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Biofuel Subsidies: An Open-Economy Analysis

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Abstract

We present a general equilibrium analysis of biofuel subsidies in an open-economy context. In the small-country case, when a Pigouvian tax on conventional fuels such as crude is in place, the optimal biofuel subsidy is zero. When the tax on crude is not available as a policy option, however, a second-best biofuel subsidy (or tax) is optimal. In the large-country case, the optimal tax on crude departs from its standard Pigouvian level and a biofuel subsidy is optimal. A biofuel subsidy spurs global demand for food and confers a terms-of-trade benefit to the food-exporting nation. This might encourage the food-exporting nation to use a subsidy even if it raises global crude use. The food importer has no such incentive for subsidization. Terms-of-trade effects wash out between trading nations; hence, any policy intervention by the two trading nations that raises crude use must be jointly suboptimal.

JEL Codes: F1, H2, O1

Keywords: Optimal Biofuel Subsidy; Pigouvian Tax; Terms-of-Trade; Pollution Externality.

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1. Introduction

The literature on trade and the environment has proceeded largely along two paths. One strand of the literature has examined the impact of trade itself on pollution (see Copeland and Taylor, 1994, 2003). It has highlighted the fact that by fostering economic growth, trade can have two opposing effects on environmental quality. On the one hand, the higher output resulting from trade would contribute to pollution (the "scale" effect).[1] On the other hand, higher income would result in greater demand for a cleaner environment and might, therefore, result in the adoption of pollution-reducing technologies (the "technique" effect).[2,3] A second strand of the literature has modeled strategic interactions between two trading partners. An important conclusion drawn by this line of inquiry is that, contrary to popular wisdom, it might not be optimal for a government to impose weak environmental standards on domestic industries to give them a competitive advantage. Strict standards might instead be optimal if firms compete in prices (Barrett, 1994). It has also been argued that the choice between a tax on the origin of a polluting good and a tax on its destination is not clear because each could be optimum under certain circumstances (Cremer and Gahvari, 2006).

There is a gap in the trade and environment literature in that it does not account for the policy challenges presented by the use of biofuels, especially bioethanol, as an integral part of the strategy to meet new emission standards.[4] Policies to promote the use of biofuels cannot be discussed in isolation from two related issues. First, it is generally accepted that the growth of

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[1] If, however, pollution quotas are enforced through the issuance of a fixed number of pollution permits, the environmental impact of trade liberalization might be negligible. Further, it can be shown that if pollution taxes are adjusted to equate the marginal cost of pollution with the marginal benefits of the associated production, the net impact on pollution is indeterminate (Lopez, 1994; Rauscher, 1997; Copeland and Taylor, 2003).

[2] Empirical evidence suggests that the effects of rising income might be the stronger driver of the trade-environment relationship, resulting in a positive impact of trade on environment in higher-income countries (Frankel and Rose, 2005).

[3] See Antweiler, Copeland and Taylor (2001).

[4] The European Union (EU) has set a goal of 5.75% of motor fuel use by 2010, and 10% by 2020. The United States has mandated the use of about 28 billion liters of biofuels for transportation by 2012. Brazil has a target of 5% biodiesel use in all diesel by 2013. In India, 9 states requires a 5% ethanol blend in all gasoline, and, in China, 5 provinces require a 10% blend. (Sources: von Braun and Pachauri, 2005; Ernst & Young, 2007)

the biofuel industry in all countries except Brazil, where it has attained scale economies, is contingent on significant subsidy.[5] Such subsidies, in turn, can be the basis for trade wars as countries impose tariffs on imports of subsidized biofuels from other nations.[6] Second, given the energy inefficiency of biofuels, an aggressive strategy to promote the use of biofuels can divert food from direct consumption and lead to a significant increase in the world prices of food items.[7] For example, according to von Braun and Pachauri (2006), without significant improvements in agricultural productivity, by 2020 the prices of cassava, a staple food in African countries, would rise by as much as 135%.[8] Developed countries would be affected also if, as projected, there is a steep increase in the prices of staple items like corn (41%) and wheat (30%). Such projections clearly warrant a discussion about the efficacy of opting for biofuel subsidies.[9]

We contribute to the literature by taking into consideration those issues that are conventionally addressed by researchers examining the trade and environment relationship, as well as those issues that are relevant for biofuel policy. In our model, the utility of representative consumers depend on environmental quality, among other things. In addition, we assume that energy production requires the use of both fossil fuel and biofuel, and that the alternative use of

[5] In the U.S., where bioethanol production is corn based, the break-even price for petroleum is $54 per barrel, and in Europe, where bioethanol production is wheat based, the break-even price is $72 per barrel (Larson, 2008). The U.S. government provides a subsidy of 51 cents per gallon to producers of bioethanol. In Germany, where the growth of the production and use of biofuels was among the fastest in EU member countries, biofuel producers not only enjoy a 35% tax advantage vis-a-vis the producers of traditional fuels, but the state also subsidizes construction of biofuel production units up to 50%. Not to be left behind, the Australian government has waived the excise duty on fuel production for producers of bioethanol until 2011.

[6] The EU imposed 5-year tariffs on US biodiesel to counter American subsidies and dumping (Bloomberg, 7 July 2009). The tariff is €237 per metric ton to counter American subsidies and €198 per metric ton to counter dumping. This translates into a tariff rate of about 41%. Ironically, in 2007, the United States itself had imposed a tariff of 54 cents per gallon on imports of Brazilian bioethanol, resulting in a trade dispute that has not been resolved yet.

[7] For example, corn-based ethanol has 57% energy efficiency while petroleum has 81% efficiency. OECD (2006) estimates suggest that, to account for 10% of vehicular fuel, 60-70% of the current crop area in the U.S., Canada, and the EU-15 countries would have to be devoted to crops that can be used to produce ethanol.

[8] Runge and Senauer (2007) have argued that by pushing up the price of crops that are staples for the world's poor population, by 2025 biofuels could nearly double the number of people who are chronically hungry.

