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Micro-economic modelling of biofuel system in France to determine tax exemption policy under uncertainty

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Abstract

Liquid biofuel support program launched in 1993 in France is implemented through tax exemptions to biofuels produced by agro-industrial chains. Activity levels are fixed by decree and allocated by the government to the different chains. Based on earmarked budget increase voted in the parliament, total quantity of biofuels will be increased by 50% in the horizon 2002–2003. A micro-economic biofuel activity model containing a detailed agricultural sector component, that is represented by 700 farms, is used to estimate costs and surpluses generated by the activity at the national level as well as tax exemption levels. Furthermore, Monte Carlo simulation has been used to search for efficient tax exemptions policies in an uncertain environment, where biofuel profitability is significantly affected by petroleum price and soja cake prices. Results suggest that, for the most efficient units both at the industry level (large size biomass conversion units) and at the agricultural sector level (most productive farms), unitary tax exemptions could be decreased by 10–20% for both biofuels, ethyl ether and methyl ester, with no risk for the viability of any existing chain.

Keywords: Liquid biofuels; Monte Carlo simulation; LP modelling; Tax exemption policy

1. Introduction

Biofuel Production (ethanol-to-ETBE and methyl esters)[1] has reached a significant level in France, where about half of total European production of ethanol and methyl esters is produced. This development is triggered by the EU revised Common Agricultural Policy of 1992, that obliged large farms to set aside a part of their land previously cultivated by cereals in order to control overproduction related expenses. In France, the government attempted to alleviate farmers' revenue decrease due to the obligatory set-aside that meant to them an unacceptable idleness rate of machinery, through the implementation of an ambitious support program to incite liquid fuel production from biomass. A tax exemption of $0.35\,€\,l^{-1}$ for methyl ester from vegetable oil and $0.50\,€\,l^{-1}$ for bioethanol as well as a budget of 1.2 billion francs have been allocated to biofuels. As a result, farmers have cultivated energy crops in set-aside land (according to the revised CAP land set-aside could be cultivated by crops not destinated to food markets) since the 1993–1994 period.

The development of both biofuel chains depends actually on two interrelated elements: the European Union regulations and their transposition to the national law system through industrial capacity approvals by regulation authorities and second on tax exemptions. The European Commission decree (9 April 1997) that approved the tax exemption regime applied to predefined volumes of biofuels was based on the notion of pilot projects supporting the development of non-polluting activities (directive 92/81-Article 8-section 2). After BP Chemicals Ltd. lodged a complaint against France, the European court verdicted that given the level of development of the activity it could no longer be considered as a pilot project. In response to that France has demanded that dispensations may be granted according to section 4 of the directive 92/81-Article 8 focusing on specific policies of member states. At the time being two proposals are examined by the Commission services: The first concerns a modification of the directive 92/81 to give the possibility to apply less tax rates to fuels containing biomass-origin components. Secondly, it is seriously considered an obligation of incorporation of biofuels to fuels of fossil origin.

By the year 2000, the cultivated surface reached 400 000 ha and the total amount of biofuels production

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[1] ETBE: ethyl tertio-butyl ether, RME: rapeseed methyl ester.

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in France has crossed the line of 400 000 t, marking an increase of 19% comparing with the year 1999 (Table 10 in the appendix). Biofuel volume currently represents approximately 536 000 t (considering that 92 000 t of ethanol are equivalent to 196 000 t of ETBE), or 1.5% of the national liquid fuel consumption. The conversion of biomass to biofuels is concentrated in a few plants (Table 11 in the appendix), whereas the agricultural raw material is produced by thousands of farms located in different parts of the country at varying costs. Total production will increase according to new agreements allocated to the industry by the French government (three more conversion units), to reach in 2002–2003 the quantities shown in Table 1.

The increased importance of the biofuel development program in France stimulated our interest to improve modelling tools used in the past to evaluate public policy (Sourie et al., 1997; Bard et al., 2000) and to attempt to build a biofuel system encompassing model in order to complete recent studies that focus on a mono-chain biofuel analysis (concerning ME production, Costa and Requillart, 2000). A micro-economic supply chain model has been developed for this purpose, based on the detailed description of the agricultural sector that has been used to evaluate Berlin EU summit decision impacts to arable cultures in France. An industry model of French biofuel chains (ETBE from wheat and sugarbeet, rapeseed biodiesel), as well as demand functions of products and by-products are integrated in such a way that a partial equilibrium model to be formulated.

A micro-economic analysis of the French biofuel system is undertaken using this model in order to estimate biomass-to-energy opportunity costs as well as agents' surpluses. Welfare increases or losses due to the biofuel activity can thus be calculated as well as minimum tax exemptions for the three chains operating in France to break even. First results of this model have been published indicating that tax exemptions allow the industry to realise non-negligeable profits and farmers to benefit as well, although in a lessen extent (Rozakis and Sourie, 2002); a multi-criteria analysis have been carried out considering greenhouse gases emission reduction due to the biofuel substitution for fossil fuels (Rozakis et al., 2001). It is important though to assess systematically the project risk, as biofuel chains operate in an uncertain environment (highly volatile petroleum price—see Fig. 1, by-product price fluctuations directly influenced by the soja cake world market). As a matter of fact tax exemptions compensated for low oil prices whereas by the end of the 1990s a boom of oil prices resulted in high market prices for biofuels so that most of the tax exemption was transformed in net benefit for the industry. Even analysts[2] close to stakeholders point out "the modulation of tax exemption levels, as a function of oil and oil-seed grain world prices regarding ME and oil price regarding ETBE, is on the agenda" in order to adjust tax exemption levels taking into account oil price evolution since 1989. Efficiency and equity issues are of prime importance in the eyes of the taxpayer and the perpetuation of the support program will depend on reasonable adjustments of tax exemptions to biofuels.

