U.S. Comparative Advantage in Bioenergy: A Heckscher-Ohlin-Ricardian Approach

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Much of the current literature on trade in biofuels is focused on the partial equilibrium welfare effects in the U.S. ethanol sector of potentially distorting policy instruments such as tax credits to blenders and import tariffs (see Elobeid and Tokgoz [2006]; de Gorter and Just [2007]). However, recent studies by the OECD (2006) and the World Bank (Kojima, Mitchell, and Ward 2007) have expanded the analysis to consider the future prospects for trade in both ethanol and biodiesel, paying particular attention to current production costs across countries and the connection between threshold prices for crude oil prices and biofuel production costs as well as the land requirements needed to meet the types of biofuel production mandates being implemented in the United States, the European Union (E.U.), and elsewhere.

Two key stylized facts can be gleaned from these latter studies: while increasing crude oil prices have improved the economic viability of say U.S. corn-based ethanol, Brazil continues to have a significant comparative advantage in producing ethanol from

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sugarcane (OECD 2006; Kojima, Mitchell, and Ward 2007); second, the land requirements necessary to meet targets being set for the proportion of biofuels used in transport fuel consumption show that again Brazil has a clear comparative advantage. For example, Brazil only requires 3 percent of its agricultural land to meet a 10 percent share of biofuels in domestic transport fuel consumption, compared to 30, 36, and 72 percent respectively in the U.S., Canada, and the E.U. (OECD 2006).

This all seems to point to a simple, but rather predictable story of trade in biofuels: in the absence of trade-distorting policy instruments, Brazil currently has a comparative and maybe even an absolute advantage in producing biofuels, based on lower ethanol feedstock costs and relative abundance of agricultural land. Even in the presence of trade distortions, Brazil exported 20 percent of its production during the 2006-07 harvest season (Kojima, Mitchell, and Ward 2007), and this would increase substantially if the U.S. removed its ethanol import tariff of 54 cents per gallon (Elobeid and Tokgoz 2006). However, the margin for competitiveness in biofuels is rather narrow, only 10 percent of production being traded internationally, of which Brazil accounts for 50 percent (Kojima, Mitchell, and Ward 2007).

This is a static story, though, based on current crop yields as well as existing biofuel production technologies. Consequently, in trying to analyze the potential for U.S. comparative advantage in biofuels production, it is important to account for technological innovation that may occur within the next decade, notably in the production of ethanol from cellulosic material. To that end a stylized trade model is set out in the first part of this paper, which allows for the possibility that the United States could become a future exporter of biofuels. The model draws on a Heckscher-Ohlin-Ricardo approach originally due to Davis (1995), as well as analysis of trade in the presence of external economies (Helpman and Krugman 1985). Given this analysis, the second part of the paper is concerned with the possibility that current U.S. policy towards corn-based ethanol production may actually stymie the potential for future exports, drawing on recent literature analyzing the infant-industry argument for protection (Sauré 2007).

Trade in Biofuels

Basic Model

First, a basic model is laid out to capture the current potential for trade in biofuels in the absence of policy distortions. Assume that there are two countries j =1,2, the U.S. and the Rest of the World (ROW), with goods X_i, i = 1 to 3, produced with n = 1,2, factors of production, capital (K) and land (L), where good X_1 is capital-intensive and goods X_2 and X_3 have the same factor intensities, both being land-intensive. In addition X_2 and X_3 are substitutes in consumption (fuel blending), but X_2 uses land embodied in feedstock 1 (sugarcane), while X_3 uses land embodied in feedstock 2 (corn). Assuming the technologies are the same across countries, the production functions can be written as: $X_1^j = f(K_1^j, L_1^j), X_i^j = g(K_i^j, L_i^j)$, i = 2, 3. The total available quantities of the factors in the world economy, is given by the vector: $\bar{V} = (\bar{V}_1, \bar{V}_2) \equiv (K, L)$, with each country j receiving an initial endowment of: $V^j = (V_1^j, V_2^j) \equiv (K^j, L^j)$. The production functions are quasi-concave and exhibit constant returns to scale, the associated unit cost functions are given as $c_i(w)$, with w being a vector of factor prices. Preferences are homothetic, and thus the share of spending on each good is a function only of prices $\alpha_i(p)$.

