

Killing Two Birds With One Stone: US and EU Biofuel Programmes.

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Abstract

Several countries have recently launched biofuel policies to mitigate greenhouse gas (GHG) emissions from fossil fuels and secure their energy supply. The price increase due to this new demand for feedstock reduces the need for farm support programmes. Subsidy policies aimed at reaching relatively low production levels of biofuel may actually lead to a decrease in the total public outlay. Diminishing the cost of farm support programmes also induces relatively low levels of imports of agricultural feedstocks and larger subsidies for biofuel produced from domestic feedstock than from imports. Considering the enforcement of the environmental standard, we show that for high levels of biofuel production, cross-compliance provisions are a more expensive way of enforcing environmental policy than fining farmers.

Keywords: Biofuels, Income support, Environmental enforcement.

In the European Union (EU) as in the United States (US), new programmes aim to develop biofuels significantly. As pointed out by several studies (see, e.g. Elobeid et al., 2006, Tokgoz and Elobeid, 2006, Schmidhuber, 2006 and Gohin, 2007), subsidizing the

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biofuel industry raises the price of agricultural feedstock.¹ In the EU, the development of biofuel production will allow the agricultural sector to benefit from dual support (taken in a broad sense): on the one hand, states hand out decoupled payments to farmers (Single Farm Payments), and on the other, they give large support to the biofuel industries² whose production costs exceed the price at which they can sell their output. The increase in agricultural commodity prices raises the farmers' revenue, and reduces the need for direct income support. Hence, for a given objective in terms of agricultural income, the regulator is able to operate a partial substitution between direct agricultural income support and subsidies to the biofuel industry. Owing to the importance of the Common Agricultural Policy (CAP) in the EU budget,³ the question of a partial substitution of biofuel subsidies for CAP payments could be on the EU political agenda very soon. In the US, the ethanol programme might lead to a long-lasting price increase for maize, wheat and soyabeans, which could temporarily stop the counter-cyclical and loan deficiency payments (Babcock, 2006). Of course, this competition with biofuel firms for the same input is harmful for the European agro-food industry, which opposes the policy in favour of the first generation of biofuels (see Unilever, 2006, Forbes, 2006 and Confederation of the Food and Drink Industries of the EU, 2006). Goldman Sachs (Financial Times, 2006) points to a possible decrease in agro-food firm profits owing to biofuel production. With rising revenues for farmers, decreasing profits for the agro-food industry and a reduced consumer surplus, the net effect on European welfare is unclear.

This article is related to the literature on the transfer efficiency of agricultural programmes (see, e.g. Alston and Hurd, 1990, Alston and James, 2002 and Gardner, 1983), which notably considers the incidence of the opportunity cost of public funds in the relative

¹The so-called first generation of biofuels is produced using crops identical to those used by the food processing industry. Hence, competition is likely between food and energy crops for the same agricultural feedstock. In the EU, this competition mainly involves rapeseed, which is valuable both for the agro-food and biodiesel industries. In the USA, the main biofuel being maize ethanol, the competition concerns the ethanol processing industries and cattle breeders.

²See e.g. Koplou, 2006 and Kutas and Lindberg, 2007.

³In 2007, it represents more than 40 billion euros, i.e. 37% of the EU budget, (European Commission, 2007).

efficiency of economic instruments aimed at supporting farmers' incomes. Indeed, biofuel subsidies (and mandatory blending) could be considered a new element in the already wide range of instruments at the regulator's disposal. Some authors have begun to investigate the links between agricultural policies and the new policies aiming at developing biofuels, as in Gardner (2007) and de Gorter and Just (2008).

We develop a model that disentangles the various effects that the support granted to biofuels may trigger. We show that with no constraint on biofuel production (e.g. coming from security of energy supply concerns), the government may find it worthwhile to implement a biofuel programme to diminish the social cost of the farm support programme: indeed, it may be socially beneficial to implement such policies if costs of public funds are high. This result might explain why biofuel programmes have been in place in the EU and the US for more than a decade. Considering the possibility of importing agricultural feedstock, the government may still take advantage of substitution between the farm support programme and the biofuel subsidy policy. This effect leads to a higher domestic price of the agricultural commodity than the world price, relatively low import levels, and the biofuels produced from imported agricultural feedstock benefiting from a lower subsidy than biofuels produced from domestic input. When the biofuel production constraint is binding, the optimal domestic production of feedstock exceeds the optimal (unconstrained) level of supply of agricultural raw product that prevails in autarky.

The effects of biofuels on environmental policies are double-edged. On the one hand, biofuels are one of the main features of GHG mitigation policies in the transportation sector. On the other hand, sizeable production of energy crops will have major implications on environmental policies for the agricultural sector. Hence, the environmental externalities are positive for GHG emissions, but negative for agricultural production. There is thus an essential contradiction between setting a prominent objective for biofuel production that will lead (through higher prices) to higher yields and thus to an intensification of agricultural production, and the adoption of sound agricultural practices.⁴ The positive environmental externalities of biofuels regarding GHG emissions ought to be weighed against the nega-

⁴In the USA, the increased production of corn might well lead to local pollution problems, as well as soil erosion concerns (Marshall and Greenhalgh, 2006).

tive externalities generated by the production process of the agricultural raw material. We analyze the optimal trade-off between GHG mitigation and sound agricultural production practices. We show that because of the social cost of public funds, the optimal standard is stricter than the Pigouvian level. Indeed, by setting a stringent environmental standard, the regulator increases the marginal cost of production, hence the price of the agricultural feedstock, which reinforces the substitution effect between the biofuel subsidy policy and the farm support programme. However, this standard is less stringent if the cost of enforcing the environmental policy is taken into account. We analyze the effects of a monitoring cost on biofuel production (assuming that production levels are not constrained) and on the agricultural environmental standard, assuming that the government can inflict two types of monetary sanctions: fines and cross compliance provisions. We compare these two policies and show that for a high level of biofuels, cross compliance provisions are less effective than fines.

The paper is organized as follows. First, our model is presented and the optimal production of energy crops is derived. The following section deals with the import scenario. Last, the environmental consequences of increased agricultural production are addressed, notably pertaining to the enforcement of the environmental policies directed at agriculture.

