Efficiency of a Biofuel Subsidy Policy in the Presence of Environmental Externalities

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Abstract

The object of this paper is to analyze, in a general equilibrium setting with four markets, the efficiency of a biofuel subsidy policy. The analysis takes into account environmental externalities associated both with the production and the consumption of biofuels, as well as associated with the production of agricultural raw material. Our preliminary numerical results, applied to the biodiesel subsidy policy in France, first show that this policy increases the utility of the representative consumer compared to the laissez-faire solution. The same policy action leads, however, to an increased level of agricultural and GHG emissions, in comparison with the laissez-faire solution.

Keywords: biofuels, subsidy, environment

Topics: environment and resources, market and demand analysis

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1 Introduction

There is a need to stimulate the use of biofuels given their cost of production is higher than that of petroleum products, such as oil or gasoline[1]. The development of biofuels has been encouraged by the European Union through various directives[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 is generally justified by the existence of two market failures: energy security and greenhouse gas (denoted as GHG, hereafter) emissions due to the use of fossil fuels in the transport sector (Tyner (2007), p.2). This study[3] takes into account only the market failure due to GHG emissions and examines the relative efficiency of a biofuel tax credit policy in this context[4]. A biofuel tax credit is equivalent, in some ways, to subsidize one alternative to petroleum.

This paper analyzes the efficiency of a biofuel subsidy policy by taking into account different sources of environmental externalities such as, production externalities, associated with the production of agricultural crop and the production of biofuel, and also consumption externalities, associated with the consumption of petroleum fuel and the consumption of biofuel. This analysis allows us to compare the outcomes, in terms of efficiency, of the laissez-faire solution with the biofuel subsidy policy. 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 recent biodiesel subsidy policy of France.

In order to evaluate the relative efficiency of a biofuel subsidy policy,

[1]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.

[2]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 minimum of 10 % of biofuels for each Member State.

[3]This paper resulted from a common reflexion with Florence Jacquet and Stephan Marette.

[4]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).

we use a general equilibrium setting with four markets: the labor market, the agricultural sector, the sector of biofuel production, and the sector of distribution of petroleum products. We assume that all these markets are competitive. We exclude the possibility of international trade in biofuels. Even though the European tariffs on the imports 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 Gorter and Just (2007b). These authors 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[5]. Gardner (2007) studies the income effects of an ethanol subsidy and farm price support. Nevertheless, none of these partial equilibrium models take into account environmental externalities associated with the production and use of biofuels.

The contribution of this paper to the literature is threefold. First, the general equilibrium framework allows us to consider general equilibrium effects on agricultural and biofuel prices. Second, it attempts to analyze the efficiency of a biofuel subsidy policy by taking into account environmental externalities associated with the production and consumption of biofuels. Finally, this analysis is applied, in a numerical example, to the biodiesel subsidy policy of France.

The paper is organized as follows: Section 2 presents the model and describes different equilibria associated with different institutional arrangements. Preliminary results of a numerical illustration of the biodiesel policy in France 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 four agents in the economy: a representative consumer, a farmer, a biofuel producer\vendor and a gasoline\oil vendor. We assume that the biofuel producer and the biofuel vendor are the same entity.

[5]In a different paper, Gorter and Just (2007a) analyze, in a similar way, the efficiency of a biofuel tax credit and the interaction effects with a price contingent farm subsidy.

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. Biofuel is indexed by 2, with price (p_2). Last, the gasoline\oil 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.

The environmental externalities could come, on the one hand, from production activities, either agricultural production or biofuel production. 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 β_1 is a positive constant. This pollution could be caused by the use of nitrogen fertilizers or pesticides to increase agricultural productivity. The carbon emission function associated with the biofuel production can be written as, $e_2 = \beta_2 x_2$, where β_2 is a positive constant. On the other hand, the environmental externalities could also come from consumption decisions, either from the use of biofuels or the use of petroleum products. The carbon emission function related to the consumption of biofuel writes as, $e_4 = \beta_4 q_2$, where β_4 is a positive parameter. Finally, the carbon emission function associated with the gasoline\oil consumption is represented by $e_3 = \beta_3 q_3$, where β_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 $R = w(L_1 + L_2) = L$.

The consumer's utility function is written in the following way:

$$U = A - a_1(q_1 - \bar{q_1})^2 - a_2(q_2 - \bar{q_2})^2 - a_3(q_3 - \bar{q_3})^2 \tag{1}$$

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 $q_3 < \bar{q_3}$. This utility function is assumed to be concave and additively separable.

