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The Socially Optimal Import Tariff and Tax Credit for Ethanol with Farm Subsidies

Harry de Gorter, David R. Just, and Qinwen Tan

We determine how the U.S. ethanol tax credit and import tariff affect the corn-ethanol-gasoline markets and how farm subsidies interact with these policies. We show how the ethanol tax credit and import tariff each uniquely affect the ethanol and gasoline prices. The ethanol import tariff alone increases the terms of trade in ethanol imports and corn exports, but decreases the terms of trade in gasoline imports and the tax costs of farm price supports. With price-contingent farm subsidies in place, the optimal tariff and tax credit will depend on the price level. When farm subsidy expenditures are high, import subsidies for ethanol may increase social welfare due to the substantial size of the fuel market relative to the corn market.

Key Words: biofuels, ethanol, tariffs, tax credit, welfare

RFA [Renewable Fuels Association] president Bob Dinneen argued that ethanol has played a central role in reducing oil imports and lowering gasoline prices. But that played right into UNICA's [Uniao de Industria de Cana-de-Acucar] hands, because UNICA's argument is that if U.S. corn ethanol lowers gasoline prices, as Dinneen says, cheaper Brazilian ethanol would lower prices even more.

— Keith Johnson, *Wall Street Journal*

The most salient set of recent criticisms of ethanol policy relate to the impact on food crop prices and the environment. Rapidly escalating food prices have stressed many developing countries and poor households, while recent studies argue that indirect land-use changes due to biofuels may enhance greenhouse gas emissions (Runge and Senauer 2007, Searchinger et al. 2008). Meanwhile, proponents argue that U.S. ethanol policies bestow benefits to the economy in the form of

lower gasoline prices and farm subsidies, while corn diverted to ethanol production not only withholds corn from world markets (allowing the United States to act as a large country exporter on world corn markets), but also increases fuel supply and hence improves the U.S. terms of trade in oil imports (Schmitz, Moss, and Schmitz 2007, Rajagopal et al. 2007).¹ The literature to date has been silent on the optimal import tariff for ethanol. The U.S. tax credit by itself increases the terms of trade for the ethanol exporter (e.g., Brazil), but these social benefits in the United States are augmented by existing price-contingent farm subsidy programs like deficiency payments (de Gorter and Just 2009). No research has determined the optimal ethanol import tariff and how it interacts with the optimal tax credit. Adjusting these policies jointly or independently affects the

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¹ We define a change in the terms of trade due to a policy as the change in social welfare due to a change in the market price of an export and of an import. For a simple import tariff, the change in terms of trade equals the old world price less the new world price times the new level of imports (it is a rectangle). This is the traditional definition of the change in terms of trade with respect to an import tariff in a partial equilibrium setting. In general equilibrium, there are imports and exports and the definition of the terms of trade is as Feenstra and Taylor (2007) define it. But we calculate the terms of trade for each individual sector and do not have a general equilibrium model that closes the economy: Y is fixed. The first paper to recognize terms of trade improvements in both corn and oil markets due to the tax credit is de Gorter and Just (2007a).

terms of trade in oil imports and corn exports, and the tax costs of farm subsidies.

Because first-best policies like export taxes on corn and import tariffs on oil are not allowed (due to the Constitution of the United States and the World Trade Organization, respectively), we assume that the only policies available are those currently in use: ethanol tax credit, ethanol import tariff, and corn production subsidies. These policies exist primarily due to non-economic objectives such as concerns for the environment or farm income. Furthermore, we assume the level of farm subsidies to be exogenous due to political concerns and derive the optimal ethanol import tariff and ethanol tax credit.²

We model ethanol as a perfect substitute for oil-based gasoline in consumption. Further, we assume constant returns to scale in converting corn into ethanol, thus linking corn prices directly to gasoline prices. This relationship is complicated by the particular farm support and biofuel policies in place. For example, if the loan rate is above the price of corn, then oil prices can impact only consumer prices for corn and not producers who will receive the loan rate. Ethanol tax credits increase the demand for corn as an input, and thus have the effect of increasing corn prices for consumers in this case. If the corn prices rise above the loan rate, then gasoline prices and ethanol subsidies will impact both consumer and producer prices for corn.

The federal tax credit for corn-based ethanol was recently reduced from 51 to 46 cents per gallon, while state tax credits average 6 cents per gallon (Koplow 2007). Alternatively, cellulosic ethanol tax credits are \$1.01 per gallon. Given Babcock's (2008a) projections on corn-based ethanol use if mandates are filled, the total tax costs could exceed \$34 billion per year by 2022. The recent spike in oil prices increased corn prices above the loan rate, thus activating the effect of the tax credit on market prices for corn. In this scenario, effectively the only production subsidies for corn are \$2 billion per year in direct payments. The new ACRE program bases payments on current price relative to recent average prices. Thus two years of high corn prices followed by a

\$2/bu price could precipitate billions of dollars in farm subsidies again (Babcock 2008b).

Additionally, there is currently little trade in biofuels mainly because of high tariffs (Howse, van Bork, and Hebebrand 2006). The import tariffs on ethanol total are around 57 cents per gallon (54 cents per gallon plus an *ad valorem* duty of 2.5 percent), almost equal to the federal and state tax credits of 57 cents per gallon before the 5 cent per gallon federal tax credit reduction in the recent Farm Bill. The import tariff was put in place explicitly to offset the tax credit. At the same time, it is widely believed that developing countries have a comparative advantage in biofuel production, including Africa (UNCTAD 2006, Kojima, Mitchell, and Ward 2007). Because the import tariff affects exports from Brazil where ethanol from sugar cane contributes far more to reducing greenhouse gases than ethanol derived from corn in the United States, many commentators have remarked on how an ethanol tariff contradicts the goals of improving the environment, reducing reliance on oil and oil imports, and diversifying energy sources (Jank et al. 2007, Kojima, Mitchell, and Ward 2007, Howse, van Bork, and Hebebrand 2006, Doornbosch and Steenblik 2007). Clearly, other political goals such as enhancing farm incomes, reducing the tax costs of farm subsidy programs, and promoting rural development are also very important (Rajagopal and Zilberman 2007, Tyner 2007).

