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Fuel Ethanol Subsidies and Farm Price Support

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Abstract

Ethanol subsidies are well established in U.S. policy and have high priority in corn growers' political agenda. This paper develops a vertical market model of ethanol, byproducts, and corn which is used to analyze whether corn growers would prefer the government's subsidy dollar to be spent directly on corn subsidies (though deficiency payments) rather than on a subsidy on ethanol made from corn. Because the subsidy dollar has to be shared with ethanol manufacturers under the ethanol subsidy, it is to be expected, and the model confirms, that a dollar spent on a direct corn subsidy increases corn growers' producer surplus more than an a dollar spent on an ethanol subsidy under many plausible values of the relevant parameters. But there are equally plausible parameter values under which the ethanol subsidy is preferred by corn growers. The economics of this result turn mainly on the price discrimination an ethanol subsidy creates between ethanol and corn used for feed and export purposes, reducing the buyers' price of ethanol and byproducts but increasing the price of corn fed and exported. This enables producers of corn and ethanol to increase their joint producer surpluses above the total value of subsidies paid. The paper also analyzes the social cost (deadweight loss) of these subsidies, and finds the ethanol subsidy to generate deadweight losses likely to be in the billions of dollars annually.

KEYWORDS: ethanol, subsidies, bioenergy, biofuels

1. Introduction.

Ethanol subsidies are a controversial element in both U.S. energy policy and agricultural policy. Farmers have come to value fuel ethanol as a market for corn, rivaling commodity programs on their political agenda. Commentators have emphasized the gains to ethanol producers, notably corporations such as Archer-Daniels-Midlands, the country's largest producer, and have criticized the subsidies as wasteful spending (e.g., Bryce, 2007).[1] The debate has heated up as ethanol increased its share of U.S. corn consumption to about a fifth of U.S. production in 2007. This paper analyzes the determinants of gains to farmers from ethanol subsidies. It considers under what conditions, if any, a dollar spent on ethanol subsidies is as effective for farmers' economic interests as a dollar spent on commodity programs. It also considers whether ethanol subsidies may be preferable to agricultural commodity subsidies from a general welfare viewpoint.

2. Background

The United States started its current subsidization of the use of ethanol in motor fuel in 1978 as part of a policy response to the 1970s disruptions in petroleum supplies from the Middle East. The subsidy, which from its inception has been near its current level of 51 cents per gallon of ethanol used, takes the form of tax credits to energy companies as opposed to payments to ethanol producers. Producers of corn, by far the predominant source of U.S. fuel ethanol, see this policy as beneficial to them – it has been a high priority in the legislative agenda of the National Corn Growers Association from the start, at times even giving ethanol subsidies priority over direct payments to corn producers.

Corn-growing states, notably Iowa, have added ethanol subsidies of their own, in the form of tax benefits related to state motor fuel taxes and financial incentives for investment in ethanol plants. Demand for ethanol was further boosted in the Clean Air Act Amendments of the 1990s by mandates for the use of oxygenates as gasoline additives as a means to improve air quality in certain urban areas, and by the Renewable Fuels Standards, which as of 2007 called for 7.5 billion gallons of fuel from renewable sources to be used as transportation fuel by 2012 (for more details pertaining to this and the following paragraph, see Miranowski, 2007).

Since 2000, two further developments have intensified ethanol issues. First, the petroleum-based oxygenate MTBE, which oil companies generally

[1]See also, for example, editorials in the *New York Times*, August 10, 2007 and the *Wall Street Journal*, January 27, 2007.

found equal or preferable to ethanol as a gasoline additive even though it is unsubsidized, ran afoul of environmental problems because of its toxicity and persistence in soil or water when spilled. In California MTBE residues were found in surface water in 2001 and by 2005, 20 states be banned MTBE as a fuel additive. Liability concerns led to general abandonment of MTBE elsewhere, leaving the oxygenate field almost completely to ethanol. Second, the sharp rise in oil prices increased the market demand for ethanol as an alternative fuel even beyond the demand for it as an oxygenate. Under longstanding investment incentives and new ones for farmer-owned ethanol plants, production capacity expanded rapidly after 2000. Production in 2006 of 4.9 billion gallons was in 2007 forecast to double by 2008 based on plants now under construction or final planning stages. Further projected increases would likely be sufficient to maintain the farm price of corn at a projected by USDA at $3.25 per bushel in 2007-2010 as compared to $2.00 per bushel in 2000-05. This mix of policy and market events made corn production highly profitable in 2006-07, as reflected in rental rates for good corn land about doubling in 2007 as compared to 2005. Corn growers are now strongly attached to ethanol. The question is how much of their increased prosperity now and to be expected in the future may be attributed to U.S. ethanol policy.

This paper approaches the question by analyzing the determinants of benefits to corn producers resulting from a given amount of subsidy payments provided directly as a subsidy on corn production as compared to the benefits resulting from that same amount provided indirectly as a subsidy on ethanol production.

3. The Model

To analyze the issue in as simple a framework as possible that still permits a meaningful assessment, consider the following supply and demand model. Corn is used either for traditional feed/food uses or as raw material for ethanol. Ethanol is produced using corn, with 1 bushel of corn yielding 2.5 gallons of ethanol and aggregated plant, equipment and other inputs in a Leontief (fixed proportions) production function.[2] In addition to ethanol, corn yields feed by-products. Both plant-and-equipment and corn are specific factors to the ethanol industry.