Table 1
Biofuel production in France

	Sugarbeet	Wheat	Rapeseed	Total
Production ETBE (t)	249 333	124 667		374 000
Production RME (t)			387 507	387 507

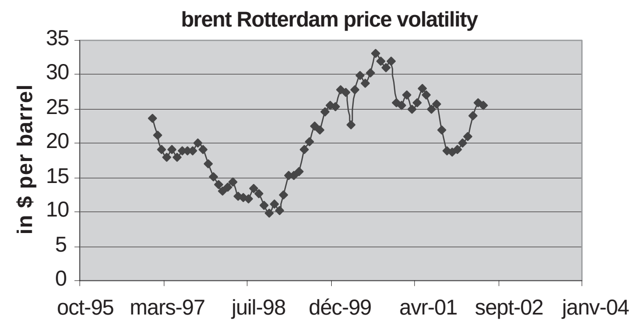

Fig. 1. Oil price evolution in the late 90s.

We assume that model parameters such as product and by-product prices are related to oil and soja cake world prices through simple functions estimated using regression analysis. Then Monte Carlo simulation method that is extensively used to analyse conjuctural impacts on project rates of return (Houdayer, 1999) is implemented to estimate the impact of the oil and soja price fluctuation to biofuel chain benefits and to explore feasible tax exemption adjustments as a compromise between the objectives of budget concerns and the operation viability.

This paper is organised as follows. The partial-equilibrium model is briefly presented in the next section. Model results on biofuel cost of chains operating currently in France under different policy scenarios are presented and analysed. Next, the contribution of micro-economic modelling for the exploration of possibilities of biofuel cost reduction in the short- and medium-term is pointed out. Finally, Monte Carlo simulation is implemented to cope with the uncertainty question and results are presented along with estimations of minimal tax exemption levels for the viability of the activity; remarks on policy implications conclude the paper.

[2] Les Cahiers de l'ONIOL, October 2001, "La jachère industrielle", p. 11.

2. A partial equilibrium model for the economic analysis of biofuel chains

A partial equilibrium economic model based on mathematical programming principles (OSCAR)[3] was built in order to assist in the micro and macro-economic analyses of the multi-chain system of the biofuel industry. This approach, which models the existing biofuel chains in France—sugarbeet and wheat to ETBE, rapeseed to RME—implies the following:

- that a comprehensive and systemic method is required (due to the biofuel chains interdependency), not only at the resource production level but also at the output level,
- that detailed modelling of the agricultural supply is required to take into account the diversity of the arable farming system, agronomic constraints and production techniques (see Sourie, 2000, 2002).
- that it is possible to proceed to the economic optimisation of the whole system and to use multi-criteria methods to assist in policy making.

Each chain consists of five production stages: biomass production, collection, first and second transformation, demand for biofuels and by-products. The model determines:

- the optimal biomass supply and farmers' surplus, given the policy context and agronomic environment,
- the opportunity cost of biofuels, depending on crop supply, industrial costs and the demand for biofuel and by-products,
- the optimal tax exemption allocation to biofuel chains and agents' surpluses in different market contexts (monopoly, cartel, etc.),
- biofuel contribution to the reduction in the greenhouse gas emissions, along with the economic cost incurred by society for the different scenario of budgetary expenses and tax exemption levels. The levels of activity for each chain, the funding required, as well as the aggregate welfare benefit can be determined by maximising biofuel contribution to cope with the greenhouse effect.

The structure of this model allows for consideration of additional chains, such as straw to ETBE. Environmental effects generated by the activity, together with other objectives, can be determined by means of multi-criteria decision-making.

2.1. Model specification

The micro-economic model represents the agro-energy chain structure. It integrates the agricultural sector[4] and a biofuel industry model (in this case, the French multi-chain biofuel system) based on mathematical programming principles[5] in order to simultaneously optimise economic surplus. The model proposes a decentralised decision solution based on the agents' behaviour in the respective markets. When industrial capacity is a continuous variable, OSCAR is an LP, otherwise it becomes an 0–1 LP bilevel model[6] where integer variables (number of plants) are transformed to 0–1 using binary auxiliary variables (Williams, 1999); its generic mathematical form is specified below.

Indices and variables

e	farm indices
w	relative weight of each farm in the model (to project results to the national level)
al	vector of food crop surface in ha
ja	vector of set-aside land surface in ha
nal	vector of food crop surfaces in ha
tr	vector of variable quantities of energy crops transformed to biofuels in t
vt	vector of biofuel quantities in t
vc	vector of co-product quantities in t

Coefficient matrices (technical parameters used are presented in Table 7, Appendix)

A	submatrix of technical agricultural production coefficients
R	submatrix of non-food crop yields in t
T	submatrix of conversion coefficients
$[I]$	unitary matrix
sub	vector of unitary subsidies to biofuels

[3] OSCAR: "Optimisation du Surplus économique des Carburants Agricoles Renouvelables".

[4] Optimisation model with a matrix of technical coefficients of 7500×6800. The agricultural sector component aggregates 700 elementary arable farm models located in sugarbeet and cereal production regions.

[5] Models are written in GAMS code (Brooke et al., 1998).

[6] An equivalent model of the biofuel energy system assigning transformation units of fixed capacities using discrete variables is presented by Mavrotas and Rozakis (2002).