In this paper, we determine how the ethanol tax credit and import tariff affect the corn-ethanol-gasoline markets (for a given volumetric fuel tax) and assess how alternative levels of farm subsidies affect the outcome. We will determine the link between ethanol and corn prices, and show how the ethanol tax credit and import tariff each uniquely affect the ethanol and gasoline prices. The intercept of the ethanol supply curve can be above the gasoline price and also above the corn price itself. When the intercept of the ethanol supply curve is above the gasoline price, policies leading to ethanol production generate what we call "rectangular deadweight costs": part of the extra revenues to ethanol producers due to the tax credit costs taxpayers, but nobody benefits until the gap between the gasoline price and intercept of the ethanol supply curve is first closed. These deadweight costs are much higher than standard inefficiency costs estimated in the form of deadweight cost triangles. If the intercept of the etha-

² For an analysis on how the impacts of an ethanol import tariff differ between a tax credit and mandate, see de Gorter and Just (2007b).

nol supply curve is above the corn price, not only are there rectangular deadweight costs but we will show how corn production subsidies were the sole cause of ethanol production. Ethanol production would otherwise be zero, even with the tax credit in place.

We also show that the ethanol import tariff alone increases the terms of trade in ethanol imports and corn exports but decreases the terms of trade in gasoline imports and the tax costs of farm price supports. With both a tax credit and ethanol import tariff (and if they are equal, as they are in the United States), the effects of the ethanol tariff on the terms of trade are substantially different. The tariff in addition to the tax credit reduces the tax costs of the tax credit. The net outcome on welfare depends on the sensitivity of gasoline prices to ethanol supply (domestic and imports), which is itself dependent on supply and demand parameters and relative quantities of ethanol supply, gasoline imports, and corn output. Our results lend support to the hypothesis of Schmitz, Moss, and Schmitz (2007) and Rajagopal et al. (2007) that there is a trade-off between the social costs of taxpayer-financed tax credits and the improved terms of trade in gasoline imports. As both studies correctly argue, the change in gasoline prices due to increased ethanol supply need not be large because the quantity of gasoline consumption is so high. We indeed find that in some circumstances import subsidies for ethanol (in addition to or instead of tax credits) are socially optimal.

UNICA's suggestion in support of RFA President Bob Dinneen's concern for overall welfare in the United States to eliminate the import tariff—expressed in the statement quoted at the beginning of this paper—did not go far enough: not only should the import tariff for ethanol be removed, in some cases it should be negative! When the loan rate is effective, farmers do not benefit from the tax credit and are not hurt by ethanol imports. It is therefore possible that corn farmers, gasoline consumers, and ethanol exporters will all be better off with reduced import tariffs for ethanol (to the point that they can go negative) while reducing or eliminating tax credits when price-contingent farm subsidies are in place. The results of this paper highlight the importance of analyzing the interaction between ethanol import tariffs and tax credits with alternative levels of farm subsidies.

This paper is organized as follows. The next section develops the link between corn, ethanol, and gasoline markets, and how policies affect prices. We then develop the optimal relationship between the tax credit and the ethanol import tariff to allow one to assess what key factors affect the market. Then we provide some empirical results. The final section concludes.

Equilibrium under Ethanol and Farm Policies

In this section we model the corn and gasoline markets under an ethanol tax credit, import tariff, a fuel tax, and their interaction with loan deficiency payments. The equilibrium price relationships we derive in this section form the basis for the welfare analysis in the subsequent section. We follow the model detailed in de Gorter and Just (2008). According to this model, a bushel of corn can be converted into ethanol at a constant cost of c_0 , resulting in β gallons of ethanol and δ bushels of byproduct which can be sold back into the corn market. Estimated values of c_0 , β , and δ in the empirical analysis to follow are 1, 2.8, and 0.31, respectively (Eidman 2007). Constant returns to scale is a simplifying assumption, given recent indications of increasing returns to scale in ethanol production in the United States. If this is the case, the industry may see significant cost economies in expanding production facilities, reducing the marginal cost of transforming corn to ethanol. Despite cost economies, it seems likely that, given current yield levels and land use, ethanol producers would run into significant market diseconomies in using corn as an input. This must be a priority in future research.

A bushel of corn can be purchased for the market price of corn, P_C , and converted to ethanol and corn resulting in revenue of $\beta P_E + \delta P_C$, where P_E is the market price of ethanol per gallon. This results in a total marginal profit of $\pi' = \beta P_E + (\delta - 1)P_C - c_0$. Given that markets function well, if marginal profits from converting corn to ethanol are positive, $\pi' > 0$, then producers will continue to demand corn for ethanol until the price of ethanol is bid down and the price of corn bid up, resulting in zero marginal profit. Thus, in equilibrium, the price of ethanol and corn must follow the relationship

$$(1) \quad P_C = (\beta P_E - c_0) / (1 - \delta)$$

so long as ethanol is produced in equilibrium. Otherwise, $P_C > (\beta P_E - c_0)/(1 - \delta)$, implying negative marginal profits from converting corn to ethanol.

Ethanol can be mixed with gasoline to produce fuel. We treat ethanol as a perfect substitute for gasoline. While fuel containing high concentrations of ethanol (such as E85) can currently be used only by a small percentage of the cars on the road in the United States, nearly all automobiles can use fuel containing lower levels of ethanol (such as E10). Hence our treatment of ethanol as a perfect substitute for gasoline is an abstraction. However, less than one percent of ethanol is sold in concentrations higher than that found in E10. Thus, for the concentrations of fuel found in the market, ethanol can reasonably be expected to perform as a perfect substitute.

