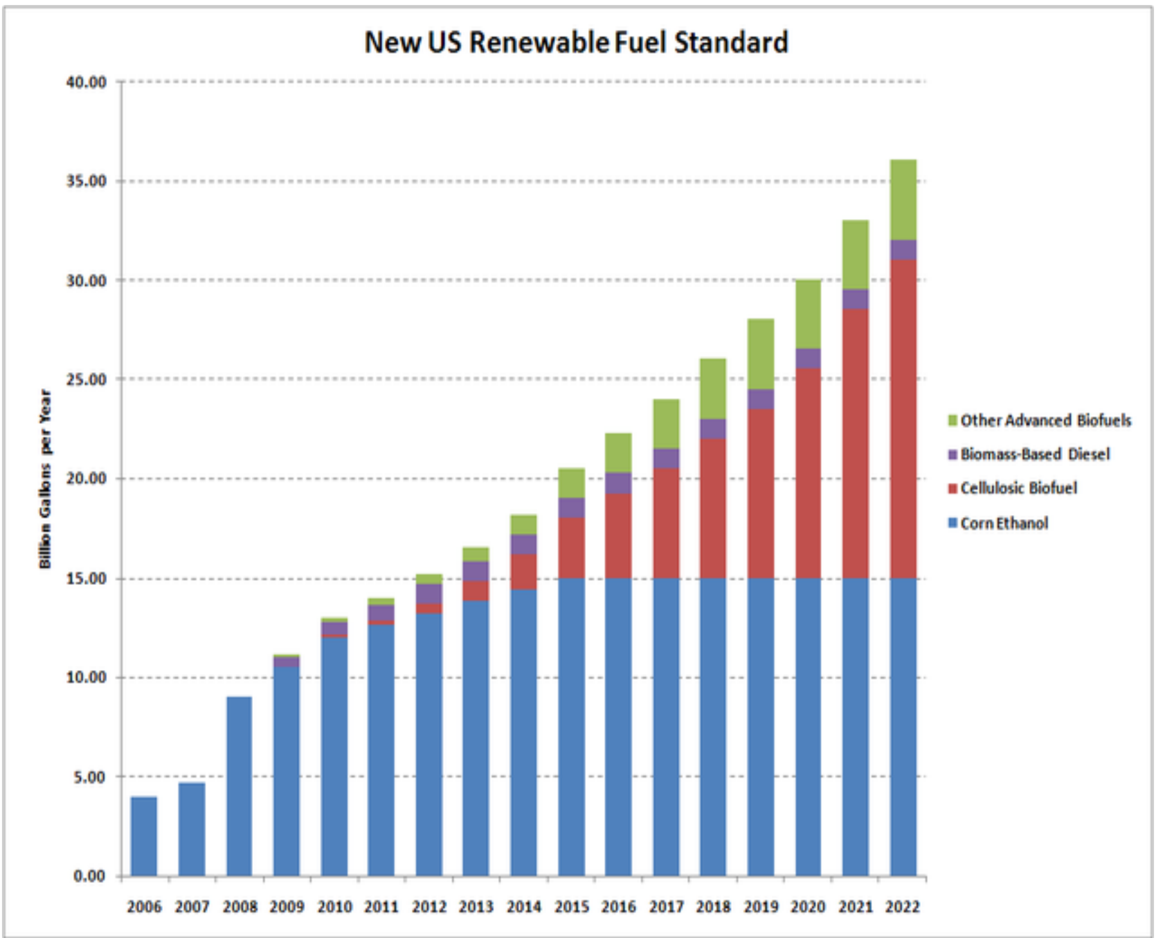
Also noteworthy is the big welfare gain in the pollution sector when compared to other alternative policy sets ($1.6 Billion as oppose to the next best $0.168 Billion). This is mainly due to the high oil import tariff, causing oil and fuel use to decrease. Global warming is certainly becoming more and more of a concern to welfare. Thus, lowering carbon emission and pollution damage can be a big plus.

Taken these four sets of motor fuel and ethanol policies (sans the infeasible optimal condition), I would recommend eliminating the current corn ethanol subsidy. The effects of cellulosic ethanol are too small to make a policy call. However, this recommendation can change if cellulosic ethanol (or corn-based ethanol for that matter) becomes more commercially viable production-wise.