1 The model

Consider an economy with an agricultural sector, a food sector and an energy sector. All agents in this economy are price-takers. The production cost of the agricultural product is affected by the farmers' environmental practices. Denote by $C(X, e)$ the cost function of the representative farm, where X is the production level and $e \in [0, e_M]$ is an environmental index (e.g. the polluting emission level), with $C_{Xe} < 0$. Hence, the more the farmer pollutes, the lower the marginal cost of production.⁵ Both the food and energy industries use the agricultural feedstock in order to produce their own outputs (food products and biofuels, respectively). The total quantity of the agricultural product is thus split between the food (x_F) and energy (x_E) sectors: $X = x_F + x_E$. The production function of the representative

⁵We also assume $C(X, e)$ convex: we have $C_{XX} > 0$, $C_{ee} > 0$ and $C_{XX}C_{ee} - C_{Xe}^2 > 0$.

firm in the food industry is denoted by $y_F = f_F(x_F)$ with $f'_F > 0$ and $f''_F < 0$. The production function of the energy sector is $f_E(x_E) = \gamma x_E$, where $\gamma < 1$ is a positive parameter. Profit maximization of the representative farmer determines the inverse agricultural supply function, given by $C_X(X, e)$. Denote by $p_F(y_F)$ and p_E the prices for the food and the energy products. p_E is supposed unaffected by the production of biofuel and such that:

$$C_X(X, 0) - \gamma p_E > 0$$

i.e. the energy firm production cost is greater than its revenue, whatever environmental standard e . We shall first consider in the following that the government has decided to grant energy firms a per unit subsidy σ_E which allows biofuel firms to break even,⁶ and then discuss mandatory blending.⁷ As $C_{XX} > 0$, the subsidy should rise with the desired quantity of energy crops, as the price of the domestic crop becomes higher. Hence, the demand coming from the energy firms for the agricultural product is determined by the biofuel objective of the government. Total demand for the agricultural product is determined by the demand coming from the food industry and is deduced as follows. Solving the programme of the representative firm of the food industry, given by:

$$\Pi_F \equiv \max_{x_F} p_F(y_F) f'_F(x_F) - C_X(X, e) x_F, \quad (1)$$

where $p_F(y_F)$ and $C_X(X, e)$ are considered as constant, the equilibrium condition on the input market leads to an optimal input demand x_F satisfying:

$$g(x_F, x_E, e) \equiv p_F(y_F) f'_F(x_F) - C_X(x_F + x_E, e) = 0, \quad (\text{EC})$$

for all $x_E \geq 0$. For a given environmental index e , (EC) implicitly defines x_F as a function of x_E .

1.1 Optimal biofuel policy in autarky

The objective of the regulator is to maximize the sum of the surpluses of the different agents in the economy: farmers profits Π_A , food and energy industry profits, Π_F and Π_E , the

⁶We assume that the energy firm has no private information: the regulator knows the firm's technology and cost function.

⁷We discuss the mandatory blending framework at the end of this section. Of course, other policies are possible, like, first of all, a Pigouvian tax on fossil fuels.

consumer surplus CS ,⁸ and the taxpayer surplus T . It also takes account of a guaranteed income $\bar{\Pi}_A$ for farmers. Hence, the taxpayer must finance the biofuel programme on the one hand and the direct payments to farmers on the other. The total cost of subsidizing the energy crops is given by $\gamma x_E \sigma_E$, while the parity income constraint leads to spending equal to $\bar{\Pi}_A - \Pi_A$, corresponding to the decoupled payments awarded to farmers. The total public spending is affected by $1 + \lambda$ in the Social Welfare Function (SWF), where λ is a positive parameter representing the social cost of public funds (see Fullerton, 1991 for a discussion on the value of λ). We thus have:

$$T = (1 + \lambda)[(C_X - \gamma p_E)x_E + \bar{\Pi}_A - \Pi_A].$$

The environmental effects of the agricultural production are summarized in an environmental damage function $D(e)$, with $D'(e) > 0$, i.e., the larger the farms' emissions, the greater the environmental damages. One of the regulator's tasks is to determine a socially desirable environmental standard \bar{e} for agriculture. Of course the regulator also has to make sure that farmers do comply with the environmental guidelines. We first characterize the situation of costless enforcement implying $e = \bar{e}$, and discuss the enforcement problem in a specific section. Last, an environmental benefit stemming from the GHG mitigation effect of biofuels is also accounted for in the SWF: let $B(x_E)$ be this environmental benefit and assume that $B'(x_E) = q > 0$. As explained above, the profit of the biofuel industry Π_E is equal to zero. Absent any constraint on biofuel production level, the government's program is given by:

$$\max_{x_E, x_F, \bar{e}} \{ \bar{\Pi}_A + CS + \Pi_F - (1 + \lambda)[(C_X - \gamma p_E)x_E + \bar{\Pi}_A - \Pi_A] + B - D : (EC) \} \quad (2)$$

International agreements or energy supply security concerns may oblige the agency to produce at least some given level Q of biofuel. This would introduce another constraint in programme (2), given by: $x_E \geq Q/\gamma$. To simplify the presentation, we do not include this constraint in the government programme, but we discuss the case of a binding biofuel production constraint in the following. Neglecting constant $\bar{\Pi}_A$, the Lagrangian of programme (2) may be written as:

$$\mathcal{L} = CS + \Pi_F - (1 + \lambda)[(C_X - \gamma p_E)x_E - \Pi_A] + B - D - \beta g(x_F, x_E, \bar{e})$$

⁸ CS is the Marshallian consumer surplus deriving from the consumption of food:

$CS(x_F) = \int_0^{y_F(x_F)} p_F(y_F(x_F)) dy_F$. For a discussion on the use of consumer surplus, see Willig (1976).

where β is the Lagrange multiplier corresponding to the market equilibrium condition (EC). The optimal policy satisfies the following first-order conditions:

$$\frac{\partial \mathcal{L}}{\partial x_F} = \lambda x_F C_{XX} - \beta(\partial g / \partial x_F) = 0 \quad (3)$$

$$\frac{\partial \mathcal{L}}{\partial x_E} = \lambda x_F C_{XX} - (1 + \lambda)[C_X - \gamma p_E] + q - \beta(\partial g / \partial x_E) \leq 0 \quad (x_E^* \geq 0) \quad (4)$$

and

$$\frac{\partial \mathcal{L}}{\partial \bar{e}} = \lambda x_F C_{Xe} - (1 + \lambda)C_e - D' - \beta(\partial g / \partial e) = 0. \quad (5)$$

Besides, we define the derivative of x_F with respect to x_E for a given environmental standard \bar{e} : $\frac{dx_F}{dx_E} = -\frac{\partial g / \partial x_E}{\partial g / \partial x_F}$.

