AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

Biofuels, Food & Feed Tradeoffs

Proceedings of a conference April 12-13, 2007, in St. Louis, Missouri.

Edited by

Joe L. Outlaw

Agricultural and Food Policy Center
Texas A&M University
College Station, TX

James A. Duffield

Office of Energy Policy and New Uses
US Department of Agriculture
Washington, DC

David P. Ernstes

Agricultural and Food Policy Center
Texas A&M University
College Station, TX

Sponsored by

Farm Foundation
USDA Rural Development
USDA's Office of Energy Policy and New Uses

75 Farm Foundation
SINCE 1933

Ethanol Subsidies, Who Gets the Benefits?

Farzad Taheripour and Wallace E. Tyner[1]

Introduction

Ethanol has been produced for fuel in the United States for at least 27 years. The industry launch was initiated by a subsidy of $0.40/gallon (gal) provided in the *Energy Policy Act of 1978*. Between 1978 and today, the federal ethanol subsidy has ranged between $0.40/gal and $0.60/gal (Tyner, 2007). Presently, the federal subsidy is $0.51/gal. In addition to the federal blending credit, there are also some other federal and state subsidies. In fact, Koplow (2006) calculated the total subsidy available for ethanol in 2006 to range between $1.05/gal and $1.38/gal of ethanol (or between $1.42/gal and $1.87/gal of gasoline equivalent).

These subsidies have been controversial. Several popular press articles have addressed the subsidy issue,[2] but few papers have analyzed these issues using a formal economic approach.[3] In this paper we develop stylized analytical general and partial equilibrium models in the context of the theory of tax incidence to investigate distributional impacts of these subsidies.[4] Following the seminal work of Harberger (1962), the theory of tax incidence has been widely used to address the distributional impacts of tax and subsidy polices. This theory explains that the statutory incidence of a tax (or a subsidy) can be different from its economic incidence. For example, the person who has the right to receive a subsidy may not be the person whose welfare is raised by the presence of the subsidy (Fullerton and Metcalf, 2002).

Several papers have studied the incidence of gasoline taxes. For example, Chouinard and Perloff (2003) have examined the incidence of the federal and state gasoline taxes. Their work shows that consumers and wholesalers each pay roughly half of the federal gasoline tax. In more recent work, Alm *et al.* (2005) have shown that consumers bear the full burden of gasoline taxes. Their work indicates that changes in gasoline taxes are reflected almost instantly in the tax-inclusive gasoline price[5], whereas gasoline retail prices exhibit a weak and gradual response to change in gasoline wholesale prices.

The government pays ethanol subsidy in terms of a tax credit. Blenders receive a tax credit of $0.51 for each gallon of blended ethanol. While this tax credit may affect the retail price of gasoline eventually, and some of it might be passed on to consumers, we ignore the possible impacts of the subsidy on the gasoline price, and examine the distributional impacts of ethanol subsidies on the production side of the market. We first use a simple analytical general equilibrium model to analyze the distribution of ethanol subsidies between ethanol and gasoline producers. From this model we conclude that the ethanol industry receives most of the ethanol subsidies. Then we examine conditions under which this industry can retain these benefits. We show that ethanol producers will pass subsidy benefits to farmers when they become a major corn buyer and the supply of corn is limited. Finally, we show that farmers will pass these benefits to land owners.[6]

Distribution of Ethanol Subsidies between Ethanol and Gasoline Producers

Consider a blender who uses gasoline, G and ethanol, E, to produce a homogeneous blend product, B. The blender maximizes its profit and sells its product in a competitive market. The government pays a fixed amount of subsidy, S, per unit of blended ethanol. Furthermore, we assume there is no mandatory fuel standard. This assumption will be removed at the end of this section. We consider a general production function with no specific functional form. However, we assume that the production function is homogeneous of the first degree and that it is twice differentiable with respect to both inputs. In addition, we assume that the price of the blend is the numeraire. Finally it is assumed that the supplies of gasoline and ethanol are functions of their prices and prices of inputs. We can write the model in the following form.

Blender Production Function:

$$B = B(G, E). \tag{1}$$

First order profit maximization equations:

$$P.B_G = P_G, \tag{2}$$

$$P.B_E = P_E - S. \tag{3}$$

[1] Taheripour is a postdoctoral fellow and Tyner is a professor in the Department of Agricultural Economics, Purdue University, West Lafayette, Indiana.