Predicting Results w/More Commercially Viable Cellulosic Ethanol

Using 2011 baseline numbers, cellulosic ethanol had almost no impact on welfare. The main reason for this is that the technology for producing this second generation biofuel is still not advanced enough. However, the EPA is excepting cellulosic ethanol production and consumption to increase rapidly in the next few years. The following chart depicts the EPA's projections:

Chart 2.



I will run this model again with the same 2011 baseline values, but also with the EPA projections of cellulosic ethanol technology in 2020 (15 billion gallons of cellulosic ethanol produced).

Market Equilibrium Values w/ Potential 2020 Cellulosic Ethanol Production

In examining the following equilibrium values, it is important to note that the only change occurring to the baseline prices is the production of cellulosic ethanol from 0.00414 Billion GEEG to 9.45 Billion GEEG. Therefore, total fuel consumption increases for the status quo condition. Given everything else the same, this change in cellulosic ethanol production will then change both the status quo cellulosic ethanol supply function ($S_p = e^{-5.63}P_p^{5.01}$) as well as the status quo fuel demand function ($D_f = e^{5.65}P_f^{-0.5}$). The equilibrium values of different policy sets that were derived from this change are given below.

Table 9. Potential Equilibrium Market Values for Different Policies in 2020

	No Ethanol Policy	No Corn Ethanol Policy	No Cellulosic E Policy	Status Quo	Optimal
Fuel tax ($/Gallon)	0.39	0.39	0.39	0.39	0.226
Ethanol Subsidy ($/gallon)	0	0	0.45	0.45	0.09
Cellulosic E Subsidy ($/gallon)	0	1.01	0	1.01	0.21
Oil Tariff ($/barrel)	0	0	0	0	32.59
Corn Tariff (S/barrel)	0	0	0	0	11.3
Fuel Price ($/GEEG)	4.05	3.93	3.93	3.83	4.73
Gasoline Price ($/GEEG)	3.66	3.54	3.54	3.44	4.5
Cellulosic E Prices ($/GEEG)	3.43	4.91	3.31	4.82	4.71
Ethanol Price ($/GEEG)	3.48	3.36	4.02	3.92	4.53
Ethanol Price ($/gallon)	2.4	2.32	2.77	2.7	3.13
Petroleum by-product P($/GEEG)	2.46	2.74	2.74	3	3.21
U.S. Oil Price ($/barrel)	106.07	103.19	103.19	100.74	130.37
Oil import Price	106.07	103.19	103.19	100.74	97.78
U.S. Corn Price ($/bushel)	3.86	3.76	6.55	5.98	5.65
Corn Export Price	3.86	3.76	6.55	5.98	16.95
Gasoline Quantity (Billion GEEG)	139.01	131.75	131.75	125.81	121
Ethanol Quantity (Billion GEEG)	2.532	2.064	10.917	9.62	11.78
Cellulosic E Quantity (Billion GEEG)	0.13086	10.4	0.09673	9.45	2.012
Petroleum by-product Q (B GEEG)	116.45	110.37	110.37	105.4	101.95
Oil domestic supply (Billion Barrels)	2.0814	2.07	2.0699	2.0601	2.169
Net oil Import (billion Barrels)	3.6302	3.3425	3.3435	3.1091	2.844
Corn Production (billion Bushels)	10.839	10.754	12.702	12.36	12.151
Corn Demand as Food (B Bushels)	6.134	6.1665	5.5186	5.62	5.684
Net Corn export (Billion Bushels)	3.394	3.53	1.5354	1.76	0.3688
Corn used for Ethanol (B Bushels)	1.31	1.0683	5.65	4.98	6.097

One thing that stands out about the table above is how taking away all ethanol policies sharply increase the fuel price (from $3.83/GEEG to $4.05/GEEG) and oil price ($100.74/barrel to $106.07/barrel). I predict this will increase P.S. for domestic oil producers and C.S. for petroleum by-products. This will probably decrease C.S. for fuel significantly as well. The decrease in corn prizes (from $5.98/bushel to $3.86/bushel) also suggests that P.S. for corn supply will fall, while C.S. for corn as food will rise. All in all, the direction of movement in the numbers is very similar to that of the 2011 baseline model, where cellulosic ethanol isn't advanced in production.