From this the factor-price equalization (FPE) set can be defined as:

$$\text{FPE} = \left\{ (V^1, V^2) \middle| \exists \lambda_i^j \geq 0, \sum_{j=1}^{2} \lambda_i^j = 1 \text{ for all } i, \text{such that } V^j = \sum_{i=1}^{3} \lambda_i^j \bar{V}(i) \text{ for all } j \right\}, \text{ where}$$

λ_i^j are the shares of country j in the integrated equilibrium production of good i. For $V \in \text{FPE}$ each country can fully employ its resources when the output levels are $X_i^j = \lambda_i^j \bar{X}_i$ for all i and j. In other words where factors of production are immobile, there is an allocation of such factors among countries that will equalize factor prices through trade in goods, and also reproduce a hypothetical *integrated* equilibrium, where factors of production and goods are internationally mobile.

In figure 1 the dimensions of the box are given by: $\bar{V} = (\bar{K}, \bar{L})$, while the FPE set is the parallelogram $0^1 Q 0^2 Q'$, where $0^1 Q$ is the factor employment level in industry 1, and $Q0^2$ is the combined factor employment level in industries 2 and 3. Combining the employment vectors for goods 2 and 3 follows from the assumption concerning their production technologies (see Davis 1995). It should also be noted that this resolves the problem of determining a unique pattern of production and trade when the number of goods exceeds the number of factors of production (see Dixit and Norman 1980).

The distribution of factor endowments $V^j = (K^j, L^j)$ is at E, the U.S. being relatively well-endowed in capital and ROW being relatively well-endowed in land; the slope of the negatively sloped line through E is the ratio of factor prices w_K / w_L, and C on the diagonal represents the GDP level of each country. Constructing parallelograms between 0^1Q (0^2Q) and E/C, and $0^1Q'$ ($0^2Q'$) and E/C, the U.S. (ROW) produces $X_1^1 (X_1^2)$ and consumes $CX_1^1 (CX_1^2)$ of good 1 and produces $X_2^1 = 0, X_3^1 > 0$ $(X_2^2 > 0, X_3^2 > 0)$ and consumes CX_{2+3}^{1} (CX_{2+3}^{2}) of goods 2 and 3 (i.e., sugarcane-based and corn-based ethanol are consumed in the U.S. and ROW, but only the latter is produced in the U.S.). The trade pattern is such that the U.S. exports the capital-intensive good, while importing the land-intensive good, and vice-versa for ROW, which imports the capital-intensive good and exports the land-intensive good, the vector *EC* being the factor content of net trade flows. Given the stylized facts noted earlier and absent trade distorting instruments, this would seem a reasonable characterization of trade in biofuels (i.e., the ROW, which includes Brazil, has a comparative advantage in producing biofuels that are land-intensive in production).

Technological Change and Trade in Biofuels

The U.S. Energy Independence and Security Act of 2007 requires that by 2022, almost 50 percent of the mandated use of renewable fuels be met by second-generation biofuels such as cellulosic ethanol. Irrespective of whether this target will actually be met, it is interesting to consider what the potential implications are for trade in biofuels if the technology to produce cellulosic ethanol is developed in the U.S. over the next ten to fifteen years.

In order to allow for this possibility, the model outlined in the previous section is extended through introduction of another good X_4 which is produced from cellulosic feedstock. It is assumed that this good is relatively capital-intensive in production as compared to goods X_2 and X_3 which are relatively land-intensive in production. In addition the U.S. is assumed to have an absolute advantage in the production of X_4. Specifically, the production function for cellulosic ethanol is written as $X_4^j = a^j h(K_4^j, L_4^j)$, j = 1, 2, a^1>1, which ensures that the U.S. has an absolute advantage in producing X_4 (Davis 1995). This production function is quasi-concave and positively linear homogenous in the vector of inputs $V_4^j = (K_4^j, L_4^j)$ with firms operating under constant returns to scale.