[9] By contrast, the discussion in the trade and environment literature largely involves policies that either cap pollution through fiat and permits or raise the cost of producing the polluting good (see Copeland and Taylor, 2004, for a discussion).

the food product used to produce biofuel is direct consumption. This enables us to capture the impact of policy on food prices, and to compare the impact of subsidizing the use of biofuel with that of taxing the use of fossil fuel. Our model illuminates the debate about the relative efficacy of conventional pollution taxes and biofuel subsidies along the lines of similar debates in the public economics literature (see Ballard and Medema, 1993; Fullerton and Metcalf, 2001).

We show first that in the small open-economy case, the optimal policies are a Pigouvian tax on crude and a zero subsidy on biofuel. If, on the other hand, the option of crude taxation is not available, a biofuel subsidy (or tax) might be the second-best policy. A subsidy encourages energy producers to reduce crude use by substituting biofuel as an input, conferring environmental benefits. On the other hand, the subsidy tends to reduce the price of energy and spurs its demand. If this second effect is strong, a tax rather than a subsidy may be welfare augmenting. We extend the analysis to consider two large open economies that trade food (the source of biofuel) and a manufactured good. In contrast to the small-country case, terms-of-trade considerations make it optimal for the food-exporting nation to use a biofuel subsidy (or tax) even if an optimal tax on crude is in place.[10] Finally, we consider a Nash game in biofuel subsidies between the trading nations. We find that terms-of-trade considerations may lead to a jointly suboptimal Nash policy equilibrium that is associated with too much pollution.

The rest of the paper is organized as follows: In Section 2, we present the small open-economy model. Section 3 considers the large-country case, where the change in the terms-of-trade for food plays a central role. Section 4 concludes.

[10] We assume throughout the paper that nations do not use trade taxes like an export tax or an import tariff. There are two reasons for this assumption. The first is that we want to focus on the terms-of-trade effects of biofuel subsidies, which, as explained above, are being increasingly used in different nations. The second reason is that an explicit trade policy to improve terms of trade is inconsistent with the multilateral trade liberalization process. A biofuel subsidy to domestic producers of energy, however, does not conflict with WTO rules guiding trade policies.

2. The Base Case: A Small Open Economy

Let us consider a small open economy with representative consumers. Each consumer maximizes utility given by $U = U(\tilde{F}, \tilde{E}, \tilde{M}, G)$, where $\tilde{F}$, $\tilde{E}$, $\tilde{M}$, and G are consumption levels of food, energy, a manufactured good, and clean environment, respectively. M is the numeraire good. If p is the price of food and q is the price of energy, the expenditure function is

$$e(p, q, 1, u, G) \equiv \text{Min } p\tilde{F} + q\tilde{E} + \tilde{M}, \text{ subject to } u = U(\tilde{F}, \tilde{E}, \tilde{M}, G), \tag{1}$$

which yields the usual Hicksian demand functions. In addition, $e_u > 0$ [11] and $e_G = -e_u U_G < 0$.[12]

In this economy, all commodities are produced using constant returns to scale (CRS). Food (*F*) is produced using labor (L^F) and land (T). Assuming that land is specific to food and that its endowment is given, we have

$$F = F(L^F, T) = f(L^F), \text{ where } f'(.) > 0 \text{ and } f''(.) < 0. \tag{2}$$

Competitive profit maximization ensures that $w = pf'(.)$, implying that $L^F = L^F(p, w)$. Similarly, the manufactured good is produced using labor (L^M) and energy (E^M):

$$M = M(L^M, E^M). \tag{3}$$

The profit maximization conditions are $w = M_L(L^M, E^M)$ and $q = M_E(L^M, E^M)$. Labor supply is given at $\bar{L}$, such that

$$L^F + L^M = \bar{L}. \tag{4}$$

Finally, energy is produced using food for biofuel (*B*) and crude oil (*R*) – our proxy for fossil fuel. All of *R* is assumed to be imported at a given price *r*:

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[11] Throughout the paper we use the convention that unless specified otherwise, ϕ_i and ϕ_{ij} are, respectively, the first- and second-order partial derivatives of any function $\phi(x_i, x_j)$.

[12] Consider quasi-linear preferences and separability of *G*: $U = \theta(\tilde{F}, \tilde{E}) + \tilde{M} + \gamma(G)$. The expenditure function associated with this utility function is: $e(p, q, u, G) = p\tilde{F}(p, q) + q\tilde{E}(p, q) + u - \theta[\tilde{F}(p, q), \tilde{E}(p, q)] - \gamma(G)$, which implies $e_p = \tilde{F}(p, q)$, $e_q = \tilde{E}(p, q)$, $e_u = 1$, $e_G = -\gamma'(G) < 0$, and $e_{pu} = e_{qu} = 0$

$$E = E(B,R).\qquad (5)$$

The corresponding profit maximization conditions equate the net input prices to the values of their marginal products.

2.1 Optimal Subsidy on Biofuel and an Optimal Tax on Crude

The government subsidizes the use of biofuel (*B*) such that its input price in energy production, net of subsidy *s*, is $p^s = p - s$. Also, the government uses a tax *t* on crude, so the domestic price of crude is $r^d = r + t$. Finally, we assume that although all activities are potentially polluting, the damage to the environment is larger when crude oil is used to produce energy. Further, noting that in the small country case crude used by the rest of the world (R^*) is given for the domestic nation, we model clean environment as a decreasing function of the amount of crude used in this economy[13]

$$G = G(R),\ G'(R) < 0.\qquad (6)$$

The obvious policy implication is that if the government wants to improve environmental quality, it would have to reduce the use of crude in energy production, *ceteris paribus*. It is also evident from the above discussion that the instruments available to achieve this change are the subsidy for biofuel and the tax on crude.