The reader can easily verify that solving equations (3)-(5) for \bar{e} , x_E and x_F leads to the following result:

Proposition 1 *The optimal policy \bar{e}^* , x_E^* and x_F^* is implicitly defined by (EC),*

$$\lambda x_F C_{XX} \left[1 + \frac{dx_F}{dx_E} \right] - (1 + \lambda)[C_X - \gamma p_E] + q \leq 0 \quad (x_E^* \geq 0) \quad (6)$$

and

$$\lambda x_F C_{XX} \left[1 + \frac{dx_F}{dx_E} \right] = \frac{C_{XX}}{C_{Xe}} \{(1 + \lambda)C_e + D'\}. \quad (7)$$

Proof: See the appendix.

To interpret (6), consider the case $\lambda = 0$. We would have

$$C_X(X, \bar{e}) - \gamma p_E = q$$

i.e., the Pigouvian rule that the optimal subsidy should equalize the marginal benefit of GHG mitigation. With $\lambda > 0$, a binding constraint (6) implies that the optimal subsidy for biofuels (which entails the shadow cost of public funds) exceeds the marginal benefit of GHG mitigation. More precisely, without any constraint on biofuel production, the regulator must choose a quantity of energy crops up to the point where the marginal social loss of subsidizing the biofuel sector equals the sum of the GHG positive externality and the

marginal social gain of the transfer of revenue from the food sector to farmers. Indeed, the increase in the price of the agricultural raw product makes it possible to diminish the direct payment to farmers: a marginal increase dx_E in biofuel demand transfers a revenue equal to $-(d/dx_E)[CS + \Pi_F] = x_F C_{XX}(X, \bar{e}) dX/dx_E$ from the food sector (the food industry and consumers) to farmers. This transfer allows the government to reduce the extent of the farm support programme, hence the corresponding tax distortions caused in the rest of the economy. For high levels of x_F , the total subsidy outlay may in fact diminish: indeed, for a given environmental standard \bar{e} , we have:

$$\frac{d}{dx_E} [(C_X(X, \bar{e}) - \gamma p_E)x_E + \bar{\Pi}_A - \Pi_A] = C_X(X, \bar{e}) \left[\frac{C_X(X, \bar{e}) - \gamma p_E}{C_X(X, \bar{e})} - \frac{dX}{dx_E} \frac{x_F/X}{\epsilon(X, \bar{e})} \right]$$

where $\epsilon(X, \bar{e})$ is the price elasticity of the agricultural crop supply, given by $\epsilon(X, \bar{e}) = C_X(X, \bar{e})/[XC_{XX}(X, \bar{e})]$. Hence, the variation in total public spending may be negative provided that the elasticity of agricultural supply is low and x_F/X , the share of food sector demand in the total demand for feedstock, is large. A sufficient condition to have a strictly positive level of biofuel at the optimum of the government's programme is that (6) being strictly positive when no biofuel programme is in place and all the agricultural crops are used as an input for the food industry (i.e., $x_E = 0$ and $x_F = X_0$, the feedstock production level bought by the food sector when no biofuel is produced):

$$\lambda X_0 C_{XX}(X_0, \bar{e})(dX/dx_E)|_{x_E=0} - (1 + \lambda)[C_X(X_0, \bar{e}) - \gamma p_E] + q > 0$$

Leaving aside GHG mitigation concerns (i.e. even with $q = 0$), we have $x_E^* > 0$ if $\lambda \geq \lambda_s(\bar{e})$ defined by:

$$\lambda_s(\bar{e}) = \frac{C_X(X_0, \bar{e}) - \gamma p_E}{X_0 C_{XX}(X_0, \bar{e})(dX/dx_E)|_{x_E=0} - (C_X(X_0, \bar{e}) - \gamma p_E)}$$

Consequently, when the shadow cost of public funds is large, the regulator should implement a biofuel programme for the reason that transferring income from the food sector to farmers allows it to reduce the social cost of the farmer income support policy. In order to give a hint of the value of λ_s , consider rapeseed production in the EU-15. With a price elasticity of the agricultural crop supply equal to 0.28 (see the FAPRI elasticity database), $\gamma p_E/C(X_0, \bar{e}) = 0.5$ and a 10% decrease in the consumption of rapeseed by the food industry, i.e. $(dx_F/dx_E)|_{x_E=0} = -0.1$, we have $\lambda_s = 0.18$. This value is below the lower boundary of

the range of λ given in the literature (0.2 to 0.6). Therefore, a strictly positive quantity of biodiesel ought to be produced in the EU-15, on purely redistributive grounds.

Equation (7) allows us to characterize the optimal standard policy. The last term of (7) corresponds to the marginal social surplus of agricultural production under standard \bar{e}^* : $D'(\bar{e}^*)$ is the marginal damage and $-C_e(X^*, \bar{e}^*)$ the marginal reduction in production cost which corresponds to a social benefit $-(1 + \lambda)C_e(X^*, \bar{e}^*)$ in public funds.⁹ The Pigouvian rule calls for an environmental standard that nullifies this surplus. The first term of (7) corresponds to the marginal social surplus of biofuel production, with the marginal social loss of subsidizing the biofuel sector given by $(1 + \lambda)[C_X(X^*, \bar{e}^*) - \gamma p_E]$ and the value of the social benefit of GHG mitigation given by q . The Pigouvian level also requires that this marginal surplus is null. However, we know from (6) that this marginal surplus is equal to the marginal social gain of the transfer of revenue from the food sector to farmers, which is positive whenever $\lambda > 0$. With a positive social cost of public funds, as C_{XX}/C_{Xe} is negative, the marginal damage of agricultural production is lower than its marginal social benefit, implying that the optimal standard \bar{e}^* is lower than the Pigouvian level. This can be easily understood: by setting a stringent environmental standard, the regulator increases the marginal cost of production (we have $C_{Xe} < 0$), hence the price of the agricultural feedstock which reinforces the substitution effect between the biofuel subsidy policy and the farm support programme.

Let us now consider the case of a policy constrained to reach a given level of biofuel production Q . We then have $x_E = Q/\gamma$ and the first-order conditions with respect to x_F and \bar{e} lead to the optimal policy (x_F^c, \bar{e}^c) that satisfies:

$$\lambda x_F^c C_{Xe}(X^c, \bar{e}^c) \frac{dX}{dx_E} \Big|_{X=X^c} = (1 + \lambda)C_e(X^c, \bar{e}^c) + D'(\bar{e}^c) \quad (8)$$

where $X^c = Q/\gamma + x_F^c$. Again (8) implies that \bar{e}^c is lower than the Pigouvian level \bar{e}^P corresponding to the production level X^c implied by Q .