Agricultural sector

$A1_e(al_e, ja_e, nal_e)$	$\leqslant w_e t_e$	agronomic constraints	(C1)
$A2_e(al_e, ja_e, nal_e)$	$\leqslant w_e f_e$	flexibility constraints	(C2)
$A3_e(al_e)$	$\leqslant w_e q_e$	market outlets—quotas	(C3)
$A4_e(ja_e, nal_e)$	$\geqslant w_e s_e$	set-aside land constraints	(C4)

Biomass availability, conversion process and biofuel demand constraints

$-\sum_e R_e nal_e + [I]tr \leqslant 0$		biomass raw material supply	(C5)
$-T1tr + [I]vt$	$\leqslant 0$	biofuel minimal supply	(C6)
$-T2tr + [I]vc$	$\leqslant 0$	co-product minimal supply	(C7)
$sub.vt$	$\leqslant \max Sub$	maximal subsidy to biofuels	(C8)

Objective function: to maximise global surplus

(O1)

$$S = \sum_e (ma_e al_e + mja_e ja_e - cnal_e nal_e) - ctr \cdot tr + (pvt + sub)vt + pvc \cdot vc$$

ma	vector of gross margins of food crops FF/ha
mja	vector of gross margins of set-aside land FF/ha
cnal	vector of variable costs of non-food crops
ctr	vector of total costs of biomass collection and conversion to biofuels
pvt	biofuel price vector
sub	subsidies(unitary tax exemptions) to biofuels vector
pvc	co-product price vector

2.2. Surplus allocation to farmers and industry

Taking into account exogenously fixed tax exemptions and biofuel demand levels technical parameters (Table 12, appendix), the industry's technology level and cost structure,[7] as well as the material input cost (based on energy crop supply curves),[8] the producer surplus can be estimated as shown graphically in Fig. 2. The agents' (producer) surplus is maximised by determining activities for both chains, given a maximum fixed amount of government expenditure. Dual prices that correspond to biomass availability constraints (relationship C5) are equal to the opportunity cost of the agricultural resource. The marginal value of the total subsidy is equal to the dual value of constraint (C8), denoted by *eff*. The farmers' surplus or farm income increase due to energy crop production is: $S - eff_* maxsub$. The industry surplus is then equal to $eff_* maxsub$. If the budgetary constraint is not bound ($eff = 0$), the global surplus is equal to farmers' surplus. The graph in Fig. 2 illustrates the above reasoning in the case of a single biofuel chain model. When no budgetary constraint exists, the production equilibrium is defined by the intersection of the demand and supply curve; in this case, point B″. At this point, the produced quantity equals OO″. The producer's surplus, which in this case coincides with the agricultural surplus, total budget expenses and the deadweight loss of the activity, can be determined graphically (see Box 1):

When the maximum total budgetary amount earmarked to biofuels equals CC′A′A (Fig. 2), biofuel activity level is reduced from OO″ to OO′, farmers'surplus is reduced whereas industry earns now excess benefits (see Box 2).

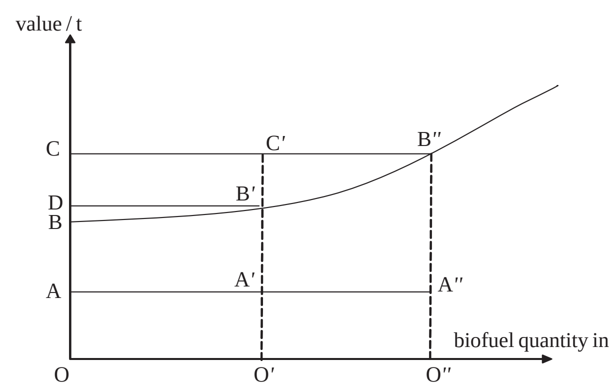

Fig. 2. Economic surpluses generated by the biofuel production and tax exemption policy.

[7]Transformation costs economies due to technical developments have been taken into account. Industrial cost estimation is based on the opportunity cost of capital higher than the market discount rate. Industrial units are assumed to be homogeneous having the same costs. Capacities are considered continuous variables, thus economies of scale are not taken into account in this exercise.

[8]As price discrimination is not possible, the opportunity cost of the least efficient producer determines the price of the resource; in other words, the cost of the resource for industry. Efficient producers enjoy a surplus. The aggregate surplus is called *agricultural surplus*.

Box 1
Case A: tax exemption to biofuels (no budgetary constraints)

BB′B″: biofuel supply curve = biomass opportunity cost + conversion cost-coproduct value
OA: biofuel market price (perfectly elastic demand curve)
OC: biofuel value = biofuel market price + tax exemption (AC)
OO″: quantity produced at the equilibrium level (biofuel value equal to its marginal cost)
CBB″: producer (agricultural sector) surplus
CB″A″A: budget cost to the government of the biofuel support program
ABB″A″ = CB″A″A-CBB″: deadweight loss

Box 2
Case B: tax exemption of biofuels under budgetary constraint

CC′A′A: total budget earmarked to biofuel
OO′: biofuel quantity produced (agreements approved by the government that depend on earmarked budget)
CA: tax exemption for biofuel (depends on budget)
DBB′: producer (agricultural sector) surplus
DCC′B′: industrial surplus
ABB′A′ = CC′A′A-DBB′-DCC′B″: deadweight loss

In a multi-chain context when activity levels as well as public expenses are fixed by the government, the surplus maximisation in the model is equivalent to the minimisation of costs and the determination of minimal unitary tax exemptions. Also, the model determines surfaces to be cultivated by energy crops as well as the prices (opportunity costs) to be paid to the farmers in order to incite them to produce the desired quantities.

3. French biofuel chains in 2002: production levels and profitability

In practice, however, since 1993 when the biofuel activity kicked-off, the government has been engaged in preserving an equilibrium among different chains (for historical and lobbying reasons). Thus, policy-makers would prefer to introduce fixed quantities into the model to produce for all three chains and to examine how much the bill would cost and the surplus level generated for agents involved.