The expenditure-revenue identity for this economy (equivalently, its trade balance equation) is given by

$$e(p,q,1,u,G) = pf(L^F) + M(L^M, E^M) + qE(B,R) - pB - rR - qE^M.\qquad (7)$$

Given the difficulties in trading energy over long distances in its final form, we assume that *E* is a nontraded good, with its price determined by the zero profit condition:

[13] An alternative would be to propose that *G* is a function of biofuel and crude, with biofuel being relatively less polluting. To keep the model simple, we assume that while crude is polluting, biofuel is not.

$$q = C(p^s, r^d, 1) \Rightarrow q = q(s,t), q_s = -\frac{B}{E}, \text{ and } q_t = \frac{R}{E}, \tag{8}$$

where $C(.)$ is the unit cost of producing energy. The assumption of CRS implies that $qE - pB - rR = -sB + tR$. Substituting this expression in (7), and using (8), total differentiation of (7) yields

$$e_u du = -sdB + (t - e_G G')dR, \tag{9}$$

where the first term on the right-hand side is the loss due to the distortion in input use, and the second term is the net benefit due to the reduction of crude use. From (9), the optimal subsidy condition is

$$e_u \frac{\partial u}{\partial s} = 0 \Rightarrow s^{opt} = (t - e_G G')\frac{R_s}{B_s}.[14] \tag{10}$$

Using (10),

$$e_u \frac{\partial u}{\partial t} = (t - e_G G')\left(R_t - \frac{R_s B_t}{B_s}\right) = 0 \Rightarrow t^{opt} = e_G G' > 0, \text{ assuming } R_t - \frac{R_s B_t}{B_s} \neq 0. \tag{11}$$

Notice that $e_G G'$ measures the amount of the numeraire good that the consumer will need to be compensated for a unit rise in R (and hence pollution). Therefore, using (10) and (11), it is clear that the optimal crude tax is the Pigouvian tax, which equals the marginal damage from pollution. Also, when this tax is in place, the optimal biofuel subsidy is zero.

Proposition 1: In a small open economy that produces energy using crude oil (which is polluting) and biofuel (assumed to be clean), the optimal policy is to use a Pigouvian tax on

[14] Part B of the appendix derives R_s, R_t, B_s and B_t for both the small- and the large-country cases using a quasi-linear utility function that is also separable in G. This provides a tractable example, and there is no loss in generality. Indeed, the analysis in the text is for general utility functions. Details of derivations for the general case, which allows for income effects, are available from the authors on request.

crude equaling its marginal damage to the environment. The optimal biofuel subsidy is zero when such a tax is in place.

The above finding is not surprising because, in a small open economy, the only source of market failure is the environmental externality of crude production. An appropriate tax is enough to rectify this failure, and no other instrument is necessary.[15] This is a useful benchmark for the analysis and results below, where we extend the model to consider situations where either a tax is not available as an instrument or other externalities exist (such as a terms-of-trade externality) that the tax instrument cannot address fully.

2.2 Second-Best Biofuel Subsidy (when a crude tax is not feasible)

In certain nations and in certain situations, a tax on crude might not be available as a policy instrument, perhaps because of the country's political economy.[16] On the other hand, the presence of a strong agricultural lobby can make biofuels attract policy attention. Consider ethanol produced from corn, which is mixed with crude to make the final fuel. Although the efficiency of making corn-based ethanol is questionable, it is quite popular in the United States because it is good for the corn farmers and draws support from the agricultural lobby. The analysis below describes the biofuel subsidy as a second-best instrument.

Using $t = 0$ in (9),

$$e_u \frac{\partial u}{\partial s} = 0 \Rightarrow s^{SB} = -e_G G' \frac{R_s}{B_s}, \tag{12}$$

[15] This result is consistent with that of Ballard and Medema (1993), who found that a Pigouvian tax on pollution might have better implications for welfare than a subsidy toward abatement cost. On the other hand, Fullerton and Metcalf (2001) posit that taxes and subsidies (and indeed command and control policies) might have equivalent welfare effects. However, their results were driven by the construct that allowed for reductions of labor market distortions through corresponding reductions in income tax rates, the latter facilitated by the revenue raised through pollution taxes.

[16] We do not pursue an explicit political economy analysis in this paper. It is possible to do that in future work along the lines of Fredriksson (1997), among others.

where s^{SB} is the second-best biofuel subsidy. Note that

$$R = C_r(.)E \Rightarrow dR = C_r(.)dE - EC_{rp^s}(.)ds. \tag{13}$$

Also, total energy use must equal the amount used as an input in the manufacturing sector plus the amount used directly in consumption:

$$E = e_q\left[p, q(s), 1, u, G(R)\right] + E^M(p,q)^{17} \Rightarrow dE = \left(e_{qq} + E_q^M\right)dq + e_{qu}du + e_{qG}G'dR. \tag{14}$$

Using (13) and (14),

$$dE = \delta\left[\left\{\left(e_{qq} + E_q^M\right)q_s - EC_{rp^s}e_{qG}G'\right\}ds + e_{qu}du\right], \text{ where, } \delta = 1\big/\left(1 - C_rG'e_{qG}\right). \tag{15}$$

Using (8), note that when $t = 0$, $q = q(s)$ and $q_s = -B/E < 0$. Using this fact, along with (13) and (15), we have

$$dR = \left(Aq_s + Z\right)ds + Ydu, \tag{16}$$

where $A = \delta(e_{qq} + E_q^M)C_r < 0$, $Z = -\delta EC_{rp^s} < 0$, and $Y = \delta e_{qu}C_r$.[18,19] At the utility-maximizing s, $du = 0$ and

$$R_s = Aq_s + Z. \tag{17}$$

Following a similar set of steps as above, we can compute the impact on food demand of a biofuel subsidy:

$$dB = \left(A^F q_s + Z^F\right)ds + Y^F du, \tag{18}$$

where $A^F = \delta C_{p^s}(e_{qq} + E_q^M) < 0$, $Z^F = -E(\delta C_{rp^s}e_{qG}G'C_{p^s} + C_{p^sp^s}) > 0$,[20] and $Y^F = \delta e_{qu}C_{p^s}$. Once again, at the utility-maximizing subsidy rate, $du = 0$ and

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[17] The zero profit condition in manufacturing is $C^M(w,q,1) = p^M = 1$. This implies that $w = w(q)$ and that $E^M = -w'(q)L^M$. Using (2) and (4), $L^M = L^M\left(p, w(q)\right) = L^M(p,q)$. Thus, $E^M = E^M(p,q)$.