[2] For example, see Barrionuevo (2006).

[3] For examples, see Gardner (2003).

[4] For a detailed discussion on the theory of tax incidence, see Atkinson and Stiglitz (1980) and Fullerton and Metcalf (2002).

[5] The tax-inclusive gasoline price is defined as the inflation-adjusted retail price of unleaded gasoline.

[6] Throughout this paper we analyze impacts of a marginal change in the ethanol subsidies on the prices of ethanol, gasoline and corn. An alterative method is to develop numerical models and examine distributional impacts of ethanol subsidies due to a large change in the ethanol subsidy.

Supply function of gasoline:

$$G^S = G(P_G, P_O). \tag{4}$$

Supply function of ethanol:

$$E^S = E(P_E, P_C, P_N). \tag{5}$$

Here P, P_G, P_O, P_E, P_C and P_N are the prices of the blend, gasoline, crude oil, ethanol, corn and natural gas, respectively. B_G and B_E indicate derivatives of the production function with respect to inputs G and E, respectively. Finally, G^S and E^S denote supplies of gasoline and ethanol. In this model P_O, P_C and P_N are exogenous variables. Following comparative statics principles and using this model we can determine the share of the subsidy received by the ethanol producer in terms of impacts of a change in the market price of ethanol due to a change in the ethanol subsidy. It is straightforward to show that:

$$\frac{dP_E}{dS} = \frac{\alpha \frac{\eta_G}{\sigma} + 1}{\alpha \frac{\eta_G}{\sigma} + (1-\alpha)\frac{\eta_E}{\sigma} + 1}. \tag{6}$$

Here η_G and η_E are supply elasticities of gasoline and ethanol with respect to their price, respectively. Parameter σ represents the elasticity of substitution between gasoline and ethanol and finally α is the share of ethanol in total blend production costs.[7] Appendix A shows the detailed derivation of Equation 6. This equation shows that the share of the subsidy received by the ethanol industry, dP_E/dS, is a function of four important factors of η_G, η_E, σ and α. We can rewrite Equation 6 in the following from as well.

$$\frac{dP_E}{dS} = \frac{\alpha\eta_G + \sigma}{\alpha\eta_G + (1-\alpha)\eta_E + \sigma}. \tag{7}$$

[7] Note that: $\alpha = P_E E/(P_E E + P_G G)$.

We now analyze the impacts of these factors on the share of the ethanol subsidies received by the ethanol and gasoline producers.

Impacts of the Elasticity of Substitution

To examine the impact of the elasticity of substitution on the share of the subsidy received by the ethanol industry we assume η_G, η_E and α are positive and constant. Under this assumption we can distinguish the following two major cases from Equations 6 and 7:

Case 1. When the elasticity of substitution between gasoline and ethanol tends to infinity (*i.e.* $\sigma = \infty$), then from Equation 6 we can show that

$$\frac{dP_E}{dS} = 1.$$

This means that under this condition the whole subsidy benefit goes to the ethanol producer.

Case 2. When gasoline and ethanol are compliments (*i.e.* $\sigma = 0$), then it is apparent from Equation 7 that both the gasoline and ethanol producers get benefit from the subsidy and that the share of ethanol producer depends on the share of ethanol in the total costs of production.

In general, for all values of $0 \leq \sigma < \infty$ both the gasoline and the ethanol producers share the subsidy. To show the importance of the elasticity of substitution we calculated the share of the subsidy received by the ethanol industry for several values of σ and three values of α. In this analysis we assume $\eta_G = 0.5$, $\eta_E = 0.5$ (we will analyze the impacts of alternative supply elasticities in the next section). Figure 1, shows that the share of the subsidy received by the ethanol industry increases with the size of the elasticity of substitution for