This model can be depicted graphically as shown in Figure 1, a combination of the standard derived demand model for joint products with an excess supply model in which the raw material has a second (feed/export) use. The top panel shows the demand for industrial corn products in two vertically

[2] Higher rates of conversion, up to 2.8 gallons per bushel, have been achieved in some production processes, but the average for operational plants has not exceeded 2.5 gallons per bushel.

additive components: ethanol and by-products. The horizontal axis can be measured in gallons of ethanol, tons of by-products, or bushels of corn, since the products are generated in fixed proportions from corn. Since corn is the common raw material for both industrial products, bushels of corn are the quantity units used in the diagram. This means that the prices of ethanol and by-products are quoted in terms of dollars paid for the final product that results from 1 bushel of corn, e.g., if ethanol's price is $2 per gallon we quote a $5.00 price for the amount of ethanol obtained from each bushel of corn at the conversion rate of 2.5 gallons per bushel; that is we measure the quantity of ethanol in 2 ½ gallon units. The total demand curve for industrial products from corn, D_t, is the vertical sum of D_y, the demand for ethanol, and the demand for by-products, which is the vertical distance between D_t and D_y. The derived industrial demand for corn, shown in the lower panel as D_{x1}, is obtained as the vertical distance between D_t and S_w the supply of non-corn inputs in ethanol production (rental value of ethanol plant, energy, labor). Industrial demand is however only part of the demand for corn.

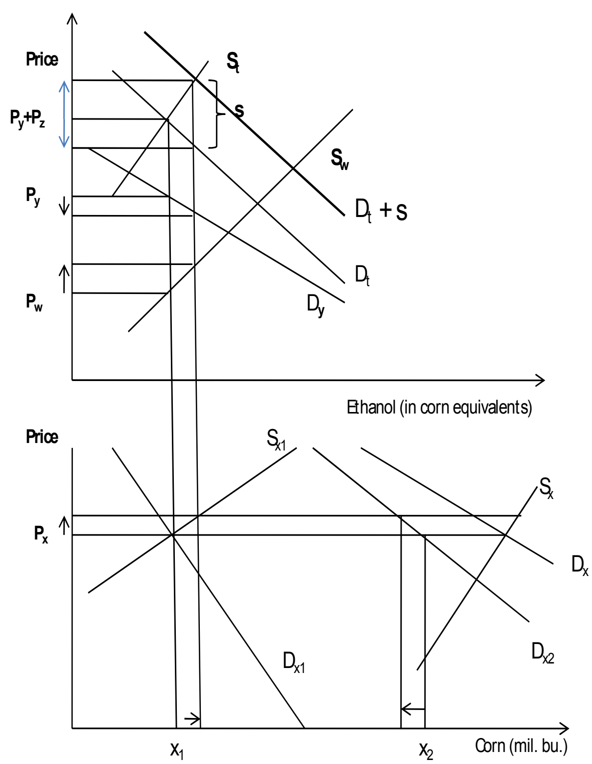

Figure 1. Ethanol and Corn Markets with Ethanol Subsidy

We add (horizontally) the quantity of corn purchased for feed and export, D_{x2}, at each price to obtain D_x, the total demand for corn. The model is closed by adding the supply function of corn, S_x. Once we know S_x, we can find the price of corn, P_x, and from P_x we know the quantity of corn used in feed/export, x_2, and in industrial products, x_1. The level of x_1, with fixed proportions, determines the quantities of ethanol and by-products. Thus, given x_1 we know the prices of all products, as labeled.

Two policies are considered, an ethanol subsidy and a corn production subsidy via deficiency payments that make up the difference between the market price and a legislated target price of corn. Starting with the effects of the ethanol subsidy, to show this graphically we first find the excess supply curve of corn for industrial purposes from the (horizontal) difference between S_x and D_{x2}, the demand for corn for feed and export, at each price. This curve is shown as S_{x1} in Figure 1. To get the derived demand for corn in ethanol production, begin with the demand function for ethanol, D_y, add vertically the demand for ethanol by-products to get D_t, and then subtract the supply (cost) of ethanol plant services, S_w, to get the derived demand D_{x1}. S_{x1} crosses D_{x1} at P_x. Adding S_{x1} (vertically) to S_w in the upper panel obtains the derived supply of industrial products from corn, S_t.

The ethanol subsidy, s, is analyzed as a wedge between S_t and D_t, which has the effect of shifting the demand for corn used in ethanol to D_t+s. The ethanol subsidy as sketched generates the price changes shown by arrows. The producer price of ethanol and by-products rises as shown, and the buyers' prices fall, the sum of the changes being s. The buyers of ethanol are fuel users, who gain not only through cheaper ethanol but also through lower gasoline prices to the extent the added ethanol increases the total supply of fuel (not shown in diagram). Ethanol producers gain the producers' surplus generated by the P_w increase as shown. Corn producers also gain from the ethanol subsidy, since the increased use of ethanol increases the derived demand for corn. The producers' surplus gain is the area of the increase in P_x to the left of S_x delimited by the rise in P_x. Given the slopes of function used in Figure 1, it appears that corn producers gain more than ethanol producers, but this depends on parameter values (elasticities) as will be discussed later. While buyers of ethanol and by-products gain, as indicated by their price declines in the upper panel, but buyers of corn for feed/export lose the area to the left of D_{x2} delimited by the rise in P_x in the lower panel.

The second policy is a deficiency payment (corn production subsidy) program. As illustrated in Figure 2, this program generates payments of v per bushel of corn to raise the price to producers while reducing the market price of corn as shown by the arrow in the lower diagram. This causes larger output and a lower market price of corn. The effect in the ethanol market is to reduce the price of both ethanol and by-products and to increase the producers' surplus of ethanol plants.

