Biofuel Policies in the Presence of Environmental Externalities

Preliminary Version (Please do not quote)

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Abstract

The objective of this paper is to compare, in a general equilibrium setting with three goods, the relative efficiency of biofuel subsidy and biofuel mandate policies with the laissez-faire solution. The outcomes of these institutional arrangements are also compared to that of the optimal solution. This analysis takes into account several environmental externalities such as those associated with the production of biofuels. Our numerical results, applied to the biodiesel policy of France in 2006, show that both policies decrease the utility of the representative consumer compared to the laissez-faire solution. The biofuel subsidy policy also increases overall emissions.

Keywords: biofuels, subsidy, mandate, environment

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1 Introduction

The development of biofuels has been encouraged by the European Union through various directives.\(^1\) There is a need to stimulate the use of biofuels given their higher cost of production than that of petroleum products, such as oil or gasoline.\(^2\) The Directive 2003/96/CE of the European Commission authorizes Member States to implement tax credits to encourage the use of biofuels (Guindé et al. (2007), p.3). The support towards biofuels in the European Union is mainly justified by the objective of reducing greenhouse gas (denoted as GHG, hereafter) emissions due to fossil fuels in the transport sector (JRC (2008), p.8). Other objectives are to reduce the reliance on oil imports, to enhance farm incomes and to promote rural development (de Gorter and Just (2007b, p.4). This paper takes into account the market failure problem due to GHG emissions related to the development of first-generation biofuels. These emissions could arise from production externalities associated with the production of agricultural crop and the production of biofuel. We also take into account consumption externalities due to the consumption of petroleum fuel.

This study has a positive approach. The question we ask is to know whether a biofuel subsidy policy and a biofuel blending mandate are welfare-improving compared to the laissez-faire solution. These policy measures are the most widely used ones at the international level in the context of biofuel development (de Gorter and Just (2008), Kojima et al. (2007)).\(^3\) A biofuel tax credit is equivalent, in some ways, to subsidize one alternative to petroleum. We model this policy as a unit subsidy to the biofuel producer as does Gardner (2007). The expected effects of a biofuel subsidy policy are an increase in the consumption of the biofuel, thanks to the price cut of the biofuel, against the consumptions of the agricultural good and the gasoline.

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\(^1\) The Directive 2003/30/CE of the European Commission indicates an objective of 2 % of biofuels in fuels used for transport sector in 2005, and 5.75 % in 2010, whereas current estimates forecast a 4 % of biofuels in 2010. A Proposition of Directive on Renewable Energies of 23th January 2008 (2008/0016 (COD)) considers a mandatory incorporation rate of 10 % of biofuels in transport fuel by 2020 for each Member State.

\(^2\) Ryan et al. (2006) report a cost differential of 559 euros (in 2004 prices) between oil seeds-based biodiesel and fossil fuel before excise tax duties and VAT.

\(^3\) We exclude from this analysis the study of agricultural policies in relation with the production of biofuels, such as price support and acreage control, or trade policies, such as export subsidy, import tariff or export quota. A survey of the policy issues when biofuels are at stake can be found in Rajagopal and Zilberman (2007).
To these substitution effects, a negative revenue effect due to the finance of the subsidy will be added. In the case of a blending mandate, this revenue effect is absent, but now there is a constraint in the utility function on the consumptions of the biofuel and the gasoline. This last effect is a priori welfare reducing, and could decrease in turn the consumption of the agricultural product. Then it is important to analyze the negative impacts, on the utility and the level of overall emissions, of the revenue effect in the subsidy policy and of the consumption constraint in the blending policy.

In order to evaluate the relative efficiency of biofuel policies, we use a general equilibrium setting with three goods: the agricultural product, the biofuel and the gasoline. To effectuate this analysis, we take into account various sources of environmental externalities and the related environmental damages. Hence this framework is also helpful for comparing the extent of environmental externalities related to these institutional arrangements. These comparisons are made on numerical simulations with some real data concerning the biodiesel policy of France in 2006.

We assume that markets are competitive. We exclude the possibility of international trade in biofuels. Even though the European tariffs on the import of biodiesel have been small, the volume of imports has been negligible because of non-tariff barriers, such as technical standards to trade in palm oil (Guindé et al. (2007), p.6). We also assume that the oil price is exogenous and it is determined at the international level. These two assumptions are in line with some papers of the recent literature, such as the one of de Gorter and Just (2007b). This literature has mainly focused on the evaluation of ethanol policies in the United States (see among others Gardner (2007), de Gorter and Just (2007), Schmitz et al. (2007), Martinez-Gonzales et al. (2007), Taheriour and Tyner (2007), Babcock (2008), Du et al. (2008), Elobeid and Tokgoz (2008)). Gorter and Just (2007b) evaluate the effects of a biofuel mandate and excise-tax exemption, in a isolate way and also simultaneously when both policies are in place. The analytical results are applied to the case of US ethanol.\textsuperscript{4} Gardner (2007) studies the income effects of an ethanol subsidy and farm price support. Du et al. (2008) consider the same approach as Gardner (2007), but they also take into account the existing distortions due to farm payments in agricultural commodity markets before ethanol subsidies

\textsuperscript{4}de Gorter and Just (2008) analyze, in a similar way, the efficiency of a biofuel tax credit and the interaction effects with a price contingent farm subsidy. In a different paper, de Gorter and Just (2007) analyze the impact of an ethanol import tariff in conjunction with a consumption mandate and a tax credit.
are implemented. Nevertheless, none of these partial equilibrium models take into account environmental externalities associated with the development of biofuels.

The paper is organized as follows: Section 2 presents the model and describes different equilibria associated with different institutional arrangements. The numerical results of the biodiesel policy of France in 2006 are presented in Section 3. Finally, Section 4 offers some concluding remarks.