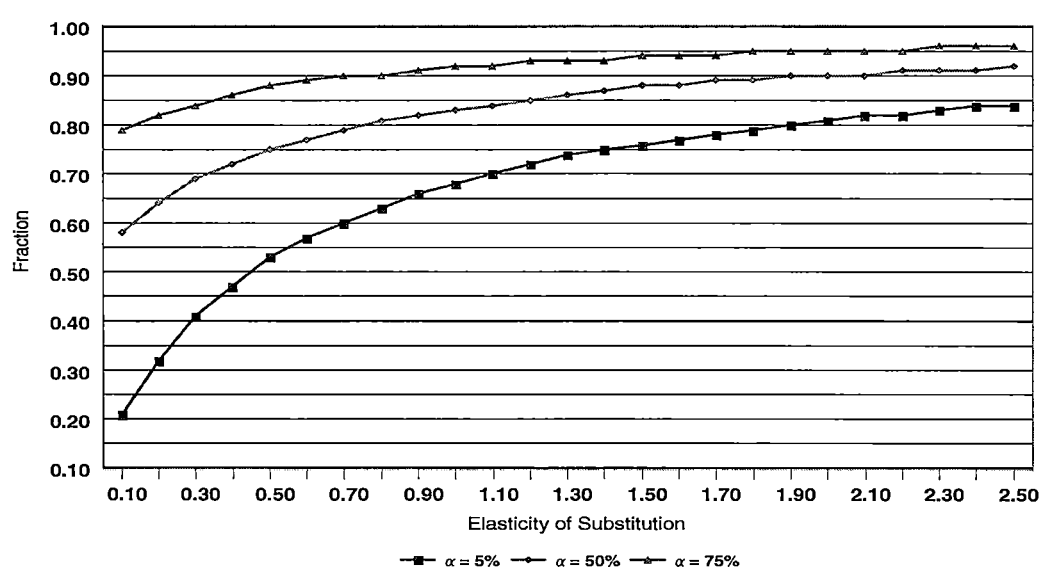

Figure 1: Share of the Subsidy on Ethanol Received by the Ethanol Industry.

all values of α.[8] In addition, Figure 1 shows that the subsidy share of the ethanol industry is increasing in α.[9] Given the fact that the ethanol industry has been expanding in recent years and that the expansion will continue to substitute out a non-trivial amount of gasoline, we can conclude that this industry will be in a better position to capture more gains from ethanol subsidies in the future regardless of its current share.

Impacts of the Supply Price Elasticities

We can distinguish the following two extreme cases from Equation 6.

Case 1. When the supply of ethanol is perfectly inelastic (*i.e.* $\eta_E = 0$), then the ethanol industry gets the whole subsidy benefit.

Case 2. When the supply of gasoline is perfectly inelastic (*i.e.* $\eta_G = 0$), then the ethanol and gasoline producers share benefits from the ethanol subsidy.

To show the importance of the supply price elasticities, we calculated the ethanol industry's share of the subsidies for several values of η_E and three values of σ. In this analysis we assume $\eta_G = 5$, $\alpha = 10\%$. Results are shown in Figure 2. This figure shows that the share of the subsidy received by the ethanol industry decreases with the size of the price elasticity of supply of ethanol for all values of σ. In addition, the figure shows that the share of the subsidy received by the ethanol industry is increasing in σ.

Impacts of a Mandatory Fuel Standard

We now introduce the possibility of having a mandatory fuel standard. Suppose the government has a targeted fuel standard of

$$\bar{\gamma} = \frac{E}{E + G}.$$

In the presence of a fuel standard, gasoline and ethanol are no longer substitutable inputs in the blend production function. In the presence of a fuel standard we can represent the blend production function with a Leontief production function with the following form:

$$B = \min\left[\bar{\gamma}E, (1 - \bar{\gamma})G\right] \tag{1.1}$$

In this production function, the inputs are compliments and they should be mixed according to the rule. In this case, the elasticity of substitution is zero and the blender has no choice on the optimal mix of inputs. We now add another restriction into the model. Suppose the capacity of ethanol production cannot support the fuel standard of $\bar{\gamma}$. The share of ethanol in total liquid supply is about 3% currently. President George W. Bush's 2007 State of the Union address proposed a fuel standard that required 15% of projected gasoline consumption or about 35 billion gal of renewable alternative fuels (including cellulosic and corn ethanol) in 2017. The current US ethanol production capacity is about 6.9 billion gal/year.

[8] The value of α is around 4% at the national level currently. This number for a typical E10 (10% ethanol and 90% gasoline) blender is about 12% to 15% currently.

[9] At present the ethanol subsidy share is large, even though the cost share is small, because the production capacity of the ethanol is low compared to the size of demand for ethanol due to the phase-out of MTBE. This point is discussed later in this article.