The program of the consumer is to maximize its utility with respect to q_1, q_2, q_3, subject to its budget constraint:

$$\begin{aligned} Max_{q_1,q_2,q_3}[U &= A - a_1(q_1 - \bar{q_1})^2 - a_2(q_2 - \bar{q_2})^2 - a_3(q_3 - \bar{q_3})^2] \quad (2) \\ s.t. .....L &= p_1q_1 + p_2q_2 + p_3q_3 \\ q_1 &< \bar{q_1}, q_2 < \bar{q_2}, q_3 < \bar{q_3} \end{aligned}$$

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*:

$$\begin{aligned} q_1^d &= \frac{Lp_1a_2a_3 - p_1a_2a_3p_3\bar{q_3} - p_1a_2a_3p_2\bar{q_2} + \bar{q_1}p_2^2a_1a_3 + \bar{q_1}p_3^2a_1a_2}{p_1^2a_2a_3 + p_2^2a_1a_3 + p_3^2a_1a_2} \quad (3) \\ q_2^d &= \frac{Lp_2a_1a_3 - p_1a_1a_3p_2\bar{q_1} - p_3a_1a_3p_2\bar{q_3} + \bar{q_2}p_1^2a_2a_3 + \bar{q_2}p_3^2a_1a_2}{p_1^2a_2a_3 + p_2^2a_1a_3 + p_3^2a_1a_2} \\ q_3^d &= \frac{Lp_3a_2a_1 - p_3a_2a_1p_1\bar{q_1} - p_3a_2a_1p_2\bar{q_2} + \bar{q_3}p_1^2a_2a_3 + \bar{q_3}p_2^2a_1a_3}{p_1^2a_2a_3 + p_2^2a_1a_3 + p_3^2a_1a_2} \end{aligned}$$

As expected, the consumer demand depends on all the prices of the economy, and also positively depends on the aggregate revenue L.

2.1.2 Program of the farmer

The farmer has at its disposal a constant returns to scale technology to produce the agricultural product[6]. This product is used both for food consumption 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.

[6]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 production function of the farmer is given by:

$$x_1 = \alpha L_1 \tag{4}$$

where α is a positive agricultural productivity parameter and L_1 is the labor force in the agricultural sector.

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:

$$\pi_1 = p_1 x_1 - C_1(x_1, e_1) \tag{5}$$

where the term $C_1(x_1, e_1)$ represents the linear cost function of the farmer. This cost is increasing with the level of production (x_1), but decreasing with the level of emissions (e_1). The last property is explained by the fact that the abatement activity is costly for the farmer.

The profit function can be rewritten in the following manner:

$$\pi_1 = p_1 x_1 - [L_1(x_1) - \gamma_1 e_1] \tag{6}$$

where γ_1 is a positive constant. The last term of the profit function, $(\gamma_1 e_1)$, represents a saving on the productive agricultural labor. The idea is that the abatement of agricultural emissions is costly in terms of productive labor. Or in other words, there is an economic gain for the farmer to emit.

The zero profit condition, $\pi_1 = 0$, implies:

$$\begin{aligned} p_1 x_1 &= L_1(x_1) - \gamma_1 \beta_1 x_1 \\ &\Longleftrightarrow \; p_1 x_1 = \frac{x_1}{\alpha} - \gamma_1 \beta_1 x_1 \Longleftrightarrow p_1 x_1 = x_1(\frac{1}{\alpha} - \gamma_1 \beta_1) \end{aligned} \tag{7}$$

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

$$p_1^d = \frac{1 - \alpha \gamma_1 \beta_1}{\alpha} \tag{8}$$

The positivity of p_1 requires that $\alpha \gamma_1 \beta_1 < 1$. It appears that the market price of the agricultural good decreases with the parameters α, γ_1 and β_1. When the agricultural productivity and the gains from emissions increase, the supply of the farmer also does. This, in turn, decreases the market price of the agricultural good.

2.1.3 Program of the biofuel producer

As the farmer, the biofuel producer operates with a constant returns to scale technology[7]. The factors of production are comprised of the productive labor, L_2, and the agricultural raw material, $\widetilde{q_1}$. These factors of production are assumed to be complementary for the production process.