The 2002 horizon selected to take into account further modifications in the CAP agreed in the year 2000. Firstly, the expected 2002 biofuel production levels are introduced into the model as targets to be attained by the system in order to calculate the biomass and biofuel costs.[9] Agricultural production is localised to cereal and sugarbeet producing farms in such a way as to minimise total biomass resource costs. The model selects the most efficient farms, i.e., the farms that generally attain the highest yields.

3.1. Opportunity cost of agricultural resource, yields and cultivated area

In order to minimise biofuel cost, OSCAR localises production to the most efficient farms. A minimal farm income increase of 76 € ha^{-1} is assumed to constitute an incentive for farmers to cultivate energy crops.[10] Opportunity costs calculated by the model appear in Table 2.

Opportunity costs[11] of rapeseed and wheat are much lower than food crop prices (175–183 € t^{-1} and 99–107 € t^{-1}, respectively). This can be attributed to the fact that rapeseed and wheat for energy are cultivated in land set-aside with very low land rent. Active set-aside land rate reaches 5%.[12] Sugarbeet costs should be compared with the costs of sugarbeet category C that competes in the world market (around 15.25 € t^{-1} in 1999).

The total surface area to be cultivated in order to satisfy the exogenous demand for biofuels is set at 287 300 ha (suggested by the model, see Table 2). This is

[9] Biofuel costs, particularly the biomass agricultural resource cost, increase with the increase in the quantities produced.

[10] With no incentive, last supplier's (or the less cost-efficient) revenue increase will be too low to compensate for additional labour devoted to the cultivation of non-food crops instead of land set aside.

[11] Opportunity costs are equal to the dual values of the biomass availability constraints of the model.

[12] The formal set aside rate is fixed at 10% of the land historically cultivated land with cereals and oil & protein seeds. A 5% rate has been used to take into account fluctuations in the rates revised by Brussels each year, depending on cereal stocks and the international market, as well as on the fixed set aside concerning low fertility marginal land that can be re-cultivated but at too high a cost.

Table 2
Opportunity costs of resources and average yields

	Yield (t)	€ t^{-1}	Q (kt)	Surface (ha)
Rapeseed	3.9	166.9	1466	246 250
Wheat	9	64.8	209	23 387
Sugarbeet	82.8	17.7	969	17 705

Table 3
Cost of biofuels (source: model OSCAR results for set-aside rate of 5%)[a]

	Resource cost[b]	Industry cost[c]	Co-product sales[d]	Biofuel costs	Biofuel value average[b]	2000[e]
ETBE wheat € l^{-1}	0.08	0.27	−0.06	0.29	0.13	0.27
ETBE sugarbeet € l^{-1}	0.08	0.25	−0.002	0.32	0.13	0.27
RME, € l^{-1}	0.37	0.22	−0.19	0.40	0.14	0.25

[a] Mass volume ratios 0.75 kg d m^{-3} for ETBE; 0.88 kg d m^{-1} for RME (source: Levy, 1993).
[b] Average 1992–2000 FOB Rotterdam brent 18.6 per barrel, \$ 1 = 0.87 €; source DIMAH.
[c] The wheat-to-ethanol study takes into consideration economies of scale for plant capacity of 300 m^3 per day instead of 100 m^3 per day (Herbert, 1995). Sugarbeet-to-ethanol costs (mission Levy-Couveihnes Mai 2000, pers. comm.) are difficult to estimate due to overlappings among the ethanol, alcohol and sugar production processing industries. ETBE costs, rapeseed methyl ester (RME), mission Levy-Couveihnes Mai 2000, pers. comm.
[d] Cattle cake prices increased from 91.5 to 130 € t^{-1}, draff prices from 102 to 122 € t^{-1}, whereas glycerine costs fell from 457 to 381 € t^{-1}.
[e] 2000 brent \$ 28.11 per barrel.

Table 4
Minimal subsidisation of biofuels (oil and dollar price averages for 1992–2000)

	Biofuel value		Biofuel cost		Minimum tax exemption			Actual tax exemption
	€ t^{-1}	€ l^{-1}	€ t^{-1}	€ l^{-1}	€ t^{-1a}	€ l^{-1a}	€ l^{-1b}	€ l^{-1b}
ETBE wheat	177	0.13	390	0.29	213	0.16	0.36	0.50
ETBE sugarbeet	177	0.13	429	0.32	252	0.19	0.43	0.50
RME	157	0.14	454	0.40	297	0.26	0.26	0.35

[a] Regarding ETBE, chain results figure per t or l of ETBE.
[b] Regarding ETBE, chain results figure per l of ethanol.

clearly lower than the actual surface area cultivated by energy crops, which is due to the high levels of average yields resulting from the optimal localisation of production. In fact, the surface area harvested in 2000 approached 400 000 ha.[13] The model selects 58 800 arable farms, i.e. 72% of the 81 000 farms with the potential to participate in the biofuel program. Each farm cultivates 4 ha of energy crops on average. If the producers' price are equal to the opportunity cost (Table 2), there is an approximate 900 € increase in income per farm. The costs of biofuels are quite different, RME costs being higher than those of ETBE (Table 3). The direct costs of ETBE are 2.2–2.4 times higher than unleaded gasoline costs, whereas RME costs are 2.9 times more expensive than those for diesel fuel. These ratios decreased significantly in 2000 due to sharp increases of oil prices, when current rates are taken into account, to 1.1 and 1.6, respectively.[14]

[13] Source: ONIOL.
[14] Note that adjustments have also to be made to measure the effect of high oil prices on the biofuel production cost.

Costs include farmers' surplus and the economic incentive of 76 € ha^{-1}. Ethanol from wheat is produced in a plant with a 300 m^3 per day capacity. It is a fact that operating units in France actually run at one-third of this capacity. The industrial cost of ethanol from sugarbeet takes into account synergies among sugar, alcohol and ethanol industry. On the other hand, ester is produced in an integrated unit similar to the one actually operating in Rouen (120 000 t RME/year).