2 Model

We use a general equilibrium model under perfect competition. There are five agents in the economy: a representative consumer, a farmer, a biofuel producer, a gasoline vendor, and the State. We assume that the biofuel producer and the biofuel vendor are the same entity.

There are three goods in the economy. The agricultural product, indexed by 1 with price \( p_1 \), is necessary for food uses and also as a raw material for biofuel production. In this sense, there is a conflict of use of the agricultural product between the two needs. We do not posit the existence of land competition between the agricultural production for food and the production of agricultural raw material for biofuel. Biofuel is indexed by 2, with price \( p_2 \). Last, the gasoline is indexed by 3, with price \( p_3 \). The demand of the market will be indexed by \( q \) and the supply by \( x \) for each product.

We only account for GHG emissions, such as CO\(_2\) and N\(_2\)O emissions, caused by different production and consumption decisions. We take into account linear emission functions for simplicity. The emission function related to the agricultural production can be written as, \( e_1 = \beta_1 x_1 \), where \( \beta_1 \) is a positive constant. For example, N\(_2\)O emissions are discharged when fertilizers are applied to increase agricultural activity. The GHG emission function associated with the biofuel production can be written as, \( e_2 = \beta_2 x_2 \), where \( \beta_2 \) is a positive constant. This pollution could come from CO\(_2\) emissions emitted during the transformation process of the agricultural raw material to biofuel. The GHG emission function related to the consumption of biofuel can be written as, \( e_4 = \beta_4 q_2 \). The value of parameter \( \beta_4 \) could be considered as null, since CO\(_2\) biofuels release are absorbed from the atmosphere during their growth. Finally, the carbon emission function associated with the gasoline\(\backslash\)oil consumption is represented by \( e_3 = \beta_3 q_3 \), where \( \beta_3 \) is a positive parameter. We discuss the magnitude of these parameters in Section 3.
Let first start by studying the decentralized equilibrium of the economy.

2.1 Decentralized Equilibrium

2.1.1 Program of the representative consumer

There is one price-taking consumer who supplies \( (L) \) units of labor inelastically. It owns all the profits of the economy. There are two productive sectors for which it can offer its labor: the agricultural sector \((L_1)\) and the sector of biofuel production \((L_2)\). The wage \( w \) is assumed to be the same in both sectors, and it is normalized to 1. The revenue of the consumer \( R \) is given exogenously by \( R = w(L_1 + L_2) + \tau K = L + \tau K \). It is made of wage earnings and of the earnings on the rental of the land used for agricultural production.

The program of the consumer is to maximize its utility with respect to the consumption of the three goods \( q_1, q_2, q_3 \), subject to its budget constraint:

\[
\begin{align*}
\text{Max}_{q_1, q_2, q_3} \left[ U = & \, A - a_1(q_1 - \bar{q}_1)^2 - a_2(q_2 - \bar{q}_2)^2 - a_3(q_3 - \bar{q}_3)^2 \\
& - D(e_1 + e_2 + e_3) \right] \\
\text{s.t.} \quad & L + \tau K = p_1q_1 + p_2q_2 + p_3q_3 \\
& q_1 < \bar{q}_1, q_2 < \bar{q}_2, q_3 < \bar{q}_3
\end{align*}
\]

where \( A, \ a_1, \ a_2, \ a_3, \ \bar{q}_1, \ \bar{q}_2, \ \bar{q}_3 \) are positive constants with \( q_1 < \bar{q}_1, q_2 < \bar{q}_2 \) and \( q_3 < \bar{q}_3 \). The parameter \( D \) explains the degree of damage from GHG emissions \( e_1, e_2 \) and \( e_3 \). The damage functions are chosen as linear functions in emissions. It is recognized in the literature that the damage due to CO₂ emissions can be represented by such functions. This utility function is assumed to be concave and additively separable. It implies that the agricultural good, the biofuel and the gasoline are imperfect substitutes. For example, ethanol is a substitute to gasoline through E85 cars, which run on gasoline blended with up to 85 % ethanol. The gasoline and the ethanol could be considered as imperfect substitutes because, one the one hand, ethanol contains less energy per gallon than does conventional gasoline (less “low heating value”). On the other hand, currently, ethanol is blended mostly at 10 % and is not available everywhere (Elobeid and Tokgoz (2008)).

At the decentralized equilibrium, the consumer takes the overall damage
from emissions as given. We call the gross utility function the one without
these environmental damages and the net utility function the one taking
them into account.

The first-order conditions of this program define the consumer demand
at the decentralized equilibrium described in Lemma 1.

**Lemma 1** The demand of the representative consumer for the
agricultural product, the biofuel and the petroleum product at the decentralized
equilibrium are given respectively by:

\[
q^d_1 = \frac{(L + \tau K)p_1 a_2 a_3 - p_1 a_2 a_3 p_3 q_1 - p_1 a_2 a_3 p_2 q_2 + \bar{q}_1 p_2^2 a_1 a_3 + \bar{q}_1 p_3^2 a_1 a_2}{p_1^2 a_2 a_3 + p_2^2 a_1 a_3 + p_3^2 a_1 a_2} \tag{3}
\]

\[
q^d_2 = \frac{(L + \tau K)p_2 a_2 a_3 - p_1 a_1 a_3 p_2 q_1 - p_3 a_1 a_3 p_2 q_2 + \bar{q}_2 p_2^2 a_2 a_3 + \bar{q}_2 p_3^2 a_1 a_2}{p_1^2 a_2 a_3 + p_2^2 a_1 a_3 + p_3^2 a_1 a_2} \tag{4}
\]

\[
q^d_3 = \frac{(L + \tau K)p_3 a_2 a_1 - p_3 a_2 a_1 p_1 q_1 - p_3 a_2 a_1 p_2 q_2 + \bar{q}_3 p_2^2 a_2 a_3 + \bar{q}_3 p_3^2 a_1 a_3}{p_1^2 a_2 a_3 + p_2^2 a_1 a_3 + p_3^2 a_1 a_2} \tag{5}
\]

As expected, the consumer demand depends on all the prices of the econ-
omy, and also positively depends on the aggregate revenue \((L + \tau K)\).