[18] It can be shown that $A < 0$ if $\delta < 0$, which is the case when $e_{qG} = -\left(U_G e_{qu} + e_u U_{Gq}\right)$ is small.

[19] Note that in the two-input case, concavity of the cost function requires that the cross effect is strictly positive.

$$B_s = A^F q_s + Z^F > 0. \quad (19)$$

Using (17) and (19) in (12) (i.e., after taking into account the impact of the subsidy on the use of crude and the demand for biofuel for energy production), the second-best subsidy is

$$s^{SB} = -e_G G' \frac{Aq_s + Z}{A^F q_s + Z^F} > 0 \text{ iff } Aq_s + Z = R_s < 0 . \quad (20)$$

Proposition 2: In the absence of a tax on crude, the second-best policy is to subsidize the use of biofuel if and only if the cross input substitution effect in energy production overcomes the subsidy's *scale effect* via a reduction in the price of energy.

The term Aq_s captures the *scale effect* of the subsidy on crude demand, while Z is the *cross-substitution effect* between the two inputs in energy production. The latter effect is easy to understand. The biofuel subsidy reduces the relative price of biofuel, thereby providing an incentive to substitute biofuel for crude in the production of energy. Its magnitude depends on the elasticity of substitution between the two inputs. Consider now the scale effect. The subsidy reduces the net input price of biofuel. This is passed on as a reduction in energy price, which stimulates the aggregate demand for energy, which in turn raises production (the scale effect). The net impact of these two effects is *ex ante* ambiguous and is determined by demand-side parameters and the aforementioned elasticity of substitution. If technology is Leontief type, for example, the cross-substitution effect will disappear altogether. In such a case, the demand for crude would unambiguously increase with a subsidy, and a government that aims to improve environmental quality should tax biofuel rather than subsidize it. On the other hand, the demand for food as an input in energy production would rise because of the own-price substitution effect

[20] We assume here that the environment-generated income effect on energy demand (i.e., e_{qG}) is sufficiently small, such that the own-price effect $C_{p^s p^s}$ dominates.

– as energy producers substitute biofuel for crude – and the scale effect that increases the demand for energy itself.[21]

The proposition highlights the fact that biofuel subsidies might not be innocuous. Just as economic growth associated with trade has a "scale" effect that might increase pollution, subsidization of biofuels might increase pollution by increasing the demand for energy. Notice, however, that in our model, the rise in the demand for energy is not from a pure income effect. Rather, it is a consequence of a price effect that spurs energy demand.

3. The Large-Country Case

The small-country assumption retained up to this point requires that the price for food (i.e., p) is given exogenously by the world market. An important issue regarding biofuel subsidies is that they encourage alternate uses of food products, thus reducing the net availability of food and raising its price in the global market. This issue can be modeled in the context of a large open economy where the food price is endogenous. If the subsidy raises the net global demand for food, its international price will rise, conferring terms-of-trade gains to the food-exporting nation. In addition, following the logic of the previous sections, such a subsidy will also affect pollution.

Suppose that there are three nations: home, foreign, and the rest of the world (ROW). The home country exports food to the foreign country and imports a manufactured good from it. It also imports crude from the ROW at a given terms of trade r and pays in terms of the manufactured good (the numeraire). Thus, the home trade balance requires that the value of its food exports must equal the value of its net imports of the manufactured good. The latter equals the sum of home consumption of the manufactured good and its payment to the ROW for crude,

[21] One would, of course, also have to consider the impact of the resultant change in environmental quality on energy demand, but it would be reasonable to assume that this effect would be of second-order importance and would be dominated by the own-price substitution effect.

net of home production of the manufactured good. Analogously, the foreign country's net export of the manufactured good equals its production minus the sum of its consumption demand and payment to the ROW (for crude). Finally, the ROW is assumed to not have any domestic consumption of crude, and its only role in the model is to provide crude to the home and foreign countries in exchange for the manufactured good.[22] Home and foreign trade balance conditions are, respectively,

$$pX = \tilde{M} + rR - M \text{ and } pX^* = \tilde{M}^* + rR^* - M^*, \tag{21}$$

where $X = f - e_p - B$ and $X^* = f^* - e_p^* - B^*$ are their net exports of food.[23]

3.1 Optimal Policy: The One-Sided Case

This subsection considers optimal policy choice for the home nation, where the foreign nation is passive (i.e., when $s^* = t^* = 0$). In the presence of a home tax *t* on crude and a subsidy *s* on biofuel, the home expenditure-revenue relationship is

$$e(p,q,1,u,G) = pf(L^F) + M(L^M, E^M) + qE(B,R) - pB - rR - qE^M. \tag{22}$$

Noting that in the large-country case R^* is endogenous, (6) has to be replaced by $G = G(R + R^*)$. We differentiate (22) to get

$$e_u du = Xdp - sdB + (t - e_G G')dR - e_G G' dR^*. \tag{23}$$

Equation (23) is similar to (9) in the small open-economy case, with two important differences. The first is the terms-of-trade effect, which is captured by the first term on the right-hand-side of (23). Home's utility will rise to the tune of a rise in the price of food (i.e., dp) weighted by its

[22] This structure lends tractability to the model. Admittedly, allowing for price of crude to be endogenous and for the ROW to consume crude are realistic assumptions, but they come at the cost of complicating an already-complex analysis. The central points that we make are intuitive and can be made without adding to the model's complexity.
[23] Note that production and consumption structure in both nations are the same as in section 2. The notation is similar, except that an asterisk refers to the foreign country.