The energy content of ethanol is substantially lower than that of gasoline (by about 30 percent). We suppose that individuals value ethanol and gasoline for their contributions to vehicle miles traveled. Hence, in equilibrium,

$$(2) \quad P_E = \lambda P_G,$$

where P_G is the market price of gasoline per gallon, and λ is the ratio of miles per gallon derived from ethanol to miles per gallon derived from gasoline (estimated to be 0.70). Again, if this equality did not hold, consumers would be led to adjust their consumption of ethanol and gasoline until equilibrium was achieved. This together with (1) implies that

$$(3) \quad P_C = (\beta \lambda P_G - c_0)/(1 - \delta)$$

if ethanol is produced.

The introduction of taxes and tax credits fundamentally alters the equilibrium price relationships given in (2) and (3) by altering the profit incentives and the marginal cost of vehicle miles. Let t represent the volumetric tax on all fuel, and t_c the tax credit awarded to blenders for use of ethanol. Then, we can rewrite (2) and (3) as

$$(4) \quad P_E + t - t_c = \lambda(P_G + t)$$

and

$$(5) \quad P_C = (\beta[\lambda P_G + (\lambda - 1)t + t_c] - c_0)/(1 - \delta) \equiv P_{Eb},$$

where P_{Eb} can be thought of as the bushel equivalent price of ethanol. Further, it is convenient to define $P_{Gb} \equiv (\beta[\lambda P_G + (\lambda - 1)t] - c_0)/(1 - \delta)$ as the bushel equivalent price of gasoline. The implication of equation (5) is that for every one cent per gallon change in the price of ethanol, the corn price changes by 4.06 in cents per bushel. This means the corn price is very sensitive to a change in the tax credit or gasoline price. The United States also imposes a tariff on imports of ethanol. Such a tariff alters the price received by foreign producers of ethanol, so that they receive $P_E^X = P_E - \tau$, where τ is the per gallon tariff. Thus, the price received by foreign ethanol producers equals

$$(6) \quad P_E^X = [\lambda P_G + (\lambda - 1)t + t_c] - \tau.$$

Finally, if the market price for corn falls below a certain level, L , loan deficiency payments of $L - P_C$ will be made to corn producers for each bushel of corn produced. If this program is effective, then without any ethanol production, the price of corn would be the price-inducing demand equal to the production level at a price of L . Let q^{-1D} be the inverse demand function for non-ethanol corn, and q_C^S be the supply of corn. Then the market price of corn under the loan deficiency program without ethanol production would be $P_L = q^{-1D}(q_C^S(L))$. Define P_{NE} as the price at the intersection of the corn supply and non-ethanol corn demand curves, $P_{NE} \equiv \{P \mid q^D(P) = q_C^S(P)\}$. The loan deficiency payments will be effective if $L > \max\{P_{NE}, P_{Eb}\}$. In this case, the market price of corn is equal to the maximum of P_L and P_{Eb} . These price relationships make up the building blocks of our welfare analysis.

An Algebraic Formulation of the Optimal Tax Credit–Tariff Relationship

We analyze three potential terms-of-trade improvements for the United States due to the tax credit and tariff: as an importer of gasoline, as an importer of ethanol, and as an exporter of corn. The mechanism by which each occurs is unique, given the way in which the tax credit and tariff affect the ethanol and hence gasoline markets. Market prices for gasoline decline with a tax credit even though domestic gasoline production

declines. Normally, an optimal import tariff is a subsidy on domestic gasoline production and an equal tax on domestic gasoline consumption. Domestic gasoline consumption declines because it is displaced by ethanol production. Hence, the optimal tax credit is inferior to an optimal import tariff on gasoline in terms of improving the terms of trade. The terms-of-trade improvement in corn exports, on the other hand, occurs even though domestic corn production increases and domestic consumption declines. Normally an optimal export tax does the opposite: it taxes production and subsidizes domestic consumption. Although total corn production increases, that devoted to non-ethanol uses declines, and hence the terms-of-trade improvement. Again, the optimal tax credit is expected to be inferior to an optimal export tax on corn. The question now becomes: what are the terms-of-trade effects of the ethanol import tariff? The tax credit benefits ethanol exporters and domestic producers equally. This can be shown in Figure 1, where the excess supply curve for ethanol facing the United States is given by ES_E . With neither a tax credit nor an ethanol import tariff, the price of gasoline would be P_G [equal to the price of ethanol adjusted as in equation (5)] and ethanol imports would be the distance OB .

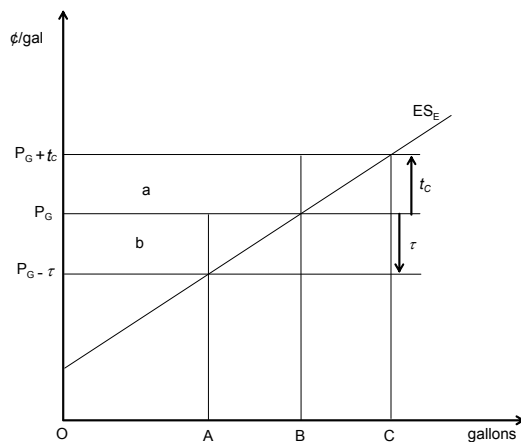


Figure 1. Effects of an Ethanol Import Tariff and Tax Credit

Now consider a tax credit, resulting in an increase in the market price of ethanol to $P_G + t_c$ (we assume for the purposes of the figure that gasoline prices are invariant to ethanol production

or ethanol imports). Exporters of ethanol benefit as U.S. ethanol imports increase to OC , and so the U.S. terms of trade in ethanol imports decline by area a in Figure 1. Assume on the other hand that only an import tariff on ethanol was imposed. World ethanol prices would decline to $P_G - \tau$ and U.S. terms of trade in ethanol imports would increase by area b in Figure 1. The ethanol import tariff alone increases the terms of trade in ethanol imports. An explanation is required for why an import tariff reduces the world price of ethanol by almost the full amount of the tariff (the world gasoline price will not increase much with the reduced amount of total world ethanol supply due to the U.S. ethanol import tariff). Normally, the market price of ethanol is determined in relation to the price of gasoline (itself tied to the price of oil) and little else can change that relationship. So why is the price of ethanol in Brazil not tied to the price of gasoline in the same way? Because the United States combines the lowest fuel tax with the highest ethanol tax credit, it will act as a price-setter—U.S. markets will determine the world market price of ethanol (de Gorter, Just, and Kliaug 2008). The Brazilian market price of ethanol is then equal to the U.S. market price less the import tariff and transportation costs. The tax credit in Brazil (if positive net of the penalty imposed by a *volumetric* fuel tax) only subsidizes ethanol consumption in Brazil (de Gorter, Just, and Kliaug 2008).