**2.1.2 Program of the farmer**

The farmer has at its disposal a constant returns to scale technology to
produce the agricultural product.\(^5\) This product is used both for food con-
sumption and as a raw material for biofuel production. In the case of ethanol
production, this agricultural product could be sugar beet, corn or wheat, and
rapeseed or sunflower in the case of biodiesel production.

The production function of the farmer is given by:

\[
x_1 = \min(\alpha L_1, \mu K) \tag{4}
\]

where \(\alpha\) and \(\mu\) are positive constants, and they represent the labor pro-
ductivity and the productivity of land respectively. \(L_1\) is the labor force in
the agricultural sector, and \(K\) is the land devoted to agricultural production.

\(^5\)This assumption is also included in the green accounting model of Brannlund et al.
(2008). However, Rubin et al. (2008) assume a decreasing returns to scale technology in
their model in which the costs and benefits of biofuels in US are quantified.
The labor is mobile across the productive sectors. We assume that the labor force in the agricultural sector and the land are complementary factors for agricultural production. This leads to:

\[ x_1 = \alpha L_1 = \mu K \]  

(5)

The production activity is a source of revenue for the farmer, \( L_1 \) (the wage is numeraire, \( w = 1 \)), but it is also a source of negative externality, in terms of agricultural emissions, \( e_1 \).

The profit of the farmer is written in the following way:

\[ \pi_1 = p_1 x_1 - L_1 - \tau K \]  

(6)

where \( \tau \) is a positive constant which represents the annual rental rate of the land by the farmer.

The zero profit condition, \( \pi_1 = 0 \), implies:

\[ p_1 x_1 = L_1 + \tau K \]

\[ \iff p_1 x_1 = \frac{x_1}{\alpha} + \frac{\tau x_1}{\mu} \iff p_1 x_1 = x_1 \left( \frac{1}{\alpha} + \frac{\tau}{\mu} \right) \]

(7)

Then, we obtain the endogenous level of the agricultural good’s price at the decentralized equilibrium:

\[ p_1^d = \frac{\mu + \alpha \tau}{\alpha \mu} \]  

(8)

It appears that the market price of the agricultural good decreases with parameters \( \alpha \) and \( \mu \). When the parameters of the agricultural productivity increase, the supply of the farmer also increases. This, in turn, decreases the market price of the agricultural good. The same price increases with an increase in parameter \( \tau \), because in this case the supply is reduced due to a higher rental cost of the land.
### 2.1.3 Program of the biofuel producer

As the farmer, the biofuel producer operates with a constant returns to scale technology. The factors of production are comprised of the productive labor in the sector of biofuel production, $L_2$, and the agricultural raw material, $\tilde{q}_1$. These factors of production are assumed to be complementary for the production process.

The production function of the biofuel producer is then given by:

$$x_2 = \min(\varepsilon L_2, \delta \tilde{q}_1)$$

(9)

where $\varepsilon$ and $\delta$ are positive constants, and they represent the labor productivity in this sector and the productivity of the agricultural input respectively. The complementarity of the factors of production leads to:

$$x_2 = \varepsilon L_2 = \delta \tilde{q}_1$$

(10)

This production activity provides a revenue for the producer, $L_2$, but induces an environmental cost, in terms of emissions, $e_2$.

The profit of the biofuel producer is written in the following way:

$$\pi_2 = p_2 x_2 - L_2 - p_1 \tilde{q}_1$$

(11)

The zero profit condition, $\pi_2 = 0$, implies:

$$p_2^d = \frac{1}{\varepsilon} + \frac{p_1^d}{\delta}$$

(12)

On the one hand, it appears that the market price of the biofuel increases with that of the agricultural good. When the latter increases, the cost of the biofuel producer also does, which in turn induces the biofuel producer to decrease its production. On the other hand, the market price of the biofuel decreases with parameters $\varepsilon$ and $\delta$. When the labor productivity, the productivity of the agricultural input in the biofuel sector increase, the supply of the biofuel producer also does. This, in turn, decreases the market price of the biofuel.

When we introduce the expression of $p_1$ of Equation 8 into Equation 12, we obtain the endogenous level of the biofuel’s price at the decentralized
equilibrium:

\[ p_2^d = \frac{\alpha \delta \mu + \varepsilon (\mu + \alpha \tau)}{\varepsilon \alpha \delta \mu} \]  

(13)

2.1.4 Program of the gasoline \( \text{oil vendor} \)

We assume that the price of petroleum products is exogenous, since the price of oil is determined at the international level by the production decisions of OPEC countries. This is a plausible assumption because EU biofuel production in 2005 is only 1.2 % of the total fuel, the majority (78 %) of this being biodiesel (EEA (2008), p.20). The zero profit condition, \( \pi_3(p_3, x_3) = p_3x_3 - p_3q_3 = 0 \), also applies for the gasoline \( \text{oil distributor} \). The given price of the oil implies that the supply of the distributor is perfectly elastic at this price. Therefore, the demand of the market determines the supply of the distributor.

