FUNDING FOR UNIVERSAL SERVICE OBLIGATIONS IN ELECTRICITY SECTOR : THE CASE OF GREEN POWER DEVELOPMENT

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Funding for Universal Service Obligations in Electricity Sector : the case of green power development

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Abstract

The process of deregulation in network industries, in particular in the electric sector, raises the problem of financing the Universal Service Obligations (USO) corresponding to the production, transport and distribution operations. In this paper, we study three ways of funding for an USO of production, especially the "green" electricity development: the financing with cross-subsidies, the implementation of a fund (financing by a tax) and finally a voluntary funding system by direct subscriptions of consumers. We notably show that this last one Pareto dominates mostly, from a welfare point of view, the other scenarios.

Key words : Electricity, Environment, Regulation, Network, Universal Service,
JEL Codes : D4, L5, L94, Q4.

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1 Introduction

With regard to the Kyoto Protocol, environmental issues seem to be more preoccupying and populations are more and more concerned with all these questions. The environment is a public good (non excludable and nonrivalrous) then the market is quite inefficient. So it is necessary to consider some regulations specially funding systems for supply of green products. In the specific case of renewable-generated electricity, this issue have been addressed (particularly in Europe) in relation to public policy concerning Universal Service Obligations.

So in this introduction, we would like to address the question of funding for the promotion of renewable-generated electricity and the magnitude of the consumer's willingness to pay for green electricity with respect to this problem.

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1.1 The question of funding for the promotion of renewable-generated electricity

The process of deregulation in network industries (telecommunications, electricity, gas, transportation, etc. ..) arises some questions about the new types of regulation, pricing mechanisms, market structures, etc... In these network utilities, the regulator imposes Universal Service Obligations (USOs) to fulfil some equity principles; on previous regulated markets, monopolies were in charge with theses USOs. The transition towards a more competitive regime, arises the relevant question of allocating and funding for these USOs.

In this general framework, our article focuses on the deregulation process in electricity market and specially, on the funding for USOs imposed in this sector. More precisely, our paper is restricted to the funding of a particular USO : the development of green electricity. In some countries, the promotion of a cleaner electricity is becoming a major concern and the new regulations in electricity sector integrate these environmental features. In many countries, "classical" measures are adopted to prioritize renewable energy : tax exemptions, subsidies for green power investments,... The promotion of electricity from renewable energy sources is a high priority of the European Community. Increased use of green electricity is one of the cornerstones in a package of measures that the Union must take to fulfil the international obligations (obligations relating to the countering of climate change, notably in the Kyoto protocol). The aim of the Community is to raise the percentage of renewable energy in the total energy supply from the current 6 % to 12 % by 2010. In this light, the Commission has adopted a proposal for a draft Council and Parliament Directive on common rules for supporting renewable-generated electricity.

Under those circumstances, the aim of our paper is to point out mechanisms of funding for the particular USO consisting in the promotion of renewable-generated electricity. In this way, our paper compares three ways of funding for this USO:

- firstly, the overcost of renewable-generated electricity could be financed by way of the classical cross-subsidies mechanism;

- secondly, this overcost could be financed by means of a fund responsible for the recovering of charges induced by the production of renewable-generated electricity (all suppliers finance the fund with the payment of a tax in proportion to the volume of electricity generated);

- thirdly, the overcost could be paid directly by consumers that are willing to pay an amount more per month on their electricity bills for power from renewable sources.

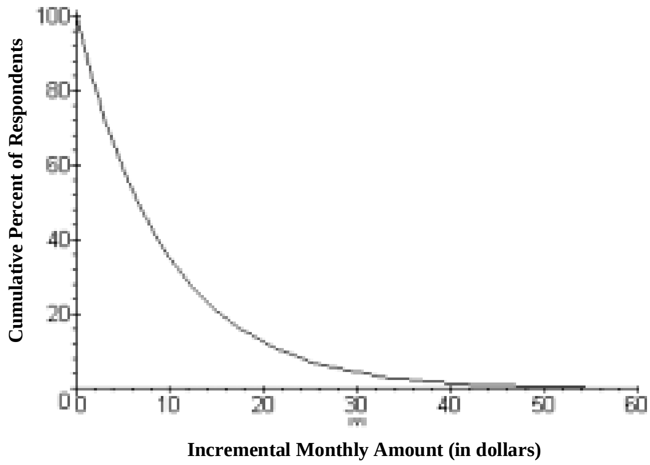
1.2 The willingness to pay (WTP) for green electricity

The third mechanism of funding for the promotion of green electricity begin to be experimented in many countries through the development of green electricity markets. On such markets, consumers have the possibility to pay more for the purchase of a "green electricity". In fact, the electricity consumers have to pay an additional amount of money for a product which continues to have the same uniform quality as before. Nothing changes at the power of individual consumers. "Green consumers" seem to be directly concerned about the state of environment and attach a great importance to the ecological impact of their electricity consumption. In this light, they are willing to pay more[1] for the promotion of green electricity; this extra charge represents their contribution to the reduction of environmental impact from the electricity sector . The willingness to pay of environmentally conscious consumers has been analyzed in may countries. For example, in USA, the data collected in 14 different surveys (conducted in 1995 through 1997 in five Western/Southwestern States, see Farhar B. 1999) reveal that:

- Majorities of 52% to 95% of residential customers are willing to pay at least a modest amount more per month on their electricity bills for power from renewable sources;

- Willingness to pay follows a predictable pattern with an average majority of 70% willing to pay at least \$5 per month more for electricity from renewable sources, 38% willing to pay at least \$10 per month more, and 21% willing to pay at least \$15 per month more.

It is likely that any utility market survey will obtain results similar to those represented by the curve below :



The equation for the curve is $Y=100e^{-0,104M}$
where Y=cumulative percentage of respondents and M=\$ more per month
$R^2=0,76$

Fig.1. Agregated Willingness-to-Pay Curve

Other surveys conducted in many countries in Europe give similar results; Wüstenhagen R., Markard J. and B. Truffer (2000) give the results of market research studies from the city of Zürich, which show much higher Willingness to Pay than customers in the UK or German markets:

[1] This green pricing could be perceived as being very close to donation programs.

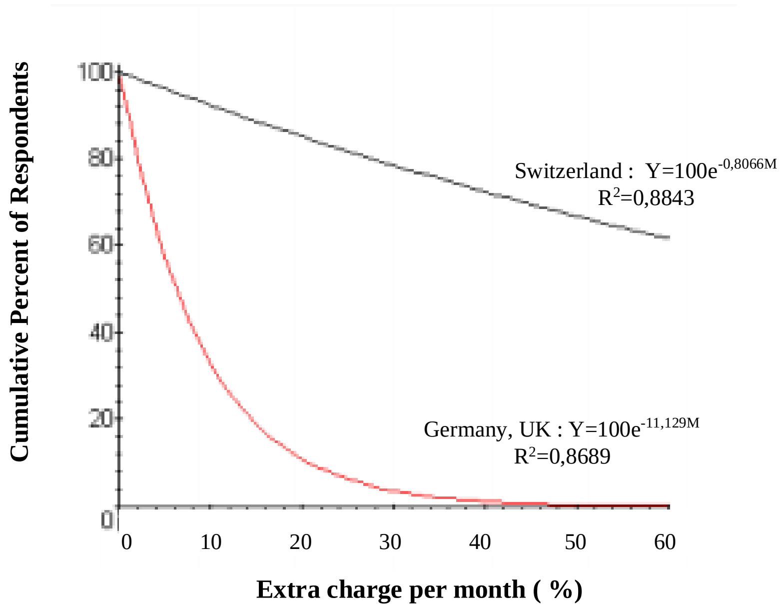


Fig.2. Willingness-to-pay for green electricity

In contrast to the high willingness to pay of customers, actual participation rates are much lower in current pricing programs. B. Truffer (1998) showed in a comparison of green pricing schemes world wide, that currently about 0,1 and 3,5% of the households are participating in the respective market areas. Nevertheless, with the adoption of targeted policies, these green markets could be rapidly developed (see B. Truffer 1998).

1.3 Framework and schedule of work

The three mechanisms of funding mentioned above will be discussed in our paper in the framework of standard network models (see for example Armstrong J., Doyle C. and Vickers J. 1996). Initiated by the economic analysis of David L. and Mirabel F. (2000) about regulation mechanisms in the context of third party access on gas network, the structure of our model is similar: two firms (an incumbent firm and an entrant firm) compete for the electricity market; the incumbent is responsible for the distribution of green electricity (considered in our paper as a Universal Service Obligation). Compared with the papers of Chone P. and alii (1999) and Mirabel F. and Poudou J-C. (2000), the segmentation of demand between "green consumers" and "classical consumers" constitutes the originality of our analysis: "green consumers" are willing to pay more in order to contribute to the development of renewable-generated electricity. In this light, the voluntary payment for green electricity constitutes a new way of funding for the "green USO".

In that case, the outline of the paper is as follows. In section 2, we draw the structure and notation of the model. In section 3, we justify (in term of welfare) the setting of rules for the development of green electricity. We investigate the classical mechanisms of funding for "green USO" in following sections (funding through cross subsidies mechanism in section 4 and funding through the taxation mechanism in section 5). The section 6 focuses on the voluntary payment of "green consumers". Section 7 contains some concluding comments concerning potential extensions of our model.

2 The model

2.1 The consumers

On electricity market, the utility functions of consumers are quasi-linear with respect to others goods consumed. The electricity consumption induces an utility increase, but the electricity generation causes environmental damages. Moreover, we assume that utility functions are increasing with respect to environmental quality (a positive externality[2]). Nevertheless, in this economy there are technological possibilities to produce some electricity without damaging environment. By simplification, we shall suppose that the quality of the environment is positively correlated to the share of the green electricity in the total production. This green electricity is supposed to be more expensive to produce, so it must be subsidized either by the regulator (the government) or directly by the consumers through a voluntary agrement. Assuming that the quantity of electricity consumed affects the level of utility in a quadratic way $u(q) = (1-q)\,q$, the utility function of a given consumer h is :

$$U_h\left(q_h, e_h, m_h\right) = u(q_h) + \theta_h \beta\left(\sum\nolimits_k e_k\right) + m_h.$$

For a given consumer h, q_h is the consumption of electricity, e_h the contribution to the production of green electricity, m_h the quantity of the numeraire commodity which she possesses and $\theta_h \in \{1, \theta\}, \theta > 1$, her preference parameter for the quality of the environment. In the model, the endogenous function $\beta(\cdot)$ represents the share of green supply in the total production of electricity. We assume that there are two consumers in this economy: the consumer who is "little worried about the quality of the environment" ($\theta_1 = 1$), and the other who is more ecologist ($\theta_2 = \theta > 1$). Besides, we suppose that information is perfect and complete, notably that all the agents are informed about preferences.

If p is the price for kWh of electricity, the optimal decision of a consumer h consists in choosing her bundle (q_h, e_h) under her budget constraint ($R_h \geq pq_h + e_h + m_h$), what means resolving:

$$\max_{\{q_h>0, e_h \geq 0\}} u(q_h) + \theta_h \beta\left(\sum\nolimits_k e_k\right) - pq_h - e_h.$$

Because of the separability of U_h, straightforwardly we have the electricity demand functions, for all h

$$u'(q_h^*) = p \Leftrightarrow q_h^*(p) = q(p) = \frac{1-p}{2} \text{ if } p < 1.$$

So the aggregate demand for electricity is $Q(p) = 2q(p)$, and the inverse aggregate market demand:

$$p = 1 - Q \equiv P\left(Q\right). \tag{1}$$

[2]See J. Greenwood and P. McAfee (1991) for a more general framework.