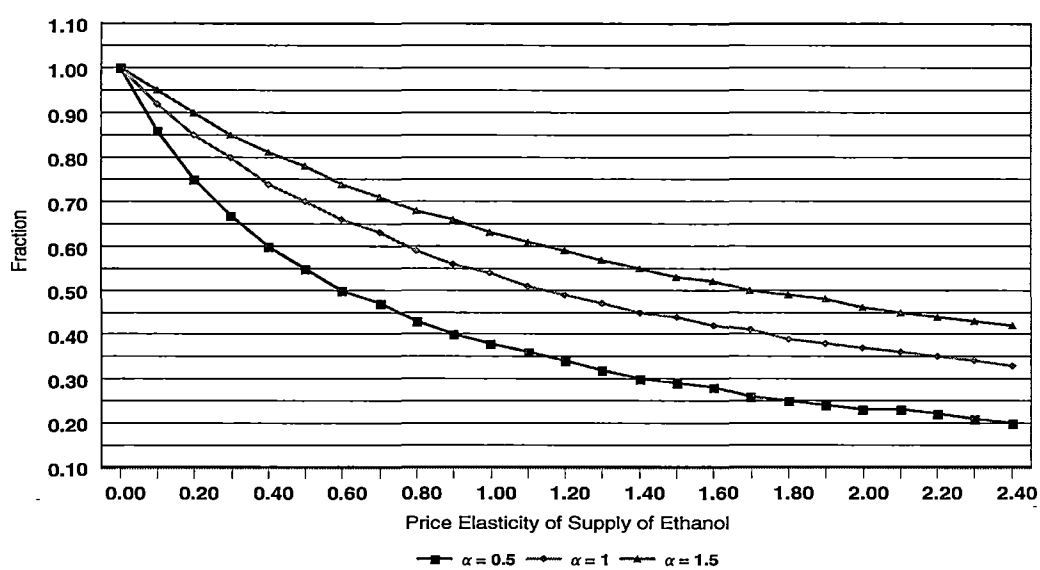

Figure 2: Share of the Subsidy on Ethanol Received by the Ethanol Industry.

This means that the current capacity of ethanol production is far below the desired level of 15%. The production function of E15 (15% ethanol and 85% gasoline) can be written as $B = \min[0.15E, 0.85G]$. In the presence of a fuel standard with limited capacity of ethanol production, the ethanol producers can get the entire ethanol subsidy. A simple model can be used to explain this argument.

Consider a market consisting of two blenders (A and B) and one ethanol producer. The capacity of ethanol production is $\bar{E}$, but there is no restriction on the capacity of gasoline production. The government forces the blenders to use the whole ethanol production. It also pays a fixed amount of subsidy, S, per unit of ethanol blended with gasoline. Suppose the market price of ethanol in the absence of the subsidy is P_E. In this case, competition between A and B will increase the price of ethanol to P_E+S and the ethanol producer will capture the whole subsidy. The fuel standard combined with the shortage in the supply of ethanol raises the bargaining power of the ethanol producer to command the entire ethanol subsidy. Indeed with the shortage in the supply of ethanol, the supply elasticity of ethanol is close to zero ($\eta_E = 0$) and hence from Equation 13 we can see that $dP_E/dS = 1$. This point is depicted in Figure 3 as well. This figure shows when the demand for ethanol is in the inelastic range of the supply of ethanol, the price of ethanol increases by the amount of subsidy.

While the ethanol industry has the potential to capture ethanol subsidies, it may pass these subsidies to farmers. We examine distribution of the subsidy between the ethanol producers and farmers in the next section.

Distribution of Ethanol Subsidies between Ethanol Producers and Farmers

We now examine the distribution of ethanol subsidies between ethanol and corn producers. We assume that the ethanol industry receives a portion, β, of the government subsidy on each unit of ethanol, $s = \beta S$. To make the analysis simple, assume that there is only one ethanol producer and one farmer and that both are price takers. In addition to the ethanol producer, other industries (such as livestock, food, feed, export...) use corn in their production processes as well. We represent their aggregate demand for corn with O and we assume it is a function of the price of corn. We show the market share of the ethanol producer in the total demand for corn with θ. Hence, the market share of other industries in the corn market will be $(1-\theta)$. Here we use a simple one factor production function for the ethanol industry and we assume that the supply of corn, C, is a function of its price, P_C and that the price of ethanol, P_E, is the numeraire. With these definitions and assumptions we can define the following model:

Ethanol production function:

$$E = E(C). \tag{8}$$

First order condition in the presence of ethanol subsidy:

$$E'(C) = q, \tag{9}$$

$$q = \frac{P_C}{P_E + s}, \tag{10}$$

Demand for corn in other industries:

$$O = O(P_C) \tag{11}$$

Supply of corn:

$$C^S = S(P_C). \tag{12}$$

Following the comparative statics principles and using this model we can show that:

$$\frac{dP_C}{ds} = \frac{\dfrac{\theta\eta_E^D}{q}}{\dfrac{\theta\eta_E^D}{q} + \dfrac{(1-\theta)\eta_O^D}{P_C} + \dfrac{\eta_C^S}{P_C}} > 0. \tag{13}$$

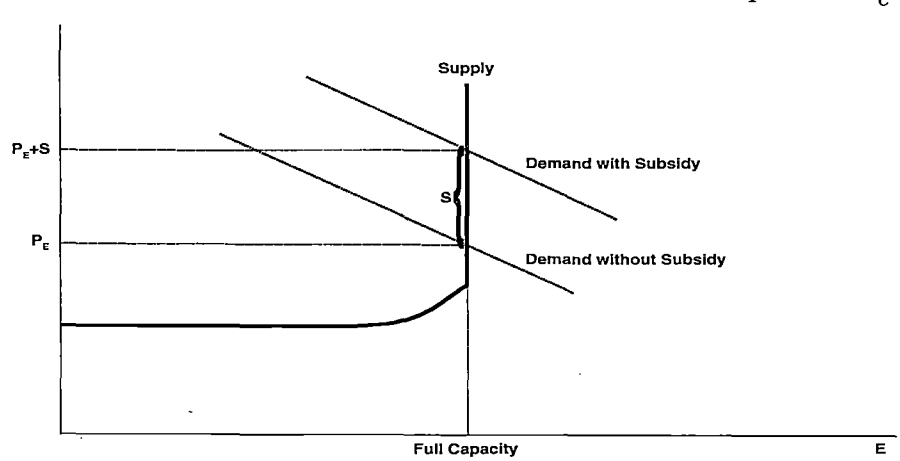

Figure 3: Share of the Subsidy on Ethanol Received by the Ethanol Industry in a Competitive Market with Limited Production Capacity.

Here η_C^S is the supply elasticity of corn, η_E^D is the elasticity of demand for corn by the ethanol industry and η_O^D is the elasticity of demand for corn by the other corn users. Appendix B shows the detailed derivation of Equation 13. This equation demonstrates that the share of the subsidy received by the farmer, dP_C/ds, is a function of the price elasticities and market shares. We now examine impacts of these elasticities and market shares on the ethanol subsidy received by the farmer.

Impacts of Market Shares

It is apparent from Equation 13 that for given values of elasticities, the ethanol subsidy received by the farmer increases with the share of ethanol industry in the corn market. When the ethanol industry has a very low share in the corn market, only a small portion of the ethanol subsidy can be received by the farmer and vise versa. To show the importance of this market share we calculated the share of subsidy received by the farmer for several values of θ. For this calculation we assume all price elasticities are equal to 0.2 (Figure 4).

This figure shows that the subsidy received by the farmer can grow rapidly with the share of ethanol industry in the corn market. Until recently, only a small portion of corn production has been used by the ethanol industry. The ethanol industry's share of the corn market was around 3% and 5% in 1980s and 1990s, respectively. This means that corn producers did not gain substantially from the ethanol subsidies in the past two decades.[10] However, the ethanol industry's share of the corn market has been increasing in recent years. For example, about 17% of corn production was used by the ethanol industry in 2006 (Tyner, 2007). If the share of the ethanol industry in the corn market continues to grow, farmers will get a major portion of the ethanol subsidy in the future. We have seen evidence of this in recent corn price increases.

[10] However, farm income was supported through the government commodity programs.

Impacts of the Price Elasticities

From Equation 13 we can show that the subsidy received by farmers increases with the price elasticity of demand for corn by the ethanol industry. Equation 13 also shows that the subsidy received by the farmer increases when the supply elasticity of corn decreases. Holding other variables constant, a reduction in the supply elasticity of corn increases the subsidy received by farmers.