2.1.5 Equilibrium levels of outcomes and emissions

The theorem of non-substitution says that the price of products is determined by the price of the factors of production, if technologies are constant returns to scale. Then, here, we can claim that the price of the agricultural product and the price of the biofuel are determined respectively by the prices of labor \( (w = 1) \) and land \( (\tau) \), and the prices of labor, the land and the agricultural raw material \( (p_1) \). Equations 8 and 13 give the expressions of prices \( p_1 \) and \( p_2 \). The same theorem also implies that the quantities are given by the demand of the economy (demand determines the supply).

**Lemma 2** The supply of the agricultural product, the biofuel and the petroleum product at the decentralized equilibrium are given respectively by:

\[
\begin{align*}
x_1^d &= q_1^d + \tilde{q}_1^d = q_1^d + \frac{x_2^d}{\delta} = q_1^d + \frac{q_2^d}{\delta} \\
x_2^d &= q_2^d \\
x_3^d &= q_3^d
\end{align*}
\]

(14)

with \( p_1^d = \frac{\mu + \alpha \tau}{\alpha \mu} \) and \( p_2^d = \frac{\alpha \delta \mu + \varepsilon (\mu + \alpha \tau)}{\varepsilon \alpha \delta \mu} \).
These equilibrium quantities imply the following equilibrium levels of emissions.

**Lemma 3**  
The equilibrium levels of emissions at the decentralized equilibrium are:

\[
e^d_1 = \beta_1 x^d_1 = \beta_1 (q^d_1 + \frac{q^d_2}{\delta})
\]

\[
e^d_2 = \beta_2 x^d_2 = \beta_2 q^d_2
\]

\[
e^d_3 = \beta_3 q^d_3
\]

with \( p^d_1 = \frac{\mu + \alpha \tau}{a \mu} \) and \( p^d_2 = \frac{\alpha \delta + \varepsilon (\mu + \alpha \tau)}{a \delta \mu} \).

We now turn to study the outcome of a subsidy policy to the biofuel producer.

### 2.2 Subsidy to Biofuel Producers

As does Gardner (2007), we model the tax exemption policy as a subsidy to the biofuel producer who produces an alternative to petroleum. More specifically, this subsidy is modeled as a unit subsidy proportional to the quantity of biofuels produced. For example, the US federal subsidy is currently 51 cents per gallon of ethanol (Tyner (2007), p.1).

With a unit subsidy \( s > 0 \), the program of the representative consumer is similar to that at the decentralized equilibrium with the exception that the budget constraint now includes the finance of the subsidy. This payment takes the form of a lump-sum transfer \( T \). The new budget constraint is written in the following way: \( L + \tau K = p_1 q_1 + p_2 q_2 + p_3 q_3 + T \). What is changing in the demand of the consumer at the equilibrium, it is the term \( (L+\tau K-T) \) instead of \( (L + \tau K) \). The term \( T \) represents a lost on the earnings associated with the productive labor. The government sets the amount of this transfer such that it exactly compensates the value of the subsidy offered to the biofuel producer: \( T = sx_2 \). However, the consumer when it decides how much to consume, it does not take this into account, because it does not possess the information.

With a unit subsidy \( s > 0 \), the profit of the biofuel producer writes:

\[
\pi_2 = p_2 x_2 - L_2 - p_1 \tilde{q}_1 + sx_2
\]
The zero profit condition, \( \pi_2 = 0 \), implies:

\[
p^*_2 = p^d_2 - s \iff p^*_2 = \frac{1}{\varepsilon} + \frac{p^*_1}{\delta} - s
\] (17)

As expected, the price of the biofuel producer, \( p_2 \), falls with the subsidy rate, because the subsidy reduces its cost of production.\(^7\)

When we introduce the expression of \( p^d_1 \) of Equation 8 into Equation 17, we obtain,

\[
p^*_2 = \frac{\alpha \delta (\mu - \mu \varepsilon s) + \varepsilon (\mu + \alpha \tau)}{\varepsilon \alpha \delta \mu}
\] (18)

The positivity of \( p^*_2 \) requires that \([\alpha \delta (\mu - \mu \varepsilon s) + \varepsilon (\mu + \alpha \tau)] > 0\).

The equilibrium levels of the quantities under the subsidy policy are defined in a similar way to those at the decentralized equilibrium. The demand is directly affected with the subsidy via its finance, but also indirectly via the change in the price of the biofuel. The supply of the biofuel, the agricultural product and the gasoline are given respectively by: \( x^s_2 = q^s_2 \); \( q^*_1 = \frac{x^*_2}{s} = \frac{q^*_2}{s} \); \( x^s_1 = q^s_1 + \tilde{q}^s_1 \); \( x^s_3 = q^s_3 \), with \( p^*_1 = p^d_1 = \frac{\mu + \alpha \tau}{\alpha \mu} \) and \( p^*_2 = \frac{\alpha \delta (\mu - \mu s_s) + (\mu + \alpha \tau)}{\varepsilon \alpha \delta \mu} \). These equilibrium quantities imply the following levels of the emissions with the policy:

\( e^*_1 = \beta_1 x^s_1 \), \( e^*_2 = \beta_2 x^s_2 \), \( e^*_3 = \beta_3 q^s_3 \).