Moreover, if the agent h's subscription is feasible from an institutional point of view, her optimal level of subscription is such that:

$$\begin{cases} \theta_h \beta' \left(e_h^* + e_{-h}\right) - 1 \leq 0 \\ \theta_h \beta' \left(e_h^* + e_{-h}\right) - 1 = 0 \text{ si } e_h^* > 0. \end{cases}$$

Right now, one can see that for any derivable function $\beta(\cdot)$, the optimal pair of subscriptions $(e_1^*, e_2^*) = (0, e)$, $e \geq 0$, is a Nash equilibrium of the game between the consumers[3], where e is such as:

$$\begin{cases} e > 0 \Leftrightarrow \beta'(e) = \frac{1}{\theta} \\ e = 0 \Leftrightarrow \beta'(0) \leq \frac{1}{\theta} \end{cases} \tag{2}$$

In that case, the individual surpluses write:

$$\begin{aligned} CS_1(p) &= u(q(p)) - pq(p) + \beta(e) \\ CS_2(p) &= u(q(p)) - pq(p) + \theta\beta(e) - e \end{aligned}$$

and the consumers surplus is given by:

$$\begin{aligned} CS(p,e) &= 2\left[u(q(p)) - pq(p)\right] + (1+\theta)\beta(e) - e \\ &= \frac{1}{2}(1-p)^2 + (1+\theta)\beta(e) - e \end{aligned} \tag{3}$$

On the other hand, if any subscription is not feasible from an institutional point of view[4], it comes:

$$CS(p,0) = \frac{1}{2}(1-p)^2 + (1+\theta)\beta(0) \tag{4}$$

2.2 The industrial structure

The supply of electricity to the customers is based on two different technologies. A traditional or fossil production (thermic plants) and one based on little polluting energy sources (wind energy, photovoltaic solar energy), that we will qualify as green production. Their respective costs are denoted $c_f(q)$ and $c_g(q)$ for q kWh supplied. In any case, technologies are common knowledge and none of the producers has some power on the market of inputs. The cost functions in every sector (i.e. $c_f(q)$ and $c_g(q)$) are the same for all the producers. In fact in our model, electricity is supplied by two firms, the historic monopoly denoted by M and the "entrant" firm indexed by E. We note $\alpha^M \in [0,1]$ (respectively α^E) the share of green production in the total production

[3] We assume here that the decentralization of their subscription decisions leads the consumers to play in a noncooperative way. Naturally, this equilibrium with free-riding is Pareto sub-optimal. In a first step, we also ignore indirect effects on electricity consumption *via* prices.

[4] That is ex ante $e_h \equiv 0, \forall h$.

of the historic monopoly (resp. the entrant). The total cost function of the historic monopoly and that of the entrant are:

$$\begin{cases} C^M\left(q^M\right) = c_g\left(\alpha^M q^M\right) + c_f\left((1-\alpha^M)q^M\right) \\ C^E\left(q^E\right) = c_g\left(\alpha^E q^E\right) + c_f\left((1-\alpha^E)q^E\right) \end{cases} \tag{5}$$

These firms compete in quantity (or in capacity); however considering his history in the industry, the monopoly is supposed to be the Stackelberg leader of the competition game. From now we normalize the production cost of the electricity from fossil energy to zero. Furthermore we suppose that the production cost of the green electricity is linear and equals kq. So we have the system (5) can be written as:

$$\begin{cases} C^M\left(q^M\right) = \alpha^M k q^M \\ C^E\left(q^E\right) = \alpha^E k q^E \end{cases}$$

For a price p for the kWh delivered to the consumers, the profits of the firms are given by:

$$\pi^E\left(q^E\right) = pq^E - C^E(q^E) = pq^E - \alpha^E k q^E \tag{6}$$

$$\pi^M\left(q^M\right) = pq^M - C^M(q^M) = pq^M - \alpha^M k q^M \tag{7}$$

If $Q(p)$ is the demand of electricity, the industry surplus is then:

$$\begin{aligned} PS(p, q^M, e) &= \pi^M\left(q^M\right) + \pi^E\left(q^E\right) \\ &= pQ\left(p\right) - k\left(\alpha^E q^E + \alpha^M q^M\right) \end{aligned} \tag{8}$$

2.3 The game structure

Because of sequential interdependence of the firms and consumers decisions among, the game so formed takes place in four stages:

1. If it is feasible from an institutional point of view, the consumers decide on the level of their subscriptions e_h according to the share of green electricity in the total production. If the total production of the industry is $Q = q^M + q^E$, as we mentioned before, this ratio is noted:

$$\beta = \frac{\alpha^M q^M + \alpha^E q^E}{Q} \in [0, 1]\,. \tag{9}$$

2. The incumbent determines his supply of electricity q^M and his share of green production, α^M.

3. The entrant determines his supply of electricity and his share of green production α^E

4. The consumers determine their optimal consumption of electricity.

The fourth stage of the game being resolved by the existence of the demand, -see (1)-, the backward induction initializes only in the third stage.

2.4 Universal service obligations

Without addressing here the question of the USO allocation, we suppose that the electricity sector regulator, appointed by the government, imposes a USO of green electricity production (or buying) which lies on the incumbent. To simplify[5], the proportion of the monopoly green production, α^M is then fixed by the regulator to an exogenous value $\alpha^M = \alpha$ and logically, the same share to the entrant firm is not regulated and fixed to $\alpha^E = 0$.[6]

The regulator also determines funding schemes for the USO. Those will be clarified in the following sections. In any case, the objective of the regulator is to maximize social surplus under budget balanced constraint of the historic monopoly. From (3) and (8), the collective surplus writes:

$$W(p, e, q^M) = CS\,(p, e) + PS\left(p, q^M, e\right) \tag{10}$$

3 Relevance of Green USOs

In this section, we show that from a strict economic point of view, green production USO's levy is justified. Indeed, theses USOs can be seen as an answer to the standard dilemma between social and private logic: firms are not ready to produce too expensive green electricity while public rationality requires it.
To illustrate it, we analyze the production choices of electricity (q) and of green electricity (α) when:

1. the industry in question is integrated and administered in the name of social welfare.

2. the industry is a private and integrated monopoly

First of all, let's assume that the industry is integrated and administered by a benevolent planner, head and director of a public company. He maximizes the collective surplus under the constraint that the industry profit PS is non negative (the so-called break-even constraint). Institutionally, the consumers cannot directly subscribe to the improvement of the environment quality, that is they are not able to put up the money for the green electricity generation, so $e_h \equiv 0$, $\forall h$. According to (3), (8), (9) and (10) , social welfare is given by:

$$\begin{aligned} W(P\,(2q)\,, 0, 2q) \;\; &\equiv \;\; W^s = 2\,[u(q) - P\,(2q)\,q] + (\theta+1)\,\beta\,(0) + 2\,[P\,(2q)\,q - \alpha k q] \\ &= \;\; 2\left[(1-q)\,q + \frac{(1+\theta)}{2}\alpha - \alpha k q\right] \end{aligned} \tag{11}$$

The planner looks so for the couple (q, α) which maximizes W^s under the constraint $PS^s \equiv 2\,[P(2q)q - \alpha k q] \geq 0$. Let $\alpha^s = \arg\max_{\alpha\in[0,1]} W^s$, then if $\theta > k$, $\alpha^s > 0$, because W^s is convex

[5] However as we mentioned in introduction, this assumption seems rather go together with the obligation of purchasing green electricity prescribed to the incumbent operator only.

[6] This choice is also the rational one of the entrant because $\forall q^E, q^M \geq 0$, $\partial\pi^E\left(q^E\right)/\partial\alpha^E = -kq^E < 0$, so $\alpha^{E*} = 0$.

in α[7]. The efficient environmental regulation is drawn in the following figure (the problem is solved into appendix B[8])

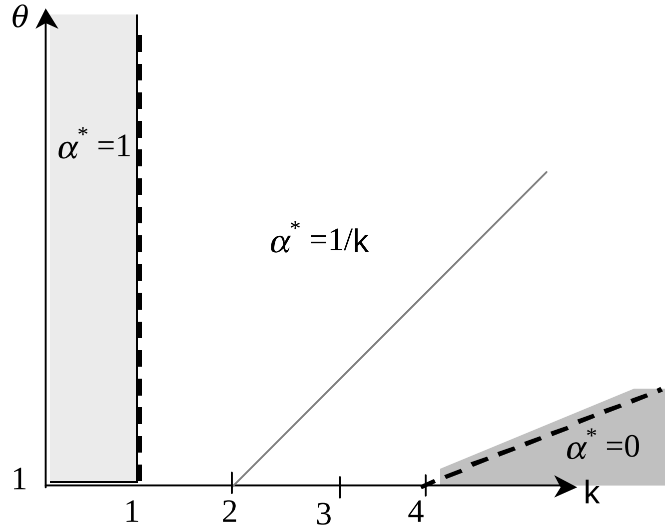


Fig. 3. Optimal solution in the (θ, k) plane

Those three previous areas are according to intuition:

- for very low green costs ($k < 1$), it is socially optimal to enforce "all green" incumbent production ($\alpha^s = 1$)
- for very high green costs ($k > 4$) and very low level of the preference parameter for the quality of the environment $\left(\theta < \frac{k}{2}\right)$, it is socially optimal not to produce green electricity $(\alpha^s = 0)$,
- in-between, α^s is all the greater that k is low.

In fact there is a relevant trade-off: the loss of productive efficiency brought about by the use of the corresponding productive capacities is to be compared to the earnings in consumer surplus attributable to the environment quality improvement. If the latter dominates the former, some green electricity has to be produced.

Let us now suppose that the state-owned firm is privatized and becomes, without any extra cost, an integrated and private monopoly. The integrated monopoly determines the couple which maximizes the profit PS^s. The solution (see also appendix B) is readily $\alpha^M = 0$ that is no green electricity is produced.

Proposition 1 If consumers cannot subscribe and if $\theta > k$, then it is socially optimal to produce some green electricity ($\alpha^s > 0$) whereas it is not optimal to make it for a private and integrated monopoly ($\alpha^M = 0$).

[7] This condition is sufficient but not necessary.

[8] Appendices are available upon request. They can be also downloaded on www.creden-montpellier.com.

Without any surprise, the optimal choices of society and private firm diverge, the same holds for the related environmental impacts. The planner internalizes the environmental externalities but not the private monopoly, this leads to the result. One concludes from it that in the situation of opening to competition and if the consumers are not directly involved in this choice, the production of green electricity will have to be ensured only using regulatory tools (in this case the regulation of the share of green generation): it is the origin of the USOs which fall on the incumbent. Afterwards, we will suppose that the share of green production is strictly positive and exogenous in the model, that is to say it is arbitrarily fixed by the regulator to the level $\alpha \in]0,1[$.[9]

4 Cross-subsidization and taxation funding

4.1 The cross-subsidization scenario

In a first scenario, we study the case without specific scheme of funding for the USOs. Clearly, this is equivalent to a system of funding by cross-subsidies. Here again, the consumers cannot subscribe, so exogenously $\forall h, e_h = 0$.

The sequential game timing (see. also p 7) is reduced to two stages:

1. The historic monopoly determines its level of output q^M
2. The entrant chooses the level of output q^E competing à la Cournot with M

We solve this game using backward induction (in order to find a subgame perfect equilibrium) and we find for this scenario (see appendix C):

- if $\alpha k > \frac{1}{2}$,

$$\begin{aligned} \widehat{q}^M &= 0, \widehat{q}^E = \frac{1}{2} \\ \widehat{\beta}(0) &= 0 \\ \widehat{W} &= \frac{3}{8} \end{aligned}$$

- if $0 \leq \alpha k \leq \frac{1}{2}$,

$$\begin{aligned} \widehat{q}^M &= \frac{1}{2} - \alpha k, \widehat{q}^E = \frac{1}{4}(1 + 2\alpha k) \\ \widehat{\beta}(0) &= 2\alpha \frac{1 - 2\alpha k}{3 - 2\alpha k} \\ \widehat{W} &= W(\widehat{p}, 0, \widehat{q}^M) = \underbrace{\frac{15}{32} - \frac{5}{8}\alpha k + \frac{7}{8}\alpha^2 k^2}_{w^1} + \underbrace{2\alpha(\theta + 1)\frac{1 - 2\alpha k}{3 - 2\alpha k}}_{w^2} \end{aligned} \tag{12}$$

[9] Naturally, this is a strong simplification. In a normative perpective, it would be more relevant to determine USO's equilibrium levels assuming that the regulator chooses them in a first stage of the generic game (e.g. maximising the social welfare). Let us just note that for the European case this part will amount to 22 per cent.