⁹The term C_{XX}/C_{Xe} corresponds to the (opposite of the) “marginal rate of substitution” between the agricultural feedstock and the environmental standard at a given price of the agricultural product: we have $(d\bar{e}/dX)|_{C_X=cst} = -C_{XX}/C_{Xe}$.

1.2 Mandatory blending

The main economic instruments to promote biofuels are subsidies. However, governments tend to rely more and more upon a second type of instrument which does not harm public finances: mandatory blending. In this situation, the consumer is compelled to use a given amount of biofuels $\gamma_E x_E$. We still assume that the biofuel firm satisfies the demand and that the government reimburses its production cost. As a result, the consumer faces a higher price for gasoline: indeed, the price of the "aggregate gasoline" (i.e. fossil fuel mixed with a given proportion of biofuel) is $p_G = p_E + (x_E/y_E)(C_X - p_E\gamma_E)$ ¹⁰. Denoting by $CS(y_F, y_G)$ the consumer's surplus corresponding to a consumption bundle (y_F, y_G) of food products and gasoline, the regulator's programme is written as follows:

$$\max_{x_E, x_F, \bar{e}} \{ \bar{\Pi}_A + CS(y_F, y_G) + \Pi_F - (1 + \lambda)[\bar{\Pi}_A - \Pi_A] + B - D : (EC) \} \quad (9)$$

Neglecting the constant $\bar{\Pi}_A$, the Lagrangian of programme (9) may be written as:

$$\mathcal{L}^{MB} = CS(y_F, y_G) + \Pi_F + (1 + \lambda)\Pi_A + B - D - \beta g(x_F, x_E, \bar{e})$$

where β is the multiplier corresponding to the market equilibrium condition (EC). The optimal policy satisfies the following first-order conditions:

$$\frac{\partial \mathcal{L}^{MB}}{\partial x_F} = \lambda X C_{XX} - \beta (\partial g / \partial x_F) = 0 \quad (10)$$

$$\frac{\partial \mathcal{L}^{MB}}{\partial x_E} = \lambda X C_{XX} - [C_X - \gamma p_E] + q - \beta (\partial g / \partial x_E) \leq 0 \quad (\tilde{x}_E^* \geq 0) \quad (11)$$

and

$$\frac{\partial \mathcal{L}^{MB}}{\partial \bar{e}} = \lambda X C_{Xe} - (1 + \lambda)C_e - D'(\bar{e}) - \beta (\partial g / \partial e) = 0. \quad (12)$$

Using (EC), (10) and (11) leads to the following condition:

$$\lambda X C_{XX}(X, \bar{e}) \frac{dX}{dx_E} - [C_X(X, \bar{e}) - \gamma p_E] + q \leq 0 \quad (x_E \geq 0). \quad (13)$$

Rearranging terms, we obtain the following result:

¹⁰The subscript "E" refers to the biofuel while "G" refers to the composite good made up of fossil fuel and biofuel, which is used by the consumer. As before, "F" refers to the aggregate food good.

Proposition 2 *If λ is large, the optimal policy with mandatory blending is implicitly defined by (EC) and*

$$[C_X - \gamma p_E] - q = \lambda X C_{XX} \frac{dX}{dx_E} = \frac{C_{XX}}{C_{Xe}} \{(1 + \lambda)C_e + D'\} \quad (14)$$

Compared to the optimal subsidy policy x_E^ , x_F^* and \bar{e}^* , we have $x_E^{MB} > x_E^*$ and $\bar{e}^{MB} < \bar{e}^*$.*

Proof: See the appendix.

The level of biofuels produced in the case of a mandatory blending framework is greater than with a subsidy. This result is hardly surprising, as the consumer surplus is affected by a weight equal to 1 in the Social Welfare Function, while the taxpayer surplus is weighted $1 + \lambda$.

As concerns environmental standard \bar{e} , the mandatory blending framework imposes a more stringent level: as the taxpayer only pays for the decoupled payment directed at the farmers, the price increase of the agricultural raw material can be pushed a step further.

1.3 Importation of energy crops

The results of the previous section are limited to a quantity produced domestically. However, buying energy crops on the world market could prove less expensive for society.¹¹ We now consider that the energy firm may also buy its raw material on the world market. Let X_E be the total quantity of energy crops, $X_E = x_E + x_I$, where x_E is the domestic energy crop and x_I ¹² the imported one, bought on the world market at price \bar{w} from a perfectly elastic supply. The subsidies awarded by the regulator to the biofuel sector are $\sigma_E = C_X(X, \bar{e})/\gamma - p_E$ for domestic energy crops, and $\sigma_I = \bar{w}/\gamma - p_E$ for imported energy crops. The biofuel subsidy is thus given by $S = \gamma(\sigma_E x_E + \sigma_I x_I)$. With no biofuel production constraint, the regulator's

¹¹A survey on biofuels trade is conducted in Energy Sector Management Program (2007). Besides, the question of the nature of biofuels (agricultural, energy or environmental product) with respect to international trade is discussed in International Policy Council (2006). Finally, Elobeid and Tokgoz (2008) build a model assessing the consequences of the removal of import duties on ethanol (i.e. mainly Brazilian) in the US.

¹²Note that we consider in this model that the imported raw material can only be used to produce biofuels. This stems, e.g., from a ban on genetically modified crops, as it is the case in the EU. This ban concerns the Canadian canola or the Argentinian Soyabean to produce biodiesel in the EU.

programme can be written as:

$$\max_{x_E, x_I, x_F, \hat{e}} \{ \bar{\Pi}_A + CS + \Pi_F - (1 + \lambda)(S + \bar{\Pi}_A - \Pi_A) + B - D : (EC) \} \quad (15)$$

Denoting by $\hat{x}_E, \hat{x}_I, \hat{x}_F$ and \hat{e} the optimal regulator choices, the biofuel feedstocks levels must satisfy the following conditions:

$$\lambda x_F C_{XX}(\hat{X}, \hat{e}) \frac{d\hat{X}}{dx_E} - (1 + \lambda) \{ C_X(\hat{X}, \hat{e}) - \gamma p_E \} + q \leq 0 \quad (\hat{x}_E \geq 0) \quad (16)$$

and

$$-(1 + \lambda)(\bar{w} - \gamma p_E) + q \leq 0 \quad (\hat{x}_I \geq 0). \quad (17)$$

where $\hat{X} = \hat{x}_E + \hat{x}_F$. The latter condition states that (absent any constraint on the biofuel production), the optimal imported crop level equates the marginal social cost of subsidizing the biofuel industry with the marginal environmental benefit of biofuel. If q is large, it is optimal to import as much agricultural commodity as possible because of the positive GHG mitigation effects. We assumed that it is not the case and consequently that we have $\hat{x}_I = 0$ when the government has no minimal biofuel production objective (i.e. we assume that $\bar{w} > \gamma p_E - q/(1 + \lambda)$). Compared to (17), condition (16) entails the marginal social gain of the transfer of revenue from the food sector to the farmers, which eases the condition for a positive level of domestic biofuel crops. As (16) is similar to (6), the resulting demand levels are the same as those obtained in the case of a closed economy: we have $\hat{x}_E = x_E^*$, $\hat{x}_F = x_F^*$ (and $\hat{x}_I = 0$).