In the following, we represent a result of comparative statics on the value of the net utility, including \( ex \ post \) environmental damage, with respect to the subsidy rate:

\[
\frac{\partial U^{\text{exp\, post}}}{\partial s} = \frac{\partial q_1}{\partial s}[-2a_1(q_1 - \tilde{q}_1) - D \beta_1] + \frac{\partial q_2}{\partial s}[-2a_2(q_2 - \tilde{q}_2) - D(\frac{\beta_1}{\delta} + \beta_2)]
+ \frac{\partial q_3}{\partial s}[-2a_3(q_3 - \tilde{q}_3) - D \beta_3]
\]

**Proposition 1**

Given that \( \tilde{q}_1 = \tilde{q}_2 = \tilde{q}_2 = 1 \), \( \frac{\partial U^{\text{exp\, post}}}{\partial s} < 0 \) if the following assumptions are satisfied:

\[
\text{A1)} \quad \frac{p_1}{p_2} > \frac{2a_1}{a_2}
\]

\(^7\)Note that the price of the farmer \( p^d_1 \) is unchanged.
Proof

In fact, $\frac{\partial q_1}{\partial s} < 0$ if Assumption A1 is satisfied; $\frac{\partial q_2}{\partial s} > 0$ if Assumption A3 is satisfied; $\frac{\partial q_3}{\partial s} < 0$ if Assumption A5 is satisfied.

Assumption A1 says that the consumption of the agricultural product decreases with the subsidy rate if its relative price is sufficiently high compared to the relative desutility coming from its consumption. Assumption A2 implies that the marginal utility of the food consumption exceeds the marginal damage due to the production of the agricultural product. Other assumptions could be read in the same way.

Proposition 1 explains that the (ex post) net utility of the consumer will decrease with the subsidy rate on the biofuel, if the relative prices of the other goods in the economy (the agricultural product and the gasoline) and the disposable income of the consumer with the subsidy policy (after the transfer is made for financing the subsidy) are sufficiently high.

In the next section, we study the outcome of a biofuel mandate.

### 2.3 Blending Mandate

A biofuel blending mandate imposes a certain percentage of consumption of biofuel in transport fuel to consumers. This policy would imply the following constraint in our framework:

\[ q = q_2 + q_3 \quad \text{(19)} \]

where \( q_2 = \theta q \) and \( q_3 = (1 - \theta)q \) with \( 0 \leq \theta \leq 1 \)

\[ \iff q_2 = \frac{\theta}{(1 - \theta)} q_3 \quad \text{(20)} \]

Here, parameter \( \theta \) represents the blending percentage of biofuel to be incorporated in fossil fuels.
When we introduce this constraint into the program of the consumer, we obtain:

$$\max_{q_1, q_2} \left\{ U = A - a_1(q_1 - \bar{q}_1)^2 - a_2(q_2 - \bar{q}_2)^2 - a_3(q_3 - \bar{q}_3)^2 - D(e_1 + e_2 + e_3) \right\}$$

s.t. \[ q_2 = \frac{\theta}{1 - \theta} q_3; \quad q_1 = \frac{L + \tau K - q_3(p_2 \frac{\theta}{1 - \theta} + p_3)}{p_1} \]

\[ q_1 < \bar{q}_1, \quad q_2 < \bar{q}_2, \quad q_3 < \bar{q}_3 \]

At the equilibrium, the consumer takes the overall damage from emissions as given.

Since the expressions of the quantities demanded by the consumer are complicated, we prefer not to report them here. The levels of prices are the same than those at the decentralized equilibrium, because the blending constraint does not directly affect the supply of the producers, but only indirectly through the change in quantities demanded. This policy instrument has different effects than the biofuel subsidy policy in our framework. First of all, this policy does not cost to public finance. Secondly, it does not affect the producer prices of the agricultural product and the biofuel. Finally, it introduces a constraint in the maximization program of the consumer, which is normally utility-reducing. However, the overall level of the utility will depend on the consumed quantities of different products, but also on the level of environmental damage which are different across the two policy regimes. To compare the effects on utility of these two policy measures on biofuels, we run numerical simulations in Section 3. Before, we present the program of the regulator.

### 2.4 Optimal Solution

The regulator now internalizes the damage associated with emissions. The program turns out to maximize the surplus of the consumer (recall that the profits are null) with respect to \( q_1, q_2 \) and \( q_3 \) subject to the budget constraint:
\[ \max_{q_1, q_2, q_3} \left\{ W = A - a_1(q_1 - \bar{q}_1)^2 - a_2(q_2 - \bar{q}_2)^2 - a_3(q_3 - \bar{q}_3)^2 \right\} \]

\[ -D[\beta_1(q_1 + \frac{\varphi}{\epsilon}) + \beta_2 q_2 + \beta_3 q_3] \]

s.t. \[ L + \tau K = p_1 q_1 + p_2 q_2 + p_3 q_3 \]
\[ q_1 < \bar{q}_1, q_2 < \bar{q}_2, q_3 < \bar{q}_3 \]

The solution of this program gives us the optimal levels of the agricultural product, the biofuel and the gasoline respectively, \( q^*_1, q^*_2 \) and \( q^*_3 \). These quantities imply the optimal levels of emissions: \( e^*_1 = \beta_1(q^*_1 + \frac{\varphi}{\epsilon}) \); \( e^*_2 = \beta_2 q^*_2 \), \( e^*_3 = \beta_3 q^*_3 \), with \( p_1^d = \frac{\mu + \alpha \tau}{\alpha \mu} \) and \( p_2^d = \frac{\alpha \delta + \epsilon (\mu + \alpha \tau)}{\epsilon \alpha \delta \mu} \).

Since the expressions of the optimal quantities are complicated, we do not report them here. The levels of prices are the same than those at the decentralized equilibrium, because the intervention of the regulator does not directly affect the supply of the producers, but only indirectly through the change in quantities demanded. The quantities demanded change because now the regulator internalizes the damage associated with emissions. To evaluate the level of the welfare at the optimum, and to compare the outcomes of second-best biofuel policies to this benchmark solution, we run numerical simulations on some real data of France.