level of food export (i.e., X). The second critical difference (compared with the small-country case) is that when the home country affects p, it affects the foreign country's net input price of biofuel as well. In turn, this changes R^*, and hence G. Given that the foreign government is assumed to be passive,

$$e_u^* du^* = X^* dp - e_G^* G' dR^W \text{ and } R^W = R + R^*, \tag{24}$$

where R^W is global crude use.[24] The market-clearing equation for food is

$$f + f^* = e_p + B + e_p^* + B^* \Rightarrow X + X^* = 0, \tag{25}$$

which implies that

$$p = p(s,t).^{25} \tag{26}$$

Using (23) and (26), the optimal subsidy and tax levels are

$$s^{opt} = \frac{\left(Xp_s - e_G G' R_s^*\right) R_t + (e_G G' R_t^* - Xp_t) R_s}{B_s R_t - R_s B_t}, \quad B_s R_t - R_s B_t \neq 0; \tag{27a}$$

$$t^{opt} = e_G G' + \frac{B_t s^{opt.} + e_G G' R_t^* - Xp_t}{R_t}. \tag{27b}$$

Proposition 3: A large open-economy's optimal tax on crude will depart from the standard Pigouvian tax of the small open-economy case. Also, even if an optimal tax on crude is in place, the optimal biofuel subsidy may be nonzero.

It is clear from an inspection of (27a) and (27b) that even if an optimal crude tax is in place, a biofuel subsidy is still required. Consider for expositional purposes the case where R_S is

[24] We relax this passivity assumption in the next subsection, where both nations may use biofuel subsidies.
[25] The terms-of-trade effects are analyzed by using a quasi-linear utility function that is also separable in G. This serves as a tractable example and does not compromise the generality of our results.

zero and p_s is positive. In this case, assuming that B_s is positive,[26] the optimal subsidy is positive if and only if the term Xp_s is larger than $e_G G' R_s^*$. The term Xp_s is the standard terms-of trade effect, while $e_G G' R_s^*$ is home's utility loss from increased crude use (and pollution) by the foreign country, induced by a rise in the price of food (and hence the price of biofuel) due to home's subsidization. These two effects are novel to the large-country case and explain why the optimal biofuel subsidy here departs from the zero level of the small-country case discussed in proposition 1. In the small-country case, the only role of the biofuel subsidy is to target the domestic crude level (R). When an optimal crude tax is in place, there is no reason to use the subsidy. This is not true in the large-country case. Even if the effect of a biofuel subsidy on domestic crude use is zero (i.e., if $R_s = 0$), there are still gains from using a biofuel subsidy.

Turning to the optimal tax on crude, it is clear from (27b) that the expression for the optimal tax here is different from $e_G G'$ (which was the optimal tax level in the small-country case). The expression differs because the tax here has three additional effects. First, it affects the use of biofuel and therefore the burden of the subsidy to the extent $B_t s^{opt.}$. Second, by changing p, the price of crude relative to the net input price of B^* is affected in the foreign nation. If this leads to an increase in foreign crude use (i.e., if $R_t^* > 0$), then home utility is reduced. Finally, if the tax raises the price of food (i.e., if $p_t > 0$), then the home nation gains to the tune of Xp_t.[27]

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[26] In the appendix we show that while B_s is necessarily positive in the small-country case, there is some ambiguity in the current context. The conditions under which B_s is positive is outlined on pages 21 and 22 in the appendix.

[27] The expression for p_t is in the appendix. Suffice it to note here that a tax affects the net global demand for food through various channels, including the substitution of biofuel for crude in energy production when crude becomes more expensive. This effect by itself will tend to raise demand and the price of food, but there are countervailing effects. For example, the tax raises the input price for energy production, in turn raising the energy price. This will tend to reduce energy demand, which will reduce the derived demand for biofuel. For details, we refer the reader to the appendix.

3.2 Nash Biofuel Subsidies

Here we consider a scenario in which a crude tax is unavailable as a policy instrument, although home and foreign can both use biofuel subsidies.[28] Each nation's subsidy affects the net global demand for food and, hence the common international price of food. Therefore, each country's biofuel subsidy affects the other's utility, raising strategic considerations for both nations. We assume that the nations play Nash in the sense that each takes the other's subsidy rate as given when choosing its own utility-maximizing subsidy. The market-clearing equation (25) yields

$$p = p(s, s^*) . \tag{28}$$

Using (22) and (28),

$$e_u u_s = Xp_s - sB_s - e_G G' R_s^W . \tag{29}$$

Assuming $B_s > 0$ (see footnote-26 and pages 21 and 22 for details), the Nash utility maximizing subsidy is

$$s^{Nash} = \frac{Xp_s - e_G G' R_s^W}{B_s} \geq 0, \text{ iff } Xp_s \geq e_G G' R_s^W . \tag{30a}$$

Analogously, we can derive the foreign subsidy rule. In addition, using $X^* = -X$, we get

$$s^{*Nash} = \frac{X^* p_{s*} - e_G^* G' R_{s*}^W}{B_{s*}^*} \geq 0, \text{ iff } Xp_{s*} \leq -e_G^* G' R_{s*}^W \tag{30b}$$

The details of the terms-of-trade effects (p_s and p_{s^*}) are analyzed in the appendix. Suffice it to say here that one of the primary effects of a biofuel subsidy is to encourage the use of biofuel instead of crude. This increases the demand for food (as biofuel) and raises its price regardless of which country is providing the subsidy. Thus, both p_s and p_{s*} are likely to be

[28] This assumption lends tractability and allows us to focus better on the role of interdependence between nations in their choice of biofuel subsidies. This is a relatively small sacrifice to make, because the fundamental insights of using a crude tax and biofuel subsidy combination have already been discussed.

positive. On the other hand, there is an asymmetry in the terms-of-trade effect on the utility of the two nations, because while home is an exporter of food (i.e., $X > 0$), foreign is an importer (i.e., $X^* = -X < 0$). First, consider the case where R_s^W is negative. Home subsidization reduces global pollution, and this benefit, coupled with the terms-of-trade gain, suggests that the Nash subsidy in (30a) is positive. On the other hand, if the scale effect makes R_s^W positive, the terms-of-trade motive and the pollution-reduction motive conflict and a subsidy might or might not be justified. Using (30b) we can see that analogous considerations suggest that the foreign country, which suffers from a terms-of-trade loss when it uses a biofuel subsidy, will subsidize only if its subsidy reduces pollution (i.e., only if $R_{s^*}^W < 0$). The foreign country will choose a subsidy if the aforementioned necessary condition is met, and if the pollution reduction effect dominates the adverse terms-of-trade effect that the foreign nation imposes on itself.