The w^1 term represents "electricity exchange" effect in the welfare, that is the standard consumer and producer surpluses. The other term w^2 represents the environmental effect.

A short study shows that the equilibrium welfare $\widehat{W}$ is always decreasing in k for $\alpha \geq \widetilde{\alpha} = \frac{1}{8(\theta+1)}$. More precisely, it is possible to interpret the both term w^1 and w^2 sensibility with respect to k :

- when k increases, $w^2 = (1+\theta)\widehat{\beta}(0)$ is decreasing for all $\theta > 1$: this represents the degradation of the environment in the relation (12) when the additional purchase cost of green electricity increases.
- when k increases, the standard surplus (w^1) is decreasing (resp. increasing) for $k < k^0 = \frac{5}{14\alpha}$, (resp. $k > k^0$). This aspect expresses a surplus redistribution among the agents:
  - a decline of the consumer surplus connected to the increase in prices when k increases and a decline of the profit of the monopoly connected to the increase in the production cost of green electricity,
  - a rise of the entrant profit who increases optimally his production because of a decline of the historic monopoly output.
  - the net effect is represented by an increase in the standard surplus whenever the entrant firm serves a big part of the demand[10].

It is worth noting that all these effects are all the less significant that the regulated share α is low. Indeed if $\alpha < \widetilde{\alpha}$, the environmental regulation pressure is so weak, that the welfare behaves like standard surplus: the entrant benefit effect strongly applies. As a result, we underline that if $\alpha < \widetilde{\alpha}$, the welfare dramatically decreases below (the welfare level without green production $W = \frac{3}{8}$), for some value of $k = k^1 < k^0$.

4.2 The taxation scenario

Let's assume now that at the beginning of the game, the regulator announces the amount of the fund, denoted F, used to finance the green production USOs. The participants in this fund are only the industrial ones and pay an unit tax t by kWh delivered. The tax is worked out to balance the fund: it compensates exactly the additional cost of green electricity production (or repurchase) and it is put back in reserve to the incumbent.

Because of fiscal levies, the firm profits are now:

$$\begin{aligned}
\pi^E\left(q^E\right) &= P\left(q^E+q^M\right)q^E - tq^E \\
\pi^M\left(q^M\right) &= P\left(q^M+q^E\right)q^M - (\alpha k + t)\,q^M + F
\end{aligned}$$

[10] Here this part corresponds to 75% because if $k = k^0$

$$\frac{\widehat{q}^E}{\widehat{Q}} = \frac{1+2\alpha\frac{5}{14\alpha}}{3-2\alpha\frac{5}{14\alpha}} = \frac{3}{4}$$

Following analogical developments of the former subsection, for any tax level t, the optimal incumbent output and the entrant output are then (if $0 \leq 2\alpha k + t \leq 1$)

$$\begin{aligned} \widehat{\widehat{q}}^M(t) &= \frac{1}{2}(1 - 2\alpha k - t) \\ \widehat{\widehat{q}}^E(t) &= \frac{1}{4}(1 + 2\alpha k - t) \end{aligned}$$

If $k > \frac{1}{2\alpha}$ then $t \equiv 0$ and we have directly $\widehat{\widehat{q}}^M = 0$ and $\widehat{\widehat{q}}^E = \frac{1}{2}(1-t) = \frac{1}{2}$. In fact, if $\widehat{\widehat{q}}^M = 0$ there is no funding problem anymore.

The regulator[11] determines the unit tax t which balances the green electricity production budget (along with $0 \leq 2\alpha k + t \leq 1$):

$$\alpha k q^M = F = t\left(q^E + q^M\right) \Rightarrow t^*(k) = \frac{1}{2} - \frac{1}{6}\sqrt{3(4\alpha k - 1)^2 + 6}$$

Let's note that $t^*(0) = t^*\left(\frac{1}{2\alpha}\right) = 0$ and $t^*\left(\frac{1}{4\alpha}\right) = \max_k t^*(k) = \frac{1}{2} - \frac{1}{\sqrt{6}}$. One will see that the tax is an increasing function of k, for $k < \frac{1}{4\alpha}$ (resp. decreasing if $k > \frac{1}{4\alpha}$). The non monotonous look of this tax with respect to the additional purchase cost of green electricity (that is $\alpha k q^M$) can be explained in that way: increasing at first to compensate the unit additional cost (αk), then, beyond a critical value of k (here $\frac{1}{4\alpha}$), decreasing in so far as the green production $\left(q^M\right)$ decreases towards zero for $k = \frac{1}{2\alpha}$, involving weaker and weaker funding need along with at the same time a larger and larger tax base.

Given this tax, the equilibrium features of the industry are ($\forall k \in \left[0, \frac{1}{2\alpha}\right]$):

$$\begin{aligned} \widehat{\widehat{q}}^M &= \frac{1}{4} - \alpha k + \frac{1}{12}\sqrt{3(4\alpha k - 1)^2 + 6} \\ \widehat{\widehat{q}}^E &= \frac{1}{8} + \frac{1}{2}\alpha k + \frac{1}{24}\sqrt{3(2k - 1)^2 + 6} \\ \widehat{\widehat{p}} &= \frac{5}{8} + \frac{1}{2}\alpha k - \frac{1}{8}\sqrt{3(2k - 1)^2 + 6} \\ \widehat{\widehat{Q}} &= \frac{3}{8} - \frac{1}{2}\alpha k + \frac{1}{8}\sqrt{3(2k - 1)^2 + 6} \end{aligned}$$

Typically, when k increases, we observe a reduction (resp. an increase) on the monopoly market share (resp. the entrant one), an increase in the price for the electricity and a logical decrease in the total consumption of electricity.

According to (9) and if $k \leq \frac{1}{2\alpha}$ ($\widehat{\widehat{\beta}}(0) = 0$ otherwise), the total share of green electricity is given by:

$$\widehat{\widehat{\beta}}(0) = 2\alpha \frac{1 - t^*(k) - 2\alpha k}{3\left[1 - t^*(k)\right] - 2\alpha k} \tag{13}$$

As the cross-subsidization case, the quality of the environment decreases in k. The welfare is

[11] Everything happens as if the regulator played in a zero stage, his policy consists only in balancing the fund.

then[12]:

$$\widehat{\widehat{W}} = W(\widehat{p}, 0, \widehat{\widehat{q}}^M) - t^*(k) Q\left(\widehat{\widehat{p}}\right) + F = W(\widehat{p}, 0, \widehat{\widehat{q}}^M) \tag{14}$$
$$= \underbrace{\frac{15}{32} - \frac{5}{8}\alpha k + \frac{7}{8}\alpha k^2}_{w^1} + \underbrace{2\alpha(\theta+1)\frac{1 - t^*(k) - 2\alpha k}{3[1 - t^*(k)] - 2\alpha k}}_{w^{2\prime}} +$$
$$\underbrace{+\frac{t^*(k)}{32}[4\alpha k - 3(2 + 3t^*(k))]}_{w^3}$$

Here again, w^1 represents the "electricity exchange" effect in the welfare and the term $w^{2\prime}$ the environmental effect. Similarly as in the cross-subsidization case, we find here again the same variations with respect to k. Namely, the environmental effect $w^{2\prime}$ has the same properties as w^2. A new term $w^3 \leq 0$ appears. It shows the traditional fiscal distortion that is the Harberger's loss. For k between 0 and a given value k^2, this loss increases to compensate the unit additional cost (αk) and tax rising. Beyond a critical value of k^2, it decreases in because the green production (q^M) and tax decreases towards zero.

5 Funding by customer subscriptions

Let us suppose now that the subscriptions are institutionally feasible for the consumers and the regulator collects them friendly to compensate for the additional green production cost (that is $\alpha k q^M$). We suppose so that the total subscription imposes a green electricity production financing constraint on the incumbent[13]:

$$\sum_h e_h \leq \alpha k q^M \Leftrightarrow e \leq \alpha k q^M \tag{15}$$

From (15), the historic operator have to produce at least the quantity of green electricity signed by the consumers via $\sum_h e_h$. On the other hand, the monopoly can exceed this obligation and spend more in green production than what the consumers are ready to pay.
The game timing is now complete (see p. 7):

1. The consumers determine their subscription level e_h
2. The historic monopoly determines its level of output q^M
3. The entrant chooses the level of output q^E competing à la Cournot with M

[12] Similar to the cross-subsidization regime, if $\alpha k > \frac{1}{2}$,$\widehat{\widehat{W}} = \frac{3}{8}$.

[13] Indeed informational problems may arise: first the consumers could manipulate information on their willingness-to-pay (standard free-riding problem), but second the operator would announce a higher green production cost (standard adverse selection problem) to the regulator. This kind of general problems are adressed in J. Greenwood and P. McAfee (1991).

On one hand, the solution of the last step of this game are analogical as before. On the other hand, the historic monopoly profit (see relation 7) takes now into account the consumer subscriptions clarified by the relation (15). So the firm M optimal output is solution of the program:

$$\begin{cases} \max\limits_{q^M \geq 0} \left\{ \pi^M \left(q^M \right) + e, 0 \right\} \\ e \leq \alpha k q^M \end{cases}$$

According to sufficient conditions, it comes the solution[14]:

$$\begin{aligned} q^{M*}(e) &= \frac{e}{\alpha k} \text{ if } \alpha k \geq e > \max\left\{ \alpha k \left(\frac{1}{2} - \alpha k \right), 0 \right\} \\ q^{M*}(e) &= \frac{1}{2} - \alpha k \text{ if } 0 \leq e \leq \max\left\{ \alpha k \left(\frac{1}{2} - \alpha k \right), 0 \right\} \end{aligned}$$

From this incumbent best-reply, we see that it does exist a situation, if e is relatively high, for which green production is increasing in subscription level (more precisely $\alpha q^{M*}(e) = \frac{e}{k}$). Note that using that best-reply allows us from (9) to evaluate the corresponding environmental index, $\beta^*(e)$, see appendix E for details.

We know from relation[15] (2) that the strategies of the consumers $h = 1, 2$ amount to choosing the pair $(0, e^*)$ such as:

$$\begin{cases} e^* > 0 \Leftrightarrow \beta'(e^*) = \frac{1}{\theta} \\ e^* = 0 \Leftrightarrow \beta'(0) \leq \frac{1}{\theta} \end{cases} \tag{16}$$

Similarly to the previous regimes, the equilibrium solutions are depending strongly on the level of exogenous parameters (θ, k, α). The tedious determination of equilibrium levels of subscription, production, price and environmental quality index are given in appendix E. We can summarize the equilibrium features in the two following figures differing from one another in the level of green production share α.

[14] For this solution, the historic monopoly profit keeps non negative. See appendix E, for details. If $e > \alpha k$, there is formally no solution to the historic monopoly problem as set here. In fact, the USOs funding constraint implies a loss for the monopoly.

[15] See also appendix A.