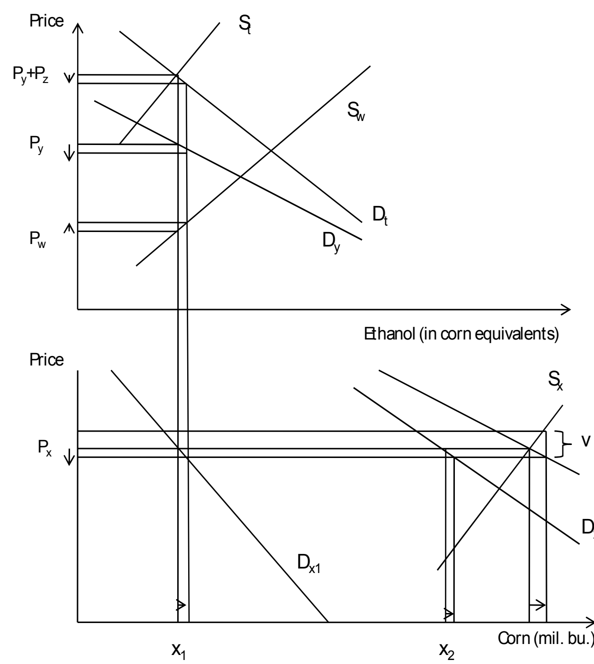

Figure 2. Ethanol and Corn Markets with Deficiency Payment

The policy issues then turn on choice of the policy instruments v and s. The graphical analysis thus indicates that both corn producers and ethanol manufacturers will gain from either an ethanol subsidy or corn deficiency payments, but corn producers gain relatively more from deficiency payments and ethanol producers gain relatively more from an ethanol subsidy. In order to analyze the issues more fully, and test their sensitivity to parameter values (such as elasticities of supply and demand) one must express the model algebraically.

Behavioral equations representing the upper panel of Figure 1, in price-dependent constant elasticity form, are:

Ethanol demand:

$$P_y = ay^{n_y} \tag{1}$$

By-product demand

$$P_z = bz^{n_z} \tag{2}$$

Supply of non-corn ethanol inputs

$$P_w = cw^{e_w} \tag{3}$$

The demand for corn used in ethanol is not independent of the preceding equations. The reason for expressing equations (1) to (3) in price-dependent form is that, following the derived demand curve in Figure 1, the demand function for corn used in ethanol is derived easily as:

$$P_x = P_y + P_z - P_w$$

$$= ay^{n_y} + bz^{n_z} - cw^{e_w} \tag{4}$$

To complete the supply-demand model, we add the supply function of corn and the demand for corn in uses other than ethanol. The supply of corn, also in inverse form, is:

$$P_x = h(x_1 + x_2)^{e_x} \tag{5}$$

The demand for non-ethanol uses of corn is

$$P_x = d(x_2 - gx_1)^{n_x} \tag{6}$$

where g is the percentage of corn going into ethanol that is recycled into a substitute for other uses of corn, notably feed by-products of ethanol.

In the preceding equations y, z, w, x_1, and x_2 are quantities, P's are prices, n's are inverse demand elasticities, e's are inverse supply elasticities, and a to h are constants. As in Figure 1, all prices and quantities are expressed in terms of bushels of corn. Thus, y is the quantity of ethanol from a bushel of corn (approximately 2.5 gallons, so our quantity unit of ethanol can be taken as a 2½ gallon can), and P_y is the dollar value of that quantity unit (a 2½ gallon can). Similarly, P_w is the price of ethanol plant services per bushel of corn used to produce ethanol. And, since the quantities are all measured in bushels of corn:

$$y = z = w = x_1 \tag{7}$$

After using (7) to eliminate y, z, and w, we are left with the six equations (1) to (6) in six unknowns, P_y, P_z, P_w, P_x, x_1 and x_2. Therefore, with well-behaved (monotonic, continuous, negatively sloped demand and positively sloped supply) functions, a unique equilibrium exists.

The system can be simplified by substitution using (4) to obtain:

$$P_x = ax_1^{n_y} + bx_1^{n_2} - cx_1^{e_w} \qquad (8)$$

Thus, equations (5), (6), and (8) provide three equations in three variables, P_x, x_1, and x_2, which contain all 11 parameters (constants and elasticities) of equations (1) to (6). To carry out comparative statics of policy alternatives, the following steps are taken. First, we add an ethanol subsidy, s, to the derived demand equation (8). The subsidy has the effect of a reduction in the cost of manufacturing ethanol (which is why s is added while $cx_1^{e_w}$ is subtracted). Second, we subtract deficiency payments per bushel, v, from equation (5). P_x is thus the market price of corn, while producers get P_x + v per bushel. Instruments s and v have different effects because equation (8) contains only x_1, while (5) contains $x_1 + x_2$.

There is no straightforward way to solve these nonlinear equations for P_x, x_1, and x_2 as a function of s or v. In the simulations below numerical methods are used to solve the system for given parameter values, to find equilibrium P_x, x_1, and x_2 for any s or v.

Note however that an analytical solution is straightforward when equations (1) to (6) are linear (or linearized as a first-order approximation to nonlinear functions). The behavioral equations are then:

$$P_y = a_0 + a_1 y \qquad (1N)$$

$$P_z = b_0 + b_1 z \qquad (2N)$$

$$P_w = c_0 + c_1 w \qquad (3N)$$

$$P_x = h_0 + h_1(x_1 + x_2) \qquad (5N)$$

$$P_x = d_0 + d_1 x_2 - d_1 g x_1 \qquad (6N)$$

Equation (8N), the inverse derived demand for corn in subsidized ethanol,

is now:

$$P_x = (a_0 + b_0 - c_0) + (a_1 + b_1 - c_1)\, x_1 + s \qquad (8N)$$

Equation (9N), obtained by solving (6N) for x_2 and substituting for x_2 in equation (5N), is:

$$x_1 = -\frac{h_0}{h^*_1} + \frac{d_0}{d^*_1} + \left(\frac{1}{h^*_1} - \frac{1}{d^*_1}\right) P_x \qquad \text{(9N)}$$

where $h^*_1 = h_1(1+g)$ and $d^*_1 = d_1(1+g)$. Equation (9N) is the excess supply of corn for ethanol use that is shown as S_{x1} in Figure 1. Solving (9N) and the excess demand (8N) simultaneously for x_1,

$$x_1 = \frac{(a_0 + b_0 - c_0 + s)(d^*_1 - h^*_1) - h_0 d^*_1 + d_0 h^*_1 + d^*_1 v}{(a_1 + b_1 - c_1)(h^*_1 - d^*_1) + d^*_1 h^*_1} \qquad \text{(10N)}$$