As before, the objective is to establish whether the distribution of the factor endowments will reproduce the integrated equilibrium. This requires that the industry producing X_4 be located in one country (i.e., the U.S.). In other words $\bar{V}(i), i = 4$ is allocated to a single country j=1, which is assured by the fact that $a^1 > 1$. From this the FPE set that will generate the integrated equilibrium can be defined as:

$$\text{FPE} = \left\{ (V^1, V^2) \middle| \exists \lambda_i^j \geq 0, \sum_{j=1}^{2} \lambda_i^j = 1, \text{for all } i, \lambda_i^j \in \{0,1), \text{for } i = 4, \text{and } V^j = \sum_{i=1}^{4} \lambda_i^j \bar{V}(i) \text{ for all } j \right\}.$$

In figure 2 if neither country has an absolute advantage in producing good 4, the factor price equalization set would be $0^1 Q\tilde{Q}0^2 Q'\tilde{Q}'$. However, if the U.S. has an absolute advantage in producing X_4, the factor price equalization set is given as the shaded area $Q\tilde{Q}0^2\bar{Q}$, where: $0^1 Q$ is the factor employment level in industry 4; $Q\tilde{Q}$ is the factor employment level in industry 1; and $\tilde{Q}0^2$ is the combined factor employment level in industries 2 and 3.

The distribution of factor endowments $V^j = (K^j, L^j)$ now determines whether there is factor price equalization in equilibrium (i.e., at endowment E_1 there will not be factor price equalization as compared to say E_2). However, at either E_1 or E_2, it is unambiguous that the U.S. will be a net exporter of capital-intensive goods; in particular the U.S. will specialize in producing cellulosic ethanol X_4 as well as having a comparative advantage in producing good X_1, while ROW will have to import any requirements for good X_4, but it will still have a comparative advantage in producing goods X_2 and X_3. This implies that even if the U.S. exports X_4, it may also continue to import some X_2 and X_3. This follows from the assumption that the U.S. still has a comparative disadvantage in producing these goods and that good X_4 cellulosic-based ethanol is different in terms of its factor-intensity in production as compared to corn-based or sugarcane-based ethanol.

To rationalize this result, which is essentially two-way trade in goods that are close substitutes in consumption, some additional structure needs to be added on the demand side. Specifically, cellulosic ethanol could be regarded by users as more environmentally friendly than either corn or sugarcane-based ethanol, thereby commanding a higher price in equilibrium. Assuming demand for low or high-quality ethanol is a function of ability to pay, with overlapping income distributions between the U.S. and ROW, two-way trade in vertically-differentiated goods would be observed along the lines suggested by Flamm and Helpman (1987).

External Economies of Scale and Trade in Biofuels

Rather than assuming that the U.S. has an absolute advantage in producing cellulosic ethanol, a similar equilibrium where only one country produces good X_4 can be derived by assuming that the U.S. has a head-start over ROW in terms of developing the basic blueprints for the production technology, but the technology is subject to external economies of scale. The production function for cellulosic ethanol becomes: $X_4^j = h(K_4^j, L_4^j; \xi)$, j = 1, 2. External economies of scale are captured in the parameter ξ, where, $\partial h(.)/\partial \xi > 0$, implying that the industry operates under increasing returns to scale, even though individual firms believe they are operating under constant returns to scale. These external economies are assumed to be the result of spillover effects that are industry and country-specific. Under these assumptions the equilibrium described in figure 2 still holds (i.e., the U.S. specializes in producing cellulosic ethanol). Kemp and Negishi (1970) argue that a country will gain from trade in this setting if there is an expansion in the increasing returns to scale sector. More specifically, Helpman and Krugman (1985) state a sufficient condition for there to be gains from trade: the value of output obtained under autarky employment levels at post-trade prices is larger in the presence of post-trade external effects than for the case of autarky external effects $p_i\{h(V^A(i);\xi)\} \geq p_i\{h(V^A(i);\xi^A)\}$, i = 4, and A stands for autarky (i.e., productivity in the U.S. cellulosic ethanol sector is higher in the trading equilibrium due to the restructuring of external effects).