The cost of the agricultural resource is important for RME, which makes the chain sensitive to input cost variations. This cost is partly compensated for by co-product sales. Wheat-to-ETBE chain co-produces distilled dry grain solubles (DDGS), which are rich in proteins. The co-products of ETBE from sugarbeet (pulp, inferior wine) have a low market value, but their industrial costs are lower than those for ETBE from wheat co-products. The minimal subsidy required for biofuel industries to break even is presented in Table 4. Taking into account the aforementioned hypotheses (only efficient farmers produce), a minimum farm income of 76 € ha^{-1} as an incentive to the less efficient

Table 5
Benefit induced by the production of biofuel crops in € m^{-3}

	Farmers' surplus	Economic incentive	CAP savings	Total benefits
ETBE wheat	4.42	10.67		15.09
ETBE sugarbeet	4.27	3.96	22.41	30.64
RME	60.22	42.54		102.76

farmers, industrial costs, average oil prices and the dollar's average value for the period 1992–2000, differences between the actual and theoretical minimum subsidies vary between 0.07 and 0.14 € l^{-1} (see Table 4).

3.2. Induced economic benefit of the agricultural production of biomass for biofuels

Farmers' surplus[15] measures the total rent enjoyed by farmers producing at a cost lower than the opportunity cost of the least efficient farmer aggregates by energy crop are shown in Table 5.

The economic incentive, presented in the third column of Table 5, corresponds to the amount of 76 € ha^{-1} given to all farmers. Due to biofuel per hectare yields, this amount is more important for RME than for ETBE.[16]

Economies over set-aside subsidies exclusively concern sugarbeet to ethanol, since its production for energy reduces the amount of direct aids to the farm.[17]

Globally, induced economic effects are very important in relative terms, especially for the RME chain. The ETBE chain reaps benefit from the set-aside subsidies. The wheat-to-ETBE chain generates the least induced economic effects at the agricultural production level.

4. Profitability of biofuel chains in a stochastic environment using Monte Carlo simulation

4.1. Methodology

In this section we examine the robustness of public support schemes taking into account the uncertain environment in competitive markets of products and co-products of biofuel chains. Factors, that add uncertainty at various degrees such as petroleum price, are considered exogenous to the partial equilibrium model OSCAR. It seems important though to take into account this uncertainty in order to measure effects to profitability of variations of cost items and prices of the biofuel activities and consequently to determine unitary tax exemptions. For this purpose the Monte Carlo simulation method is used. This method consists in simultaneously varying model parameters and then running the model for each discrete set of parameters in search of the model variable values. The set of values related to selected variables resulted by a sufficient number of model optimisations gives us their frequency distribution. This approach differs from a simple sensitivity analysis as it allows for visualising variations and extreme values of model results depending on stochastic parameters, for simultaneous variation of all the critical model parameters. Given that biofuel chains are not profitable except in case of subsidy, it is important to examine the range of unitary tax exemptions related to each biofuel, in the form of frequency distributions of variables of interest generated, so that biofuel chains break even.

The principle of Monte Carlo sampling is based on the frequency interpretation of probability and requires a steady stream of random numbers. For continuous distributions we generate random numbers using the inverse transformation method. This method requires a cumulative distribution function (cdf) $f(x)$ in closed form and consists of giving to $f(x)$ a random value and to solve for x. Data from the simulation can be analysed using a terminating simulation approach. We make n independent replications of the model using the same initial conditions but running each replication with a different sequence of random numbers. If the measure of performance is represented by the variable X, this approach gives us the estimators $X_1 \ldots, X_n$ from the n replications (Winston, 1991). These estimators are used to develop a 100 (1-a) percent confidence interval as follows

$$\bar{X}(n) \pm t_{(n-1,a/2)}\sqrt{S^2(n)/n}.$$

For a fixed value of n, it returns the confidence interval for a population mean. The confidence interval is a range on either side of a sample mean.

[15] As previously explained, this surplus is generated during the transaction of the agricultural resource between farmers and the biofuel industry, due to the fact that industry is not able to differentiate among the prices of energy corps for such a large number of farmers. In order to have a zero surplus, industry should offer each farmer its specific price. This is practically impossible due to the large number of farmers involved in the process.

[16] On the basis of the average yields shown in Table 4, RME production per hectare reaches 1.75 m^3, that of wheat-to-ETBE 7.14 m^3, and that of sugarbeet-to-ETBE 18.77 m^3 (0.59 m^3 of ethanol per t ETBE).

[17] Unlike wheat and rapeseed energy crops, sugarbeet for ethanol production does not enjoy any CAP subsidy, which saves the EU budget 425€ per hectare of sugarbeet cultivated surface.

Table 6
Cost structure of ETBE from wheat and sugarbeet chains (€/hl)[a]

Biomass input	Wheat	%	Sugarbeet	%
Material input cost (€/hl)	14.2–16.3	17–19	15.4–17.8	20–22
Harvesting transport (€/hl)	4.9		5.33	
Distillation (€/hl)	31.4		22.4	
Transport, deshydratation (€/hl)	1.83		2.28	
Anhydrous ethanol cost (€/hl)	52.3		45.4–47.9	
Anhydrous ethanol cost (€/t)	306.25	55–56	266–280.3	59–60
Iso-butane cost (€/t)	88.1		88.1	
Operational cost (€/t)	44.4		44.4	
Fixed cost (€/t)	56		56	
Total cost ETBE (€/t)	494.7–507.2	100	454.6–468.8	100
Co-product value (€/t)	71.7	11		

[a] Costs estimation based on Levy–Couveihnes report (2000), personal communication.