It is easy to see from the discussion above that terms-of-trade considerations might lead the home country to choose a biofuel subsidy even when it increases pollution, and conversely, the foreign country may choose a tax even when its subsidy reduces pollution. It is obvious that such an equilibrium is jointly suboptimal: the terms-of-trade effects wash out between the two nations while the pollution increase reduces joint welfare. This is explained below by adapting equation (23) to the current context:

$$e_u du + e_{u^*}^* du^* = (X + X^*)dp - sdB - s^* dB^* - (e_G + e_G^*)G' dR^W . \tag{31a}$$

Note that market clearing for food requires that $X + X^* = 0$. Thus, (31a) simplifies to

$$e_u du + e_{u^*}^* du^* = -sdB - s^* dB^* - (e_G + e_G^*)G' dR^W . \tag{31b}$$

Evaluating (31b) at the nonintervention outcome ($s = s^* = 0$), and normalizing marginal utility of income for both nations to unity at this outcome

$$d(u + u^*)_{|s=s^*=0} = -(e_G + e_G^*)G' dR^W . \tag{32}$$

It is clear that joint utility can rise only starting from nonintervention if global crude use falls, leading to less pollution. Therefore, any policy intervention by either nation that leads to a net rise in crude use is jointly suboptimal.

Proposition 4: The exporter of food might impose a biofuel subsidy because of the terms-of-trade motive, even if doing so leads to increased global crude use (and pollution). In contrast, the food-importing nation has an incentive to tax biofuel even when doing so raises pollution. Unless the gains from pollution reduction dominate, the food importer will not subsidize. Such a Nash equilibrium is jointly suboptimal and is better than nonintervention only if it leads to reduced crude use and, hence, less pollution.

It is clear from proposition 4 that the Nash subsidy equilibrium may be associated with too much pollution relative to nonintervention. This is necessarily the case when $R_s^W > 0$, $R_{s^*}^W < 0$, and terms-of-trade motives dominate for both nations, so that home imposes a biofuel subsidy while the foreign nation imposes a biofuel tax. Because $R_s^W > 0$ and $R_{s^*}^W < 0$ in this case, the home subsidy and the foreign tax both raise pollution. Clearly then, the Nash equilibrium is worse than the nonintervention outcome. The welfare ranking of other possible cases is not obvious, and one has to proceed on a case-by-case basis.

4. Conclusion

This paper provides an analysis of policy aimed at boosting the use of clean fuels. The small open-economy case highlights the fact that if Pigouvian taxes are available, a biofuel subsidy is not necessary to combat pollution. If a tax on crude is not available, a biofuel subsidy still might not be welfare augmenting because of conflicting substitution and scale effects.

Under certain situations, therefore, the second-best policy is not to subsidize biofuels but to tax them.

In contrast with the small-country case, the large-country analysis shows that even if a tax on crude is in place, a food-exporting nation might gain from a biofuel subsidy because of terms-of-trade gains. Also, because of these considerations, the optimal tax on crude departs from its standard Pigouvian level.

Finally, we considered the use of biofuel subsidies by the food-exporting and food-importing nations. The two countries' policies are interdependent in the large-country case because they affect the common international terms of trade for food. The Nash equilibrium that emerges is jointly suboptimal because unilateral Nash optimization fails to internalize the pollution and terms-of-trade externalities that one nation imposes on the other.

Appendix

A. *Terms-of-Trade Effects*

For tractability, we assume quasi-linearity of preferences and separability of *G* for this appendix. These assumptions allow us to abstract from income effects, considerably simplifying the discussion, without changing the thrust of our analysis. The general case is available on request. Using equations (25) and (26) from the text, it can be shown that

$$p_s = \frac{\partial p}{\partial s} = \frac{N_s}{D^F} \ , \tag{A1}$$

where $D^F > 0$, because of the Marshall-Lerner condition, and

$$N_s = \left(e_{pq} + C_{p^s}(.)E_q - f' L_q^F\right) q_s - EC_{p^s p^s} \ . \tag{A2}$$

Noting that the concavity of the unit cost function in sector *M* ensures that $w(q)$ [defined in footnote 17] is convex, we get

$$E_q = \frac{\partial E}{\partial q} = e_{qq} + E_q^M < 0 \text{ because } e_{qq} < 0 \text{ and } E_q^M = -L^M w''(q) + \frac{\left(w'(q)\right)^2}{pf''(L^F)} < 0 . \tag{A3}$$

Also,

$$L_q^F = \frac{w'(q)}{pf''(L^F)} > 0 \text{ because } w'(q) = -\left(\frac{E^M}{L^M}\right) < 0 \text{ and } f''(.) < 0 . \tag{A4}$$

Finally,

$$q = C(p - s, r + t, 1) \Rightarrow q_s = -C_{p^s} < 0 . \tag{A5}$$

Using (A3) through (A5) in (A2), and noting that $C(.)$ is concave in input prices,

$$N_s = \left(e_{pq} + C_{p^s}(.)E_q - f' L_q^F\right) q_s - EC_{p^s p^s} > 0 \text{ if } e_{pq} \le 0 . \tag{A6}$$

(A6) provides a sufficient but not necessary condition for the biofuel subsidy to raise the international price of food. Indeed, even if e_{pq} is positive (i.e., food and energy are Hicksian substitutes in consumption), the price of food will rise unless this cross-substitution effect in consumption overwhelms all the other effects.