If the country faces a minimal biofuel production level $Q > \gamma x_E^*$, energy crops produced domestically exceed level x_E^* . Indeed, substituting $Q/\gamma - \hat{x}_E$ for \hat{x}_I in programme (15) and maximizing in \hat{x}_E and \hat{x}_F gives the following condition:

$$\lambda x_F C_{XX}(\hat{X}, \hat{e}) dX/dx_E - (1 + \lambda)[C_X(\hat{X}, \hat{e}) - \bar{w}] = 0 \quad (18)$$

which implicitly defines \hat{x}_E . Plugging $x_E = \hat{x}_E$ into (16) and using (18) to substitute for the first term, we get:

$$(1 + \lambda)[C_X(\hat{X}, \hat{e}) - \bar{w}] - (1 + \lambda)[C_X(\hat{X}, \hat{e}) - \gamma p_E] + q = -(1 + \lambda)(\bar{w} - \gamma p_E) + q < 0$$

which implies that $\hat{x}_E > x_E^*$. Hence, taking imports into account, we have the following results:

Proposition 3 *When the government can import the agricultural feedstock at price $\bar{w} > \gamma p_E - q/(1 + \lambda)$:*

- *With no constraint on the biofuel production level, it is optimal to produce energy crops if λ is large. All the agricultural feedstock is produced domestically and we have $\hat{x}_E = x_E^*$, $\hat{x}_F = x_F^*$ and $\hat{x}_I = 0$.*
- *If the government has a biofuel production objective $Q > \gamma x_E^*$, it is optimal to produce energy crops domestically at level $\hat{x}_E > x_E^*$ implicitly defined by (18). Importations of raw materials are given by $\hat{x}_I = Q/\gamma - \hat{x}_E$. The internal price of the agricultural feedstock verifies $C_X(\hat{X}, \hat{e}) > \bar{w}$ leading to subsidies $\sigma_E > \sigma_I$.*

2 Policy enforcement and cross-compliance

In this section, we discuss the problem of defining the environmental standard considering the enforcement issue of such a policy, following the seminal paper by Becker (1968).¹³ Indeed, to enforce a demanding policy it is necessary for the State to inspect farms frequently and to be able to inflict sizeable penalties. We shall analyze this problem in a framework similar to Malik (1992), considering that inspecting farms is costly and that the government inflicts penalties that depend on the extent of the infringement. We analyze the two cases of an exogenous maximal penalty, and of a maximal penalty which corresponds to the farmer's decoupled payment, as is the case in the EU. We do not consider importations in this section.

Assume that whenever a farmer has chosen an emission level e that exceeds the standard \bar{e} , the agency is able to inflict a penalty that depends on the extent of the farmer's infringement, $e - \bar{e}$, and more precisely that the corresponding penalty is a fraction $f(e - \bar{e}) \in [0, 1]$ of a maximal penalty Ψ . The function $f(\cdot)$ is exogenously given (by an independent legislative body) and is assumed increasing and convex in $e - \bar{e}$, with $f(0) = 0$. The maximum penalty can either be a given amount \bar{P} (also determined by an independent legislative body), or the decoupled payment that the farmer should receive in case of compliance, i.e.

¹³For a survey on enforcement models applied to environmental economics, see Cohen, 1999 and Bontems and Rotillon, 2002.

$\bar{\Pi}_A - \Pi_A(X, \bar{e})$. The latter case corresponds to the current framework chosen by the EU to enforce environmental policies in agriculture. Let k be the probability of being inspected, and μk the corresponding cost.

Denoting by w the price of the agricultural product, the representative farmer solves the following maximization programme:

$$\max_{X,e} wX - C(X, e) - kf(e - \bar{e})\Psi$$

Maximization with respect to e gives an optimal level e^* which satisfies:

$$-C_e(X, e^*) - kf'(e^* - \bar{e})\Psi \leq 0 \quad (19)$$

i.e., the marginal cost reduction from pollution must be lower than (or equal) to the marginal expected penalty. Since there is no social benefit associated to the payment of fines, we have $e^* = \bar{e}$ at the optimum of the government's programme: no fine is paid in equilibrium. Moreover, as inspecting farms is costly, this condition is binding at the optimum of the agency programme, i.e. we have:

$$-C_e(X, \bar{e}) - kf'(0)\Psi = 0 \quad (IC)$$

The agency simultaneously chooses the optimal level of inspection, the environmental standard and the scope of the biofuel programme by maximizing the following programme:

$$\max_{x_E, x_F, k, \bar{e}} \{ \bar{\Pi}_A + CS + \Pi_F - (1 + \lambda)[(C_X - \gamma p_E)x_E + \bar{\Pi}_A - \Pi_A + \mu k] + B - D : (IC), (EC) \}$$

Assuming an interior solution for the biofuel level, we have the following result:

Proposition 4 *Taking account of the cost of inspection, the optimal (unconstrained) policies verify:*

- In the case of a fixed maximal penalty ($\Psi = \bar{P}$),

$$\begin{aligned} (1 + \lambda)[C_X - \gamma p_E] - q &= \left[\lambda x_F C_{XX} - (1 + \lambda)\mu k \frac{C_{Xe}}{C_e} \right] \frac{dX}{dx_E} \\ &= -\frac{C_{XX}}{C_{Xe}} \{ -D' - (1 + \lambda)C_e - (1 + \lambda)\mu k(C_{ee} - C_{eX}^2/C_{XX})/C_e \} \end{aligned}$$

assuming that the optimal policy \bar{e}^f , x_E^f and x_F^f is such that $x_E^f > 0$.