In conclusion, given the fact that the capacity of the ethanol industry will continue to grow in the future, this industry will use a large portion of US corn production. Since the supply of corn is fairly inelastic this means that in the future a large portion of ethanol subsidies will be captured by farmers, and ethanol producers will pass their share from these subsidies to them.

Distribution of Ethanol Subsidies Between Land and Other Factors

We now examine the distribution of ethanol subsidies between land and other factors of production in the corn industry. Following the previous section, we can argue that land will capture the main portion of ethanol subsidies, primarily because the supply of land is inelastic. In the future, the demand for corn by the ethanol industry will increase sharply. This will push up the demand for land. Since the supply of land is limited, land owners will capture most the benefits from a higher price of corn, including subsidy benefits.

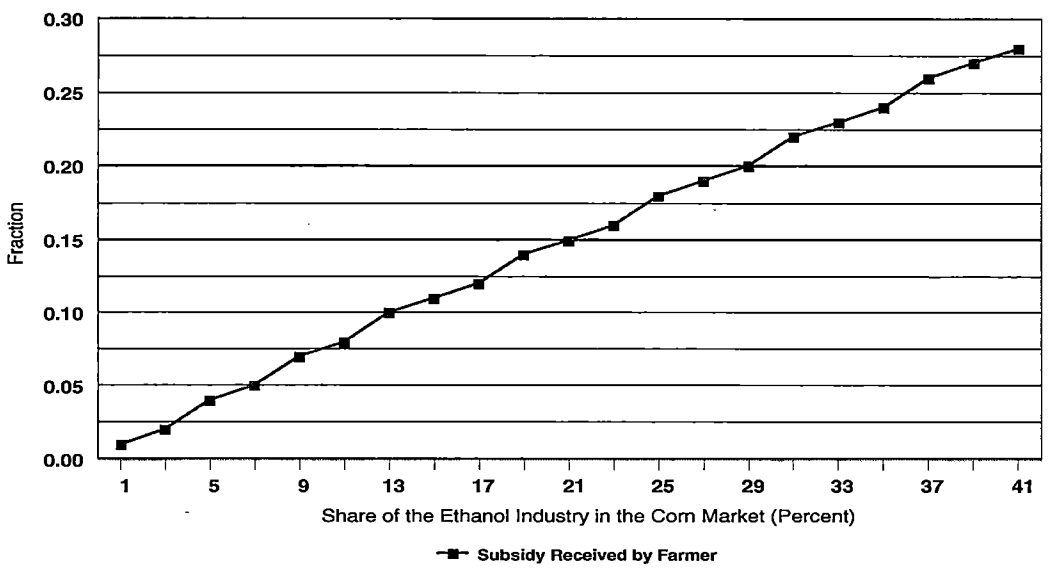

Figure 4: Share of the Subsidy on Ethanol Received by the Corn Producer.

Conclusions

From these theoretical models and from what we know about probable values of supply and demand elasticities, substitution elasticities and market shares, we can draw several important conclusions:

- In a competitive market with no fuel standard, ethanol and gasoline producers share the ethanol subsidy according to their supply elasticities and the elasticity of substitution between ethanol and gasoline.
- In the presence of a fuel standard and a limited production capacity for ethanol, the ethanol industry has the potential to capture the whole ethanol subsidy.
- The ethanol industry passes a portion of the ethanol subsidy to the corn producer. This portion increases with the share of the ethanol industry in the corn market.
- Farmers pass a large portion of their share of the ethanol subsidy to land owners.
- As ethanol production grows, we will see more significant corn price increases and the farmer capturing more of the ethanol subsidy.
- Perhaps with some lag, the higher corn price likely will be bid into land values and land rents.

These conclusions are intuitively appealing and could be important for designing future subsidy intervention mechanisms.

References

Alm, James, Edward Sennoga and Mark Skidmore. Perfect Competition, *Spatial Competition, and Tax Incidence in the Retail Gasoline Market*. Working Paper 05-09. Whitewater, WI: University of Wisconsin-Whitewater, Department of Economics, 2005. [Accessed November 14, 2007.] Available from http://academics.uww.edu/business/economics/wpapers/05_09_skidmore.pdf

Atkinson, Anthony B. and Joseph E. Stiglitz. *Lectures on Public Economics*. New York, NY: McGraw-Hill, 1980.

