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IMPLEMENTING EXTENDED PRODUCER RESPONSIBILITY: COMPARATIVE ANALYSIS OF PACKAGING WASTE MANAGEMENT

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Abstract

Extended producer responsibility is an important environmental policy expected to increase producer environmental innovation through source reduction, collection effort and recyclability. Using a model of vertical differentiation, we propose to test the effectiveness of the application of the extended producer responsibility (EPR) through two complementary measures: eco-tax and adhesion to eco-organization. We focus on the importance of funding modalities membership on the achievement of environmental objectives. Simulation results show the need of mix policy instruments in the field of packaging waste. Instruments efficiency should be evaluated with regard to environmental targets and should permit the total transfer of responsibility to producer.

JEL Classifications: Q53, Q 58, H23, L23

Keywords: Packaging waste, Tax, Policy instruments, Extended producer responsibility

ملخص

مسؤولية المنتج الموسعة هي سياسة بيئية هامة ومن المتوقع أن تزيد منتج الابتكار البيئي من خلال الحد من المصدر، وجهود جمع وإعادة التدوير. باستخدام نموذج التمايز الرأسي، نقترح تطبيق لاختبار فعالية مسؤولية المنتج الموسعة (EPR) من خلال اثنين من التدابير التكميلية: وجود ضرائب على استخدام البيئة ووجود منظمات صديقة للبيئة. ونقوم بالتركيز على أهمية تمويل العضوية اتحقيق الأهداف البيئية. وتشير نتائج المحاكاة الحاجة الى مزيج من أدوات السياسة في مجال تغليف النفايات. وينبغي تقييم كفاءة الأدوات فيما يتعلق بالأهداف البيئية، وينبغي أن تسمح بالنقل الكلي للمسؤولية على المنتجين.

1. Introduction

During the last decades, waste management has become a priority area and a real problem. Industrialization changes the structure of waste and increases the production of packaging waste even in developing countries. Studies show that changing lifestyles will increase rapidly the proportion of packaging waste in the medium term and we will have the same level as developed countries namely from 30 to 40% of the waste produced (UNEP 2011)[1]. This new movement that characterizes developing countries calls for urgent and adequate measures in the field of packaging waste. The concept of extended producer responsibility (EPR)[2] encourages producers to change their behavior and reduce the impact of their activities on the environment and can be implemented across a range of regulatory, economic and informational instruments. (OECD 2001; Widmer *et al*. 2005; Nahman 2010).

Therefore, producers will be expected to innovate in order to change their production methods to move towards ecological modernization. Producer's innovation consists in reducing materials resources and energy consumption, increasing recyclable substances, extending the useful life of products, encouraging the recovery and the reuse of products and improving the recyclability of packaging (Mckerlie et *al*. 2006). These significant changes in the production process call for new knowledge and competences and improvement of environmental innovation (Brouillat and Oltra 2012; Brouillat 2009).

The purpose of the paper is to discuss the effectiveness of policy instruments to involve producer environmental effort and to promote waste collection and prevention. Thus, we model the impact of policy instruments on attaining optimal producer environmental effort. We consider that this effort can either reduce waste at the source or ameliorate the collection and the recyclability.

Several economic instruments are intended to change producer behavior and increase environmental effort. In this paper, we focus on two complementary instruments: eco-tax and adhesion to collective organizations (Eco-collect). Modalities of fixing the adhesion to collective organizations stimulate effort and define the extent of producer's responsibility. We discern the scenario (1) where the membership fee is predetermined and static and the scenario (2) where the adhesion is variable with total delegation of collection costs to the Firm. In each alternative we define the impact on environmental effort and whether the transfer of responsibility to producers is total or partial.

The paper is structured as follows. In section 2, we present the model assumptions and debate the literature related to extended producer responsibility. In section 3, we examine scenario 1 where Firm adheres to Eco-collect and pays a fix adhesion before the firm effort decision. In section 4, we suppose that Eco-collect delegates its costs to the firm and that the adhesion is based on its overall environmental effort. In section 5, we compare the simulation results of the two scenarios and discuss the impact of policy instruments on attaining environmental targets. In the last section we conclude by summarizing the main results.

2. The Model of Extended Producer Responsibility Policies for Packaging Waste

The present paper is an extension of Loukil and Rouached (2012) model where the producer's environmental effort k is the main parameter of differentiation and expected, when rising, to induce a higher environmental benefit ($0 \leq k < 1$).