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

$$x_2 = \min(\delta\widetilde{q_1}, \varepsilon L_2) \tag{9}$$

where δ and ε are positive constants, and L_2 is the labor force in the sector of biofuel production. The complementarity of the factors of production leads to:

$$x_2 = \delta\widetilde{q_1} = \varepsilon L_2 \tag{10}$$

This production activity provides a revenue for the producer, L_2, but induces an environmental cost, in terms of emissions, e_2. This pollution could come from CO_2 emissions caused during the transformation process of the agricultural raw material to biofuel.

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

$$\pi_2 = p_2 x_2 - C_2(x_2, e_2, \widetilde{q_1}) \tag{11}$$

where the term $C_2(x_2, e_2, \widetilde{q_1})$ represents the linear cost function of the biofuel producer. This cost is increasing with the level of production (x_2), but decreasing with the level of emissions (e_2) and the level of the agricultural raw material ($\widetilde{q_1}$). Again, the second property is related to the cost of abatement activities incurred by the biofuel producer.

The profit function can be rewritten in the following manner:

$$\pi_2 = p_2 x_2 - (L_2(x_2) - \gamma_2 e_2) - p_1\widetilde{q_1} \tag{12}$$

[7] De Gorter and Just (2007b) use the same assumption for ethanol production. They mention several corn-oil price breakeven estimates in the literature which all determine a linear relationship.

where γ_2 is a positive constant. As for the profit of the farmer, the term, $(\gamma_2 e_2)$, represents a saving on the productive labor.

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

$$p_2^d = \frac{1}{\varepsilon} - \gamma_2\beta_2 + \frac{p_1^d}{\delta} \tag{13}$$

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 the parameters ε, δ, γ_2 and β_2. When the labor productivity, the productivity of the agricultural input, and the gains from emissions 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 13, we obtain the endogenous level of the biofuel's price at the decentralized equilibrium:

$$p_2^d = \frac{\alpha\delta(1 - \varepsilon\gamma_2\beta_2) + \varepsilon(1 - \alpha\beta_1\gamma_1)}{\alpha\delta\varepsilon} \tag{14}$$

The positivity of p_2 requires that $\alpha\delta(1 - \varepsilon\gamma_2\beta_2) + \varepsilon(1 - \alpha\beta_1\gamma_1) > 0$.

2.1.4 Program of the gasoline\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, $\pi_3(p_3, x_3) = 0$, also applies for the gasoline\oil distributor. We do not explicit this profit function, because 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 price of labor ($w = 1$), and the prices of labor and the agricultural raw material (p_1). Equations 8 and 14 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 biofuel, the agricultural product and the petroleum product at the decentralized equilibrium are given respectively by*:

$$\begin{aligned} x_1^d &= q_1^d + \widetilde{q_1}^d = q_1^d + \frac{x_2^d}{\delta} = q_1^d + \frac{q_2^d}{\delta} \\ x_2^d &= q_2^d \\ x_3^d &= q_3^d \end{aligned} \tag{15}$$

with $p_1^d = \frac{1-\alpha\gamma_1\beta_1}{\alpha}$ and $p_2^d = \frac{\alpha\delta(1-\varepsilon\gamma_2\beta_2)+\varepsilon(1-\alpha\beta_1\gamma_1)}{\alpha\delta\varepsilon}$.

These equilibrium quantities imply the following equilibrium levels of emissions.

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

$$\begin{aligned} e_1^d &= \beta_1 x_1^d = \beta_1(q_1^d + \widetilde{q_1}^d) \\ e_2^d &= \beta_2 x_2^d = \beta_2 q_2^d \\ e_4^d &= \beta_4 q_2^d \\ e_3^d &= \beta_3 q_3^d \end{aligned} \tag{16}$$

with $p_1^d = \frac{1-\alpha\gamma_1\beta_1}{\alpha}$ and $p_2^d = \frac{\alpha\delta(1-\varepsilon\gamma_2\beta_2)+\varepsilon(1-\alpha\beta_1\gamma_1)}{\alpha\delta\varepsilon}$.

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

2.2 Subsidy to Biofuel Producers

The most widely used policy instrument in the context of biofuel development is the biofuel tax credit (de Gorter and Just (2007a), Kojima et al.