Although the terms of trade increase with an ethanol import tariff, the latter increases the terms of trade for corn exports but reduces the terms of trade for gasoline imports (the extent to which depends on how ethanol imports affect world prices of corn and gasoline). However, the tax credit cancels the original terms-of-trade gains of the ethanol import tariff, provided that the tax credit is of equal value to the import tariff (and assuming that gasoline prices do not change with a change in ethanol supply). Nevertheless, for a given tax credit, the import tariff has a higher terms of trade improvement (area a in Figure 1) than if no tax credit existed (area b).

Because the tax credit and tariff for ethanol can have such disparate effects on welfare and trade, it is informative to derive the optimal tax credit for a large country exporter of corn and importer of gasoline. This serves as an important benchmark to understand how different market parameters determine the social welfare effects of

the tax credit policy. A positive optimal tax credit indicates that the improvement in terms of trade outweighs the additional deadweight cost of a tax credit policy. Additionally, we employ an indirect utility approach. This eliminates some of the problems inherent in consumer surplus analyses [for consumer surplus analysis of a tax credit, see de Gorter and Just (2009)].

Consider a demand sector represented by the indirect utility function $V(\tilde{P}, P_g, Y)$, where

$$\tilde{P} = \max\{P_{Gb} + t_{cb}, q^{-1D}[-\pi_1(\hat{P})]\}$$

is the consumer price for corn,

$$\hat{P} = \max\{P_{Gb} + t_{cb}, P_{NE}, L\}$$

is the producer price for corn, P_{NE} is defined implicitly as $q^S(P_{NE}) = q^D(P_{NE}) + q^X(P_{NE})$, L is the loan rate, $q^{-1D}(\cdot)$ is the inverse of the demand function for non-ethanol corn consumption, and Y is the level of income. This indirect utility function generates the demand curve for non-ethanol corn, $q^D = -V_{\tilde{P}}/V_Y$, and for fuel, $q_F^D = -V_{P_g}/V_Y$. The supply sector can be represented by $\pi(\hat{P}, P_g)$, generating the supply curve for corn, $q^S = \pi_{\hat{P}}$, where the subscript denotes the derivative. Likewise, the supply curve for gasoline is given by $q_G^S = \pi_{P_g}$. Additionally, let the foreign demand for corn be given by q_G^X and the import supply of gasoline be given by q_E^X . Finally, let q_{Eb}^X be the supply of ethanol from foreign countries. Denote the tax credit given to ethanol producers (in bushel equivalents) as t_{cb} , thus $P_c = P_{Gb} + t_{cb}$. The optimal t_{cb} solves

$$(7) \quad \max_{t_{cb}, \tau} V(\tilde{P}, P_g, Y)$$

subject to

$$\begin{aligned} Y &= Y_0 - t_{cb}[q^S(\hat{P}) - q^D(\tilde{P}) - q^X(\tilde{P})] - \theta q^S \\ &\quad + \pi(\hat{P}, P_g) + (\tau - t_{cb})q_E^M(\tilde{P} - \tau), \\ q_G^S(P_{Gb}) &+ q_G^X(P_{Gb}) \\ &+ \lambda[q^S(\hat{P}) - q^D(\tilde{P}) - q^X(\tilde{P}) + q_E^M(\tilde{P} - \tau)] \\ &= q_F^D(P_{Gb}), \end{aligned}$$

where $\theta = \max\{L - \tilde{P}, 0\}$ is the deficiency payment, and q_E^M is the import supply of ethanol.

The resulting first-order conditions can be written as

$$\begin{aligned} (8) \quad & q^D \left(1 - \frac{\partial \tilde{P}}{\partial t_{cb}}\right) - q^S \left(1 - \frac{\partial \hat{P}}{\partial t_{cb}} + \frac{\partial \theta}{\partial t_{cb}}\right) \\ & + q^X - t_{cb} \left(\frac{\partial q^S}{\partial P} \frac{\partial \hat{P}}{\partial t_{cb}} - \frac{\partial q^D}{\partial P} \frac{\partial \tilde{P}}{\partial t_{cb}} - \frac{\partial q^X}{\partial P} \frac{\partial \tilde{P}}{\partial t_{cb}}\right) \\ & - \theta \frac{\partial q^S}{\partial P} \frac{\partial \hat{P}}{\partial t_{cb}} + (\tau - t_{cb}) \frac{\partial q_E^M}{\partial P} \frac{\partial \tilde{P}}{\partial t_{cb}} - q_E^M \\ & + \mu \lambda \left(\frac{\partial q^S}{\partial P} \frac{\partial \hat{P}}{\partial t_{cb}} - \frac{\partial q^D}{\partial P} \frac{\partial \tilde{P}}{\partial t_{cb}} - \frac{\partial q^X}{\partial P} \frac{\partial \tilde{P}}{\partial t_{cb}} + \frac{\partial q_E^M}{\partial P} \frac{\partial \tilde{P}}{\partial t_{cb}}\right) = 0, \end{aligned}$$