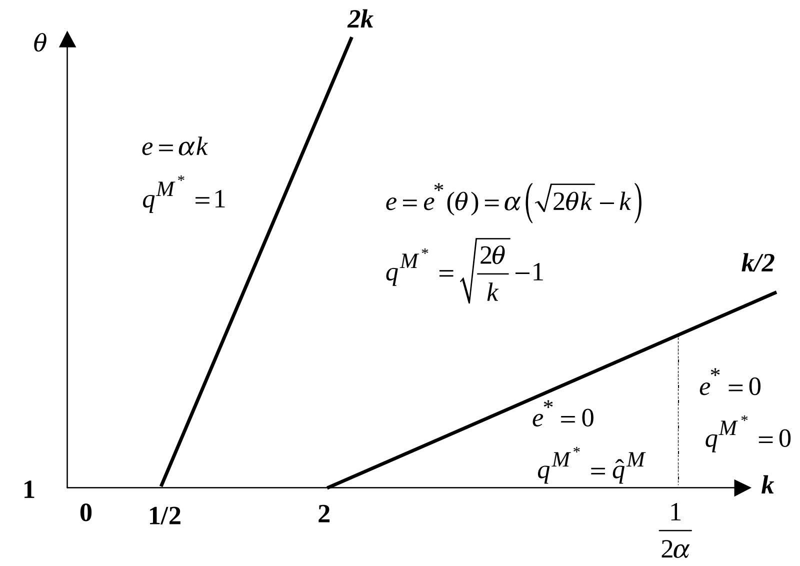


Fig.4. Equilibrium regions if $\alpha \geq \frac{1}{4}$

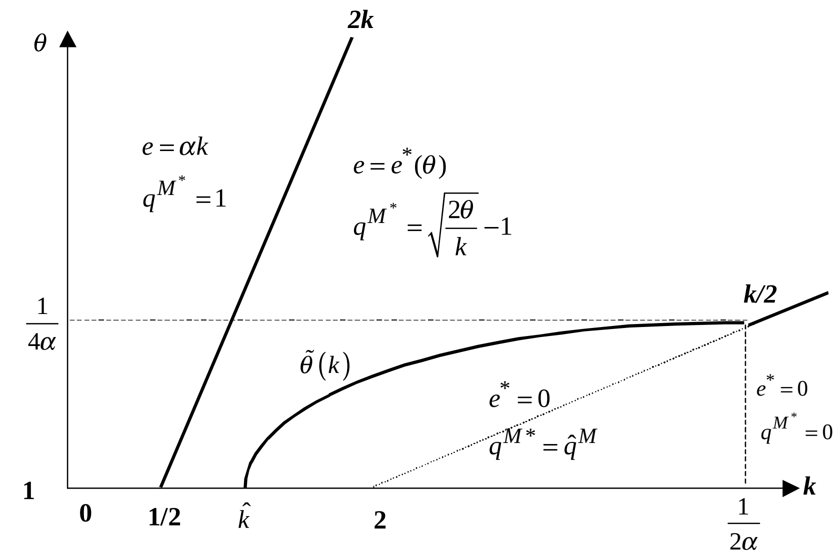


Fig. 5. Equilibrium regions if $\alpha \leq \frac{1}{4}$

Three equilibrium areas appears:

- for weak values of the green production cost k and high values of the green WTP θ, we observe a logical extreme situation: the historical monopoly production and the voluntary subscription level are maximum $\left(q^{M*} = 1, e^* = \alpha k\right)$, the price of electricity is zero (in fact at the marginal cost of traditional fossil production), then it happens as if the consumers pay electricity through their voluntary subscription.

- for intermediate values of the green production cost and WTP, according to the intuition, the voluntary subscription equilibrium level $e^*(\theta)$ is increasing with respect to the green WTP and with respect to the share of the monopoly green production α but decreasing with respect to the cost of green electricity production. The historical monopoly production is highly constrained by its green activity. Then it can be seen that q^{M*} is decreasing with respect to k and increasing with respect to the WTP θ.

- for higher values of the green production cost and lower values of the green WTP, we observe two different zones :
  - for intermediate values of the green production cost ($\max\left\{2, \widehat{k}\right\} < k < 1/2\alpha$) and low values of WTP ($\theta < \max\left\{\widetilde{\theta}(k), \frac{k}{2}\right\}$), there is no subscription. In fact, consumers are aware that monopoly production will be invariant with their subscription level: the monopoly is producing at the equilibrium because the overcosts αk are less ; in that case, the losses on green production are compensated by gains on non-green. Here the equilibrium amounts to the cross-subsidization situation we analyzed in section 4.
  - for $k > \frac{1}{2\alpha}$ and $\theta < \frac{k}{2}$, the historical monopoly production and the level of voluntary subscription are nil. It is interesting to see, that in most cases, the agents always have a stake to compel the historic monopoly in his production that for everything k and θ, constraint (15) is almost always binding. Indeed, it is optimal from consumer point of view to directly finance the green electricity production because their utility is then directly connected with their subscription level.

6 Social efficiency comparative

Before comparing the three scenarios of funding, we focus on the comparison between cross-subsidization and taxation.

As a first result, we can state the following proposition (see appendix F for a proof).

Proposition 2 With regard to the situation with cross-subsidies funding, the USOs compensation fund (if $k < \frac{1}{2\alpha}$):
a) degrades the quality of the environment,
b) increases the electricity price and decreases the incumbent green production,
c) reduces the social welfare.
If $k \geq \frac{1}{2\alpha}$, the two funding schemes are equivalent.

Financing the USOs by an industrial compensation fund degrades environmental quality because of distortions generated by the unit tax on green electricity production. In that fund case, the green electricity production market share is lower than in the cross-subsidization regime. Besides, the historic monopoly production falls ($\widehat{\widehat{q}}^M < \widehat{q}^M$), what damages the environmental quality ($\alpha \cdot \left[\widehat{\widehat{q}}^M - \widehat{q}^M\right] < 0$). From a collective point of view, financing by compensation fund is never efficient. If $k > \frac{1}{2\alpha}$, the monopoly is out of the market so there is no green electricity production: funding the USO is useless, and both regimes are equivalent.

Now we can compare the three modes of funding with respect to welfare and environmental impact. These results are summarized in the following proposition.

Proposition 3 With regard to the situations with cross-subsidies and taxation, the direct and voluntary funding for USO's:

a) never damages the environmental quality, that is $\beta^* \geq \widehat{\beta} \geq \widehat{\widehat{\beta}}$

b) never reduces the welfare, that is $W^* \geq \widehat{W} \geq \widehat{\widehat{W}}$

Proof. See appendix F for detailed proof. ■

Here W^* denotes the welfare in the voluntary subscription case (see appendix E for details). Noting $\Delta W^1 = \widehat{\widehat{W}} - \widehat{W}$, $\Delta W^2 = W^* - \widehat{W}$ and $\Delta W^3 = W^* - \widehat{\widehat{W}}$, the following figures characterize the variations of welfare between the various funding regimes.

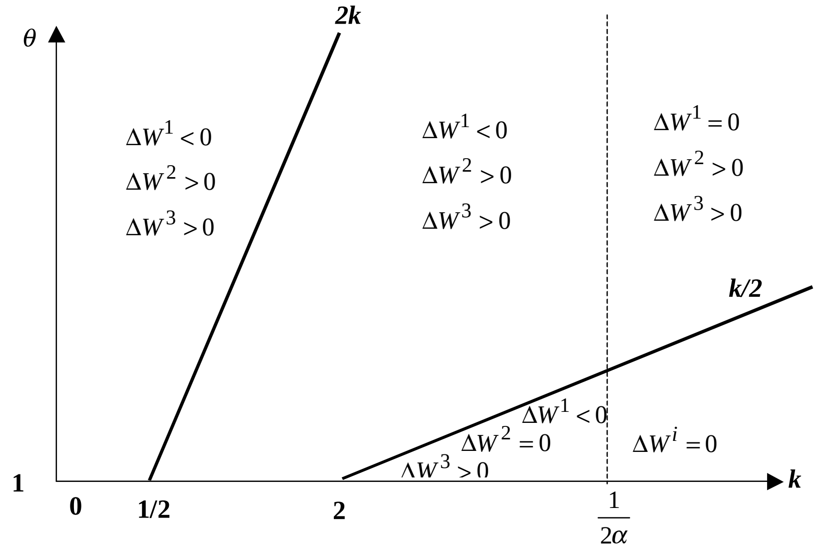


Fig. 6 . Welfare comparisons if $\alpha > \frac{1}{4}$

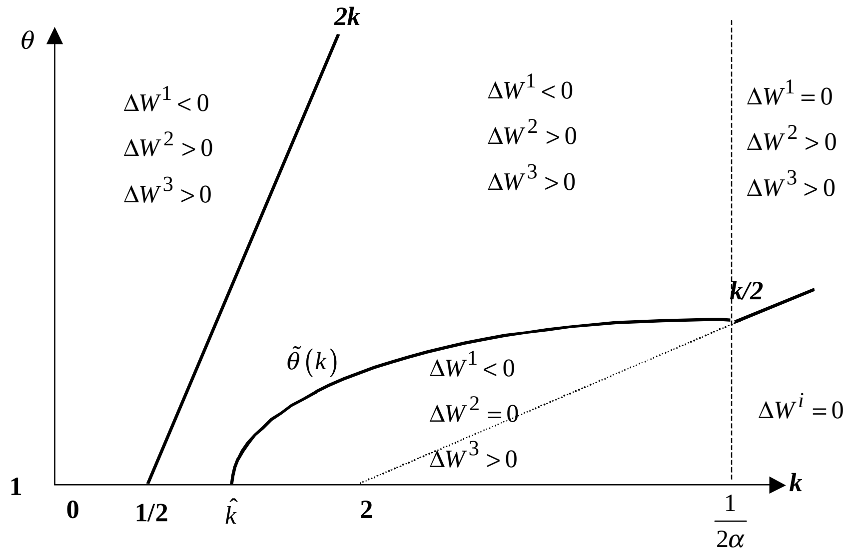


Fig. 7. Welfare comparisons if $\alpha \leq \frac{1}{4}$

Generically, the voluntary subscription scenario dominates the others ($\Delta W^2 \geq 0$ and $\Delta W^3 \geq 0$). Clearly (as pointed out in proposition 2), the tax regime is dominated by the others ($\Delta W^1 \leq 0$ and $\Delta W^3 \geq 0$) because of tax distortions appear. Nevertheless, $\Delta W^2 = \Delta W^3 = 0$ when the historical is out of the market i.e. $k > \frac{1}{2\alpha}$ and $\theta < \frac{k}{2}$. Then we can now focus on the both cross-subsidization and subscription regimes, to achieve the analysis.

For intermediate values of the green production cost and WTP, ($\theta > \max\left\{\widetilde{\theta}(k), \frac{k}{2}\right\}$), the funding regime induces higher welfare levels than the cross-subsidization one: the historical monopoly production and electricity supply is increasing, prices are falling and the environmental quality is growing, so this is a better situation for society. But for lower values of θ ($\theta < \max\left\{\widetilde{\theta}(k), \frac{k}{2}\right\}$), the equilibrium level of subscription is nil and this funding regime degenerates in the cross-subsidization one.

Furthermore, when the green production cost is very high, there is an interesting area ($\theta > \frac{k}{2}$ and $k > \frac{1}{2\alpha}$) where the subscription funding induces some green electricity production whereas the others regimes yield no electricity production from the historical monopoly: this case underlines the magnitude of subscription regime in order to promote renewable-generated electricity.

In fact, the subscription regime allows to internalize the environmental externality avoiding fiscal distortions. Then the subscription regime can be considered as an intermediate funding system: it is not a Pareto optimal one (e.g. because there is free riding in subscription...) but it is Pareto improving comparing with others systems.

7 Conclusions

In the light of our results, we underline the relevance of the analysis but we discuss also the limits and the potential extensions of our article.

Our model concerning the funding mechanisms of "green USO" provides some interesting results :

The legal obligation enforced to the incumbent to provide "green electricity" is Pareto dominant (proposition 1). In our model, it is preferable (Pareto dominant regime) for a privatized monopoly not to provide "green electricity" due to higher level of generation costs. Nevertheless, if consumers have preferences for a high environmental quality and if they have no institutional possibility to pay more for purchase of green electricity, it is socially optimal to constraint the incumbent to provide a percentage α^M of "green electricity" with respect to her electricity production level.

Comparing the two classical mechanisms of funding for the "green USO" (cross-subsidies and taxation regimes), it appears that **cross-subsidies regime is socially preferable with respect to the taxation regime** (proposition 2). Theoretical result is quite logical because the implementation of a tax scheme introduces inevitably distortions which damage the welfare. The "fund" damages the environmental quality (decline green electricity share within the total production), increases the electricity price and makes the welfare worse. Towards this result, the financing choice by a fund considered in Europe seems irrelevant. Nevertheless, this choice is in keeping with the general pattern of the government's policy to reduce cross-subsidies, regarded as the origin of unfair situations.