Table 7
RME cost structure (€/hl)[a]

Base	Rouen type esterification unit
Material input cost	29.27
Collection	5.03
Grinding	6.71
Esterification	11.52
Transport ester	0.40
Transformation cost	23.78
Total cost	76.68
Co-product value (cakes and glycerine)	15.55 or 20% of total cost

[a] Costs estimation based on Levy–Couveihnes report (2000), personal communication.

4.2. Data set in the context of the case study

As biofuel quantities commercialised in France are negligible (about 1.5%) compared to fossil fuel aggregate consumption, it seems reasonable to suppose the prices of RME and ETBE are related directly to gasoline and diesel. These latter depend on brent petroleum Rotterdam price. Fossil fuels are used, on the other hand, as input for the production of biofuels as methanol (esterification process) and iso-butane (IC4) reacting with ethanol to produce ETBE. Especially iso-butane is a significant cost component of ETBE, counting approximately for 19% of ETBE from wheat and for 20% of ETBE from sugarbeet (Table 6). Thus, full direct impacts of oil price variation in the Rotterdam market are considered related to sales, but also to cost items of biofuel activity.

We observe also that the market value of co-products of the biofuel production, such as rapeseed cakes, glycerine and DDGS, contribute much to the profitability of the activity (Table 7). Cakes are sold for feedstock where soja cake is the product of reference, its price being cleared in the world market.

Using time-series of monthly data for a 3-year period, we estimated ETBE and RME price relationship to brent prices, that as an independent variable explains well variations of the depended variables (with an R^2 over 92%).

$$p_{etbe} = \underset{(4.58)}{23.6} + \underset{(20.92)}{6.278} p_{brent} \quad R^2 = 0.925, \tag{1}$$

$$p_{rme} = \underset{(4.59)}{29.75} + \underset{(22.15)}{5.727} p_{brent} \quad R^2 = 0.939, \tag{2}$$

$$p_{methanol} = \underset{(3.99)}{45.07} + \underset{(7.19)}{4.024} p_{brent} \quad R^2 = 0.633, \tag{3}$$

p_{etbe}, p_{rme}, $p_{methanol}$ in FF/hl, p_{brent} in \$/barrel.

Prices of RME estimated by (1) and (2) are adjusted by the relative efficiency ratio of RME vs. diesel in terms of km per litre and then inserted to the model.[18]

$$p'_{rme} = p_{rme} r_{eff} \quad p'_{rme} : p_{rme} \text{ adjusted by } r_{eff} = (0.072/0.069) \text{ efficiency ratio RME vs. diesel.}$$

Concerning by-products which are destinated to the feedstock markets, it has been attempted to estimate their relationships to the exogenous variable 'soja cake price'. For this purpose, data series (T. soja 48 Rotterdam in \$/t, T. rapeseed 00 Métropolitaine Dieppe, DDGS Maize DdB Ports Ouest-proxy for wheat-to-ethanol DDGS, January 1991–November 2000, CEREOPA)[19] have been used on a 3-month basis. The explained part of dependent variables applying linear regression to soja cake price is acceptable with R^2 coefficients of about 50%. Linear regression parameters are significant at a 5% probability level as shown below (t-student estimates in parentheses).

[18] Calculations are based on fuel efficiency factors biodiesel/diesel price = 0.0721 km^{-1} biodiesel/0.0691 km^{-1} diesel, Vollebergh, 1997).

[19] Database maintained by Lapierre and Pressenda (2000), research team CEREOPA.

Table 8
Statistics of brent petroleum price and soja cake international market price

	Price brent 1998–2000	Soja cake Rotterdam 1991–2000
Mean	18.815	223.8
Standard deviation	7.00	45.73
Maximum(1)	33.14	310
Minimum(1)	9.82	150
Confidence level (95.0%)	2.44	15.71

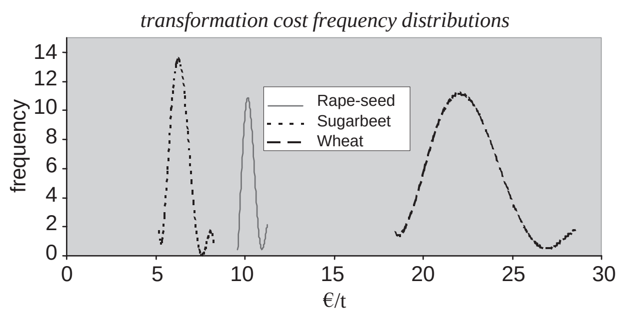

Fig. 3. Frequency distribution of transformation costs by biofuel chain.

$$P_{cakes} = \underset{(10.09)}{65.55} + \underset{(5.18)}{0.147}\, p_{soja} \quad R^2 = 0.448, \tag{4}$$

$$P_{DDGS} = \underset{(3.82)}{33.18} + \underset{(6.69)}{0.254}\, p_{soja} \quad R^2 = 0.575$$

$$P_{cakes}, P_{DDGS}, \text{ in FF/q}, p_{soja} \text{ in \$/t}. \tag{5}$$

Concerning fossil fuel used as input in the processes of biofuel production there are no price series available. For this reason, iso-butane price is linked to ETBE price and methanol price to brent on a pro-rata basis. Glycerine is supposed to be sold in a stable market so it is considered constant.

In this example, brent and soja cake prices are supposed to vary according to the normal distribution function. By generating random numbers normally distributed, specified for the parameters (using averages and standard deviations) of Table 8, one can determine frequency distributions of biofuels and by-product prices as well as transformation costs (Figs. 3 and 4).

If we relate these (product and by-product prices as well as production costs) to oil and soja prices, in other words append to the model relationships (1)–(5) and solve the model parametrically varying those exogenous prices, results will indicate the profitability variance of the biofuel chains and consequently minimum tax exemption levels required to support them for viability (Fig. 5).