To see the effect of a change in the ethanol subsidy, s, differentiate (10N) with respect to s to obtain

$$\frac{dx_1}{ds} = \frac{1}{\dfrac{1}{1/h^*_1 - 1/d^*_1} - (a_1 + b_1 - c_1)} \qquad \text{(11N)}$$

and

$$\frac{dP_x}{ds} = \frac{dP_x}{dX}\frac{dX}{ds} + \frac{ds}{ds} = \frac{(a_1 + b_1 - c_1)}{\dfrac{1}{1/h^*_1 - 1/d^*_1} - (a_1 + b_1 - c_1)} + 1 \qquad \text{(12N)}$$

where $(a_1 + b_1 - c_1)$ is the slope of the inverse derived demand curve (< 0) and $(1/h^*_1 - 1/d^*_1)$ is the slope of the excess supply curve (> 0).[3]

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3 In the case where the derived demand and excess supply functions of corn for ethanol use is linear in logs, equations (13) and (14) become:

$$\frac{Ex}{Es} = \frac{1}{1/\varepsilon_I - 1/\eta_I}, \quad \frac{EP_x}{Es} = \frac{1}{1 - \varepsilon_I/\eta_I}$$

where E is the percentage change operator, ε_I is the excess supply elasticity of corn for industrial uses and η_I is the derived demand elasticity for corn in industrial uses. Note that if either $\varepsilon_I = 0$, or $\eta_I \rightarrow \infty$, i.e., corn for ethanol is fixed in supply or perfectly elastic in demand, P_x rises by the full amount of the subsidy. This means corn growers get all the gains.]

Next we turn to the evaluation of these redistributional effects for empirically relevant parameter values.

4. Effects of an Ethanol Subsidy Compared to Deficiency Payments

The key parameters are the elasticities from equations (1) to (5), or the corresponding slopes in (1N) to (5N). The following uses parameter values from Miranowski (2007) and U.S. Department of Agriculture (2007). The corn supply elasticity has generally been estimated to be quite small, 0.2 to 0.4, and USDA's estimate is at the lower end of this range, 0.23. The elasticity of demand for corn in feed and export uses has been estimated by USDA as -0.91.[4] These are short-term elasticities, Miranowski's ethanol demand from monthly data, 1995-2006, and USDA's implied from a year-ahead simulation of policy alternatives.

The effect of s on the price of non-corn inputs (a proxy for the profits of ethanol manufacturers) is

$$\frac{dP_w}{ds} = \frac{dx}{ds} \bullet \frac{dP_w}{dx} = \frac{dx}{ds} \bullet \frac{dP_w}{w} = \frac{c_1}{e-n}$$

where $e = (1/h_1 - 1/d_1)^{-1}$ and $n = a_1 + b_1 - c_1$. Similarly,

$$\frac{dP_y}{ds} = \frac{a_1}{e-n}, \; \frac{dP_z}{ds} = \frac{b_1}{e-n} \qquad (9)$$

Thus,

$$\frac{d(P_y + P_z + P_w + P_x)}{ds} = \frac{-a_1 - b_1 + c_1 + e}{e-n} = \frac{-n+e}{e-n} = 1 \qquad (10)$$

Since $-dP_y$ and $-dP_z$ are proportional to the gains to buyers of ethanol and by-products, and P_w and P_x the gains of ethanol producers and corn producers, equation (10) simply says that all the gains add up to ds, the change in the subsidy. The interest groups share in the gains is $-a_1$/ds for ethanol buyers, $-b_1$/ds for by-product buyers, c/ds for ethanol producers, and e/ds for corn producers. However, corn producers gain not only on the corn they produce for ethanol, but also on the corn used for other purposes, and the buyers of this (feed and exported) corn bear a loss. Corn producers' gain is e/ds/α, where α is the share of corn that goes into ethanol.

[4] These values are calculated from USDA (2007), Tables 4 and 8, using their projections of production and use under expanded ethanol use as compared to the USDA baseline with less rapidly growing ethanol use. These elasticities indicate responses given full adjustments in competing commodities, notably soybeans, rather than assuming soybean and other commodity prices are held constant.

Supply and demand parameters for ethanol are impossible to estimate with precision because only a few years of market data exist under structural conditions favoring fuel ethanol use (i.e., technology, institutions, and regulations). Miranowski (2007) discusses difficulties in estimating demand elasticities stemming from current policies. Reformulated fuel requirements imply very inelastic demand at levels mandated by law, but higher elasticities at combinations of oil and corn prices that make ethanol competitive with gasoline as a fuel source. On the supply side, the elasticity of supply of non-corn inputs into ethanol is especially conjectural because these inputs are an aggregate of disparate goods and services. Energy and labor are essentially perfectly elastic in supply to the ethanol industry. But with respect to plant and equipment, ethanol production is severely constrained in the short run by the existing production capacity, while in the long run the supply of ethanol is expected to be quite elastic since there are no inherent resource constraints that would limit the building of plants, leaving only the limitations of corn production as constraining ethanol production from corn. Using the available monthly data, Miranowski estimates the short-run elasticity of demand at -0.89 and the elasticity of supply at 0.29.[5] The supply elasticity would however be substantially larger in the longer term as the constraints imposed by fixed ethanol production capacity, and capacity in the ethanol plant building industry, are relaxed. Evidence on the appropriate long-run elasticity is lacking. I use a range of 2 to 10 as the elasticity of supply of all non-corn inputs, which combined with the corn supply elasticity of 0.23 from USDA (2007) gives ethanol supply elasticities ranging from about 1 to 5 in the long run. For the short run, I combine USDA's 0.23 corn supply elasticity and Miranowski's 0.29 ethanol supply elasticity to obtain a supply elasticity of non-corn inputs into ethanol of 0.35.