The primary effect of the subsidy is to raise the use of biofuel as an input into energy at given prices. This is captured by the term $-EC_{p^s p^s} > 0$. The subsidy also reduces the price of energy because of a reduction in the unit cost (i.e., $q_s < 0$). The lower energy price directly raises food demand if they are Hicksian complements (i.e., if $e_{pq} < 0$). It also boosts the demand for energy for consumption and as an input in manufacturing, thereby raising the demand for food as an input in energy production: $C_{p^s}\left(e_{qq} + E_q^M\right)q_s > 0$. Finally, the lower energy input price expands the manufacturing sector at the expense of the food sector, driving down food supply: $-f'L_q^F < 0$ because $L_q^F > 0$. All these effects contribute to a rise in the net demand for food (unless e_{pq} is positive and larger than the sum of the other effects), raising the price of food. This confers a terms-of-trade benefit to the home country as the exporter of food, and a loss to the foreign country.

Similarly,

$$p_t = \frac{\partial p}{\partial t} = \frac{N_t}{D^F} \quad , \tag{A7}$$

where,

$$N_t = \left(e_{pq} + C_{p^s}(.)E_q - f'L_q^F\right)q_t + EC_{p^s r^d} \ , \tag{A8}$$

and,

$$q_t = C_{r^d}(.) > 0 \, , \ C_{p^s r^d} = -\left(\frac{p-s}{r+t}\right)C_{p^s p^s} > 0 \, . \tag{A9}$$

Using equations (A3) to (A6),

$$e_{pq} + C_{p^s}(.)E_q - f' L_q^F < 0 \text{ if } e_{pq} \leq 0 . \qquad \text{(A10)}$$

Using (A9) and (A10) in (A8), we see that while the first term on the right-hand side of (A8) is negative, the second term is positive. Thus the sign of N_t is ambiguous. This happens for the following reasons. First, the tax raises the relative price of crude as an input and increases the input demand for biofuel (and, therefore, for the food product) via the cross-substitution effect. On the other hand, the remaining effects all reduce demand for food as follows: (i) The crude tax raises the price of energy, which results in reduced consumption demand for food, if food and energy are Hicksian complements in consumption, (ii) The rise in the price of energy reduces the demand for energy, resulting in a decline in the derived demand for biofuel in energy production, (iii) Since $L_q^F > 0$, the rise in the energy price raises home's supply of food, reducing the excess demand for food.

If, in the final analysis, the effects of the induced change in energy price are dominated by the primary cross-substitution effect, then $N_t > 0 \Rightarrow p_t > 0$. The analysis for p_{s^*} is similar to that for p_s above.

B. *Effects of Policy Variables on Biofuel and Crude Use*

Noting that $C(p-s, r+t, 1)$ is the unit cost function in the energy sector, CRS ensures that

$$B = EC_{p^s}(p-s, r+t, 1) . \qquad \text{(A11)}$$

Under quasi-linearity and separability in *G*,

$$E = e_q(p, q) + E^M . \qquad \text{(A12)}$$

Noting that $w = w(q)$, using $E^M = -L^M w'(q)$ from (A4), and using (2) and (4) [which yields $L^M = L^M(p, w)$], we get

$$E^M = E^M(p,q) \equiv -L^M\left[p, w(q)\right]w'(q), \tag{A13}$$

where $E_p^M = -w'(q)L_p^M < 0$, and $E_q^M < 0$ as shown in (A3).

Allowing for all the policy variables considered in this paper to be present, the market clearing equation for food dictates that

$$p = p(s,t,s^*). \tag{A14}$$

Using (A5),

$$q = C(p - s, r + t, 1) \Rightarrow q = q(p, s, t), \text{ where}$$

$$q_p = C_{p^s} > 0, \quad q_s = -C_{p^s} = -q_p < 0, \text{ and } q_t = C_{r^d} > 0. \tag{A15}$$

Using (A12) through (A15),

$$E = E(s,t,s^*) \equiv e_q\left[p(.), q\left(p(.), s, t\right)\right] + E^M\left[p(.), q\left(p(.), s, t\right)\right],$$

$$\text{where } p(.) = p(s,t,s^*). \tag{A16}$$

Using (A11) and (A16),

$$B(s,t,s^*) = E(s,t,s^*)C_{p^s}(p(.) - s, r + t, 1). \tag{A17}$$

Using (A17) and simplifying, we get

$$B_s = C_{p^s}(e_{qp} + E_p^M)p_s + \left[C_{p^s}q_s(e_{qq} + E_q^M) - EC_{p^s p^s}\right](1 - p_s). \tag{A18}$$

In the small-country case, $p_s = 0$ and (A18) reduces to

$$B_s = C_{p^s}q_s(e_{qq} + E_q^M) - EC_{p^s p^s} > 0, \tag{A19}$$

because of the concavity of expenditure and cost functions and because $q_s < 0$ and $E_q^M < 0$ from (A3).

Using (A18), it is clear that in the large-country case, if $1 > p_s > 0$, then $B_s > 0$ if the last term on the right-hand side of (A18) dominates or if $e_{qp} > 0$ and dominates the negative term E_p^M.

Similarly, using (A17),

$$B_t = E\left(C_{p^s p^s} p_t + C_{p^s r^d}\right) + C_{p^s} E_t ,$$

where $E_t = (e_{qp} + E_p^M) p_t + (e_{qq} + E_q^M)(q_p p_t + q_t) < 0$, if $p_t > 0$ and $e_{qp} \leq 0$. (A20)

In the small-country case, $p_t = 0$ and (A20) boils down to

$$B_t = EC_{p^s r^d} + C_{p^s} E_t , \; E_t = (e_{qq} + E_q^M) q_t < 0 . \quad \text{(A21)}$$

The two terms on the right hand side of the first equality in (A21) have opposite signs. Therefore, the sign of B_t is ambiguous even in the small-country case. Using (A20) we can infer that the same is true in the large-country case.