The introduction of a direct and voluntary financing by the consumers does constitute the originality and interest of our analysis. The comparison of the two classical mechanisms with respect to this "new" funding mode allows us to make three enlightening remarks on efficiency comparative. According to the consumer's environmental preferences intensity (value of θ) and according to the level of the green electricity cost supported by the historic operator (value of k), it is possible to classify our various funding regimes depending on levels of welfare (proposition 3) :

- for high values of the green electricity cost and weak values of the consumer's environmental preference intensity, agent's subscription levels are nil and the incumbent operator does not supply any green electricity if k is prohibitive or just produces its cross-subsided level. The consumers have a too weak willingness to pay for improving the environmental quality, especially when the green electricity production cost is high. In that case, the welfare is at the same level in the subscription and cross-subsidization regimes.

- If the environmental preference intensity becomes stronger (increase of θ) when the green electricity cost is high ($k > \max\left\{2, \hat{k}\right\}$), then the **subscription mechanism becomes better from a collective point** of view. When k decreases towards $\max\left\{2, \hat{k}\right\}$, the monopoly market share aims towards hundred percent with an environmental quality improvement at the same time (the share of green electricity in the global production tends towards its maximum, that is $\beta = \alpha^M = \alpha$).

- When k is weak, the subscription funding regime is always preferred from a collective point of view whatever are preferences expressed for the quality of the environment.

The model presented here contains however some restrictive assumptions we have to highlight:

- First of all, it would be profitable to extend the USO of production for the entrants: as we have already underlined, there is only institutional reasons to impose USO on the historic operator alone, one could imagine a system where all the operators would have also the obligation to supply some green electricity. This system could be assimilated as a "Pay or Play" regulation (see Chone, P., L. Flochel and Perrot, 2000).

- In a more normative framework, we could analyze a scheme similar to German regulation where there would be no more green USO's. As for the German case, certificates and labels would be distributed to every producer according to the percentage of green electricity in the total production. Progressively, theses systems could evolve in the way of a real segmentation of the electricity market with two differentiated products: green and non green. Using the theory of contract framework, firms would propose some mixed electricity contracts (different shares of green and non green).

- At last, we would like to set up a more global modelling of the funding for the electricity USO's. This article focuses on green electricity USO, but ignores others classes of universal obligations concerning transport and distribution activities. Mirabel and Poudou [2000] article is related to distribution activity. It could be profitable to extend our analyses in order to yield a more general framework for USO in electricity sector.

References

[1] Aloy, E. and F. Lévêque (1997), "La définition, les outils d'évaluation et de financement du Service Public en situation de concurrence ouverte", *rapport technique*, CERNA.

[2] Amstrong, J., R. Doyle and J. Vickers (1996) "The Access Pricing Problem: a Synthesis", *Journal of Industrial Economics*, XLIV(2), 131-150.

[3] Chone, P., L. Flochel and A. Perrot (2000) "Universal Service Obligations and Competition", *Information Economics and Policy*, 12(3), 249-259.

[4] Greenwood J., McAfee P. (1991) "Externalities and Asymmetric Information", *The Quarterly Journal of Economics*, 103-121

[5] Mandil C. (1993), "La réforme de l'organisation électrique et gazière française", *rapport technique*, Ministère de l'Industrie des Postes et Télécommunications et du Commerce Extérieur, Direction Générale de l'Energie et des Matières Premières.

[6] Syrota J. (2000), "Evaluation des missions de service public de l'électricité", rapport publié par la Commission de Régulation de l'Electricité, Février 2000.

[7] Mirabel, F. and J.-C. Poudou (2000) "Mechanisms of Funding for Universal Service Obligations : the Electricity Case", *miméo* CREDEN.

[8] R. Wyser, M. Fowlie, E. Holt, (2001), "Public goods and private interest: understanding non-residential demand for green power", *Energy Policy*, 29, 1085-1097.

8 Appendices

8.1 Appendix A. Nash equilibrium of the subscription game

From the text (see p. 6), optimal subscriptions $e_h^* \geq 0$ follow the system:

$$\left\{\begin{array}{l} e_1^* \left(\beta'\left(e_1^* + e_2\right) - 1\right) = 0 \\ \beta'\left(e_2\right) - 1 \leq 0 \\ e_2^* \left(\theta\beta'\left(e_2^* + e_1\right) - 1\right) = 0 \\ \theta\beta'\left(e_1\right) - 1 \leq 0 \end{array}\right. \tag{17}$$

Ab absurdo, if at the Nash equilibrium, $e_1^* > 0$ then from (17):

$$\left\{\begin{array}{l} \beta'\left(e_1^* + e_2^*\right) = 1 \\ e_2^*\left(\theta - 1\right) = 0 \\ \theta\beta'\left(e_1^*\right) - 1 \leq 0 \end{array}\right. \Rightarrow \left\{\begin{array}{l} \beta'\left(e_1^*\right) = 1 \\ e_2^* = 0 \\ \theta - 1 \leq 0 \end{array}\right.$$

which leads to the contradiction of the assumption $\theta > 1$.
Hence at the equilibrium $e_1^* = 0$. System (17) then imply:

$$\left\{\begin{array}{l} \beta'\left(e_2^*\right) \leq 1 \\ e_2^*\left(\theta\beta'\left(e_2^*\right) - 1\right) = 0 \\ \theta\beta'\left(0\right) - 1 \leq 0 \end{array}\right. \Rightarrow \left\{\begin{array}{l} e_2^* > 0 \Leftrightarrow \beta'\left(e_2^*\right) = \frac{1}{\theta} < 1 \\ e_2^* = 0 \Leftrightarrow \beta'\left(0\right) \leq \frac{1}{\theta} \end{array}\right.$$

Noting $e_2^* = e$, we find the relations (2).
On can see that $\beta\left(\cdot\right)$ is not an increasing function at least from a given interval to $\left]\frac{1}{\theta} - \varepsilon, \frac{1}{\theta} + \varepsilon\right[, \varepsilon > 0$, the equilibrium subscription is then zero. The agent 2 (the ecologist) doesn't pay if his expenditure doesn't really improve environmental quality.

8.2 Appendix B. Social optimum and private monopoly

8.2.1 Social optimum

We determine the second best social optimum. Given the concavity in q of functions W^s and PS^s (see relation 11), but not in α, let us find $q(\alpha)$ which solve the problem. Let $\lambda \geq 0$, the sufficient conditions are:

$$\left\{\begin{array}{l} 2\left\{1 - 2q - \alpha k + \lambda\left(1 - 4q - \alpha k\right)\right\} = 0 \\ \lambda\left[2q\left(1 - 2q - \alpha k\right)\right] = 0 \end{array}\right. \Leftrightarrow \left\{\begin{array}{l} \left(1 - 2q - \alpha k\right)\left(1 + \lambda\right) - 2q\lambda = 0 \\ \lambda\left(1 - 2q - \alpha k\right) = 0 \end{array}\right.$$

$$\Leftrightarrow \left\{\begin{array}{l} 1 - \alpha k - 2q\left(\lambda + 1\right) = 0 \\ \lambda\left(1 - 2q - \alpha k\right) = 0 \end{array}\right.$$

$\lambda > 0$ leads to the contradiction : $q = \frac{1}{2}\left(1 - \alpha k\right) > 0$ and $-\left(1 - \alpha k\right)\lambda = 0$, which implies that $\lambda = 0$.
Therefore $\lambda = 0$ and $q^s\left(\alpha\right) = \frac{1}{2}\left(1 - \alpha k\right) \geq 0$. For $q = q^s\left(\alpha\right)$, collective surplus become:

$$W^s_{|q=q^s(\alpha)} \equiv W^s\left(\alpha\right) = \frac{1}{2} + \alpha + \left(\theta - k\right)\alpha + \frac{1}{2}\left(\alpha k\right)^2$$

One can see that $W^s(\alpha)$ is convex in α since $\frac{\partial W^s}{\partial \alpha} = k^2 > 0$. Then the problem can be written now as:

$$\left\{ \begin{array}{l} \max_{\alpha} W^s(\alpha) \\ 0 \leq \alpha \leq \min\left\{1, \frac{1}{k}\right\} \end{array} \right.$$

Let $\overline{\alpha}(k) = \min\left\{1, \frac{1}{k}\right\}$. The optimal solution α^s follows these sufficient conditions (with $\mu \geq 0$):

$$\left\{ \begin{array}{l} \theta + 1 + k(\alpha k - 1) - \mu \leq 0 \\ \alpha\left[\theta + 1 + k(\alpha k - 1)\right] = 0 \\ \mu\left(\overline{\alpha}(k) - \alpha\right) = 0 \end{array} \right. \tag{18}$$

1. If $\alpha = 0$, relation (18) becomes:

$$\left\{ \begin{array}{l} \theta + 1 - k \leq 0 \\ \mu\overline{\alpha}(k) = 0 \end{array} \right. \Leftrightarrow \left\{ \begin{array}{l} \theta \leq k - 1 \\ \mu = 0 \end{array} \right.$$

   Under the conditions $\theta \leq k - 1$ and $k > 2$, $\alpha = 0$ is a local maximum of W^s.

2. $\alpha > 0$ is solution if:

$$\left\{ \begin{array}{l} \theta + 1 + k(\alpha k - 1) - \mu \leq 0 \\ \alpha\left[\theta + 1 + k(\alpha k - 1)\right] = 0 \\ \mu\left(\overline{\alpha}(k) - \alpha\right) = 0 \end{array} \right.$$

   (a) for an interior solution $\alpha \in \left]0, \overline{\alpha}(k)\right[$, the system (18) yields a minimum for W^s because it is convex in α.

   (b) if the solution is $\alpha = \overline{\alpha}(k)$, from the system (18), we have:

$$\theta + 1 + k\left(\overline{\alpha}(k)\, k - 1\right) \geq 0 \Leftrightarrow \theta \geq k\left(1 - \overline{\alpha}(k)\, k\right) - 1$$

   that is

$$\theta \geq \left\{ \begin{array}{ll} -1 & \text{si } \overline{\alpha}(k) = 1/k < 1 \text{ soit } k > 1 \\ k(1-k) - 1 < 0 & \text{si } \overline{\alpha}(k) = 1 \text{ soit } k \leq 1 \end{array} \right.$$

   Consequently $\alpha = \overline{\alpha}(k)$ is a local maximum of W^s.

3. From above:

   (a) if $0 < k \leq 1$, for all $\theta > 1$, the optimal solution is $\alpha^s = 1$,

   (b) if $1 < k \leq 2$, for all $\theta > 1$, the optimal solution is $\alpha^s = 1/k$

   (c) To find the optimal solution when $k > 2$, let us compare the surpluses for the both candidates:

$$\Delta W^s = W^s\left(\frac{1}{k}\right) - W^s(0) = \frac{\theta + 1}{k} - \frac{1}{2}$$

When $k > 2$, $\Delta W^s \ \mathsf{S}\ 0$ if $\theta \ \mathsf{S}\ \frac{k}{2} - 1 > 0$. Now we assumed that $\theta > 1$, so

$$
\begin{aligned}
\Delta W^s &\geq 0 \text{ if } k \leq 4 \\
\Delta W^s &\ \mathsf{S}\ 0 \text{ if } \theta \ \mathsf{S}\ \frac{k}{2} - 1 \text{ et } k > 4
\end{aligned}
$$

Therefore the optimal solution is

$$
\begin{aligned}
q^s &= \frac{1}{2}(1-k), \alpha^s = 1 \text{ for } 0 < k \leq 1 \\
q^s &= 0, \alpha^s = \frac{1}{k} \text{ for } 1 < k \leq 4 \\
q^s &= 0, \alpha^s = \frac{1}{k} \text{ for } k > 4 \text{ et } \theta \geq \frac{k}{2} - 1 \\
q^s &= \frac{1}{2}, \alpha^s = 0 \text{ for } k > 4 \text{ et } \theta < \frac{k}{2} - 1
\end{aligned}
$$

Hence $\theta > k$ is a sufficient condition for α^s to be positive.