The elasticity of demand for by-products, mainly corn gluten feed and distillers dried grains (DDG) depends on their substitutability with other livestock feeds. Five billion gallons of ethanol, roughly the 2007 level of production, uses 2 billion bushels (50 million tons) of corn, and generates an estimated 7.5 million tons of corn gluten feed and 6.5 million tons of DDG (see Ferris and Joshi, 2005, p. 160). The feed by-products thus amount to tonnage that is about 7 percent of the corn and soybean meal fed in the U.S. With any reasonable degree of substitutability between the by-products and corn and soy-based feeds, the price effects of ethanol expansion on by-product prices would be expected to be small, since even a doubling from the 5 billion gallon ethanol production level would increase the U.S. feed supply by only 7 percent. Ferris and Joshi (2007, Table 7.2) estimate a 30 percent increase in DDG production generating a price decline

[5]The supply elasticity as estimated holds the prices of corn and feed by-products (corn gluten feed) constant. Holding the price of corn constant overstates the elasticity of the curve S_T in Figure 1, because the latter lets the price of corn rise along with the ethanol price.

of less than 1 percent – an elasticity of demand of about -30. Their estimation, however, does not hold the prices of corn and soybeans constant but rather lets those prices rise as ethanol production rises. Therefore DDG and gluten feed demands increase as the predominant substitute prices rise, which largely offsets the price-reducing effects of additional by-product production. Because of the substantial uncertainty about the correct by-product demand elasticity, I will consider a wide range of values, from -1.0 to -30.

With respect to the direct substitution of feed by-products for corn, the approach here simply takes the average of 16.4 pounds of dry matter per 56-pound bushel of corn (Eidman, 2007, p. 11) as providing half the feed value of corn itself, on average. This implies a coefficient g in equation (5) of 0.146.

An issue that has become more prominent as the proportion of corn used for ethanol production has increased is the effects on the availability of corn for livestock feed and export. The increased availability of the feed by-products discussed in the preceding paragraph is not enough to compensate for the lost feed value of corn that goes into ethanol. The most comprehensive available estimates of the effects of increased ethanol on the cost of corn used in feed are derived from the analysis in USDA (2007). They estimate that increasing corn use in ethanol by 700 million bushels would, given a one-year adjustment period, result in 421 million bushels less corn used in feed and exports. The corresponding corn price increase is 24 cents per bushel or 6.5 percent using the 2008 USDA baseline values (USDA, 2007, Tables 1 and 8). The 421 million bushels is 5.7 percent of baseline export and feed use quantities, implying an elasticity of demand for the feed-export aggregate of -0.89. The USDA estimates allow all commodity markets to adjust simultaneously, so that this is not a partial elasticity (holding all prices other than the price of corn constant) but rather allows the prices of soybeans and other related commodities to adjust to the changed situation.

4.1 Simulation of ethanol subsidy effects

As base quantities and prices to work from, I take the levels for the 2006 corn crop (estimates from USDA 2007 and FAPRI 2007). Production is 11 billion bushels, of which 2 billion bushels is used for fuel ethanol, and the average farm price of corn is $3.00 per bushel. The price of ethanol is $5.00 per bushel of corn ($2.00 per gallon of ethanol). The price of by-products is $1.10 per bushel (value of DDG, gluten feeds, and corn oil per bushel of corn). In addition, following equation (8) and as depicted in Figure 1, we add the ethanol subsidy of $1.30 per bushel of corn used in ethanol production (51 cents per gallon of ethanol) to obtain the total gross value received by users of corn going into ethanol of (5+1.1+1.3=) $7.4 per bushel. The price of non-corn inputs in ethanol production is an aggregate estimated as FAPRI’s value of ethanol plus byproducts plus subsidy minus the value of corn used to produce ethanol, per bushel of corn used. The total is (7.40-3.00=) $4.40 cents per bushel of corn. Note that by construction the value of corn plus non-corn inputs (3.00+4.40) equals the value of ethanol plus by-products plus subsidy (5.00+1.10+1.30). The value of ethanol produced is (2*5) $10 billion and the value of the corn crop is (11*3.0) $33 billion.

To simulate the effects of removing the subsidy, numerical solutions of equations (4), (5), and (6) are found, first with s=1.30 and then with s=0. The solution algorithm is the one embedded in Excel's "solver" tool. Consider first short-run effects, using the short-run elasticity values from the preceding discussion, with the geometric mean of the values where a range is given (e.g., $-(1*30)^{0.5}=-5.5$ for ethanol by-products). With the base levels and elasticities just given, we can parameterize each of equations (1) to (5). For example, for equation (1), ethanol demand, we have $P_y=5$, y=2, and $n_y=(-1/0.89)$. Solving for $a=P_y/y^{ny}$ obtains a=10.9, so that equation (1) is completely specified numerically. Then, using equations (6) and (7) we have two equations in two unknowns, x_1 and P_x. While the system is nonlinear and not tractable for an analytical solution, in equation (6) P_x is monotonically decreasing in x_1, and in equation (7) after solving for x_1 it is straightforward to show that x_1 is monotonically increasing in P_x, so a unique solution exists if there is one. Given the parameters, the equations are solved numerically for $P_{x,}$ $x_{1,}$ and x_2 that results from eliminating the subsidy by setting s=0. The resulting values are used in equations (1) to (5) to get the other prices and quantities that result when there is no subsidy.