We suppose that, the producer's environmental effort is decomposed in three components: reduction at source, collection and recyclability.

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[1] UNEP (2011), Emerging issues in our global environment, United Nations Environment Program. Nairobi, February 2011.

2The EPR should not be confused with product stewardship (PS). This later approach stipulates that all actors implicated in the product life cycle: producer retailer, seller consumer, government are responsible for reducing environmental impact. So the responsibility is shared in PS and not limited to the producer.

We use the Mussa-Rosen model (1978) of vertical differentiation for a duopoly market product and we assume that the overall effort *k* is observed and known by consumers and that they are aware of the relationship between effort and the environmental impacts induced by the consumption of product.

We examine how to combine policy instruments to promote producer innovation and to attain the optimal effort. As Walls (2004), we suppose that the assessment of each policy instruments should be linked to the EPR targets clearly defined and at the lowest cost.

2.1 Environmental effort components and EPR targets

Each environmental policy should provide incitation to producers to innovate in order to ensure reduction at source, selective collection and recyclability efforts.

2.1.1 Eco-design and effort at source (X)

The eco-design is a new approach in the field of packaging waste. It contributes to reduce the quantity and the toxicity of waste produced and so enhances environmental and economic products performance (Lim *et al.* 2013). In this regard, eco-design is related to waste prevention and considered a priority for many national policies. According to Zorpas *et al.* (2013), waste prevention includes qualitative and quantitative reduction at the source to decrease hazardous contents of waste and their environmental impact[3]. To reach an effective waste prevention, legal targets of waste reduction are defined at national and international level.

Sluisveld and Worrell (2013) identify two options for source reduction. Firstly, we enhance material efficiency. Firms can minimize packaging by choosing the option of larger volumes, more lightweight composition, concentrating the product or removing the need of transport or of reducing waste toxicity. Secondly, the effort can focus on increasing energy efficiency through reducing energy intensity and the embedded carbon in packaging. The re-use of packaging or the extension of the life span of products contributes not only to material efficiency but also to saving more energy. Through design in durability, the action is ported in how to extend the lifetimes of packaging (Ashby 2009).

The cost of waste reduction at the source is related to the cost of innovation and effort to implement waste prevention programs. Formally, we assume that each unit produced causes waste

$$\alpha_i = 1 - X_i \qquad (H_1)$$

α_I is decreasing with the level of effort at the source provided by the firm *i*, denoted X_i. The amount of waste by α_I function is described in the following properties: $0 < \alpha_i \leq 1$; $\alpha_i' < 0$.

We denote by q_I the amount of product sold by each firm $i (i = 1, 2)$.

2.1.2 Selective collection effort (S)

Efforts to boost packaging waste selective collection contribute to reduce the quantity of waste going to landfills or incinerated and then to extend the lifespan of landfills (Fullerton and Kinnaman 1995). The process of collection needs complex and expansive logistics related to investments in selective collection, sorting and additional transport costs (Cruz*et al.* 2012). The collection requires not only high costs, but also suffers from the lack of effective funding mechanisms. We can compare, as Defeuilly and Quiron (1995), the marginal cost curve of selective and undifferentiated collection. When we increase the fraction of waste collected,

[3] In this paper, we consider that the reduction of the impact of waste generated contributes to efforts downstream of the process of production of waste; efforts in the different axes are interdependent.

the cost of selective collection raises but the quality of waste collected decreases[4]. Firms should innovate to decrease the cost of selective collection and increase the quantity collected.

In our model, we admit certain the lack of selective collection system in place so that the waste produced by firms are not perfectly collected and treated. The hypothesis (H2) reflects this imperfection.

On the quantity of waste (per unit of output), only a certain amount is recovered by collectors, which is normalized without lost of generality to zero. (H2)

2.1.3 Recyclability effort(R)

As Walls (2005) and Brouillat *et al.* (2012), we consider that the recyclability is related to the product ability to be recycled and expected to ameliorate the quantity and the quality of waste recycled. In many countries, regulatory targets or norms frame recyclability. So when the firm product does not attain the norm, two policies can be applied. The firm can either be not authorized to sell its product or penalized by paying a fine.

The recycled inputs substitute virgin materials and are supposed to be a better choice from an environmental view (Sluisveld and Worrell 2013). For this, the recyclability of materials decreases raw material consumption and waste going to the landfill.