8.2.2 Private monopoly

The private monopoly program is

$$\max_{(q,\alpha)} P^s$$

The optimal couple obeys the following sufficient conditions:

$$
\left\{
\begin{array}{l}
2(1 - 4q - \alpha k) = 0 \\
-\alpha(2kq + \mu) = 0 \\
-(2kq + \mu) \leq 0 \\
\mu(1-\alpha) = 0
\end{array}
\right.
\Leftrightarrow
\left\{
\begin{array}{l}
q = \frac{1}{4}(1-\alpha) \\
\alpha = 0 \\
-(2kq + \mu) < 0 \\
\mu = 0
\end{array}
\right.
\Rightarrow
\left\{
\begin{array}{l}
q^M = \frac{1}{4}\left(1 - \alpha^M\right) = \frac{1}{4} \\
\alpha^M = 0 \\
\mu = 0
\end{array}
\right.
$$

8.3 Appendix C. Cross-subsidization and taxation equilibria

8.3.1 Cross-subsidization

Entrant strategy

From (1) and (6), the entrant profit is (recalling that $\alpha^E = 0$):

$$
\begin{aligned}
\pi^E\left(q^E\right) &= P(Q)\, q^E - C^E(q^E) = P\left(q^E + q^M\right) q^E \\
&= \left[1 - q^E - q^M\right] q^E
\end{aligned}
$$

Using Nash conjectures, the entrant considers the production of the incumbent as optimal. So he offers $q^E > 0$, level that maximizes $\pi^E\left(q^E\right)$:

$$\frac{\partial \pi^E\left(q^E\right)}{\partial q^E} = 0 \Leftrightarrow 1 - 2q^E - q^M = 0$$

The entrant best-reply is then:

$$\widehat{q}^E\left(q^M\right)=\frac{1}{2}\left(1-q^M\right) \tag{19}$$

The total supply writes $Q\equiv q^M+\widehat{q}^E\left(q^M\right)=\frac{1}{2}\left(1+q^M\right).$

Historic monopoly strategy

From the entrant best-reply (19), the historic monopoly chooses $q^M>0$ that maximizes his profit π^M, see (7) :

$$\begin{aligned}\pi^M\left(q^M\right) &= P\left(q^M+\widehat{q}^E\left(q^M\right)\right)q^M-\alpha kq^M \\ &= \left[\frac{1}{2}\left(1-q^M\right)-\alpha k\right]q^M \end{aligned} \tag{20}$$

The optimal monopoly output obeys to the sufficient condition:

$$\begin{aligned}\frac{\partial\pi^M\left(q^M\right)}{\partial q^M} &= 0\Leftrightarrow\frac{1}{2}-\alpha k-q^M=0 \\ &\Rightarrow\ \widehat{q}^M=\frac{1}{2}-\alpha k \end{aligned} \tag{21}$$

The production of the historic monopoly is positive if $0\leq\alpha k\leq\frac{1}{2}$. The corresponding profit is then:

$$\pi^M\left(\widehat{q}^M\right)=\frac{1}{8}\left(1-2\alpha k\right)^2\geq 0 \tag{22}$$

Manipulating (21) and (19), the entrant reply writes $\widehat{q}^E\equiv\widehat{q}^E\left(\widehat{q}^M\right)=\frac{1}{4}\left(1+2\alpha k\right)$ and the price for electricity becomes:

$$\widehat{p}=P\left(\widehat{q}^M+\widehat{q}^E\right)=\frac{1}{4}\left(1+2\alpha k\right) \tag{23}$$

Hence industry total supply equals $\widehat{Q}=Q(\widehat{p})=\frac{1}{4}\left(3-2\alpha k\right)$. $\widehat{Q}$ is strictly positive if $\widehat{q}^M>0$, i.e. if $0\leq\alpha k\leq\frac{1}{2}$.

Equilibrium

The subgame perfect equilibrium of this scenario is

$$\begin{aligned}\widehat{q}^M &= \frac{1}{2}-\alpha k,\ \widehat{q}^E=\frac{1}{4}\left(1+2\alpha k\right),\text{ si }0\leq\alpha k\leq\frac{1}{2} \\ \widehat{q}^M &= 0,\ \widehat{q}^E=\frac{1}{2},\text{ si }\alpha k>\frac{1}{2}\end{aligned}$$

Welfare and environmental quality

From relations (3), 8) and (10), the social surplus is:

$$\begin{aligned}W(p,0,q^M) &= \frac{1}{2}\left(1-p\right)^2+\left(\theta+1\right)\beta\left(0\right)-\alpha kq^M \\ &= \frac{1}{2}\left(1-p^2\right)+\alpha\left(\theta+1\right)\frac{q^M}{Q\left(p\right)}-\alpha kq^M\end{aligned}$$

From (9), the equilibrium "market share" of green electricity $\beta(0)$, if $\alpha k \leq \frac{1}{2}$, is given by ($\beta(0) = 0$ otherwise):

$$\widehat{\beta}(0) = 2\alpha \frac{1-2\alpha k}{3-2\alpha k}$$

Moreover if $\alpha k \leq \frac{1}{2}$, social surplus is written by:

$$\widehat{W} = W(\widehat{p}, 0, \widehat{q}^M) = \underbrace{\frac{15}{32} - \frac{5}{8}\alpha k + \frac{7}{8}\alpha^2 k^2}_{w^1} + \underbrace{2\alpha(\theta+1)\frac{1-2\alpha k}{3-2\alpha k}}_{w^2}$$

Notice that if $\alpha k > \frac{1}{2}$, $\widehat{W} = \frac{3}{8}$.

Here we show that $\widehat{W}$ is decreasing in k for $\alpha \geq \widetilde{\alpha} = \frac{1}{8(\theta+1)}$. In fact for $k \leq \frac{1}{2\alpha}$, $\frac{d\widehat{W}}{dk} = \frac{\alpha}{8(3-2\alpha k)^2} f(k)$, where $f(k) = 2k\alpha\left(93 - 94\alpha k + 28\alpha^2 k^2\right) - 64\alpha(\theta+1) - 45$. The function $f(k)$ is increasing from $f(0) = -64\alpha(\theta+1) - 45 < 0$ to $f\left(\frac{1}{2\alpha}\right) = 8 - 64\alpha(\theta+1)$. Hence $f\left(\frac{1}{2\alpha}\right)$ T 0 if α S $\frac{1}{8(\theta+1)}$ which implies that $\frac{dW^*}{dk} < 0$ for $\alpha > \frac{1}{8(\theta+1)}$. Furthermore, since $W^*_{|k=\frac{1}{2\alpha}} = \frac{3}{8}$, if $\alpha \leq \frac{1}{8(\theta+1)}$ it does exit a value k^1 of k such that for $\frac{1}{2\alpha} > k$ T k^1, W^* S $\frac{3}{8}$.

8.3.2 Taxation

This taxation scenario is analogical with respect to the cross-subsidization scenario, so we do not develop the detailed calculation of the equilibrium. We just show that $w^3 < 0$ for all $k \in \left[0, \frac{1}{2\alpha}\right]$. In fact, $w^3 = -\frac{15}{64} + \frac{1}{4}x - \frac{3}{8}x^2 + \left(\frac{5}{64} - \frac{x}{48}\right)\sqrt{3(4x-1)^2 + 6}$ where $x = \alpha k$, which is a convex function of x upper bounded by 0 for all $x \in \left[0, \frac{1}{2}\right]$.

8.4 Appendix D. Monopoly equilibrium with subscription

From (20), let the historic monopoly program due to direct funding be:

$$\left\{ \begin{array}{l} \max\limits_{q^M \geq 0} \left\{\pi^M\left(q^M\right) + e, 0\right\} \\ e \leq \alpha k q^M \end{array} \right. \Leftrightarrow \left\{ \begin{array}{l} \max\limits_{q^M \geq 0} \left[\frac{1}{2}\left(1 - q^M\right) - \alpha k\right] q^M + e \\ \alpha k q^M - e \geq 0 \end{array} \right.$$

The constraint $\pi^M\left(q^M\right) + e \geq 0$ will be verified ex post. If $\lambda \geq 0$ is the Kuhn-Tucker multiplier corresponding to the funding constraint $\alpha k q^M - e \geq 0$, the sufficient conditions are:

$$\left\{ \begin{array}{l} q^M\left[\frac{1}{2}\left(1 - 2q^M\right) + \alpha k(\lambda - 1)\right] = 0 \\ \frac{1}{2}\left(1 - 2q^M\right) + \alpha k(\lambda - 1) \leq 0 \\ \lambda\left(\alpha k q^M - e\right) = 0 \end{array} \right.$$

- If $q^M = 0$, it comes:

$$\left\{ \begin{array}{l} \frac{1}{2} + \alpha k(\lambda - 1) \leq 0 \\ -\lambda e = 0 \end{array} \right.$$

  - $e > 0$ contradicts the constraint ($\lambda = 0$ and $-e > 0$)

– if $e = 0$ then $0 \leq \lambda \leq \frac{2\alpha k - 1}{2\alpha k}$, which is possible if $k \geq \frac{1}{2\alpha}$

- If $q^M > 0$, it comes:

$$\begin{cases} \frac{1}{2}\left(1 - 2q^M\right) + \alpha k\left(\lambda - 1\right) = 0 \\ \lambda\left(\alpha k q^M - e\right) = 0 \end{cases}$$

  – if $\alpha k q^M > e \geq 0$:

$$\begin{cases} \frac{1}{2}\left(1 - 2q^M\right) - \alpha k = 0 \\ \lambda = 0 \end{cases} \Leftrightarrow q^M = \frac{1}{2} - \alpha k$$

  with the related conditions:

$$\begin{aligned} q^M &> 0 \Rightarrow 0 < \alpha k < \frac{1}{2} \\ \alpha k q^M &> e \Rightarrow 0 \leq e < \alpha k\left(\frac{1}{2} - \alpha k\right) \end{aligned}$$

  – if $\alpha k q^M = e$

$$\begin{cases} \frac{1}{2}\left(1 - 2\frac{e}{\alpha k}\right) + \alpha k\left(\lambda - 1\right) = 0 \\ q^M = \frac{e}{\alpha k} \end{cases} \Leftrightarrow \begin{cases} \lambda = 1 + \frac{2e - \alpha k}{2(\alpha k)^2} \\ q^M = \frac{e}{\alpha k} \end{cases}$$

  with the related conditions:

$$\begin{aligned} q^M &> 0 \Rightarrow e > 0 \\ \lambda &\geq 0 \Rightarrow e \geq \alpha k\left(\frac{1}{2} - \alpha k\right) \end{aligned}$$

  One can note that if $k > \frac{1}{2\alpha}$, $\alpha k\left(\frac{1}{2} - \alpha k\right) < 0$, so the last condition is always fulfilled.

We now verify the profit non negativity constraint: $\pi^M\left(q^M\right) + e \geq 0$.

- If $e = 0$ and $q^M = 0$ then $\pi^M\left(q^M\right) + e = 0$
- If $0 \leq e < \alpha k\left(\frac{1}{2} - \alpha k\right)$ and $k < \frac{1}{2\alpha}$, $q^M = \frac{1}{2} - \alpha k$ then $\pi^M\left(q^M\right) + e \geq 0$, for $\pi^M\left(q^M\right) = \frac{1}{2}\left(\frac{1}{2} - \alpha k\right)^2 > 0$
- If $e > \alpha k\left(\frac{1}{2} - \alpha k\right)$, $q^M = \frac{e}{\alpha k}$ then

$$\pi^M\left(q^M\right) + e = \frac{e\left(\alpha k - e\right)}{2\left(\alpha k\right)^2} \geq 0 \text{ si } 0 \leq e \leq \alpha k$$

  Hence for $e > \alpha k$, there is no solution because both constraints are incompatible (control set is empty).