U.S. Policy and Trade in Biofuels

The way external economies are treated in the previous section assumes that the benefits of learning are fully appropriated, given the U.S. has a technological lead in cellulosic ethanol production. However, external learning economies are a dynamic concept with two important ideas at play: first, over time firms “learn-by-doing,” resulting in lower unit costs of production; and second, these economies are external to firms in the sense that any knowledge gained by learning over time spills over to other firms. If the future benefits of current production cannot be entirely appropriated by a firm or firms because other firms in an industry can freely benefit from such spillovers, then firms will under-invest in current production (i.e., there is a market failure). In other words even if the U.S. has an initial technological advantage in producing cellulosic ethanol, it will not necessarily fully realize the benefits of external economies in the sector.

Suppose the ROW ethanol industry abroad is mature such that all available learning economies have been realized, with minimum unit costs of production reaching a constant level $\overline{c}_{2+3}^{2}$ equal to the world price, $\overline{c}$ being constant minimum unit costs, the superscript/subscript(s) referring to ROW/sugarcane and corn-based ethanol production respectively. Over a period of time and some range of the average cost curve, there is potential for U.S. firms producing cellulosic ethanol to learn-by-doing, their minimum unit costs falling with greater experience of production. Due to the fact that firms can learn freely from the experience of other firms, there is no barrier to firms entering the market with the same cost level as firms that have already entered the market. In the absence of any intervention by the U.S. government, no firm will be willing to enter the industry at any time while $c_{4}^{1} > \overline{c}_{2+3}^{2}$, as they will make a loss, their minimum unit costs of production exceeding the world price. For the U.S. cellulosic industry to be able to compete with ROW, it will be necessary to provide temporary protection over the period when $c_{4}^{1} > \overline{c}_{2+3}^{2}$, in order to correct for the market failure due to under-production.

This is of course the infant-industry argument for temporary protection, which has long been considered the only legitimate exception to free trade since the arguments of Mill in the 19th century. This can be achieved through a tariff on ROW imports which is lowered progressively over time to zero when U.S. firms' minimum unit costs are equal to those of firms abroad $c_4^1 \leq \overline{c}_{2+3}^2$, and they are able to compete at the world price of ethanol. This argument reinforces two basic ideas Mill was attempting to convey: first, protection is necessary because no firm will be willing to enter the industry if the future benefits of learning-by-doing are freely available to other firms. Second, the tariff should decline over time and eventually fall to zero. Of course, if these learning economies are *internal* to firms that initially enter the market, then there is no reason at all for the U.S. government to provide any temporary protection (Baldwin 1969; Corden 1974). This follows from the fact that firms can borrow to cover their losses over the period when $c_4^1 > \overline{c}_{2+3}^2$, in the expectation that they will make additional profits once $c_4^1 \leq \overline{c}_{2+3}^2$, new firms not having had the benefit of learning-by-doing up to that point.

Infant-industry protection can also be achieved with a subsidy (Bardhan 1971; Melitz 2005). Like the tariff, the subsidy should decline over time until the U.S. industry's minimum unit costs have fallen to those of ROW $c_4^1 \leq \overline{c}_{2+3}^2$. The difference between the policy instruments is that under a subsidy, domestic consumers continue to pay the world price for ethanol, whereas under a tariff, they pay a price higher than the world price until $c_4^1 \leq \overline{c}_{2+3}^2$. While the tariff corrects for under-production by the domestic industry, it also distorts domestic consumption, whereas the subsidy only corrects for under-production (i.e., the least distorting policy instrument, the subsidy, should be used to correct the market failure [Melitz 2005]).