$$\begin{aligned} (9) \quad & -q^D \frac{\partial \tilde{P}}{\partial P_{Gb}} - q_F^D \\ & - t_{cb} \left(\frac{\partial q^S}{\partial P} \frac{\partial \hat{P}}{\partial P_{Gb}} - \frac{\partial q^D}{\partial P} \frac{\partial \tilde{P}}{\partial P_{Gb}} - \frac{\partial q^X}{\partial P} \frac{\partial \tilde{P}}{\partial P_{Gb}}\right) \\ & + \left(\frac{\partial \hat{P}}{\partial P_{Gb}} - \frac{\partial \theta}{\partial P_{Gb}}\right) q^S - \theta \frac{\partial q^S}{\partial P} \frac{\partial \hat{P}}{\partial P_{Gb}} + q_G^S \\ & + (\tau - t_{cb}) \frac{\partial q_E^M}{\partial P} \frac{\partial \tilde{P}}{\partial P_{Gb}} \\ & + \mu \left[\frac{\frac{\partial q_G^S}{\partial P} + \frac{\partial q_G^X}{\partial P}}{\frac{\partial q^S}{\partial P} \frac{\partial \hat{P}}{\partial P_{Gb}} - \frac{\partial q^D}{\partial P} \frac{\partial \tilde{P}}{\partial P_{Gb}} - \frac{\partial q^X}{\partial P} \frac{\partial \tilde{P}}{\partial P_{Gb}} + \frac{\partial q_E^M}{\partial P} \frac{\partial \tilde{P}}{\partial P_{Gb}}} \right] = 0, \end{aligned}$$

and

$$(10) \quad q_E^M + (\tau - t_{cb}) \frac{\partial q_E^M}{\partial P} - \mu \lambda \frac{\partial q_E^M}{\partial P} = 0.$$

Explicit solutions to equations (8)–(10) are not possible without further assumptions. If we assume that the model curves are approximately linear near the observed equilibrium, we can solve this system explicitly as a function of the observed tax credit, tariff, gasoline prices, and quantities.

The definitions $\hat{P} = \max\{P_{Gb} + t_{cb}, P_{NE}, L\}$ and $\tilde{P} = \max\{P_{Gb} + t_{cb}, q^{-1D}(\hat{P})\}$, and $\theta = \max\{L - \tilde{P}, 0\}$, imply the following contingencies:

- (i) If $P_{Gb} + t_{cb} > P_{NE}, L$, then $\hat{P} = P_{Gb} + t_{cb}$, $\tilde{P} = P_{Gb} + t_{cb}$, $\theta = 0$, and substituting into equations (8)–(10) obtains

$$t_{cb} = \frac{q^X - 2q_E^M}{\left(\frac{\partial q^S}{\partial P} - \frac{\partial q^D}{\partial P} - \frac{\partial q^X}{\partial P}\right)}$$

$$\tau - t_{cb} = -\frac{q_E^M}{\frac{\partial q_E^M}{\partial P}}.$$

The last relationship is very similar to the standard formula of the optimal import tariff, which is a function of the elasticity of import supply only. Here, it implies that the optimal tariff is always smaller than the optimal tax credit. Alternatively, the sign and size of the optimal tax credit depends on the relative size of the corn export and ethanol import markets. The larger the corn export market relative to the ethanol import market, the larger the tax credit.

- (ii) If $L > P_{Gb} + t_{cb} > P_{NE}$ or $L > P_{NE} > P_{Gb} + t_{cb} > P_L$, then $\hat{P} = L$, $\tilde{P} = P_{Gb} + t_{cb}$, and $\theta = L - P_{Gb} - t_{cb}$, and substituting into equations (8)–(10) obtains

$$t_{cb} = \frac{1}{\left(-\frac{\partial q^D}{\partial P} - \frac{\partial q^X}{\partial P}\right)} \times \left[q^S + q^X - 2q_E^M + \frac{2\lambda q^S \left(\frac{\partial q^D}{\partial P} + \frac{\partial q^X}{\partial P} - 2\frac{\partial q_E^M}{\partial P}\right)}{\left(\frac{\partial q_F^D}{\partial P} - \frac{\partial q_G^S}{\partial P} - \frac{\partial q_G^X}{\partial P}\right)} \right]$$

$$\tau - t_{cb} = -\frac{q_E^M}{\frac{\partial q_E^M}{\partial P}} + \frac{\lambda q^S}{\left(\frac{\partial q_G^S}{\partial P} + \frac{\partial q_G^X}{\partial P} - \frac{\partial q_F^D}{\partial P_{Gb}}\right)}.$$

Under this regime the tariff may exceed the tax credit, and the sign of both equations will depend

upon the relative slopes of the various supply and demand curves. The first term of the tariff equation is negative, while both the numerator and denominator of the second term must be positive. In particular the tariff is larger when the excess demand for ethanol is relatively less elastic than the supply of ethanol imports, or when the domestic supply of corn is large relative to the amount of ethanol imports. Standard optimal tariff analysis corresponds to the first term of the equation above and does not involve the excess demand curve. The interaction of the farm subsidies and resulting tax costs introduces the excess demand curve as a necessary component in determining the optimal tariff.

- (iii) If $L > P_{NE} > P_L > P_{Gb} + t_{cb}$, then $\hat{P} = L$, $\tilde{P} = P_L$, and $\theta = L - P_L$. The tax credit does not appear in equations (8) or (9), hence an optimum obtains when $t_{cb} = 0$:

$$\tau - t_{cb} = -\frac{q_E^M}{\frac{\partial q_E^M}{\partial P}} + \frac{\lambda(q_F^D - q_G^S)}{\left(\frac{\partial q_G^S}{\partial P} + \frac{\partial q_G^X}{\partial P} - \frac{\partial q_F^D}{\partial P_{Gb}}\right)}.$$

Again, the first term corresponds to standard optimal tariff analysis, while the second term explicitly accounts for the farm subsidies and gasoline market effects. The tariff may be positive if excess demand for ethanol is relatively less elastic than the supply of ethanol imports, or if the consumption of ethanol is large relative to the imports of ethanol. In this case the deadweight costs of subsidizing domestic ethanol production do not justify a tax credit.