  Then the optimal reply of firm M is:

$$\begin{aligned} q^{M*}\left(e\right) &= \frac{e}{\alpha k} \text{ if } \alpha k \geq e > \max\left\{\alpha k\left(\frac{1}{2} - \alpha k\right), 0\right\} \\ q^{M*}\left(e\right) &= \frac{1}{2} - \alpha k \text{ if } 0 \leq e \leq \max\left\{\alpha k\left(\frac{1}{2} - \alpha k\right), 0\right\} \end{aligned}$$

Using (19) in the text, we have the entrant best-reply:

$$\begin{aligned} q^{E*}(e) &= \frac{1}{2}\left(1-\frac{e}{\alpha k}\right) \text{ and } Q^*(e)=\frac{1}{2}\left(1+\frac{e}{\alpha k}\right) \text{ if } \alpha k \geq e > \max\left\{\alpha k\left(\frac{1}{2}-\alpha k\right),0\right\} \\ q^{E*}(e) &= \frac{1}{4}(1+2\alpha k) \text{ and } Q^*(e)=\frac{1}{4}(3-2\alpha k) \text{ if } 0\leq e\leq \max\left\{\alpha k\left(\frac{1}{2}-\alpha k\right),0\right\} \end{aligned}$$

From the text and relations (9), (21) and (12), the green electricity market share is:

$$\begin{aligned} \beta^*(e) &= \frac{2\alpha e}{e+\alpha k} \text{ if } \alpha k \geq e > \max\left\{\alpha k\left(\frac{1}{2}-\alpha k\right),0\right\} \\ \beta^*(e) &= \widehat{\beta}(0) \text{ if } 0\leq e\leq \max\left\{\alpha k\left(\frac{1}{2}-\alpha k\right),0\right\} \end{aligned}$$

8.5 Appendix E. Subscription equilibrium

From the text and appendix A, the subcription strategy pair $(0, e^*)$ of the consumers $h = 1, 2$ is such as:

$$\left\{\begin{array}{l} e^*>0 \Leftrightarrow \beta'(e^*)=\frac{1}{\theta} \\ e^*=0 \Leftrightarrow \beta'(0)\leq\frac{1}{\theta} \end{array}\right.$$

From $\beta^*(e)$ in appendix D, we obtain,

$$\begin{aligned} \beta'^*(e) &= \frac{2\alpha^2 k}{(e+\alpha k)^2} \text{ if } \alpha k \geq e > \max\left\{\alpha k\left(\frac{1}{2}-\alpha k\right),0\right\} \\ \beta'^*(e) &= 0 \text{ if } 0\leq e < \max\left\{\alpha k\left(\frac{1}{2}-\alpha k\right),0\right\} \end{aligned}$$

If $\alpha k \geq e > \max\left\{\alpha k\left(\frac{1}{2}-\alpha k\right),0\right\}$, it comes the interior solution:

$$2\frac{k\alpha^2}{(e^*+k\alpha)^2}=\frac{1}{\theta} \Leftrightarrow e^*(\theta)=\alpha\left(\sqrt{2\theta k}-k\right) \tag{24}$$

Moreover $e^*(\theta) \geq 0$ if $\theta \geq \max\left\{1, \frac{k}{2}\right\}$ and $e^*(\theta) \leq \alpha k$ if $\theta \leq \max\{1, 2k\}$. Also, $e^*(\theta) > \alpha k\left(\frac{1}{2}-\alpha k\right)$, $\forall\theta, k$, and $\alpha \geq \frac{1}{4}$.Indeed

- if $\alpha k \leq \frac{1}{2}$ then $\alpha k\left(\frac{1}{2}-\alpha k\right) \geq 0$ and $e^*(\theta) \gtreqless \alpha k\left(\frac{1}{2}-\alpha k\right)$ if $\theta \gtreqless \widetilde{\theta}(k) = \frac{k}{8}(3-2\alpha k)^2$. Well if $\alpha k < \frac{1}{2}$ and $\alpha \geq \frac{1}{4}$, $\widetilde{\theta}(k) \leq 1$ then $e^*(\theta) \geq \alpha k\left(\frac{1}{2}-\alpha k\right)$. But if $\alpha < \frac{1}{4}$, $\widetilde{\theta} > 1$ then for some θ and k such that $\frac{1}{2} < \widetilde{k} < k < \frac{1}{2\alpha}$ where $\widetilde{\theta}\left(\widetilde{k}\right) = 1$, $e^*(\theta) < \alpha k\left(\frac{1}{2}-\alpha k\right)$, so $e^* = 0$ for these values.

- if $\alpha k > \frac{1}{2}$ then $\alpha k\left(\frac{1}{2}-\alpha k\right) < 0 \leq \min\{e^*(\theta), \alpha k\}$

Then if $\theta < \max\left\{1, \frac{k}{2}\right\}$, $e^*(\theta) < 0$ and from (**??**), it comes $e^* = 0$. In the same way, if $\theta > \max\{1, 2k\}$, $e^*(\theta) > \alpha k$, the solution is restricted[16] to $e^* = \alpha k$. Hence the optimal

[16]We have seen that if $e > \alpha k$, there is no production from the green producer (*i.e.* monopoly). For the green electricity production to be materialized and the funding constraint not to be violated, the consumers would prefer choosing $e^* = \alpha k$.

subscription strategy writes:

$$e^* = \begin{cases} 0, \forall \theta \in \left[1, \max\left\{1, \frac{k}{2}, \widetilde{\theta}(k)\right\}\right] \\ e^*(\theta), \forall \theta \in \left[\max\left\{1, \frac{k}{2}, \widetilde{\theta}(k)\right\}, \max\{1, 2k\}\right] \\ \alpha k, \forall \theta > \max\{1, 2k\} \end{cases}$$

where $\widetilde{\theta}(k) = \frac{k}{8}(3-2\alpha k)^2$ is the value of θ such that $e^*(\theta) = \alpha k\left(\frac{1}{2} - \alpha k\right)$.
Let us now write all the equilibrium features

First of all, one notices that for all $k \in \left[0, \frac{1}{2}\right]$, $\theta > 1$ and $\alpha \in [0,1]$, the equilibrium is given by: $e^* = \alpha k, q^{M*} = 1, q^{E*} = 0, p^* = 0$ et $\beta^* = \alpha$. If $k > 1/2$ equilibrium features are brought together in the tables.

θ	$[1, 2k]$	$> 2k$
e^*	$e^*(\theta)$	αk
q^{M*}	$\sqrt{\frac{2\theta}{k}} - 1$	1
q^{E*}	$1 - \sqrt{\frac{\theta}{2k}}$	0
p^*	$1 - \sqrt{\frac{\theta}{2k}}$	0
β^*	$\alpha\left(2 - \sqrt{\frac{2k}{\theta}}\right)$	α

Table 1.a: $\alpha > \frac{1}{4}$ et $\frac{1}{2} < k \leq 2$

θ	$\left[1, \frac{k}{2}\right]$	$\left[\frac{k}{2}, 2k\right]$	$> 2k$
e^*	0	$e^*(\theta)$	αk
q^{M*}	$\frac{1}{2} - \alpha k$	$\sqrt{\frac{2\theta}{k}} - 1$	1
q^{E*}	$\frac{1}{4}(1 + 2\alpha k)$	$1 - \sqrt{\frac{\theta}{2k}}$	0
p^*	$\frac{1}{4}(1 + 2\alpha k)$	$1 - \sqrt{\frac{\theta}{2k}}$	0
β^*	$\widehat{\beta}(0)$	$\alpha\left(2 - \sqrt{\frac{2k}{\theta}}\right)$	α

Table 1.b: $\alpha > \frac{1}{4}$ et $k > 2$

θ	$[1, 2k]$	$> 2k$
e^*	$e^*(\theta)$	αk
q^{M*}	$\sqrt{\frac{2\theta}{k}} - 1$	1
q^{E*}	$1 - \sqrt{\frac{\theta}{2k}}$	0
p^*	$1 - \sqrt{\frac{\theta}{2k}}$	0
β^*	$\alpha\left(2 - \sqrt{\frac{2k}{\theta}}\right)$	α

Table 2.a: $\alpha \leq \frac{1}{4}$ et $\frac{1}{2} < k \leq \widetilde{k}$

θ	$[1, \phi(k)]$	$[\phi(k), 2k]$	$> 2k$
e^*	0	$e^*(\theta)$	αk
q^{M*}	$\frac{1}{2} - \alpha k$	$\sqrt{\frac{2\theta}{k}} - 1$	1
q^{E*}	$\frac{1}{4}(1 + 2\alpha k)$	$1 - \sqrt{\frac{\theta}{2k}}$	0
p^*	$\frac{1}{4}(1 + 2\alpha k)$	$1 - \sqrt{\frac{\theta}{2k}}$	0
β^*	$\widehat{\beta}(0)$	$\alpha\left(2 - \sqrt{\frac{2k}{\theta}}\right)$	α

Table 2.b: $\alpha \leq \frac{1}{4}$ et $k > \widetilde{k}$

where $\widetilde{\theta}\left(\widetilde{k}\right) = 1$ and $\phi(k) = \max\left\{\frac{k}{2}, \widetilde{\theta}(k)\right\}$

To simplify, let us define five regions ($\mathcal{A}$ to $\mathcal{E}$) for the vector of parameters (θ, k): let $\mathcal{X} = [1, \infty[\times \mathsf{R}_+$,

- $\mathcal{A} = \{(\theta, k) \in \mathcal{X} |\, \theta > 2k\}$
- $\mathcal{B} = \left\{(\theta, k) \in \mathcal{X} |\, 2k \geq \theta > \frac{1}{2}k\right\}$
- $\mathcal{C} = \left\{(\theta, k) \in \mathcal{X} |\, \frac{1}{2}k \geq \theta\right\}$
- $\mathcal{D}(\alpha) = \begin{cases} \left\{(\theta, k) \in \mathcal{X} |\, \theta \leq \widetilde{\theta}(k)\right\} & \text{if } \alpha \in \left[0, \frac{1}{4}\right[\\ \emptyset & \text{if } \alpha \in \left[\frac{1}{4}, 1\right] \end{cases}$

- $\mathcal{E}(\alpha) = \left\{ (\theta, k) \in \mathcal{X} | \, k \leq \frac{1}{2\alpha} \right\}$

So equilibrium can also be written:

$$\begin{aligned}
\left(e^{*}, q^{M*}, p^{*}, \beta^{*}\right) &= \\
&= \left\{ \begin{array}{ll} (\alpha k, 1, 0, \alpha) & \text{if } (\theta, k) \in \mathcal{A} \\ \left(e^{*}(\theta), \sqrt{\frac{2\theta}{k}} - 1, 1 - \sqrt{\frac{\theta}{2k}}, \alpha\left(2 - \sqrt{\frac{2k}{\theta}}\right)\right) & \text{if } (\theta, k) \in \mathcal{B} \backslash \mathcal{D}(\alpha) \\ \left(0, \frac{1}{2} - \alpha k, \frac{1}{4}(1 + 2\alpha k), \widehat{\beta}(0)\right) & \text{if } (\theta, k) \in \mathcal{C} \cup \{\mathcal{D}(\alpha) \cap \mathcal{E}(\alpha)\} \end{array} \right.
\end{aligned}$$

According to the equilibrium features (see appendix D), the subcription welfare is:

$$\begin{aligned}
W^{*} &= W(p^{*}, e^{*}, q^{M*}) + e \\
&= \left\{ \begin{array}{l} \frac{1}{2} + \alpha(\theta + 1 - k) \ \text{ if } \ (\theta, k) \in \mathcal{A} \\ W^{*}(\theta) \ \text{ if } \ (\theta, k) \in \mathcal{B} \backslash \mathcal{D}(\alpha) \\ \widehat{W} \ \text{if } \ (\theta, k) \in \mathcal{C} \cup \{\mathcal{D}(\alpha) \cap \mathcal{E}(\alpha)\} \end{array} \right.
\end{aligned}$$

where $W^{*}(\theta) = \frac{1}{2}\left[1 - \left(1 - \sqrt{\frac{\theta}{2k}}\right)^{2}\right] + \alpha k\left(1 - \sqrt{\frac{2\theta}{k}}\right) + \alpha(1 + \theta)\left(2 - \sqrt{\frac{2k}{\theta}}\right)$.