Of course any argument in favor of infant–industry protection of cellulosic ethanol production is based upon the political-economic assumption that disinterested governments only implement policies that maximize the net economic benefits to society. This ignores the obvious possibility that policies are established by self-interested vote-seeking politicians, subject to lobbying by firms (i.e., protection is "for sale"). In particular once infant-industry protection is in place, firms will typically continue to make political contributions to maintain it (Beesley 2007).

The latter is an argument that could be made against current U.S. policy towards corn-based ethanol production (i.e., the blending tax credit and import tariff, policies that have been in place since 1978 and 1980, respectively). If there ever were any external learning economies in this sector, they are likely to have been exhausted after nearly thirty years, and if the U.S. sector still cannot compete, this is not an argument for infant-industry protection (Sheldon 2008).

However, in the context of the current discussion, perhaps the strongest argument against protection of the corn-based ethanol sector is that it will prevent realization of the benefits that the U.S. could reap from any absolute/comparative advantage it might have in cellulosic ethanol production as well as any potential external economies of scale that may exist in this sector. Adapting an argument developed by Sauré (2007), firms in the U.S. have to decide between production using either corn-based ethanol technology or cellulosic-based ethanol technology, but they do not internalize dynamic learning economies. Consequently, they will choose whichever technology generates the highest instantaneous returns (i.e., $\max[p_4\{h(V^j;\xi)\}, p_3\{g(V^j\}]$ for $j = 1$). Therefore, if policy instruments targeted at corn-based ethanol production ensure that $p_4\{h(V^j;\xi)\} < p_3\{g(V^j\}]$, $j = 1$, firms will not invest in cellulosic ethanol production, even if the technology is available. Consequently, current U.S. ethanol policy should not just be seen in terms of the direct distortions it creates but also the risk that it will impose negative externalities on investment by firms in a more productive technology in which the U.S. might have an absolute/comparative advantage.

Summary and Conclusions

In this paper the conditions under which the U.S. might export biofuels have been examined. Specifically, it was shown that the U.S. would need either to have an absolute advantage in cellulosic ethanol production or be first to develop the blueprints for a technology subject to external economies of scale. Given this analysis, the remainder of the paper was concerned with the policy implications of this analysis. Specifically, it was argued that cellulosic ethanol production might be a candidate for temporary infant-industry protection. More importantly, and drawing on recent criticism of the infant-industry argument, it was suggested that current U.S. policy towards corn-based ethanol production might actually prevent future exports of cellulosic ethanol. Therefore, apart from the static deadweight losses already being incurred due to the US blending tax credit and import tariff, there may be additional losses in the future from failing to realize dynamic learning economies in the cellulosic ethanol sector.

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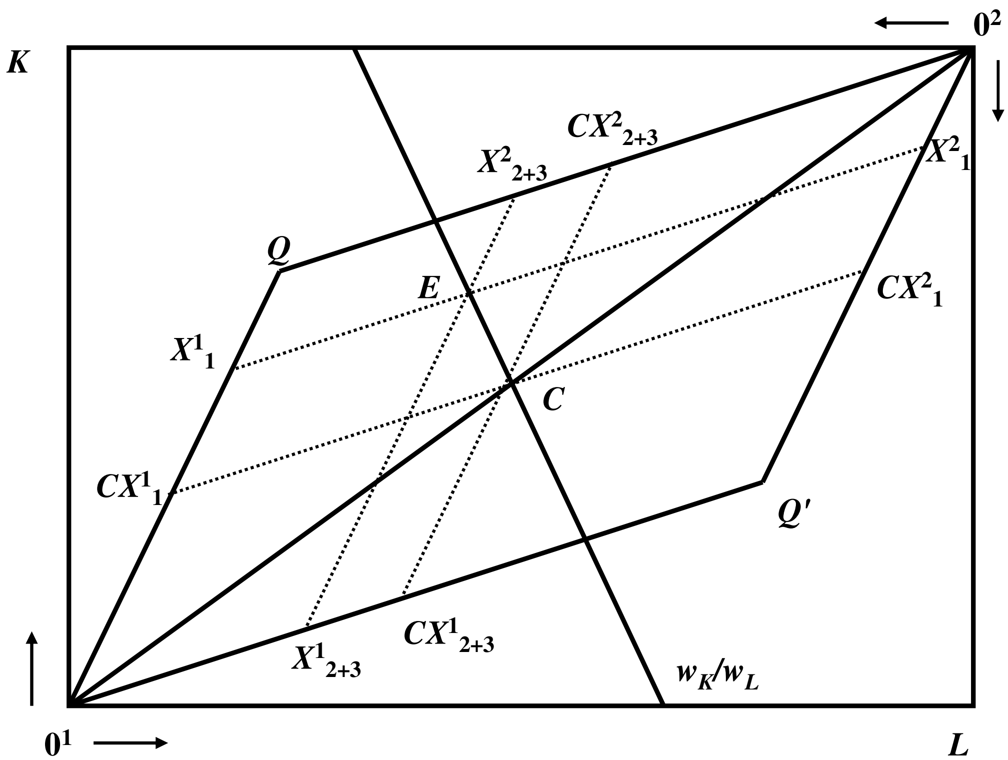