Analogous to (A11),

$$R = EC_{r^d} (p - s, r + t, 1) . \quad \text{(A22)}$$

Using (A16), we can differentiate (A22) to obtain:

$$R_t = C_{r^d} E_t + E\left(C_{r^d p^s} p_t + C_{r^d r^d}\right), \quad \text{(A23)}$$

where E_t is defined in (A20) above. In the small-country case,

$$R_t = C_{r^d} E_t + EC_{r^d r^d} = C_{r^d} (e_{qq} + E_q^M) q_t + EC_{r^d r^d} < 0 . \quad \text{(A24)}$$

Using (A23) and (A20) we can see that there is ambiguity in the large-country case, but $R_t < 0$ if the term $\left(C_{r^d p^s} p_t > 0\right)$ is sufficiently small and if $e_{qp} \leq 0$. Using (A22) and (A16),

$$R_s = C_{r^d} E_s - EC_{r^d p^s} (1 - p_s) ,$$

where $E_s = \left[e_{qp} + E_p^M + \left(e_{qq} + E_q^M \right) q_p \right] p_s + \left(e_{qq} + E_q^M \right) q_s$. (A25)

In the small-country case, (A25) reduces to

$$R_s = C_{r^d} \left(e_{qq} + E_q^M \right) q_s - EC_{r^d p^s} . \tag{A26}$$

Since $C_{r^d} \left(e_{qq} + E_q^M \right) q_s > 0$ and $EC_{r^d p^s} > 0$, the sign of R_s is ambiguous even in the small-country case.

Finally, consider foreign crude use R^*. Analogous to (A22), and noting that $t^* = 0$,

$$R^* = E^* C_r^* (p - s^*, r, 1) . \tag{A27}$$

Like (A16),

$$E^* = E^*(s,t,s^*) \equiv e^*_{q^*} \left[p(.), q^* \left(p(.), s^* \right) \right] + E^{M*} \left[p(.), q^* \left(p(.), s^* \right) \right],$$

where $p(.) = p(s,t,s^*)$. (A28)

Thus,

$$R_s^* = E_s^* C_r^* (p - s^*, r, 1) + E^* C^*_{rp^{s*}} p_s = \left(Z^* C_r^* + E^* C^*_{rp^{s*}} \right) p_s$$

where $E_s^* = Z^* p_s$, $Z^* = e^*_{q^* p} + E_p^{M*} + \left(e^*_{q^* q^*} + E^{M*}_{q^*} \right) q_p^*$ (A29)

It is clear from (A29) that in the small-country case $R_s^* = 0$. In the large-country case, the sign is ambiguous because $Z^* < 0$ if $e^*_{q^* p} \leq 0$. Similar derivations yield

$$R_t^* = \left(Z^* C_r^* + E^* C^*_{rp^{s*}} \right) p_t . \tag{A30}$$

Therefore, $R_t^* = 0$ in the small-country case, whereas its sign is ambiguous in the large-country case.

References

Antweiler, W., Copeland, B.R. and Taylor, M.S. (2001). Is free trade good for the environment? *American Economic Review* 91(4), 877-908.

Ballard, C.L. and Medema, S.G. (1993). The marginal efficiency effects of taxes and subsidies in the presence of externalities: A computational general equilibrium approach. *Journal of Public Economics* 52(2), 199-216.

Barrett, S. (1994). Strategic environmental policy and international trade. *Journal of Public Economics* 54(3), 325-338.

Bloomberg, (2009). EU hits U.S. biodiesel makers with five-year tariffs. July 7, 2009. http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aMEeSlftJdR0

Copeland, B.R. and Taylor, M.S. (1994). North-South trade and the environment. *Quarterly Journal of Economics* 109(3), 755-787.

Copeland, B.R. and Taylor, M.S. (2003). *Trade and the Environment: Theory and Evidence*. Princeton: Princeton University Press.

Copeland, B.R. and Taylor, M.S. (2004). Trade, growth and the environment. *Journal of Economic Literature* XLII, 7-71.

Cremer, H. and Gahvari, F. (2006). Which border taxes? Origin and destination regimes with fiscal competition in output and emission taxes. *Journal of Public Economics* 90(10-11), 2121-2142.

Ernst & Young (2007). *Biofuels country attractiveness index*.

Frankel, J.A. and Rose, A.K. (2005). Is trade good or bad for the environment? Sorting out the causality. *Review of Economics and Statistics* 87(1), 85-91.

Fredriksson, P. (1997). The political economy of pollution taxes in a small open economy. *Journal of Environmental Economics and Management* 33(1), 44-58.

Fullerton, D. and Metcalf, G.E. (2001). Environmental controls, scarcity rents, and pre-existing distortions. *Journal of Public Economics* 80(2), 249-267.

Larson, E.D. (2008). Biofuel production technologies: Status, prospects and implications for trade and development. United Nations Conference on Trade and Development, New York and Geneva.

Lopez, R. (1994). The environment as a factor of production: The effects of economic growth and trade liberalization. *Journal of Environmental Economics and Management* 27(2), 163-184.

Organisation for Economic Cooperation and Development. (2006). Agricultural market impacts of future growth in the production of biofuels. *OECD Papers* 6(1), 1-57.

Rauscher, M. (1997). *International Trade, Factor Movements, and the Environment*. Oxford: Clarendon Press.

Runge, C.F. and Senauer, B. (2007). How biofuels could starve the poor. *Foreign Affairs* 86(3), May/June 2007, 41-53.

von Braun, J. and R.K. Pachauri, (2006). The promises and challenges of biofuels for the poor in developing countries. IFPRI 2005-2006 Annual Report Essay. Washington, D.C.: International Food Policy Research Institute.