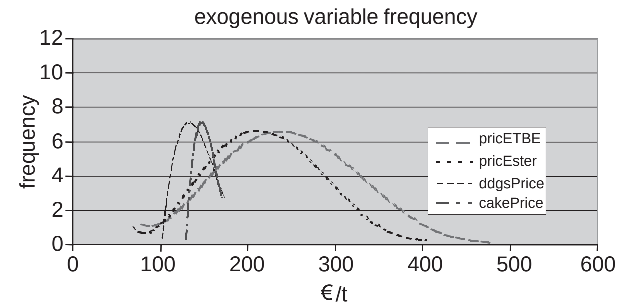

Fig. 4. Frequency distribution biofuel processes' product and by-product prices.

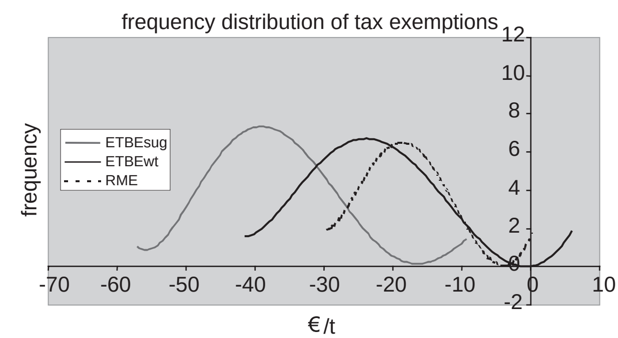

Fig. 5. Frequency distributions of required subsidies by biofuel to attain viability.

Table 9
Current and minimal tax exemption levels (€ h l^{-1})

	RME	Sugarbeet ethanol	Ethanol wheat
Current tax exemptions	34.9	50.0	50.0
Average deficit	18.4	38.1	23.5
Standard deviation	6.3	9.5	9.9
Maximum value	20.6	41.5	27.0
Minimum value	16.1	34.7	20.0

4.3. Results and discussion

OSCAR model is solved optimising global surplus assuming that quantities to produce from each biofuel are fixed at the 2002 predicted levels. It allocates agricultural energy crops to set-aside land optimising farmers' surplus and determines the opportunity cost of biomass resource and of biofuels. Public decision makers would be interested to find average unitary tax exemptions (Table 9) but also to examine the worst conjunctural impacts (when all exogenous factors simultaneously take the less favourable values to biofuels). What would be, in that case, tax exemption minimal requirements and will this amount always be lower than Interior Tax on Petroleum Products?[20]

[20] Current tax exceptions to biofuels in France are calculated as a percentage of ITPP rates (about 90%).

Table 10
Energy crop cultivated surfaces and biofuel production in France in the period 1993–2001

Hectares	1993	1994	1995	1996	1997	1998	1999	2000	2001
Rapeseed	36 478	177 569	325 331	209 506	154 664	150 586	306 054	301 414	272 084
Sunflower	1381	24 763	37 632	32 387	37 361	33 138	59 071	58 732	49 926
Wheat ethanol	7724	7673	8835	12 033	10 427	12 797	18 186	16 299	13 885
Sugarbeet ethanol	—	643	6251	10 182	12 476	8097	7666	7342	6854
Total biofuels	45 583	210 648	378 049	264 108	214 928	204 618	390 977	383 787	342 749
Other industrial crops	27 300	53 022	29 973	17 886	15 398	21 251	39 994	30 452	23 637
Total industrial crops									
	72 883	263 670	408 022	281 994	230 326	225 869	430 971	414 239	366 386
Biofuel consumption in France, t									
RME	7809	64 425	153 588	216 858	251 420	226 096	246 484	308 632	
Ethanol	27 525	38 518	37 931	60 340	83 374	97 907	90 853	92 548	

Source: Les Cahiers de l'ONIOL, October 2001.

Table 11
Biofuel production capacity in France and projection to 2002–2003

	Production ETBE in t			Production RME in t	
	1998	2002		1999	2002
Plant sites			Plant sites		
Feyzin	85	85	Rouen (Haute Normandie)	180	280
Dunkerque	65	65	Compiegne (Oise)	60	60
Gonfreville	70	70	Boussens (Haute Garonne)	33	33
Fos-sur-mer	9		Verdun (Meuse)	33	33
La Mède + Donges		155	Leer (Germany)	10	10
Totals	230	375		316	416

Source: specialised press, AgraValor, EuropeAgro.

Results confirm that average values of the population of unitary tax exemption levels do not, in any case, become higher than 40 €/hl. The chain sugarbeet-to-ETBE, that is the less performant, deficit per litre exceeds actual tax exemption level set at 50 € hl^{-1} with 95% probability. There is statistical evidence that other chains do require less than 19 € hl^{-1} for biodiesel and less than 24 € hl^{-1} for wheat-to-ETBE, which confirms the idea that tax exemption levels could be adjusted downwards without any significant risk for the viability of the system.[21]

5. Conclusions

OSCAR is a partial equilibrium model that allows for a comprehensive micro-economic analysis of biofuel production system in France applying an integrated (chain oriented) and systemic (multi-chain optimisation) approach. It can be used for economic analyses taking into account micro-economic realities but also for multi-criteria and environmental policy analysis. Data used by this model are highly detailed and allow for the implementation of parameterisation of technical and economic coefficients.