Figure 1. Comparative advantage and trade in biofuels

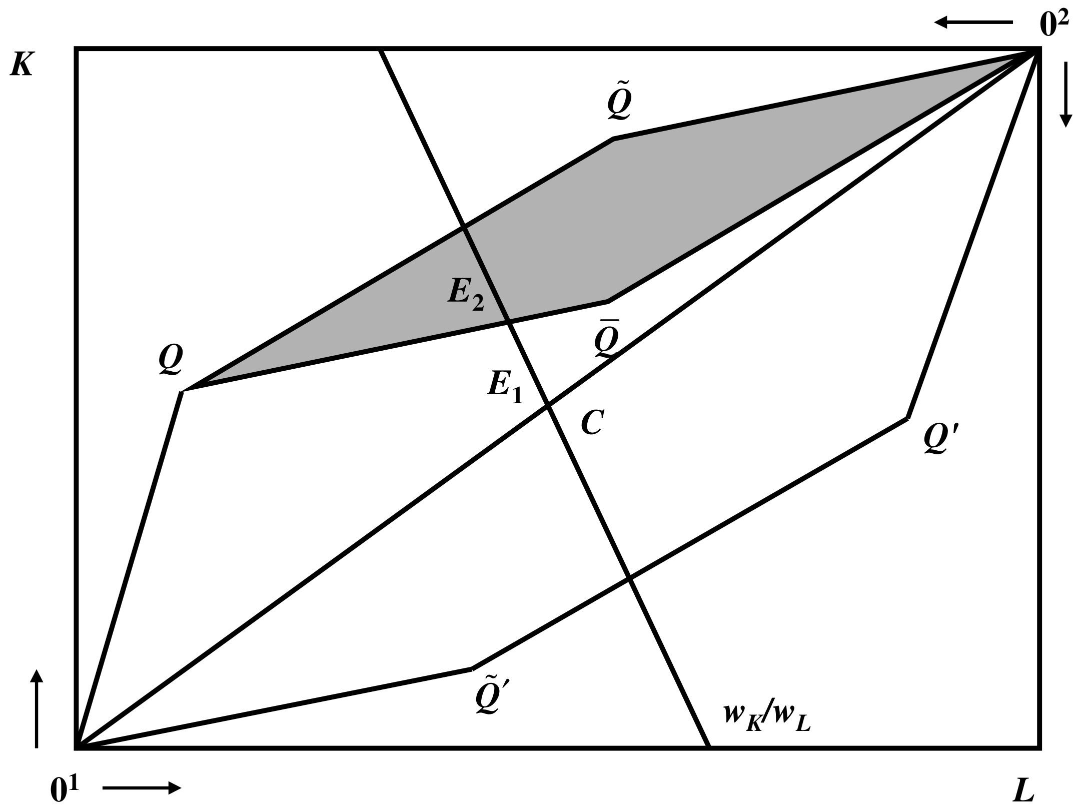

Figure 2. Absolute advantage and trade in biofuels