8.6 Appendix F. Comparisons

8.6.1 CS-T comparison

We compare here the features of these two funding regimes CS and T, concentrating ourselves on the relevant interval, $k \in \left[0, \frac{1}{2\alpha}\right]$.

- comparison of environmental quality indices:

$$\forall k \in \left[0, \frac{1}{2\alpha}\right], \widehat{\widehat{\beta}}(0) - \widehat{\beta}(0) = -8\frac{t^{*}(k)\,\alpha k}{(3[1 - t^{*}(k)] - 2\alpha k)(3 - 2\alpha k)} < 0$$

- comparison of production levels (incumbent and entrant):

$$\begin{aligned}
\widehat{\widehat{q}}^{M} - \widehat{q}^{M} &= -\frac{1}{2}t^{*}(k) < 0 \\
\widehat{\widehat{q}}^{E} - \widehat{q}^{E} &= -\frac{1}{4}t^{*}(k) < 0
\end{aligned}$$

- comparison of electricity prices:

$$\widehat{\widehat{p}} - \widehat{p} = \frac{3}{4}t^{*}(k) > 0$$

- comparison of welfare levels: $\forall k \in \left[0, \frac{1}{2\alpha}\right]$ et $t^{*}(k) > 0$:

$$\Delta W^{1} = \widehat{\widehat{W}} - \widehat{W} = (\theta + 1)\left[\widehat{\widehat{\beta}}(0) - \widehat{\beta}(0)\right] + w^{3} < 0$$

8.6.2 Comparison between all scenarios

Here we make the welfare and environmental quality index comparisons.

1. Environmental quality index (β).

   (a) When $k > \frac{1}{2\alpha}$ -that is $(\theta, k) \in \mathcal{X} \backslash \mathcal{E}(\alpha)$-, we know that $\widehat{\beta}(0) = \widehat{\widehat{\beta}}(0) = 0$. Then from tables 1 and 2 in appendix D, one checks that $\beta^*(e^*) \geq 0$ for all relevant values of θ, k and α.

   (b) When $k \leq \frac{1}{2\alpha}$, there are several cases depending on (θ, k):

      i. if $(\theta, k) \in \mathcal{A}$, then for all $\alpha \in [0, 1]$

$$\beta^*(e^*) = \alpha > 2\alpha \frac{1 - 2\alpha k}{3 - 2\alpha k} = \widehat{\beta}(0) > \widehat{\widehat{\beta}}(0)$$

      ii. if $(\theta, k) \in \mathcal{B} \backslash \mathcal{D}(\alpha)$,

$$\text{if } k < \frac{1}{2\alpha} : \beta^*(e^*) = \alpha \left(2 - \sqrt{\frac{2k}{\theta}}\right) > 2\alpha \frac{1 - 2\alpha k}{3 - 2\alpha k} = \widehat{\beta}(0) > \widehat{\widehat{\beta}}(0)$$

      because $\alpha\left(2 - \sqrt{\frac{2k}{\theta}}\right) \gtrless 2\alpha\frac{1-2\alpha k}{3-2\alpha k}$ for $\theta \gtrless \widetilde{\theta}(k)$ and here $\theta > \widetilde{\theta}(k)$.

$$\text{if } k \geq \frac{1}{2\alpha}, \mathcal{B} \backslash \mathcal{D}(\alpha) = \mathcal{B} : \beta^*(e^*) = \alpha \left(2 - \sqrt{\frac{2k}{\theta}}\right) > \widehat{\beta}(0) = \widehat{\widehat{\beta}}(0) = 0$$

      iii. if $(\theta, k) \in \mathcal{D}(\alpha) \cap \mathcal{E}(\alpha)$ and if[17] $\alpha \leq \frac{1}{4}$, then $\beta^*(e^*) = \widehat{\beta}(0) > \widehat{\widehat{\beta}}(0) > 0$

2. Welfare levels

   (a) When $k > \frac{1}{2\alpha}$ -that is $(\theta, k) \in \mathcal{X} \backslash \mathcal{E}(\alpha)$-, we know that $W^* \geq \widehat{W} = \widehat{\widehat{W}} = \frac{3}{8}$. Indeed, for all $\alpha \in [0, 1]$:

      i. if$(\theta, k) \in \mathcal{A}$, then $W^* = \frac{1}{2} - \alpha(\theta + 1 - k) > \frac{3}{8}$ because $\theta > 2k$,

      ii. if $(\theta, k) \in \mathcal{B}$, then $W^*_{\theta = \frac{k}{2}|} = \frac{3}{8}$ and $W^* > \frac{3}{8}$ for $\theta > \frac{k}{2}$. More precisely, if $\theta = \eta\frac{k}{2}$ with $\eta > 1$ then

$$W^* = \underbrace{\frac{1}{8}(4\sqrt{\eta} - \eta)}_{> \frac{3}{8}} + 2\alpha \underbrace{\left(1 - \frac{1}{\sqrt{\eta}}\right)}_{> 0} + k\alpha(1 - \sqrt{\eta})^2 > \frac{3}{8}$$

      iii. if $(\theta, k) \in \mathcal{C}$ then $W^* = \widehat{W} = \widehat{\widehat{W}} = \frac{3}{8}$,

   (b) When $k \leq \frac{1}{2\alpha}$,

[17] Indeed if $\alpha > \frac{1}{4}$, the region $\mathcal{C} \cup \mathcal{D}(\alpha) \cap \left\{(\theta, k) | \, k \leq \frac{1}{2\alpha}\right\}$ is empty

i. if $(\theta, k) \in \mathcal{A}$, then for all $\alpha \in [0,1]$,

$$W^* = \frac{1}{2} - \alpha k + (\theta+1)\,\beta^*(e^*) > \widehat{W} = \frac{15}{32} - \frac{5}{8}\alpha k + \frac{7}{8}\alpha k^2 + (\theta+1)\,\widehat{\beta}(0)$$

in fact the θ value such that $W^* = \widehat{W}$ is negative[18] and $\left(W^* - \widehat{W}\right)$ is increasing in θ because we have seen that $\beta^*(e^*) > \widehat{\beta}(0)$.

ii. if $(\theta, k) \in \mathcal{B} \backslash \mathcal{D}(\alpha)$,

A. we know from the point 1.b.ii. above that $\beta^*(e^*) = \widehat{\beta}(0)$ if $\theta = \widetilde{\theta}(k)$. Furthermore, in that case $e^* = e^*\left(\widetilde{\theta}(k)\right) = \frac{k}{2}(1 - 2\alpha k)$ so $q^{M*} = \widehat{q}^{M*}$ which implies $W^* = \widehat{W}$ if $\theta = \widetilde{\theta}(k)$, that is $W^* - \widehat{W} = 0$.

B. For all others couple (θ, k) such that $\theta > \widetilde{\theta}(k)$ then $W^* > \widehat{W} > \widehat{\widehat{W}}$. Indeed, $\left(W^* - \widehat{W}\right)$ is an increasing function of θ for $2k > \theta > \max\left\{1, \widetilde{\theta}(k)\right\}$. More precisely, $\frac{d\left(W^* - \widehat{W}\right)}{d\theta} = \frac{\Phi(\theta,k,\alpha)}{4(3-2\alpha k)\sqrt[3]{\theta k}}$. To sign $\frac{d\left(W^* - \widehat{W}\right)}{d\theta}$ we study the variations of function[19] Φ with respect to θ. So it exists a value[20] $\widetilde{\widetilde{\theta}}(k)$ such that $\frac{\partial \Phi\left(\widetilde{\widetilde{\theta}}(k),k,\alpha\right)}{\partial\theta} = 0$ and $\widetilde{\widetilde{\theta}}(k) \leq \widetilde{\theta}(k)$ (resp. $\widetilde{\widetilde{\theta}}(k) > \widetilde{\theta}(k)$) if $k \in \left[0, \frac{1}{22\alpha}\right] \cup \left[\frac{17}{86\alpha}, \frac{1}{2\alpha}\right]$ (resp. $k \in \left]\frac{1}{22\alpha}, \frac{17}{86\alpha}\right[$). Consequently after tedious calculations, if $k > \frac{1}{6\alpha}$ then $\frac{\partial\Phi(\theta,k,\alpha)}{\partial\theta}$ T 0 for θ T $\widetilde{\widetilde{\theta}}(k)$ else if $k \leq \frac{1}{6\alpha}$ then $\frac{\partial\Phi(\theta,k,\alpha)}{\partial\theta}$ S 0 for θ T $\widetilde{\widetilde{\theta}}(k)$. Therefore, it is now possible to give the variations of function $\Phi(\theta,k,\alpha)$ in the following tables: -with $\widetilde{\Phi} = \Phi\left(\widetilde{\theta}(k), k, \alpha\right) > 0$ and $\overline{\Phi} = \Phi(2k, k, \alpha) > 0$-

for $k \in \left[\frac{17}{86\alpha}, \frac{1}{2\alpha}\right]$

θ	$\widetilde{\theta}(k)$		$2k$
Φ'		$+$	
Φ	$\widetilde{\Phi}$	$\nearrow$	$\overline{\Phi}$

for $k \in \left[\frac{1}{6\alpha}, \frac{17}{86\alpha}\right]$

θ	$\widetilde{\theta}(k)$		$\widetilde{\widetilde{\theta}}(k)$		$2k$
Φ'		$-$	0	$+$	
Φ	$\widetilde{\Phi}$	$\searrow$	$\widetilde{\widetilde{\Phi}}$	$\nearrow$	$\overline{\Phi}$

with $\widetilde{\widetilde{\Phi}} = \Phi\left(\widetilde{\widetilde{\theta}}(k), k, \alpha\right) > 0$

for $k \in \left]\frac{1}{22\alpha}, \frac{1}{6\alpha}\right[$

θ	$\widetilde{\theta}(k)$		$\widetilde{\widetilde{\theta}}(k)$		$2k$
Φ'		$+$	0	$-$	
Φ	$\widetilde{\Phi}$	$\nearrow$	$\widetilde{\widetilde{\Phi}}$	$\searrow$	$\overline{\Phi}$

for $k \in \left[0, \frac{1}{22\alpha}\right]$

θ	$\widetilde{\theta}(k)$		$2k$
Φ'		$-$	
Φ	$\widetilde{\Phi}$	$\searrow$	$\overline{\Phi}$

with in this latter case $\widetilde{\Phi} > \overline{\Phi}$.

From these tables, we conclude that for all admissible couples (θ, k), the function $\Phi(\theta, k, \alpha)$ is non negative. Therefore $\frac{d\left(W^* - \widehat{W}\right)}{d\theta} > 0$ and $W^* > \widehat{W}$ for (θ, k) such that $2k > \theta > \max\left\{1, \widetilde{\theta}(k)\right\}$.

[18] This value is $\theta = -\frac{7}{8}\alpha k^2 + \frac{11}{8}k - \frac{3}{32\alpha} - 1 < 0$ for $k \leq \frac{1}{2\alpha}$

[19] where $\Phi(\theta, k, \alpha) = \sqrt{k}\,(18\alpha k - 3)\,\sqrt[3]{\theta} + \sqrt{2}\left(8\alpha(\alpha k)^2\right)\theta + \sqrt[3]{2}k^2\alpha(3 - 2k\alpha)$

[20] Exactly $\widetilde{\widetilde{\theta}}(k) = \frac{8}{81}k\left(\frac{3 - 14\alpha k + 8\alpha^2 k^2}{1 - 6\alpha k}\right)^2$

iii. if $(\theta, k) \in \mathcal{D}(\alpha) \cap \mathcal{E}(\alpha)$ then for all $\alpha \in [0,1]$,

$$W^* = \widehat{W} > \widehat{\widehat{W}}$$

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