### 3 A Numerical Application

#### 3.1 Calibration

France set more ambitious targets in terms of biofuel consumption than the European Union: 7\% of biofuel to be incorporated in fuels in 2010 and 10\% in 2015. In 2006, the consumption of biodiesel was 630,000 t, which was greater than that of corn based ethanol 230,000 t. Therefore, we first focus on the biodiesel policy of France. Biofuel production units benefit from partial tax credits on the “internal tax on consumption” (TIC). This tax applies to consumed volumes of fuel, and it is equal to 42,84 euros/hl for gasoline. In 2006, the level of the tax credit for biodiesel (EMHV) was 25 euros/hl (Guindé et al. (2007)). So the TIC which applies to the biodiesel is equal to 17,84 euros/hl. Then, the market prices of gasoline and biodiesel integrate this tax in the calibration of the model.
Concerning the biodiesel subsidy policy, let the unit subsidy, \( s \), be given by the amount of the tax exemption for biodiesel, i.e. \( s = 25 \) euros/hl. To compare the outcomes of the biodiesel subsidy policy with the blending mandate, we impose a blending ratio of biodiesel in gasoline (in the policy of blending mandate) the one which results from the program of the biodiesel subsidy policy. Then, our objective is to evaluate the relative efficiency of the two regimes to attain the same blending ratio \( q_2^* / q_3^* = 0.07 \) in simulations, so \( \theta = 0.07 \).

We consider the following values of the parameters which respect the concavity of the utility function of the consumer. It is important to note that the values of the parameters in the first table are not calibrated specifically for the French economy.

<table>
<thead>
<tr>
<th>( q_1 = q_2 = q_3 )</th>
<th>( A = L )</th>
<th>( a_1 )</th>
<th>( a_2 )</th>
<th>( a_3 )</th>
<th>( D )</th>
<th>( \alpha(t/h) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>100000</td>
<td>0.8</td>
<td>0.4</td>
<td>0.4</td>
<td>100</td>
<td>0.001</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \tau(\epsilon/ha/h) )</th>
<th>( \delta(hl/t) )</th>
<th>( \epsilon(hl/h) )</th>
<th>( \mu(t/ha) )</th>
<th>( \tau K )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.007</td>
<td>2</td>
<td>1000</td>
<td>3</td>
<td>0.518</td>
</tr>
</tbody>
</table>

Sources: \( \tau, \tau K \) (RICA, 2006); \( \mu, \delta, \epsilon \) (Sourie et al., 2005)

To calibrate the values of the emission parameters, we proceed in the following way. GHG emissions arising from the agricultural production and the biofuel production, as well as from the gasoline consumption are all encountered in the calibrated values of the parameters \( \beta_1, \beta_2 \) and \( \beta_3 \). Biofuels produce lower GHG emissions than petroleum products, when we do not take into account the indirect emissions due to the land use change that could be provoked by the biofuel production (Searchinger et al. (2008)). The JEC (2007) study carried out under the supervision of JRC indicates that “most EU commercial processes save between 18 and 50 % GHG” (JRC (2008), p.8). Then, one can claim that the value of the parameter \( \beta_3 \) is higher than the sum of \( (\beta_1 + \beta_2) \). We use the following set of values of these parameters: \( \beta_1 = 0.7, \beta_2 = 0.1, \beta_3 = 0.9 \). This set implies the pessimistic estimation of GHG savings of biofuels compared to petroleum products. These values imply the ratio \( \frac{\beta_1 + \beta_2 + \beta_3}{\beta_3} = 50\% \).

\(^8\)We take into account the parameter \( \beta_1 \), and not \( \beta_1 \), because we only account for agricultural emissions associated with the demand of agricultural raw material \( q_1 \). We exclude those emissions related to the food demand \( q_1 \).
These values of the parameters imply the related levels of the market prices of the agricultural raw material and the biofuel. Since the numeraire in this model is the wage, \( w = 1 \), we must express all the prices in terms of the wage. Then, we divide all the prices with the gross minimum wage per hour in France for the year 2006, which is equal to 8.27 euros. We obtain: \( p_d^1 = 120 \), \( p_d^2 = 62 \), \( p_s^2 = 59 \). We set the price of gasoline as \( p_3 = 60 \) such that the price of the biofuel with no subsidy exceeds the gasoline price, a scheme which is in line with the trend in 2006.

### 3.2 Results

In the following, we summarize respectively the outcomes of the optimal solution, the laissez-faire solution, the biofuel subsidy policy and the biofuel mandate. Let denote by \( E_T \) the total level of emissions, and by \( r = \frac{e_1 + e_2}{e_3} \) the ratio of GHG emissions savings thanks to the use of biofuels against the gasoline.

<table>
<thead>
<tr>
<th>Optimal solution</th>
<th>( W^* )</th>
<th>( q_d^1 )</th>
<th>( q_d^2 )</th>
<th>( q_s^2 )</th>
<th>( q_d^2/q_d^3 )</th>
<th>( e^*_1 )</th>
<th>( e^*_2 )</th>
<th>( e^*_3 )</th>
<th>( E^*_T )</th>
<th>( r^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-0.1109984208 \times 10^7)</td>
<td>39</td>
<td>27</td>
<td>777</td>
<td>0.03</td>
<td>37</td>
<td>2</td>
<td>699</td>
<td>738</td>
<td>0.016</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decentralized solution</th>
<th>( U^d )</th>
<th>( W^d )</th>
<th>( q_d^1 )</th>
<th>( q_d^2 )</th>
<th>( q_s^2 )</th>
<th>( q_d^2/q_d^3 )</th>
<th>( e^d_1 )</th>
<th>( e^d_2 )</th>
<th>( e^d_3 )</th>
<th>( E^d_T )</th>
<th>( r^d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(-0.1031421921 \times 10^7)</td>
<td>(-0.1114561566 \times 10^7)</td>
<td>31</td>
<td>31</td>
<td>883</td>
<td>0.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Decentralized solution</th>
<th>( e^d_1 )</th>
<th>( e^d_2 )</th>
<th>( e^d_3 )</th>
<th>( E^d_T )</th>
<th>( r^d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>3</td>
<td>795</td>
<td>830</td>
<td>0.017</td>
<td></td>
</tr>
</tbody>
</table>