Table 1 summarizes the results. Under the assumed parameters for elasticities and base-case price and quantities for the short-run case (one-year period of adjustment), the ethanol subsidy generates an increase in corn going into ethanol by 140 million bushels (from 1.86 to 2.00 billion bushels the latter generating roughly 5 billion gallons of ethanol), at a cost to the government of $2.6 billion (=$1.30 per bushel of corn in ethanol times 2 billion bushels). The price of corn rises by 4 cents per bushel generating a $425 million gain in producers' surplus to corn growers and a loss to buyers in feed and export markets of $350 million. The market price of ethanol falls 8.2 percent as its production increases, generating a gain to ethanol buyers of $818 million. (This analysis cannot determine whether that gain accrues to the fuel industry or is passed through to final consumers of fuels). The buyers of DDGs and other feed by-products gain $28 million as these prices fall (but only slightly because of the high elasticity of demand assumed). The owners of ethanol plants, some of whom are themselves farmers, are the big gainers, with increased producers' surplus of $1,588 million.

Other details are shown in the "short run" columns of Table 1. The key points are while corn growers gain from the ethanol subsidy, owners of ethanol plants gain substantially more. This occurs despite the fact that the demand for corn increases and the assumed elasticity of supply of corn (0.23) is smaller than the elasticity of supply of ethanol plant capacity (0.35). The reason is that the ethanol subsidy generates a substantially smaller increase in corn production than in ethanol production (measured in corn-equivalent units), because of the reduction in feed and export uses (see "change in quantities" in Table 1).

Longer-term indicators of ethanol subsidy effects are perhaps more relevant, as the policy has been in place for some time and is expected to remain so. A key change in the longer run is that the supply of ethanol plant capacity is more responsive to ethanol price increases. Following the earlier discussion, in moving from the short-run to long-run context, where long-run means a 10-year period of adjustment as projected in USDA (2007), increases in most of the relevant elasticities for equations (1) to (5) can be inferred. The values used to generate the long-run columns of Table 1 are: ethanol plant, 5 long-run as compared to 0.35 short-run; corn supply, 0.5 long-run as compared to 0.23 short-run; ethanol demand, -10 long-run as compared to -0.91 short-run, and feed/export demand, -1.12 long-run as compared to -0.89 short-run. Now we find that ethanol plant owners, while they gain $875 million, do not benefit as much as corn growers, who gain $2,029 million. This occurs because ethanol plants become much more elastic in supply as there are few fixed inputs over a ten-year horizon, while the land constraint still keeps corn supply inelastic over the longer term. Note also that ethanol plants and corn growers together gain substantially more over the longer term than they did in the short term. This result turns on the long-run ethanol demand being more elastic than the feed/export demand for corn. The elastic ethanol demand means the subsidy draws a lot of corn into ethanol production without driving down the ethanol price much (which is why ethanol buyers' surplus gains are less in the long run), while the relatively inelastic feed-export demand means that diverting more corn to ethanol has a larger price effect in the corn market. The ethanol subsidy thus benefits producers over and above the value of the subsidy itself by creating price discrimination among buyers in which the elastically demanded corn products increase in quantity and the less elastically demanded corn products decrease in quantity (by 674 million bushels in Table 1).

Summing up the gains and losses gives the deadweight loss of the ethanol subsidy, $91 million under the short-run scenario and $665 million under the long-run scenario. The $91 million as a percentage of the subsidy is 91/2600=3.5 percent. The $665 million generates a substantially larger percentage deadweight loss, 665/2600=26 percent. What generates the large inefficiency loss is the high elasticity of demand for ethanol and excess supply of corn to ethanol. The direct (linearized) measure of deadweight loss (a check on the preceding adding up) is the triangle whose area is ½ times subsidy times quantity change, i.e., (½)(1.3)(1,024)=666, using the long-run values.

Table 1. Changes Resulting from an Ethanol Subsidy of 51 Cents per Gallon[a]

	Short Run		**Long Run**	
Change in quantities	**Mil. bu.**	**% change**	**Mil. bu.**	**% change**
Corn	32	0.3	349	3.2
Corn in ethanol	140	7.2	1,024	71.7
Corn fed/exported	-107	-1.3	-674	-7.2
Changes in prices	$ per bu. corn	% change	$ per bu. corn	% change
Corn	.04	1.3	.19	6.5
Ethanol	-.42	-8.2	-.37	-7.2
By-Product feeds	-.01	-1.0	-.15	-2.1
Ethanol plant	.82	20.7	.59	14.3
Gains from subsidy	Mil. Dollars		Mil. Dollars	
Corn producers	425		2,029	
Ethanol plants	1,588		875	
Ethanol buyers	818		553	
By-Product buyers	28		228	
Corn Feed/Export buyers	-350		-1,959	
Sum	2,510		1,935	
Taxpayers	-2,600		-2,600	
Deadweight Loss	91		665	

[a.] Short-run elasticities: of demand, ethanol, -0.89; byproducts, -5.5; feed/export corn, -0.91; of supply, corn 0.23; ethanol plant, 0.35. Long-run elasticities: of demand, ethanol, -10.; byproducts, -5.5; feed/export corn, -1.12; of supply, corn 0.5; ethanol plant, 5.0. See text for sources.

4.2 Deficiency payment compared to ethanol subsidy

Consider a deficiency payment program, a direct subsidy to corn producers, that costs the same to taxpayers as the ethanol subsidy. At the initial values used above, 11 million bushels of corn produced and 2 billion bushels used in ethanol, this requires payment of $1.30 times 2/11 = $0.236 per bushel. Using the same short- and long-run elasticity scenarios as previously, the resulting gains and losses are summarized in Table 2. The deficiency payment generates a gain to ethanol manufacturers, since it reduces the market price of the raw material. But ethanol producers' gain is tiny, only $6 million in the short-run scenario and

$34 million in the long run. Corn producers however do much better in the short run with a deficiency payment, gaining $2.0 billion. Thus, corn producers would prefer the government's subsidy dollars to be spent on deficiency payments rather than on an ethanol subsidy. However, with the longer-run elasticities corn producers prefer the ethanol subsidy. Note that the deadweight loss is much smaller under the deficiency payment program. The reason is that the deficiency payment, being spread over all corn production and not focused on ethanol, does not generate the large quantity change in that elastically demanded product. The distortion is now in the whole corn market where output is increased 350 million bushels which with a 23.6 cent per bushel subsidy gives a deadweight loss triangle of $41 million.