Looking at just the *No Corn Ethanol Policy Set* and the *No Cellulosic Ethanol Policy Set*, however, is very interesting. The two policy conditions seem to have many of the same values. For instance, fuel price, gas price, oil price, petroleum by-product price and quantity, and overall fuel quantity are all the same. One reason why this happened might be because the two types of ethanol are very close to each other in the amount produced at the status quo condition (9.62 GEEG Billion for corn-based ethanol and 9.45 GEEG Billion for cellulosic ethanol). Thus, when one's subsidies are taken away, the other type of ethanol steps up as a substitute, or vise versa. Thus, the difference between the two policy sets really comes down to the corn market, subsidy spending, and pollution. I predict cellulosic ethanol will have a better impact on the environment given its relative pollution parameter. But just having cellulosic ethanol subsidies will also mean more subsidy spending ($1.01/natural gallon instead of $0.45/natural gallon). Also, corn-based ethanol drives corn prices up higher than cellulosic ethanol ($6.55/bushel for just corn ethanol subsidies as oppose to $3.76/bushel for just cellulosic ethanol subsidies). The higher corn prices will make the P.S. for corn higher under the no cellulosic ethanol policy and the C.S. for corn as food lower. Based on this, and on how elastic corn supply is, I predict the *No Cellulosic Ethanol policy* will have a more positive impact on welfare than the *No Corn Ethanol Policy*.

The optimal condition values seems very similar to that of the 2011 optimal policy, in that oil and fuel prices are a lot higher, quantity of fuel is a lot lower, and there are a lot of tariff revenues from oil imports.

Welfare Condition with Potential 2020 Cellulosic Ethanol Production

Using the same method as before, the welfare values on the following table was derived.

Table 10. Potential Welfare Calculations in 2020: As Changes from Status Quo

($billions)	No Ethanol Policy	No Corn Ethanol Policy	No Cellulosic E Policy	Optimal
P.S. Oil domestic supply	11.038	5.0603	5.0603	62.71
P.S. Corn supply	-24.84	-25.93	7.192	-4.072
P.S. Cellulosic E supply	-7.3807	0.8946	-7.44136	-6.42
C.S. Corn as food demand	12.719	13.2	-2.482	2.237
C.S. Fuel demand	-31.29	-14.33	-14.33	-93.3445
C.S. Petroleum by-P demand	59.197	25.0242	25.0242	-21.55
Fuel Tax Revenue	-1.3962	-0.5733	-0.5733	-4.6137
Subsidy Spending	19.56	3.405	14.149	10.5157
Oil Tariff Revenue	0	0	0	92.686
Corn Tariff Revenue	0	0	0	4.17
Pollution Effect	-1.2936	0.11302	-1.3	0.89686
Social Welfare Gain	**36.3135**	**6.86382**	**25.29884**	**43.21536**

As mentioned I was expecting that by eliminating cellulosic ethanol subsidies, social welfare will increase more than if corn ethanol subsidies were eliminated. But I was very surprised by how much more (about $18.5Billion). The increase in oil consumption and oil prices increased producer surplus for domestic oil supply and consumer surplus for petroleum by-product. Also, the absence of cellulosic ethanol means more corn ethanol needs to be produced as well. Thus, producer surplus for corn increased too. Another big increase in welfare came from the amount saved on government subsidy spending at 14.348 billion dollars. In this scenario, it is assumed that the 15 billion gallons of cellulosic ethanol is produced with the help of a $1.01/gallon subsidy. If technology and cost-efficiency for cellulosic ethanol can advance to a stage in which 15 billion gallons can be produced without (or with very little) governmental subsidy, the welfare implications of cellulosic ethanol would be better.

However, it is also important to note that cellulosic ethanol can also help drive down fuel prices, thus increasing consumer surplus for fuel; and it can limit carbon emission, thus decreasing pollution damage. These were the two main issues of oil use, and the reasons for investing in an alternative energy source.