| Biofuel subsidy policy | \( U^s \) | \( W^s \) | \( q_d^1 \) | \( q_d^2 \) | \( q_d^2/q_d^3 \) | \( e^s_1 \) | \( e^s_2 \) | \( e^s_3 \) | \( E^s_T \) | \( r^s \) |
|------------------------|-----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| \(-0.1032070321 \times 10^7\) | \(-0.1115370864 \times 10^7\) | 14 | 64 | 881 | 0.07 |

<table>
<thead>
<tr>
<th>Biofuel subsidy policy</th>
<th>( T - sq_2 )</th>
<th>( e^s_1 )</th>
<th>( e^s_2 )</th>
<th>( e^s_3 )</th>
<th>( E^s_T )</th>
<th>( r^s )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.017</td>
<td>32</td>
<td>6</td>
<td>793</td>
<td>831</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

| Blending mandate | \( U^b \) | \( W^b \) | \( q_d^1 \) | \( q_d^2 \) | \( q_d^2/q_d^3 \) | \( e^b_1 \) | \( e^b_2 \) | \( e^b_3 \) | \( E^b_T \) | \( r^b \) |
|------------------|-----------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| \(-0.1032151059 \times 10^7\) | \(-0.1115128618 \times 10^7\) | 14 | 66 | 877 | 0.07 |

<table>
<thead>
<tr>
<th>Blending mandate</th>
<th>( e^b_1 )</th>
<th>( e^b_2 )</th>
<th>( e^b_3 )</th>
<th>( E^b_T )</th>
<th>( r^b )</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>6</td>
<td>790</td>
<td>829</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
</table>

We first make some observations about the equilibrium quantities for all institutional arrangements. Our numerical findings first indicate that the
gasoline is the most consumed good thanks to its low price and its low relative desutility in the utility function. We also notice that the consumption of the agricultural good in second-best cases (the laissez-faire solution and the two biofuel policies) is not enough compared to the optimal level, but that of the biofuel and the gasoline is too much high compared to the optimal level. Finally, the ratio of biofuel consumption on gasoline consumption at the decentralized equilibrium $q_2^d/q_3^d$ appears to be optimal and is equal to 0.03. For the biofuel subsidy policy and the biofuel mandate, this ratio (0.07) exceeds the optimal one. Generally, the outcome of the laissez-faire solution is less far away from the optimal solution than the outcomes of the biofuel policies under consideration.

Let us first assess the effects on the economic and environmental efficiency of a biofuel subsidy policy over the laissez-faire solution. We note that this policy decreases the gross utility ($U^s < U^d$) of the representative consumer. In fact, this policy implies a reduction in the market price of the biofuel ($p^s_2 < p^d_2$), as well as an increase in the consumption of the biofuel $q^s_2 > q^d_2$. However, the increase in the biofuel consumption does not compensate the decrease in the consumptions of the agricultural product and the gasoline. Secondly, the level of the utility with environmental impacts also decreases with the biofuel subsidy policy ($W^s < W^d$). Even though the GHG emissions caused by conventional gasoline are reduced thanks to a lower fossil fuel consumption ($q^d_3 > q^s_3$), the level of emissions provoked by the biofuel production is increased. The emissions caused by agriculture do not move with the policy shift, because the reduction in emissions related to the food demand ($\beta_1 q_1$) exactly compensates, in this example, the increase in emissions associated with the agricultural raw material demand ($\beta_1 q^s_2 q^s_2$). In sum, the level of total emissions increases and the GHG emissions savings thanks to the use of biofuels decreases.

Let us now assess the effects on the economic and environmental efficiency of a biofuel mandate over the laissez-faire solution. We obtain similar effects than those in the biofuel subsidy policy. We note this policy decreases the gross utility of the representative consumer. Again, the increase in the biofuel consumption, thanks to the mandate, does not compensate the decrease in the consumptions of the agricultural product and the gasoline. Secondly, the level of the net utility also decreases with the biofuel mandate. Even though the GHG emissions caused by conventional gasoline is reduced thanks to a lower fossil fuel consumption, the emissions provoked by the biofuel production is increased. Contrary to the subsidy policy, the emissions due
to the agricultural production are also increased in a small amount. In sum, the level of overall emissions is decreased in a small amount, but the GHG emissions saving thanks to the use of biofuels is again decreased.

Let finally analyze the economic and environmental effects of a biofuel subsidy policy over the blending mandate option. In terms of the gross utility, the biofuel subsidy policy slightly outperforms the mandate. This shows that, for the blending mandate, the lost of utility due to the blending constraint in the utility function is higher than the gain associated with the absence of public funding. In terms of the net utility, the mandate outperforms the biofuel subsidy policy. This last effect is due to the lower level of total emissions in the mandate policy than those implied by the subsidy. Both policies achieve the same suboptimal ratio of GHG emissions savings thanks to the use of biofuel against the gasoline.