Barrionuevo, Alexei. "For Good or Ill, Boom in Ethanol Reshapes Economy of Heartland." *The New York Times*, June 25, 2006, p. 1.

Chouinard, Chouinard and Jeffrey M. Perloff. *Incidence of Federal and State Gasoline Taxes*. CUDARE Working Paper 952. Berkley, CA: University of California, Berkeley, Department of Agricultural and Resource Economics, 2003. [Accessed November 14, 2007.] Available from http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1030&context=are_ucb

Fullerton, Don and Gilbert E. Metcalf. *Tax Incidence*. NBER Working Paper 8829. Cambridge, MA: National Bureau of Economic Research, March 2002. [Accessed November 14, 2007.] Available from http://www.nber.org/papers/w8829

Gardner, Bruce. *Fuel Ethanol Subsidies and Farm Price Support: Boon or Boondoggle?* WP 03-11. College Park, MA: University of Maryland, College Park, Department of Agricultural and Resource Economics, October 2003. [Accessed November 14, 2007.] Available from http://www.arec.umd.edu/publications/papers/Working-Papers-PDF-files/03-11.pdf

Harberger, Arnold C. "The Incidence of the Corporation Income Tax," *The Journal of Political Economy* 70(3)(June 1962): 215-240. [Accessed Novemer 14, 2007.] Available from http://links.jstor.org/sici?sici=0022-196206%2970%3A3%3C215%3ATIOTCI%3E2.0.CO%3B2-E

Koplow, Doug. *Biofuels – At What Cost? Government Support for Ethanol and Biodiesel in the United States*. Geneva, Switzerland: Global Subsidies Initiative of the International Institute for Sustainable Development, October 2006. [Accessed November 14, 2007.] Available from http://www.globalsubsidies.org/IMG/pdf/Brochure_-_US_Report.pdf

Tyner, Wallace E. *U.S. Ethanol Policy – Possibilities for Future*. ID-342-W. West Lafayette, IN: Purdue University, Department of Agricultural Economics, 2007. [Accessed November 14, 2007.] Available from http://www.ces.purdue.edu/extmedia/ID/ID-342-W.pdf

Appendix A

This appendix shows derivation of equation (6) from equation (1) to (5). Since we assume that the price of ethanol is numeraire, we can rewrite equation (1) to (5) in the following from:

$$B = B(G,E), \qquad (1)$$

$$B_G = P_G, \qquad (2)$$

$$B_E = P_E - S, \qquad (3)$$

$$G^S = G(P_G, P_O), \qquad (4)$$

$$E^S = E(P_E, P_C, P_N). \qquad (5)$$

We now take total differentiations from equation (2) to (5) with respect to a change in the subsidy. Note that since prices of corn, crude oil, and natural gas are exogenous they do not change with respect to the change in the subsidy. For this reason we will the following simplification notations:

$$\frac{\partial G(P_G,P_O)}{\partial S}\frac{dP_G}{dS} = G'(P_G)\frac{dP_G}{dS} \text{ and } \frac{\partial E(P_E,P_C,P_N)}{\partial S}\frac{dP_E}{dS} = E'(P_E)\frac{dP_E}{dS}$$

Using these definitions we can write:

$$B_{GG}\frac{dG}{dS} + B_{GE}\frac{dE}{dS} = \frac{dP_G}{dS} \qquad 2.1, \qquad B_{EG}\frac{dG}{dS} + B_{EE}\frac{dE}{dS} = \frac{dP_E}{dS} - 1 \qquad 3.1$$

$$\frac{dG}{dS} = G'(P_G)\frac{dP_G}{dS} \qquad 4.1, \qquad \frac{dE}{dS} = E'(P_E)\frac{dP_E}{dS}. \qquad 5.1$$

From 2.1, 4.1 and 5.1 we can write: $B_{GG}G'(P_G)\frac{dP_G}{dS} + B_{GE}E'(P_E)\frac{dP_E}{dS} = \frac{dP_G}{dS}$. 2.2

From 3.1, 4.1 and 5.1 we can write: $B_{EG}G'(P_G)\frac{dP_G}{dS} + B_{EE}E'(P_E)\frac{dP_E}{dS} = \frac{dP_E}{dS} - 1$. 3.2

From 2.2 and 3.2 we can write : $\frac{dP_E}{dS} = \frac{-1}{\frac{B_{GE}^2 G'(P_G)E'(P_E)}{1 - B_{GG}G'(P_G)} + B_{EE}E'(P_E) - 1}$. 2.2.1

From Euler theorem we have: $B_{EE} = -\frac{G}{E}B_{EG}$ and $B_{GG} = -\frac{E}{G}B_{GE}$. Therefore: $B_{EE}B_{GG} = B_{EG}^2$.