Firstly, marginal cost of biofuels resulting from the minimisation of the agricultural resource costs of production, to the horizon 2002, have been estimated. This minimisation is extremely important for the RME chain because of the weight of the agricultural input on the total biofuel cost. ETBE cost has been estimated at 0.29–0.32 € l^{-1} and RME cost at 0.40 € l^{-1}. The agricultural resource is produced at least cost by the most intensive farms, which makes the optimal surface proposed by the model to be cultivated by energy crops to be lower than that currently cultivated by these crops. Optimisation of industrial costs is treated in less detail due to insufficient available information at this moment. Results mentioned here should not lead to premature conclusions on the relative interest of particular chains. Nevertheless, minimal subsidy estimations (equal to deficits of biofuels chains by unit of product) are

[21] It has to be noted at this point that in the beginning of 2003, a reduction of subsidies to ethanol is decided according to Levy–Couveihnes report suggestions to 0.38€/l of ethanol (report commanded by the prime minister (Lionel Jospin) in order to respond to farmers'demands to the Ministry of Agriculture for increasing biofuel production. It is kept confidential supposedly because its authors conclusions. It can be considered the most complete report regarding the biofuel economics).

Table 12
Biofuel production by crop and hectare of cultivated land

Technical coefficients of biofuel chains	Chain		ETBE		ETBE		RME	
			Sugarbeet		Wheat		Rapeseed	
	Input	Output	Input	Output	Input	Output	Input	Output
Production stages								
Agricultural production—energy crop first stage of transformation	Land (ha)		1		1		1	
		Biomass (t)		83		9		3.9
	Biomass (t)		83		9		3.9	
Distillation (ethanol)		Ethanol volume (hl[a])		83		32		
		Ethanol (t)		6.8		2.6		
		DDGS (t)[b]			3.8	3.8		
Trituration—grinding		Rapeseed oil (t)						1.56
		Cakes (t)						2.18
Second stage of transformation								
Production ETBE	Ethanol (hl)		83		32			
	Iso-butane (t)		8.2		3.1			
		ETBE (t)		14		5.3		
		ETBE volume (hl)		187		60		
Transesterification	Rapeseed oil (t)						1.56	
	Méthanol (t)						0.156	
		Glycerine (t)						100
		RME (t)						1.56
		RME volume (hl)						17.7

[a] hl = 100 l.
[b] DDGS, Distillers Dried Grain Solubles.

available, depending on oil and dollar prices, to be justified by macro-economic effects and by positive externalities generated by the biofuel activity.

In order to deal with uncertainty introduced by oil, dollar and feedstock market fluctuations, Monte Carlo simulation has been used to search for efficient tax exemption policies in an uncertain environment, where biofuel chain profitability is significantly affected by petroleum price and feedstock cake prices. Results suggest that, for the most efficient units both at the industry level (large size biomass conversion units) and at the agricultural sector level (most productive farms), unitary tax exemptions could be decreased by 10–20% for both biofuels, ethyl ester and methyl ester, with no risk for the viability of any existing chain.

Appendix

Biofuel production statistics are provided in Tables 10–12.

References

Bard, J.-F., Plummer, J., Sourie, J.-C., 2000. A bilevel programming approach to determine tax credits for biofuel production. European Journal of Operational Research 120, 30–46.

Brooke, A., Kendrick, D., Meeraus, A., Raman, R., 1998. General Algebraic Modeling System, A User's Guide. GAMS Development Co., Washington.

Costa, S., Requillart, V., 2000. Evaluation publique de la production des bio-carburants. Application au cas de l'ester méthylique de colza. Economie et Prévision, 142-1, 27–46.

Herbert, V., 1995. Analyse technico-économique de la production d'éthanol carburant de blé, Mémoires et thèses, no. 13, INRA ESR Grignon.

Houdayer, R., 1999. Evaluation Financière des projets. Economica, Paris.

Lapierre, O., Pressenda, F., 2000. Evaluation des conséquences de l'arrêt des incorporations de produits d'origine animale dans les formules d'aliments composés, Prospective aliment, CEREOPA, URL: www.inapg.inra.fr/ens_rech/dsa/cereopa/

Lévy, J.D., Couveihnes, P., 2000. Evaluation des coûts des filières biocarburants et perspectives pour l'avenir. Conseil général du GREF et Conseil général des Mines (unpublished).

Levy, R.H., 1993. Les biocarburants. Ministère de l'Industrie et du Commerce extérieur, France.

Mavrotas, G., Rozakis, S., 2002. A mixed 0-1 MOLP approach for the planning of biofuel production. In: Rozakis, S., Sourie, J.-C. (Eds.), Comprehensive Bio-energy Modelling, Options Méditerranéennes, Série A, no. 48, pp. 47–58.

Rozakis, S., Sourie, J.-C., 2002. Micro-economic modelling of the biofuel chain system in France. In: Rozakis, S., Sourie, J.-C. (Eds.), Comprehensive Bio-energy Modelling, Options Méditerranéennes, Série A, no. 48, pp. 23–33.

Rozakis, S., Sourie, J.-C., Vanderpooten, D., 2001. Integrated micro-economic modeling and multi-criteria methodology to support public decision-making: the case of liquid bio-fuels in France. Biomass and Bioenergy 20-5, 385–398.

Sourie, J.-C., 2000. Contributions aux travaux de la mission Biocarburants JD Levy, P Couveihnes, unpublished document, INRA ESR Grignon.

Sourie, J.-C., 2002. Agricultural raw materials cost and supply for biofuel production: methods and concepts. In: Rozakis, S., Sourie, J.-C. (Eds.), Comprehensive Bio-energy Modelling, Options Méditerannéenes, Series A, no. 48, 1–23.

Sourie, J.-C., Hautcolas, J.-C., Bonnafous, P., 1997. Un bilan micro et macro-économique des biocarburants et les perspectives de réduction des coûts. Actes du colloque Agrice, pp. 49–57.

Vollebergh, H., 1997. Environmental externalities and social optimality in biomass markets. Energy Policy 25 (6), 605–621.

Williams, H.P., 1999. Model Building in Mathematical Programming. John Wiley & Sons.

Winston, W.L., 1991. Operations Research: Applications and Algorithms. Duxbury, California.