Table 2. Gains and Losses from Ethanol Subsidy and Deficiency Payments[a]

Policy	**Corn Producers**	**Ethanol Producers**	**Buyers of Ethanol, By-Products, and Feed Corn**	**Tax Payers**	**Sum (Deadweight Loss)**
	------------------------million dollars of annual gains----------------------------------				
Ethanol Subsidy (SR)	425	1,588	496	-2,600	-91
Deficiency Payment (SR)	2,017	6	505	-2,600	-18
Ethanol Subsidy (LR)	2,029	875	-969	-2,600	-665
Deficiency Payment (LR)	1,824	34	704	-2,600	-37
[a.]Parameters same as Table 1, except feed demand elasticity changes from -1.12 above to -2 in two rows below.					
Ethanol Subsidy (LR)	1,490	907	-393	-2,600	-689
Deficiency Payment (LR)	2,062	22	474	-2,600	-41

How robust are these estimates to the elasticity parameters used? Corn producers and ethanol plant owners do better when each of their respective supply functions is less elastic, but changing the these elasticities by, for example, halving or doubling them from the values used in the long-run analysis does not substantially alter the relative merits of the ethanol subsidy compared to deficiency payment, from the viewpoint of corn producers. The parameter that is most sensitive in this aspect of the relative merits of the two policies is the elasticity of demand for feed/export uses of corn. The bottom two lines of Table 2 show the results of letting the elasticity of demand for feed/export uses be -2 rather than -1.12 as assumed previously. With this change the deficiency payment makes corn producers better off, because with more elastic demand, a given subsidy generates a larger increase in sales and thus generates more producers' surplus. A larger change occurs in the corn producers' gains from the ethanol subsidy, which now is substantially less favorable for corn producers than it was. The reason is that diverting corn to ethanol no longer generates such a large increase in the corn price, so much so that the overall losses to buyers of corn and its products are cut by more than half when feed/export demand is more elastic.

4.3 Politics and ethanol mandates

Even under the circumstances where farmers get less of the taxpayers' subsidy dollar than ethanol producers, farmers may be well advised to focus on ethanol policy. One reason is political: farmers can get lobbying assistance from ethanol producers for the ethanol subsidy. The ethanol industry can be expected to do some of the heavy political lifting, while farmers can save their political capital for other efforts.

A second reason for farmers' enthusiasm about ethanol is that policies supplementary to the ethanol subsidy, namely ethanol mandates under the Clean Air Act Amendments of 1990 and the Renewable Fuels Standard mentioned earlier, have further advantages. These mandates currently require the purchase by gasoline manufacturers of ethanol that takes about 3 billion bushels of corn by 2012. Analytically, it is apparent from Figure 1 that the corn-price effects and producer gains caused by an ethanol subsidy of s can be exactly duplicated by a mandate that adds a quantity to the demand for ethanol equal to the horizontal distance between S_T and D_T at the producer price achieved at the subsidy s. The only difference is that the government subsidy cost is replaced by increased expenditures of the same amount by the gasoline industry. Thus, there exists a level of mandated ethanol use that generates the results shown in each line of Table 1. This policy could be attainable even when the deficiency payments of Table 2 are not politically feasible because of government budget stringency.

Some mandated levels of ethanol use considered by Congress in 2007 are large. The Senate in summer 2007 passed an energy bill that would require 15 million gallons of ethanol to be used by 2015. This would generate 6 billion bushels of demand for corn devoted to ethanol production. In a long-run simulation using parameters of Table 1, this policy would increase the use of corn by 5 times as much as the 51 cent ethanol subsidy does. The gains to corn growers and ethanol producers are accordingly much larger, an $8.8 billion annual producer surplus gain for corn growers compared to a $2.03 billion gain in Table 1, and a $5.9 billion gain for ethanol producers under the mandate compared to the $0.9 billion gain in Table 1. But the losses to taxpayers are larger assuming the 51 cent ethanol subsidy is continued, rising from $2.6 billion in Table 1 to \$7.8 billion under the mandate. And, the mandate places a substantially greater squeeze on feed/export uses of corn, with their losses rising from \$1.96 billion in Table 1 to \$6.12 billion under the mandate.

An additional cost under the ethanol-use mandate is borne by those who have to pay the higher cost of ethanol due to the higher corn and ethanol production costs that the mandated output expansion generates. With the long-run supply elasticities assumed, the cost of ethanol rises to \$6.92 per bushel of corn used (\$2.77 per gallon of ethanol). At the same time the value of ethanol, even with the high demand elasticity of -10 used in the long-run scenario, falls from \$5.40 per bushel of corn used to \$4.48. A big cost of the ethanol mandate will occur to whoever has to pay the difference between the \$6.92 cost of ethanol and its \$4.48 value (value being measured in the sense of willingness to pay). If the mandate were to take the form of buyers being forced to buy, fuel consumers would pay. With the mandate in the form it has in the Senate bill, of gasoline producers being forced to use ethanol and sell ethanol-containing products for what they will bring in the motor fuel market, then the motor fuel industry will pay. However, this industry also receives the \$1.30 per bushel ethanol subsidy, so the net cost of the mandate to them, again using the Table 1 long-run parameters, is \$0.24 cents per bushel of corn used in ethanol or \$1.43 billion annually.