- In the case of cross-compliance provisions ($\Psi = \bar{\Pi}_A - \Pi_A$),

$$\begin{aligned} (1 + \lambda)[C_X - \gamma p_E] - q &= \left[\lambda x_F C_{XX} - (1 + \lambda) \mu k \frac{C_{Xe} - k f'(0) X C_{XX}}{C_e} \right] \frac{dX}{dx_E} \\ &= -\frac{C_{XX}}{C_{Xe}} \left\{ -D' - (1 + \lambda) C_e - (1 + \lambda) \mu k (C_{ee} - C_{eX}^2 / C_{XX} + k f'(0) C_e) / C_e \right\} \end{aligned}$$

assuming that the optimal policy \bar{e}^{cc} , x_E^{cc} and x_F^{cc} is such that $x_E^{cc} > 0$.

- We have $\bar{e}^f > \bar{e}^*$ and $x_E^{cc} < x_E^f < x_E^*$.

Compared to the costless enforcement policy (x_E^*, \bar{e}^*) , the cost of inspections introduces distortions in the agency's trade-offs, resulting in lower biofuel production levels and less stringent environmental standards. However, the distortion on the production side is lower with a fixed penalty than under cross-compliance provisions. Not surprisingly, the emissions level taking the cost of inspection into account is higher than when enforcement is costless. Indeed, allowing for more emissions reduces the farmer's gain from exceeding the environmental standard, which in turn allows the frequency of inspection to be diminished.

Consider now that the government is constrained by a biofuel objective Q and suppose it desires to enforce a given environmental standard \bar{e} . Denote by $X(Q, \bar{e})$ the agricultural production implied by the equilibrium condition (EC). The corresponding monitoring efforts under fixed penalty, k^f , and cross-compliance, k^{cc} , can be deduced from (IC). We have:

$$k^f > k^{cc} \iff \Pi_A(X(Q, \bar{e}), \bar{e}) < \bar{\Pi}_A - \bar{P},$$

and the same condition holds for the welfare levels reached under the two alternative governmental policies. Hence, cross-compliance may prove the most efficient policy if \bar{P} is low compared to the parity income and if agricultural production $X(Q, \bar{e})$ is low. However, for large biofuel objectives, the government is more likely to choose a fixed penalty policy. Indeed, $e^{cc}(Q)$, the optimal environmental standard under cross-compliance given the biofuel objective Q , increases implying that $\Pi_A(X(Q, e^{cc}(Q)), e^{cc}(Q))$ also strictly increases with Q . Hence, for any objective greater than $Q_s \equiv \inf\{Q \geq 0 : \Pi_A(X(Q, e^{cc}(Q)), e^{cc}(Q)) \geq \bar{\Pi}_A - \bar{P}\}$, the government is able to implement the optimal environmental standard of the cross-compliance policy with a fixed penalty policy and to reduce its monitoring effort and thus the cost of the enforcement policy.

Conclusion

The main results of this paper can be summed up as follows. First, we have shown that biofuel programmes may allow the regulator to operate a partial substitution between decoupled payments and the support for biofuels. This substitution is detrimental to the food industries (and to consumers). However, when the social cost of public funding is high, the regulator should finance a biofuel programme because of its redistributive property. Of course, this result rests on the existence of sufficiently high distortions in the tax system. The positive environmental externalities attributed to the substitution of biofuels for fossil fuels tend to push the optimal biofuel quantity a step further. We also developed a simple framework which took account of the possibility of imports: thanks to the saving of public funds permitted by biofuels, the optimal level of energy crops produced domestically is set at a level where the interior price exceeds the world price for energy crops. The conclusions drawn in the case of a biofuel programme financed through subsidies can also be made when biofuels are promoted thanks to a mandatory blending scheme. The optimal level of biofuels that ought to be produced is even higher in that case.

The second part of the article has been dedicated to the environmental consequences of biofuel programmes in the agricultural production process. It is generally acknowledged that the environmental externalities linked to use of biofuels in cars are positive, while the environmental externalities of agricultural production are negative. Our model suggests that the regulator ought to set an environmental standard that is more stringent than the Pigouvian level. This increases the price of the raw material, thereby enhancing the substitution effect between the programme of decoupled payments and the biofuel programme. Taking the environmental policy enforcement problem into account, the monitoring cost on the one hand and the incentive constraints on the other hand change the optimal energy crop quantity and the optimal environmental standard.

We have tried to keep our model as simple as possible. However, many refinements could be implemented. First, we have considered that the subsidies were fine-tuned. This assumption could be criticized, as there are informational asymmetries between the regulator and the biofuel firms. In the mandatory blending framework, such informational asymmetries

are not relevant but informational rents could well be replaced by monopolistic rents for biofuel producers. For instance, the major biodiesel firm in France covers more than 75% of the market. We have also assumed a perfectly competitive agro-food sector. Relaxing this assumption may well lead to very stringent conditions for a socially valuable subsidy substitution effect between the farm support and the biofuel programmes.

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Proof of proposition 1

From (EC), we have $\partial g/\partial x_E = -C_{XX}$ and $\partial g/\partial e = -C_{Xe}$. Rearranging terms of (3) yields:

$$\beta = \lambda x_F C_{XX}/(\partial g/\partial x_F) = -\lambda x_F(\partial g/\partial x_E)/(\partial g/\partial x_F) = \lambda x_F dx_F/dx_E$$

Plugging into (4) and (5) gives:

$$\frac{\partial \mathcal{L}}{\partial x_E} = \lambda x_F C_{XX} \frac{dX}{dx_E} - (1 + \lambda)[C_X - \gamma p_E] + q \leq 0 \quad (x_E^* \geq 0)$$

and

$$\frac{\partial \mathcal{L}}{\partial \bar{e}} = \lambda x_F \frac{dX}{dx_E} C_{Xe} - (1 + \lambda)C_e - D' = 0 \quad (20)$$

Rearranging terms gives (7).

Proof of proposition 2

Denoting by $S^* \equiv (x_E^*, x_F^*, \bar{e}^*)$ the optimal subsidy policy, we have, using (10), (11) and (6):

$$\begin{aligned} \left. \frac{\partial \mathcal{L}^{MB}}{\partial x_E} \right|_{S^*} &= [\lambda X C_{XX} dX/dx_E - (C_X - \gamma p_E) + q]_{S^*} \\ &= [\lambda x_E C_{XX} dX/dx_E + C_X - \gamma p_E]_{S^*} > 0 \end{aligned}$$

hence $x_E^{MB} > x_E^*$.