- (iv) If $P_{NE} > P_{Gb} + t_{cb}, L$, then $\hat{P} = P_{NE}$, $\tilde{P} = P_{NE}$, and $\theta = 0$. The tax credit does not appear in equations (8) or (9), hence an optimum obtains when $t_{cb} = 0$:

$$\tau - t_{cb} = -\frac{q_E^M}{\frac{\partial q_E^M}{\partial P}} + \frac{\lambda(q_F^D - q_G^S)}{\left(\frac{\partial q_G^S}{\partial P} + \frac{\partial q_G^X}{\partial P} - \frac{\partial q_F^D}{\partial P_{Gb}}\right)}.$$

Again, in this case the tariff may be positive if excess demand for ethanol is relatively less elastic than the supply of ethanol imports.

Let η^i be the price elasticity of curve i . Define the elasticity of excess supply of ethanol as $\kappa_1 = \eta^S q^S - \eta^D q^D - \eta^X q^X$, the elasticity of demand for non-ethanol corn as $\kappa_2 = -\eta^D q^D - \eta^X q^X$, and the elasticity of excess demand for ethanol as $\kappa_3 = \eta_G^S q_G^S + \eta_G^X q_G^X - \eta_F^D q_F^D$. Let E be the total supply of ethanol (both domestic and imported). Finally, let

$$\{t_{cb}, \tau, P_{Gb}, q^S, q^D, q^X, q_E^M, q_F^D, q_G^S, q_G^X\}$$

be the observed parameter and variable values in current equilibrium, and $\{t_{cb}^*, \tau^*\}$ be the optimal tariff. Further, we will assume that the observed parameters follow $\tau = t_{cb}$, as has been the case since the institution of both the tax credit and the tariff in the United States. If we assume that the supply and demand curves are approximately linear between the current equilibrium and the optimum, we can solve for the optimal tax credit and tariff in terms of the current policy variables as below:

(i) If $P_L > P_{NE} > L$, then

$$t_{cb}^* = \frac{(q^X - 2q_E^M)(P_{Gb} + t_{cb})}{\kappa_1}$$

if

$$P_{Gb} - P_{NE} > -\frac{(q^X - 2q_E^M)(P_{Gb} + t_{cb})}{\kappa_1}$$

(Case A), and 0 otherwise (Case B); and

$$\tau^* - t_{cb}^* = -\frac{P_{Gb}}{\eta_E^M}$$

if

$$P_{Gb} - P_{NE} > -\frac{(2q_E^M + q^X)(P_{Gb} + t_{cb})}{\kappa_1}$$

(Case A), and

$$-\frac{P_{Gb}}{\eta_E^M} + \frac{\lambda EP_{Gb}}{\kappa_3}$$

otherwise (Case B).

(ii) If $L > P_{NE} > P_L$, then

$$t_{cb}^* = \frac{(q^X - 2q_E^M)(P_{Gb} + t_{cb})}{\kappa_1}$$

if

$$P_{Gb} - L > -\frac{(q^X - 2q_E^M)(P_{Gb} + t_{cb})}{\kappa_1}$$

(Case A), and

$$\begin{aligned} & \frac{P_{Gb} + t_{cb}}{\kappa_2} \left(q^S + q^X - 2q_E^M - 4\frac{\lambda q^S}{\kappa_3} \eta_E^M q_E^M \right) \\ & - \frac{2\lambda q^S}{\kappa_3} P_{Gb} \end{aligned}$$

if

$$\begin{aligned} L - P_{Gb} & > \frac{P_{Gb} + t_{cb}}{\kappa_2} \left(q^S + q^X - 2q_E^M - 4\frac{\lambda q^S}{\kappa_3} \eta_E^M q_E^M \right) \\ & - \frac{2\lambda q^S}{\kappa_3} P_{Gb} > P_L \end{aligned}$$

(Case C1), and 0 otherwise (Case C2); and

$$\tau^* - t_{cb}^* = -\frac{P_{Gb}}{\eta_E^M}$$

if

$$P_{Gb} - L > -\frac{(2q_E^M + q^X)(P_{Gb} + t_{cb})}{\kappa_1}$$

(Case A), and

$$-\frac{P_{Gb}}{\eta_E^M} + \frac{\lambda q^S P_{Gb}}{\kappa_3}$$

if

$$\begin{aligned} L - P_{Gb} & > \frac{P_{Gb} + t_{cb}}{\kappa_2} \left(q^S + q^X - 2q_E^M - 4\frac{\lambda q^S}{\kappa_3} \eta_E^M q_E^M \right) \\ & - \frac{2\lambda q^S}{\kappa_3} P_{Gb} > P_L - P \end{aligned}$$

(Case C1), and

$$-\frac{P_{Gb}}{\eta_E^M} + \frac{\lambda EP_{Gb}}{\kappa_3}$$

otherwise (Case C2).

The solution to this optimization problem depends primarily on the relationship between the loan rate, P_{NE} , and the price of corn, and can fall into any of four contingent cases. These cases delineate the price thresholds determining if the price of gasoline will transmit to the corn market. Thus the terms of trade in ethanol/corn will be affected differently depending on the effectiveness of the loan rate, or on whether domestic production of ethanol is warranted by the tax credit. The welfare effects of the tax credit and tariff are fundamentally different within each case:

CASE A. The loan rate is ineffectual:
($P_{Gb} + t_{cb} > P_{NE}, L$).

When the loan rate is ineffective, the optimal tax credit must be positive, and the tariff must be less than the tax credit. In this case, the tax credit and tariff combination creates a net increase in the price of corn exported. This increases the terms of trade. Additionally, the tax credit decreases the price of gasoline, creating another terms-of-trade gain.

CASE B. The loan rate is effective but below P_{NE} : ($P_{NE} > P_{Gb} + t_{cb}, L$).

Where gasoline prices are not transmitted to corn consumers due to low relative gasoline prices, the optimal tax credit is zero. This is because it is not possible to improve the terms of trade in gasoline imports or corn exports, nor to have ethanol imports affect the terms of trade for either. Within these cases, it is impossible to improve on the terms of trade enough to justify the deadweight cost of the tax credit. Yet the ethanol tariff may improve terms of trade of ethanol imports but reduce the terms of trade in gasoline imports. The optimal ethanol tariff in this case may either be positive or negative. If it is positive, it creates gains in trade in the ethanol import market and the corn export market at the expense of the terms of trade in gasoline imports. But the ethanol import tariff also reduces the tax costs of both the tax credit and farm price supports. If the gasoline market is large relative to the corn and ethanol markets, the optimal tariff may be negative.