(2007)). The motives behind the implementation of a biofuel subsidy could be numerous: to reduce the reliance on oil imports, to enhance farm incomes, and to promote rural development (de Gorter and Just (2007b, p.4). The European Commission has identified, however, the reduction of the GHG caused by fossil fuels as the principal objective of biofuel policy (JRC (2008), p.8). In our numerical example, we calibrate the reference model as to have higher GHG emissions with the gasoline than with the biodiesel.

As does Gardner (2007), we model the tax exemption policy as a subsidy to biofuel which is 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 profit of the biofuel producer writes:

$$\pi_2 = p_2 x_2 - (L_2(x_2) - \gamma_2 e_2) - p_1 \widetilde{q_1} + s x_2 \tag{17}$$

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

$$p_2^s = \frac{1}{\varepsilon} - \gamma_2 \beta_2 + \frac{p_1}{\delta} - s \tag{18}$$

As expected, the price of the biofuel producer, p_2, falls with the subsidy rate, because the subsidy reduces its cost of production[8].

When we introduce the expression of p_1 of Equation 8 into Equation 18, we obtain,

$$p_2^s = \frac{\alpha\delta(1 - \varepsilon\gamma_2\beta_2 - \varepsilon s) + \varepsilon(1 - \alpha\beta_1\gamma_1)}{\alpha\delta\varepsilon} \tag{19}$$

The positivity of p_2 requires that $\alpha\delta(1 - \varepsilon\gamma_2\beta_2 - \varepsilon s) + \varepsilon(1 - \alpha\beta_1\gamma_1) > 0$.

The equilibrium levels of the quantities under the subsidy policy are defined in a similar way to those at the decentralized equilibrium, except for the prices. The demand is not directly affected with the subsidy, but only indirectly via the change in prices. The supply of the biofuel, the agricultural product and the gasoline are given respectively by: $x_2^s = q_2^s = q_2^d$; $\widetilde{q_1}^s = \frac{x_2^s}{\delta} = \frac{q_2^s}{\delta} = \frac{q_2^d}{\delta}$; $x_1^s = q_1^s + \widetilde{q_1^s} = q_1^d + \widetilde{q_1^d}$; $x_3^s = q_3^s = q_3^d$, with $p_1^s = p_1^d = \frac{1-\alpha\gamma_1\beta_1}{\alpha}$ and $p_2^s = \frac{\alpha\delta(1-\varepsilon\gamma_2\beta_2-\varepsilon s)+\varepsilon(1-\alpha\beta_1\gamma_1)}{\alpha\delta\varepsilon}$. These equilibrium

[8] Note that the price of the farmer p_1 is unchanged.

quantities imply the following levels of the emissions with the subsidy policy: $e_1^s = \beta_1 x_1^s$, $e_2^s = \beta_2 x_2^s$, $e_4^s = \beta_4 q_2^s$, $e_3^s = \beta_3 q_3^s$.

In the next section, the comparison of the outcomes of the decentralized equilibrium with the biofuel subsidy policy is presented in a numerical example for the biodiesel subsidy policy in France.

3 A Numerical Application

France set more ambitious targets than the European Union in terms of biofuel consumption: 7 % of biofuels 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 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. The price of 1 hl of gasoline (with TIC) in 2006 is taken to be equal to $p_3 = 115$ euros.

In order to evaluate the effects of the subsidy policy over the decentralized equilibrium, we proceed in the following way. The tax exemption for the biofuel vendor is simply a subsidy for himself. We model the tax exemption as a reduction in the production cost of the biofuel producer, since the vendor and the producer are the same entity. Let the unit subsidy, s, be given by the amount of the tax exemption for biodiesel, i.e. $s = 25$ euros/hl. 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 following table are not calibrated specifically for the French economy.

$\bar{q}_1 = \bar{q}_2 = \bar{q}_2$	$A = L$	a_1	a_2	a_3	$\alpha = \gamma_1 = \gamma_2 = \delta = \varepsilon$
800	100000	0.9	0.1	0.6	0.1

To calibrate the values of the emission parameters, we proceed in the following way. The parameter β_1 is assumed to be linked only to nitrogen emissions and pesticides caused by the agricultural production. We use as an initial value for this parameter $\beta_1 = 0.1$. It is well known that the agricultural activity also causes GHG emissions such as CO_2 and N_20 emissions. In fact, we only account for CO_2 emissions in this exercice. Those arising from the agricultural production, the biofuel production and consumption, as well as from the gasoline consumption are all encountered in the calibrated values of the parameters β_2, β_3 and β_4. In general, biofuels produce lower CO_2 emissions than petroleum products. The study JEC (2007) 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 β_3 is higher than the sum of parameters β_2 and β_4. We use as initial values the following ones: $\beta_2 = 0.2$, $\beta_3 = 0.9$ and $\beta_4 = 0.2$. These values imply the ratio, $\dfrac{\beta_2 + \beta_4}{\beta_3} = 44\%$[9].