Using this result and equation 22.1 we can find: $\frac{dP_E}{dS} = \frac{B_{GG}G'(P_G) - 1}{B_{EE}E'(P_E) + B_{GG}G'(P_G) - 1}$. 2.2.2

Again from Euler theorem can rewrite equation 2.2.2 in the following form:

$$\frac{dP_E}{dS} = \frac{-\frac{E}{G}B_{GE}G'(P_G) - 1}{-\frac{G}{E}B_{EG}E'(P_E) - \frac{E}{G}B_{GE}G'(P_G) - 1}. \qquad 2.2.3.$$

We define supply elasticities for gasoline and ethanol with: $\eta_G = G'(P_G)\frac{P_G}{G}$ and $\eta_E = G'(P_E)\frac{P_E}{E}$.

Using these definitions we can rewrite equation 2.2.3 in following form:

$$\frac{dP_E}{dS} = \frac{-\frac{E}{P_G}B_{GE}\eta_G - 1}{-\frac{G}{P_E}B_{EG}\eta_E - \frac{E}{P_G}B_{GE}\eta_G - 1}. \qquad 2.2.4$$

We define the share of ethanol in total cost of production with: $a = \frac{EB_E}{EB_E + GB_G}$. Since the production function is homogeneous degree one then: $a = \frac{EB_E}{B}$. Using this definition and the first order conditions we can rewrite equation 2.2.4 with the following form:

$$\frac{dP_E}{dS} = \frac{\frac{aB}{B_G B_L} B_{EG}\eta_G + 1}{\frac{(1-a)B}{B_E B_G} B_{EG}\eta_E + \frac{aB}{B_G B_E} B_{GE}\eta_G + 1}. \quad 2.2.5$$

We define the elasticity of substitution between gasoline and ethanol by: $\sigma = \frac{B_G B_E}{BB_{EG}}$.

Using this definition and equation 2.2.5 we can get the final result presented in equation 6.

Appendix B

This appendix shows derivation of equation (12) from equation (8) to (11). We assume that the price of ethanol is the numeraire. Using this assumption we can write the model in the following form:

$$E = E(C) \;\; 8.1, \; E'(C) = q \;\; 9.1, \; q = \frac{P_C}{1+s} \;\; 10.1, \; O = O(P_C) \;\; 11.1, \; C = S(P_C) \;\; 12.1$$

Solving equation 9.1 for C will determine the derived demand for corn as a function of q. We represent this demand with $C = D(q)$. Using this definition and equation 12.1 we can define the following market clearing condition: $D(q) = S(P_C) - O(P_C)$. 12.2

Total differentiation of 12.2 with respect to s gives the following equation:

$$D'(q)(\frac{dP_C}{ds} - 1) = S'(P_C)\frac{dP_C}{ds} - O'(P_C)\frac{dP_C}{ds} \quad . \quad 12.3$$

We define the demand and supply price elasticities for corn at the equilibrium with:

$$\eta_E^D = -D'(q)\frac{q}{C}, \; \eta_C^S = S'(P_C)\frac{P_C}{C}, \text{ and } \eta_O^D = -O'(P_C)\frac{P_C}{C}.$$

Using these elasticities and equation 12.3 we can derive the following equation:

$$\frac{D(P_C)}{q}\eta_E^D(\frac{dP_C}{ds} - 1) = \frac{S(P_C)}{P_C}(\eta_C^S)\frac{dP_C}{ds} + \frac{O(P_C)}{P_C}(\eta_O^D)\frac{dP_C}{ds} \quad 12.4$$

Now we can divide both sides of equation 12.4 by $S(P_C)$ and use the definition of θ to get the final result presented in equation 13.