Similarly, using using (10), (12), (3) and (5):

$$\begin{aligned} \left. \frac{\partial \mathcal{L}^{MB}}{\partial \bar{e}} \right|_{S^*} &= [\lambda X C_{Xe} dX/dx_E - (1 + \lambda)C_e - D'(\bar{e})]_{S^*} \\ &= [\lambda X C_{Xe} dX/dx_E - \lambda x_F C_{Xe} dX/dx_E]_{S^*} \\ &= [\lambda x_E C_{Xe} dX/dx_E]_{S^*} < 0 \end{aligned}$$

hence $\bar{e}^{MB} < \bar{e}^*$.

Proof of proposition 3

Substituting $Q/\gamma - x_E$ for x_I in the government's programme leads to the following Lagrangian (neglecting the constants):

$$\mathcal{L} = CS + \Pi_F - (1 + \lambda)[(C_X - \bar{w})x_E - \Pi_A] - D(\bar{e}) - \beta g(x_F, x_E, \bar{e})$$

The first-order conditions are:

$$\frac{\partial \mathcal{L}}{\partial x_F} = \lambda x_F C_{XX} - \beta(\partial g / \partial x_F) = 0$$

$$\frac{\partial \mathcal{L}}{\partial x_E} = \lambda x_F C_{XX} - (1 + \lambda)[C_X - \bar{w}] - \beta(\partial g / \partial x_E) = 0$$

and

$$\frac{\partial \mathcal{L}}{\partial \bar{e}} = \lambda x_F C_{Xe} - (1 + \lambda)C_e - D'(\hat{e}) - \beta(\partial g / \partial e) = 0$$

and give:

$$\frac{\partial \mathcal{L}}{\partial x_E} = \lambda x_F C_{XX} \frac{dX}{dx_E} - (1 + \lambda)[C_X - \bar{w}] = 0$$

and

$$\frac{\partial \mathcal{L}}{\partial \bar{e}} = \lambda x_F C_{Xe} \frac{dX}{dx_E} - (1 + \lambda)C_e - D'(\hat{e}) = 0$$

deriving the following condition:

$$\lambda x_F C_{XX} \frac{dX}{dx_E} = (1 + \lambda)[C_X - \bar{w}] = \frac{C_{XX}}{C_{Xe}} \{(1 + \lambda)C_e + D'(\hat{e})\}$$

Proof of proposition 4

Neglecting constant $\bar{\Pi}_A$, the Lagrangian of the governments' programme may be written as:

$$\begin{aligned} \mathcal{L}^f = & CS + \Pi_F - (1 + \lambda)[(C_X - \gamma p_E)x_E - \Pi_A + k\mu] + B(x_E) - D(\bar{e}) - \beta g \\ & - \xi[C_e + kf'(0)\Psi] \end{aligned}$$

where β and ξ are the multipliers corresponding to (EC) and (IC). In the case of a fixed maximum penalty, we have:

$$\frac{\partial \mathcal{L}^f}{\partial x_F} = \lambda x_F C_{XX} - \beta(\partial g / \partial x_F) - \xi C_{eX} = 0 \quad (21)$$

$$\frac{\partial \mathcal{L}^f}{\partial x_E} = \lambda x_F C_{XX} - (1 + \lambda)[C_X - \gamma p_E] + q - \beta(\partial g / \partial x_E) - \xi C_{eX} \leq 0 \quad (x_E^f \geq 0) \quad (22)$$

$$\frac{\partial \mathcal{L}^f}{\partial \bar{e}} = \lambda x_F C_{Xe} - (1 + \lambda) C_e - D'(\bar{e}) - \beta (\partial g / \partial e) - \xi C_{ee} = 0. \quad (23)$$

$$\frac{\partial \mathcal{L}^f}{\partial k} = -(1 + \lambda) \mu - \xi f'(0) \bar{P} = 0. \quad (24)$$

Using (EC), (21) and (22) leads to:

$$\frac{\partial \mathcal{L}^f}{\partial x_E} = [\lambda x_F C_{XX} - \xi C_{eX}] \frac{dX}{dx_E} - (1 + \lambda) [C_X - \gamma p_E] + q \leq 0 \quad (x_E^f \geq 0)$$

while (24) and (IC) give:

$$\xi = -(1 + \lambda) \mu / [f'(0) \bar{P}] = (1 + \lambda) \mu k / C_e$$

Consequently, we have:

$$\frac{\partial \mathcal{L}^f}{\partial x_E} = \left[\lambda x_F C_{XX} - (1 + \lambda) \mu k \frac{C_{eX}}{C_e} \right] \frac{dX}{dx_E} - (1 + \lambda) [C_X - \gamma p_E] + q \leq 0 \quad (x_E^f \geq 0)$$

Similar computations give

$$\frac{\partial \mathcal{L}^f}{\partial \bar{e}} = \lambda x_F C_{Xe} - (1 + \lambda) C_e - D'(\bar{e}) - [\lambda x_F C_{XX} - \xi C_{eX}] \frac{\partial g / \partial e}{\partial g / \partial x_F} - \xi C_{ee}$$

Using $\partial g / \partial e = -C_{Xe}$ and $\partial g / \partial x_E = -C_{XX}$ we get:

$$\begin{aligned} \frac{\partial \mathcal{L}^f}{\partial \bar{e}} &= \lambda x_F C_{Xe} - (1 + \lambda) C_e - D'(\bar{e}) - [\lambda x_F C_{eX} - \xi \frac{C_{eX}^2}{C_{XX}}] \frac{\partial g / \partial x_E}{\partial g / \partial x_F} - \xi C_{ee} \\ &= \left[\lambda x_F C_{Xe} - \xi \frac{C_{eX}^2}{C_{XX}} \right] \frac{dX}{dx_E} - (1 + \lambda) C_e - D'(\bar{e}) + \xi \left[\frac{C_{eX}^2}{C_{XX}} - C_{ee} \right] \\ &= \frac{C_{Xe}}{C_{XX}} \left[\lambda x_F C_{XX} - (1 + \lambda) \mu k \frac{C_{Xe}}{C_e} \right] \frac{dX}{dx_E} - (1 + \lambda) C_e - D'(\bar{e}) \\ &\quad - (1 + \lambda) \frac{\mu k}{C_e} \left[C_{ee} - \frac{C_{eX}^2}{C_{XX}} \right] \end{aligned}$$