Adding up all the costs and benefits comparably to Table 1 gives a deadweight loss of \$3.74 billion annually from an ethanol mandate as large as the Senate bill envisages. To see roughly where that amount comes from, the essence of it is that the mandate creates a cost-value difference (“wedge”) of \$1.54 per bushel of corn used in ethanol. With the mandate stimulating 5 billion bushels of additional corn going into ethanol (as compared to an unregulated market), the linearized approximate deadweight loss triangle is ½(1.54)(5)=\$3.8 billion.

A caveat on the preceding deadweight loss calculations is that they are global in the sense that they count the gains and losses of all participants in the ethanol and corn markets. An alternative accounting would be nationalistic, excluding gains and losses to foreign buyers of U.S. corn or sellers of imported ethanol. Ethanol imports are neglected in this paper’s model, because bringing them in would require introduction of an additional policy instrument, the ethanol tariff, thus complicating the model without adding a lot from the U.S. perspective. Exports are however important to the analysis of non-ethanol uses of corn, in that the elasticity of foreign demand for U.S. corn is a major component of the parameter n_2 in the model. This means that a substantial portion of the losses to “feed/export” in Table 1 accrue to foreign buyers. With exports totaling about one-third the quantity of corn fed, this means about one-fourth of the \$1.959 billion loss shown in the long-run panel of Table 1 would not be a loss to U.S. buyers, and as such should not be subtracted from the gains of corn producers to get the deadweight loss from the U.S. viewpoint. This is important because we would then be reducing by $490 million a deadweight loss which, as calculated in Table 1, totals $665 million. Thus it would not take much change in the market situation, e.g., a slightly larger share of exports in corn use, to eliminate the deadweight loss completely. Note also that the comparison with a deficiency payment program is also substantially changed with the nationalistic viewpoint, for the deficiency payment generates a benefit to foreign buyers of U.S. corn by driving down the market price of corn (whereas the ethanol subsidy drives up the market price of corn). Therefore the ethanol subsidy becomes more attractive relative to the deficiency payment when we take the nationalistic U.S. viewpoint.

4.4 Environmental/energy security issues

The preceding analysis omits any possibilities of social gains from the ethanol subsidy. The main such gains that have been argued for are increased energy security as domestically produced ethanol replaces imported oil as an energy source for motor fuels, and environmental quality improvements resulting from use of ethanol rather than oil as the raw material for motor fuels. With respect to energy security, the largest increases in ethanol use that this paper has considered would replace about 10 percent of U.S. gasoline (see Miranowski, 2007). If one could say that this would allow the U.S. to forego the import of oil from a small but risky foreign source, the gains could be considerable, but nonetheless not quantified in available literature. Two sources of environmental gains have been prominent in discussion: cleaner air from use of ethanol as an oxygenate when used in blends such as gasohol with 10 percent ethanol; and reduced net CO_2 emissions due to replacing fossil fuel with biofuel as the energy feedstock. The perceived clean air benefits are sufficient to have gasohol included as a permitted method of meeting requirements of the Clean Air Act Amendments in areas where carbon monoxide and other harmful emissions are a problem; but questions have been raised about these benefits. Similarly, the net gain in carbon emissions from replacing gasoline with corn-based ethanol is unclear.

The estimates in this paper provide some idea of how large the environmental/security benefits must be to justify the ethanol subsidy, namely enough to offset the deadweight losses estimated earlier. In the long-run scenario of Table 1, the ethanol subsidy brings about 1 billion bushels of corn into ethanol production, at a deadweight loss (sum of gains and losses to all participants in the market) of $665 million annually. Therefore, if the subsidy is to create a net social gain, each gallon of ethanol used as fuel must create external benefits of 66.5 cents per bushel of corn used in ethanol, or 26.6 cents per gallon of ethanol produced.[6]

[6] This calculation neglects second-best gains of the ethanol subsidy through decreasing output in

5. Conclusions

The social benefit/cost analysis of this paper indicates that ethanol subsidies or mandates are unlikely to generate net social gains. The deadweight loss, for parameter values most consistent with the existing literature (admittedly not solid) suggest only small a deadweight loss for a short-run period where supply and demand responses are relatively small. In the longer run, when both supply and demand are more elastic, the deadweight loss increases substantially, especially for large interventions such as proposed in the Senate-passed 2007 energy bill, where this paper's estimate is a deadweight loss of between \$3.5 and \$4 billion annually.

Notwithstanding the likely social inefficiency of ethanol subsidies, the analysis indicates why these policies have appeal for farm interests. While it might be thought that corn growers should prefer to see the government's subsidy dollars spent directly on their product rather than on a finished product for which corn is the raw material, this is not necessarily the case. It is true that with an ethanol subsidy, suppliers of non-corn ethanol inputs, notably owners of ethanol plants, share in the gains to a larger extent than corn producers, so for a given total subsidy cost the corn producers would typically gain more from a corn deficiency payment subsidy than from an ethanol subsidy. The key prospect for overturning this result arises when the demand for uses of corn other than ethanol, mainly feed and exports, are less elastic than the derived demand for ethanol. In this situation, the ethanol subsidy induces price discrimination that results in a given amount of corn generating more revenue by shifting demand into a less price-sensitive market and out of a more price-sensitive market, so price rises more in the latter market than it falls in the former.

6. References

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related markets where output-increasing distortions exist (e.g., subsidies to corn-competing commodities) or increasing output in related markets where output-decreasing distortions exist (e.g., set-aside programs). Currently, U.S. policy does not have set-asides, and the more likely effect in related markets is increasing output of markets, notably soybeans, in which policy already is causing overproduction if it has any output effect at all. Therefore, second-best effects are probably negligible, but to the extent they exist probably add to rather than subtract from the deadweight losses estimated for the corn and corn products market in Table 1.

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