3.3 Sensitivity Analyses

By simulation results, we notice that the precise value of the desutility parameters $\tilde{q}_1 = \tilde{q}_2 = \tilde{q}_3 = \tilde{q}$ does not matter for the ranking of the different policies, but only for the levels of utility and emissions. The higher the desutility parameter (when parameter $\tilde{q}$ moves from 1000 to 1200), the lower the gross and net utility, the lower the consumptions of the agricultural product and the biofuel (except for the biofuel subsidy policy in which the biofuel consumption sometimes stays constant), the higher the consumption of the gasoline, the lower the ratio $q_2/q_3$, the lower GHG emissions coming from the agriculture and the biofuel (except for the biofuel subsidy policy in which biofuel emissions sometimes stay constant), the higher the GHG emissions coming from the gasoline.

The numerical applications also indicate that when the desutility parameters $a_1$, $a_2$, $a_3$ decrease to pass from $(a_1 = 0.8, a_2 = a_3 = 0.4)$ to $(a_1 = 0.4, a_2 = a_3 = 0.2)$, only the gross and the net utility increase, all the other variables stay constant. Hence the qualitative results on the comparison of the outcomes of biofuel policies with the outcome of the decentralized solution are not modified. If we change the values of the desutility parameters in another way around, $a_1 = 0.2$, $a_2 = 0.1$, $a_3 = 0.9$, such that now the consumption of the gasoline implies the highest desutility compared to other consumptions, we have very similar environmental and economic effects in all institutional arrangements. Hence the qualitative results on the comparison
of different regimes hold.

Now, we look at the situation in which the agricultural emission parameter moves from 0.7 to 0.16. The values of the other emission parameters are maintained: $\beta_2 = 0.1$ and $\beta_3 = 0.9$. These values give the following ratio of emission parameters $\frac{\delta_1 + \delta_2}{\beta_3} = 18\%$, instead of 50% in the preceding case. With this change, the net utility increases and agricultural emissions decrease, all the other variables stay constant. The qualitative results on the comparison of the outcomes of biofuel policies with the outcome of the decentralized solution are not modified.

We now allow the damage parameters to differ across different sources of emissions, such as $D_1e_1$, $D_2e_2$, $D_3e_3$. We use the estimations of a life-cycle- assessment study on biodiesel in France in terms of global warming potential (Fair V Programme (2000), p. 120). We set: $D_1 = D_2 = 35$ and $D_3 = 100$ such that $\frac{D_1 + D_2}{D_3} = 70\%$, instead of 100% in the preceding case. With this change, only the net utility increase, all the other variables stay constant. The qualitative results on the comparison of the outcomes of biofuel policies with the outcome of the decentralized solution are not modified.

When the biofuel subsidy rate $s$ moves from 25 to 30, the qualitative result on the comparison of the outcome of the biofuel subsidy policy with that of the decentralized solution does not change. The higher the subsidy rate (when $s$ moves from 25 to 30), the lower the gross and especially the net utility, the lower the consumption of the agricultural product, the same the consumption of the gasoline, the higher the consumption of the biofuel, the higher the GHG emissions coming from the biofuel production, the same the emissions coming from other sectors.

When the biofuel blending rate $\theta$ moves from 0.07 to 0.099, the qualitative result on the comparison of the outcome of the biofuel blending mandate with that of the decentralized solution does not change. The higher the blending rate (when $\theta$ moves from 0.07 to 0.099), the lower the gross and the net utility, the lower the consumption of the agricultural product and the gasoline, the higher the consumption of the biofuel, the higher the GHG emissions coming from the biofuel production and the agriculture, the lower

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9The life-cycle-essment of rape seed oil methyl ester versus fossil diesel for France in 2000 indicates a more pessimistic result for the biodiesel: respectively a global warming potential (GWP) of 200 g (CO$_2$ eq./MJ useful energy) and 280 g (CO$_2$ eq./MJ useful energy), which leads to the ratio, $\frac{\text{GWP (biodiesel)}}{\text{GWP (diesel)}} = 71\%$. This evaluation takes into account all GHG, especially N$_2$0 emissions (Fair V Programme (2000), p. 120).
the emissions coming from the gasoline consumption, and the lower the level of total GHG emissions.

4 Conclusion

The object of this paper was to analyze whether a biofuel subsidy policy and a biofuel blending mandate are welfare-improving compared to the laissez-faire solution. To achieve it, we have effectuated a numerical analysis of the relative economic and environmental efficiency of these three institutional arrangements and compared it to the outcome of the optimal solution. This is done in a general equilibrium setting with three goods. The data are taken for the French biodiesel policy in 2006.

Our numerical results show that the outcome of the laissez-faire solution, in terms of utility and emissions, is generally less far away from the optimal solution than those of the biofuel policies under consideration. This finding indicates the need to design an alternative biofuel policy whose objective is to increase the income of agents without compromising the environmental quality that they benefit. This calls for biofuel subsidies or biofuel blending objectives conditional to attain some environmental criteria, such as the certification of biofuels. The Proposition of Directive on Renewable Energies of the European Commission of the 23th January 2008 (2008/0016 (COD)) requires that biofuels respect a number of environmental criteria in order to be counted for the 10 % national objective. One of these criteria is that biofuels attain a minimum of 35 % saving on CO\textsubscript{2} emissions compared to fossil fuels.

This analysis is limited in scope. First, the estimation of the parameters of the utility function is lacking. Moreover, this general equilibrium analysis did not consider the market of by-products resulting from the biofuel production. Finally, the land competition across food crops and energy crops is not modeled. To enrich the model, the conventional gasoline could be introduced in the agricultural production function. As a next step, it could be interesting to investigate the efficiency of a biodiesel subsidy policy in the presence of a binding blending mandate, as it is currently the case in France. Another future research question could analyze, in our general equilibrium setting, the efficiency of biofuel policies when they are used in conjunction with biofuel trade policies, in the same vein than the papers by de Gorter and Just (2007), and Elobeid and Tokgoz (2008).
References