CASE C1. The loan rate is effective, and $P_{Gb} + t_{cb}$ is larger than the price at which all

corn production would be absorbed by non-ethanol uses: ($L > P_{Gb} + t_{cb}, P_{NE}$).

An effective loan rate results in a positive optimal tax credit. Gasoline prices are not transmitted to corn producers due to the loan rate. In this case, the consumers are the primary beneficiaries of the tax credit. The optimal tariff may be smaller or larger than the optimal tax credit, again depending on the importance of the gasoline market relative to ethanol imports and corn exports.

CASE C2. The loan rate is effective, and $P_{Gb} + t_{cb}$ is smaller than the price at which all corn production would be absorbed by non-ethanol uses: ($L > P_{Gb} + t_{cb}, P_{NE}$).

As with Case B, gasoline prices are not transmitted to the corn consumers due to low relative gasoline prices. Thus the optimal tax credit is zero, while the ethanol tariff may be either positive or negative.

The results are conditioned by the amount of fuel from foreign gasoline producers, and the ratio of the elasticities of excess supply and demand of ethanol. The higher the imports of gasoline, the lower the social cost of the tax credit. In this case, the tax credit allows fuel consumption to substitute ethanol for imported gasoline, potentially improving the terms of trade (both lowering the imported gasoline price and raising the corn price for exports). Additionally, the more negative the ratio of elasticities of excess supply and demand for ethanol, the lower the social cost of a tax credit. While the tax credit raises the corn price, the higher elasticity of supply suggests that corn producers can increase production to take advantage of the better terms of trade. Alternatively, the lower (less negative) elasticity of demand for ethanol suggests that domestic consumers of fuel do not adjust their fuel consumption very much, given the price decrease in fuel. Thus the tax credit will more directly improve the international terms of trade in corn exports.

Simulations

We look at two years: 2005/06, when loan rate deficiency payments were in place, and 2008/09, when projections indicate that no corn subsidies will be effective except for so-called “decoupled”

payments. We ignore the effects of direct payments for 2008/09. Assumed parameter values are summarized in Table 1. Simulation results are presented in Table 2. Because the intercept of the ethanol supply curve is above the gasoline price in each year, ethanol production is eliminated with the elimination of the tax credit. The associated rectangular deadweight costs are \$2.3 and \$0.5 billion in 2005/06 and 2008/09, respectively (see final row in Table 2). These deadweight costs are far higher than standard deadweight cost triangles normally estimated for analyzing the welfare economics of farm policy. The price of gasoline goes up each year, while the prices of corn and ethanol decline. Taxpayer costs are estimated to increase in 2005/06 by \$4.6 billion, as deficiency payments would have skyrocketed. However, there is a net taxpayer savings of \$6.8 billion in 2008/09. The terms-of-trade improvements are also listed in Table 2.

Table 1. Estimated Parameters for Simulations

ELASTICITIES OF DEMAND	
Fuel ^a	-0.55
Non-gasoline oil consumption elasticity	-0.20
ROW excess oil demand	-0.86
Domestic non-ethanol corn	-0.20
Corn exports	-0.50
ELASTICITIES OF SUPPLY	
Corn	0.20
Gasoline supply elasticity	0.20
OPEC oil supply elasticity ^b	2.25
Ethanol import supply elasticity	2.75
OTHER KEY PARAMETERS	
Fuel tax t ¢/gal. ^c	41
Ethanol tax credit t_c ¢/gal. ^c	57
Ethanol import tariff t ¢/gal. ^d	57
Gallons of ethanol per bushel corn β	2.8
Share of corn value returned as by-product δ^e	0.307

^a Parry and Small (2005).

^b Mid-point of range given in Leiby (2007).

^c Includes federal and state.

^d Includes the 54 cents/gal and 2.5 percent *ad valorem* tariff.

^e Eidman (2007).

as derived in the previous section. Two results need to be emphasized. First, the tariff is negative (imports are subsidized) in the years when the loan rate is effective, while the optimal tax credit is zero. This is because producers do not benefit from the tax credit when the loan rate is effective, while tax costs of the tax credit are basically being offset by tax costs of the loan rate program. Hence, to maximize terms-of-trade improvements in gasoline imports, subsidizing imports is more effective than subsidizing ethanol production (corn production remains unchanged in these cases). It appears that the social benefit of improving terms of trade in corn exports is tied to increasing corn production because the optimal tax credit is zero in these cases where corn production is unaffected by the tax credit. Domestic ethanol production is high, and depending on the situation, sometimes only because of the loan rate. Corn production is high because of the loan rate. So it is therefore sometimes better to have no tax credit and subsidize ethanol imports to maximize the sum of producer, consumer, and taxpayer welfare.

Second, the tariff is always lower than the tax credit, and sometimes significantly so. Even if the ethanol import tariff is positive, the fact that it is lower than the tax credit is an implicit subsidy on ethanol imports by the difference between the tax credit and the tariff. We will call this a net import subsidy. In reducing gasoline prices and improving terms of trade in gasoline imports, it is better to avoid the rectangular deadweight costs of domestic consumption and subsidize low-cost ethanol imports.