Denoting by $S^* \equiv (x_E^*, x_F^*, \bar{e}^*)$ the solution of programme (2), we have:

$$\left. \frac{\partial \mathcal{L}^f}{\partial x_E} \right|_{S^*} = -(1 + \lambda) \mu k \frac{C_{eX}(X^*, \bar{e}^*)}{C_e(X^*, \bar{e}^*)} \left. \frac{dX}{dx_E} \right|_{S^*} < 0$$

and

$$\begin{aligned} \left. \frac{\partial \mathcal{L}^f}{\partial \bar{e}} \right|_{S^*} &= -\frac{(1 + \lambda) \mu k}{C_e(X^*, \bar{e}^*)} \left[\frac{C_{Xe}^2}{C_{XX}} \frac{dX}{dx_E} + C_{ee} - \frac{C_{eX}^2}{C_{XX}} \right] \Bigg|_{S^*} \\ &= -\frac{(1 + \lambda) \mu k}{C_e(X^*, \bar{e}^*)} \left[\frac{C_{Xe}^2}{C_{XX}} \frac{dx_F}{dx_E} + C_{ee} \right] \Bigg|_{S^*} \end{aligned}$$

where:

$$\frac{C_{Xe}^2}{C_{XX}} \frac{dx_F}{dx_E} + C_{ee} > C_{ee} - \frac{C_{Xe}^2}{C_{XX}} > 0$$

and $C_e < 0$, implying:

$$\left. \frac{\partial \mathcal{L}^f}{\partial \bar{e}} \right|_{S^*} > 0$$

As \mathcal{L}^f is concave, we thus have $\bar{e}^* < \bar{e}^f$ and $x_E^* > x_E^f$.

In the case of a cross-compliance policy, we have $-\xi[C_e(X, \bar{e}) + kf'(0)(\bar{\Pi}_A - \Pi_A)]$ for the last term of the Lagrangian.

$$\frac{\partial \mathcal{L}^{cc}}{\partial x_F} = \lambda x_F C_{XX} - \beta(\partial g / \partial x_F) - \xi[C_{eX} - kf'(0)XC_{XX}] = 0 \quad (25)$$

$$\frac{\partial \mathcal{L}^{cc}}{\partial x_E} = \lambda x_F C_{XX} - (1 + \lambda)[C_X - \gamma p_E] + q - \beta(\partial g / \partial x_E) - \xi[C_{eX} - kf'(0)XC_{XX}] \leq 0 \quad (x_E^f \geq 0) \quad (26)$$

$$\frac{\partial \mathcal{L}^{cc}}{\partial \bar{e}} = \lambda x_F C_{Xe} - (1 + \lambda)C_e - D'(\bar{e}) - \beta(\partial g / \partial e) - \xi[C_{ee} - kf'(0)(XC_{eX} - C_e)] = 0. \quad (27)$$

$$\frac{\partial \mathcal{L}^{cc}}{\partial k} = -(1 + \lambda)\mu - \xi f'(0)(\bar{\Pi}_A - \Pi_A) = 0. \quad (28)$$

Condition (25) gives:

$$\beta = \frac{\lambda x_F C_{XX} - \xi[C_{eX} - kf'(0)XC_{XX}]}{\partial g / \partial x_F}$$

while (28) and (IC) give:

$$\xi = -(1 + \lambda)\mu / [f'(0)(\bar{\Pi}_A - \Pi_A)] = (1 + \lambda)\mu k / C_e(X, \bar{e})$$

Consequently, we have:

$$\frac{\partial \mathcal{L}^{cc}}{\partial x_E} = \left[\lambda x_F C_{XX} - (1 + \lambda)\mu k \frac{C_{eX} - kf'(0)XC_{XX}}{C_e} \right] \frac{dX}{dx_E} - (1 + \lambda)[C_X - \gamma p_E] + q \leq 0 \quad (x_E^f \geq 0)$$

Similar computations give:

$$\begin{aligned} \frac{\partial \mathcal{L}^{cc}}{\partial \bar{e}} = & \lambda x_F C_{Xe} - (1 + \lambda)C_e - D'(\bar{e}) - [\lambda x_F C_{XX} - \xi(C_{eX} - kf'(0)XC_{XX})] \frac{\partial g / \partial e}{\partial g / \partial x_F} \\ & - \xi[C_{ee} - kf'(0)(XC_{eX} - C_e)] \end{aligned}$$

Using $\partial g/\partial e = -C_{Xe}$ and $\partial g/\partial x_E = -C_{XX}$ we get:

$$\begin{aligned}
\frac{\partial \mathcal{L}^{cc}}{\partial \bar{e}} &= \lambda x_F C_{Xe} - (1 + \lambda)C_e - D'(\bar{e}) - C_{eX} \left[\lambda x_F - \xi \left(\frac{C_{eX}}{C_{XX}} - kf'(0)X \right) \right] \frac{\partial g/\partial x_E}{\partial g/\partial x_F} \\
&\quad - \xi [C_{ee} - kf'(0)(XC_{eX} - C_e)] \\
&= C_{Xe} \left[\lambda x_F - \xi \left(\frac{C_{eX}}{C_{XX}} - kf'(0)X \right) \right] \frac{dX}{dx_E} - (1 + \lambda)C_e - D'(\bar{e}) \\
&\quad + \xi \left[\frac{C_{eX}^2}{C_{XX}} - kf'(0)XC_{Xe} - C_{ee} + kf'(0)(XC_{eX} - C_e) \right] \\
&= \frac{C_{Xe}}{C_{XX}} \left[\lambda x_F C_{XX} - (1 + \lambda) \frac{\mu k}{C_e} (C_{eX} - kf'(0)XC_{XX}) \right] \frac{dX}{dx_E} \\
&\quad - (1 + \lambda)C_e - D'(\bar{e}) + (1 + \lambda) \frac{\mu k}{C_e} \left[\frac{C_{eX}^2}{C_{XX}} - C_{ee} - kf'(0)C_e \right]
\end{aligned}$$

which gives the result.

Denoting by $S^f \equiv (x_E^f, x_F^f, \bar{e}^f)$, we have

$$\left. \frac{\partial \mathcal{L}^{cc}}{\partial x_E} \right|_{S^f} = (1 + \lambda) \mu k^2 f'(0) X \frac{C_{XX}(X^f, \bar{e}^f)}{C_e(X^f, \bar{e}^f)} \left. \frac{dX}{dx_E} \right|_{S^f} < 0$$

hence $x_E^f > x_E^{cc}$. We also have:

$$\left. \frac{\partial \mathcal{L}^{cc}}{\partial \bar{e}} \right|_{S^f} = (1 + \lambda) \frac{\mu k^2 f'(0)}{C_e(X^f, \bar{e}^f)} \left[XC_{Xe} \frac{dX}{dx_E} - C_e \right] \Big|_{S^f}$$

which is ambiguous.