Moreover, the biggest disadvantage of cellulosic ethanol, the decrease in consumer surplus for petroleum by-product, can be addressed if other alternative energy sources (besides ethanol) can be used as substitutes. This, however, is outside the scope of this paper.

Furthermore, cellulosic ethanol production drives down corn ethanol production, thus limiting corn used for ethanol, which in turn increases consumer surplus for corn demand as food.

But overall, due to the huge increases in welfare, I recommend not having any cellulosic ethanol policies even when the energy source becomes somewhat commercially viable. For the same reasons, I recommend not having any corn-based ethanol policies either. Therefore, given that the optimal policy is not viable due to the tariffs, I recommend we look into other types of alternative energy besides corn-based and cellulosic ethanol.

Last Steps

A sensitivity analysis of various exogenous parameters such as relative pollution efficiencies and elasticities will be conducted.

References

"Annual Energy Review". *U.S. Energy Information Administration*. (2012). Web. <http://www.eia.gov/totalenergy/data/annual/index.cfm#renewable>

"Clean Cities Fact Sheet: Ethanol Basics". *U.S. Deparment of Energy: National Renewable Energy Lab.* (2008). Web. <http://www.afdc.energy.gov/pdfs/43835.pdf>

"Corporate Average Fuel Economy for My 2011 Passenger Cars and Light Trucks". *U.S. Department of Transportation: National Highway Traffic Safety Administration.* Host Page: www.nhtsa.gov . Downloaded Online PDF.

Cui, Jingbo, Harvey Lapan, GianCarlo Moschini, and Joseph Cooper. "Welfare Impacts of Alternative Biofuel and Energy Policies" *Am. J. Agr. Econ.* 93 (5): 1235-1256. (2011) Web. <http://ajae.oxfordjournals.org/content/93/5/1235.short>

de Gorter, Harry and David R. Just. "The Economics of a Blend Mandate for Biofuels". *Am. J. Agr. Econ.* 91 (3): 738-750. (2009). Web. <http://ajae.oxfordjournals.org/content/91/3/738.abstract>

"Documentation of the FAPRI Modeling System: FAPRI-UMC Report #12-04". *Food and Agricultural Policy Research Institute*. (2004). Web. <http://www.fapri.missouri.edu/outreach/publications/2004/FAPRI_UMC_Report_12_04 .pdf>

Eidman, Vernon R. "Economic Parameters for Corn Ethanol and Biodiesel Production". *Journal of Agricultural and Applied Economics,* 39, 2: 345-356. (2007). Web. <http://ageconsearch.umn.edu/bitstream/6519/2/39020345.pdf>

"EPA Finalizes 2011 Renewable Fuel Standards". *U.S. EPA.* (2011). Web. <http://www.epa.gov/otaq/fuels/renewablefuels/420f10056.pdf>

"Ethanol and Unleaded Gasoline Average Rack Prices". *Official Nebraska Government Website*. (2012) Web. <http://www.neo.ne.gov/statshtml/66.html>

"Ethanol Vehicle Emissions". *U.S. Deparment of Energy: Alternative Fuel Data Center*. (2012) Web. <http://www.afdc.energy.gov/vehicles/flexible_fuel_emissions.html>

Farrel, A. E., R. J. Plevin, B. T. Turner, A. D. Jones, M. O' Hare, and D. M. Kammen. "Ethanol Can Contribute to Energy and Environmental Goals." *Science* 311(5760): 506–508. (2006) Web. <http://www.sciencemag.org/content/311/5760/506>

"Feed Grains Database". *USDA: Economic Research Service*. (2012). Web. <http://www.ers.usda.gov/data-products/feed-grains-database/feed-grains-custom-query.aspx>

"Petroleum & Other Liquids: Data". *U.S. Energy Information Administration*. (2012). Web. <http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=WGFRPUS2&f=W>

"Renewable Fuels: Regulations & Standard Webpage". *U.S. EPA*. (2011). Web. <http://www.epa.gov/otaq/fuels/renewablefuels/regulations.htm>

Wang, M. "Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Computer Model". *Argonne National Laboratory*. (2007). Web. <http://www.transportation.anl.gov/software/GREET/public ations.html>