These results are not necessary but are borne out of the data, and their accuracy is highly dependent on the precision of our representation of the economic parameters of the markets. The results do reflect the relative size of the corn export market to the gasoline import market and ethanol production and imports. The results emphasize the importance of gasoline imports and how corn and ethanol policy can significantly affect the outcome. This implies first that the gasoline market is large enough that it appears to drive all welfare results. Thus, the United States would potentially benefit from subsidizing the import of alternative fuels to reduce dependence on imported gasoline. Further, the optimal import (net) subsidy on ethanol is growing due to strong increases in corn export demand (probably driven by growth

Table 3 displays the simulated optimal tax credit and tariff for the crop years 2001 to 2007

Table 2. Impacts of Eliminating the Tax Credit: 2005/06 and 2008/09 Compared

	2005/06	2008/09 ^a
INITIAL PRICES		
Corn \$/bu.	2.00	5.32
Ethanol ¢/gal.	1.497	2.930
Gasoline ¢/gal.	1.505	3.547
Loan rate \$/bu. ^b	2.39	1.95
Intercept \$/bu. ^c	1.71	3.21
IMPORTS (BIL. GALS.)		
Ethanol ^d	0.165	0.45
Oil	183.6	177.5
PRODUCTION (BIL. GALS.)		
Ethanol ^e	1,138	2,829
TAXPAYER COSTS (BIL. \$)		
Farm subsidies ^f	4.3	0
Tax credit	2.7	6.8
Import tariff revenue	0.093	0.257
CHANGES IN ...		
Ethanol production	-1,138	-2,828
Price of gasoline	-0.0048	-0.0273
Price of corn	-0.66	-2.11
Price of ethanol	-0.5667	-0.5509
Taxpayer costs	4.6	-6.8
TERMS OF TRADE (BIL. \$)		
Oil imports	0.86	4.86
Corn exports	1.5	5.9
Ethanol imports	0.093	0.257
RECTANGULAR DEADWEIGHT COSTS (BIL. \$)	2.3	0.5

^a Forecast (Babcock 2008).^b Implied loan rate for 2005/06, given observed corn price and deficiency payments.^c This is the estimated intercept of the ethanol supply curve in \$/bu.^d Includes imports under tariff rate quota with Caribbean Basin Initiative.^e Net of corn returned as by-products.^f Deficiency payments only.

in India and China). In this case, the United States can obtain fuel more cheaply through Brazilian or other imports, while preserving the tremendous benefits of the corn trade. Alternatively, the tax credit is optimally zero in every year in which the loan rate was effective. In this case, the tax credit serves only to divert corn from domestic and foreign consumption into fuel at an additional cost to taxpayers. When the loan rate is ineffective, the tax credit is positive due to the direct impact on corn production. This optimal tax credit has been

growing in recent years, again driven by higher demand for corn in export markets.

Concluding Remarks

This paper analyzes the corn-ethanol-gasoline market links and the effects of the ethanol import tariff and tax credit for alternative levels of farm subsidies. We determine that a change in the price of ethanol due to changes in either gasoline prices or ethanol policies has a huge impact on corn

Table 3. Optimal Tax and Tariff Simulations (2001 to 2007)

Crop Year	Loan Rate Effective	Optimal Import Tariff (Subsidy) per Gallon of Ethanol	Optimal Consumption Tax Credit per Gallon of Ethanol
2001/02	Yes	-\$0.07	\$0.00
2002/03	No	\$0.09	\$0.44
2003/04	Yes	-\$0.10	\$0.00
2004/05	Yes	-\$0.13	\$0.00
2005/06	Yes	-\$0.17	\$0.00
2006/07	No	\$0.14	\$0.87
2007/08	No	\$0.01	\$0.97

prices. For every one cent per gallon increase in the price of ethanol, corn prices increase 4.06 cents per bushel. However, if the intercept of the ethanol supply curve is above the price of gasoline, then part of the ethanol price premium due to the tax credit or tariff is redundant. We call this “rectangular deadweight costs,” which were \$2.3 and \$0.5 billion in 2005/06 and 2008/09, respectively. This also means that elimination of the tax credit will not cause corn prices to fall by the same amount. In fact, we determine the theoretical conditions under which a change in the price of ethanol will have no impact on corn prices. We also show the case where the price of corn is below the intercept of the ethanol supply curve, implying that the sole cause of ethanol production is the farm subsidy program itself (in addition to the tax credit).

We formally derive the optimal ethanol tax credit and import tariff for a large country exporter of corn and importer of gasoline and ethanol. This serves as an important benchmark to understand how different market parameters determine the social welfare effects of the tax credit policy. The outcome is shown to depend on supply and demand elasticities as well as shares of corn production exported and used for ethanol production, and share of fuel consumption imported in the form of gasoline. Because the primary motivation of the ethanol import tariff is to offset the tax credit, the tax credit before the recent Farm Bill was basically equal to the ethanol import tariff (approximately 57 cents per gallon). We show that although the ethanol import tariff itself directly increases U.S. terms of trade in ethanol imports, the tax credit exactly cancels these terms-of-trade improvements on the condi-

tion that the tax credit and import tariff are equal and world gasoline prices do not change with a change in ethanol supplies. Empirical simulations are used to illustrate the theory developed.

Throughout this paper we have assumed constant returns to scale in converting corn to ethanol, and a perfectly competitive ethanol industry. These are clearly abstractions from the current industry that is still facing much uncertainty about long-run capacity and profitability. Further work is needed to generalize our results to a less competitive industry and a potentially scale-sensitive production technology.

Our simulations support the findings of Schmitz, Moss, and Schmitz (2007) and Rajagopal et al. (2007). In essence, the U.S. consumption of gasoline is so large that it appears to dominate concerns for all other markets. This leads to a situation where the United States would optimally subsidize ethanol production in years when agricultural subsidies are dormant. Further, foreign producers of ethanol have a comparative advantage over U.S. producers that can be used to help break the back of gasoline dependence. To accomplish this, tariffs should be low relative to the tax credit on ethanol, and the United States should consider subsidizing ethanol imports when agricultural subsidies are effective as a means to improve the terms of trade in gasoline imports while not harming farmer welfare (agricultural price supports are given). The possible benefits of an ethanol import subsidy would be even larger if one considers that greenhouse gas emissions are much lower for ethanol produced in Brazil than in the United States. Clearly, future legislation will react to higher commodity prices by adjusting the corresponding agricultural subsidies. Future work

must consider how changing subsidies can impact ethanol and gasoline trade and the welfare implications.

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