These values of the parameters imply the following levels of the market prices of the agricultural raw material, $p_1^d = 10$, the biofuel, $p_2^d = 127$, and the biofuel with the subsidy, $p_2^s = 102$. In the following, we summarize respectively the outcomes of the laissez-faire solution and the biofuel subsidy policy:

Decentralized solution	U^d	e_1^d	e_2^d	e_3^d	e_4^d	q_1^d	q_2^d	q_3^d
	45931	203	24	613	24	793	124	682

Biofuel subsidy policy	U^s	e_1^s	e_2^s	e_3^s	e_4^s	q_1^s	q_2^s	q_3^s
	51062	267	37	595	37	791	188	661

We first make some observations about the equilibrium quantities for both institutional arrangements. Our numerical findings first indicate that the agricultural product is the most consumed good in both cases, thanks to its low price (p_1^d) and its relative weight in the utility function. Secondly, in both situations, the demand for the biofuel (q_2) is lower than that for gasoline (q_3), because of the higher market price of the biofuel on the gasoline and its lower weight in the utility of the consumer. In fact, the ratio q_2^d/q_3^d at the decentralized equilibrium is equal to 0.18. In 2006, the blending ratio of the biodiesel over the gasoline in France was equal to 0.018. Eventhough

[9] The life-cycle-assesment 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_20 emissions (Fair V Programme (2008), p. 120).

our numerical numbers are far from being similar to these real numbers, which is important is the magnitude of the changes between the outcomes of the laissez-faire solution and the biodiesel subsidy policy. In this latter case, the ratio q_2^s/q_3^s is increased to attain 0.28. Finally, the levels of CO2 emissions caused by the production and the consumption of biodiesel are always equal, $e_2 = e_4$, because the emission parameters in both cases are equal by assumption, and the supply is equal to demand at the equilibrium.

Let us now assess the effects on the relative economic and environmental efficiency of a biofuel subsidy policy over the laissez-faire solution. We first note this policy increases the utility of the representative consumer. In fact, this policy implies a reduction in the market price of the biofuel ($p_2^s < p_2^d$), as well as an increase in the quantity consumed by the consumer $q_2^s > q_2^d$. The equilibrium quantities of the agricultural product and the gasoline are only slightly decreased, because of the substitution effect between the three goods. This positive conclusion on the relative economic efficiency of the biofuel subsidy is, however, reversed if we consider environmental impacts. Even though the CO2 emissions caused by conventional gasoline (e_3) is reduced thanks to a lower fossil fuel consumption ($q_3^s > q_3^d$), the carbon emissions provoked by the biofuel production and consumption (e_2 and e_4) increase. Concerning nitrogen emissions caused by agriculture, they increase in spite of the reduction of the food consumption. This comes from the additional demand of the agricultural raw material for the biofuel production stipulated by the subsidy.

4 Conclusion

The object of this paper was to assess, with numerical simulations, the relative economic and environmental efficiency of the french biodiesel subsidy policy. This analysis is effectuated in a general equilibrium setting with four markets.

Our preliminary results first show that this policy increases the utility of the representative consumer compared to the laissez-faire solution. This is related to the relative increase of the biofuel consumption. The same policy action causes, however, an increase in nitrogen and CO_2 emissions in comparison with the laissez-faire solution. These preliminary results indicate the need to design biofuels subsidy policies whose objective is to increase the income of agents, without compromising the environmental quality that they benefit. This calls for biofuel blending objectives conditional to attain some environmental criteria, such as the certification of biofuels. The Proposition of Directive on Renewable Energies of the 23th January 2008 (2008/0016 (COD)) requires that biofuels respect a number of environmental criteria[10] in order to be counted for the 10 % national objective.

This preliminary version of the analysis is limited in scope. Our numerical application only incorporated the fuel prices, the biofuel tax credit, and some information on the life-cycle-assessment of the biodiesel versus diesel. A more complete evaluation of the french biodiesel subsidy policy would require other data, such as the ones on agricultural and biofuel productions, as well as on consumption. 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.

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