Reducing the number of material used and more, choosing one material increases the recyclability. When the use of different materials is inevitable, recyclability can be improved by facilitating materials separation.

Many other problems are related to the value and the quality of recycling output. In this context, the price of recycled materials should be cheaper than the price of virgin materials and the quantity sufficient to satisfy the demand.

In the other hand, the effort of recyclability admits a maximum threshold. When a firm decides to cross this threshold, it should integrate serious changes in the product and this effort requires incremental innovation[5]. Recyclability implies additional costs and from Calcott and Walls (2005), waste recyclability means that the benefit related to the output of recycling is higher than the recycling cost. So recycling cost is defined through the degree of waste recyclability.

So we can decompose k_i:

$$k_i = R_i^a \; S^b{}_i \; X_i^e \qquad \text{(H3)}$$

$avec\, a \geq 0$; $b \geq 0$; $e \geq 0$

This specification is inspired from many works such as Brouillat and Oltra (2012)[6]. Each variable is assumed obtained through investment in research and development, which remains a risked investment[7]. Innovation costs are synthesized under the unit price[8]. We suppose that

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[4]When we integrate the environmental impact of land filling and incineration, the marginal cost curve of selective collection increases.

[5]We suppose that R<□and that α <□□, □is the maximum collection and recyclability threshold. So a firm will support expensive costs and a transition period to go through this threshold. Also, this transition is associated with many financial risks.

[6]We assume that a+b+e=1/2. This assumption reflects the consumer absorption capacity of information and admits a limit.

7In general, a high degree of uncertainty is associated to the activity of environmental innovation and constitutes a “disincentive to innovate" (Depret and Hamdouch 2009). Indeed, the behavior of actors in a market can be unpredictable, which may affect the return on investment related to environmental innovation.

[8]In reality, the innovation process requires a transition period and depends on the firm’s learning capacity, and it’s path dependency (Dosi 1988). Learning and adaptation costs are often important especially for the firm investing firstly in the market and it is more interesting to be a follower than to be the first (Depret and Hamdouch 2009).

the effects of innovation effort occur in the same period, so there's not a transition period. This effort is a parameter of differentiation in our model that may lead to evince Firm1.

2.2 Consumer utility and demand function

We assume that each consumer buys one unit of the good or nothing from one of two firms. We consider the case where consumers can express different sensitivities concerning the global effort k_i. Runkel (2003) is the first to test the effectiveness of EPR when consumer's sensitivities are heterogeneous. Goods are identical but consumers will agree more or less importance. In the model of Fleckinger and Glachant (2010), producers exploit the heterogeneity of consumer preferences to assure quality differentiation when the quality is binary. In our model, we consider, that producer can choose different level of effort[9]. We denote by θ the preference parameter for this effort or willingness to pay for the effort. It is assumed that this preference parameter is distributed among the population on a segment [0, 1] of unit density and a uniform distribution. We consider a consumer *j* as assumed to attach to the global effort k_i the weight θ_j. The more θ_j is greater; the more the consumer provides significant weight to the firm's effort. The consumer utility is assumed separable in effort and price.

Therefore, the preferences of a consumer j (defined byθ_j) and buying at a price p_i a unit of product *I* characterized by a k_i effort are given by the expression:

$$U_j(k_i) = \theta_j k_i - p_i \qquad (1)$$

It is the surplus resulting from the consumption of good *i*. We finally assume that the market is covered.

Consumers make no effort with regard to the reduction of waste. The consumer values the overall environmental effort chosen by Firm 2. It is a parameter of differentiation. The consumer j makes a choice between buying from Firm 1or 2. A consumer sensitivity θ_j admits the utility:

o$U= \theta_j k_1 - p_1$ if he buys from Firm 1.o$U= \theta_j k_2 - p_2$ if he buys from Firm 2.

We can deduce the demand addressed to each firm and determine the position of the consumer indifferent to purchasing either Product 1 or Product 2. It is obtained by equalising the two utility functions.

We deduce:

$$\begin{cases} q_1 = \dfrac{p_2 - p_1}{k_2 - k_1} \\ q_2 = 1 - \dfrac{p_2 - p_1}{k_2 - k_1} \end{cases} \qquad (2)$$

The lack of environmental effort generates a large total waste causing environmental damage that is accompanied by deterioration in the health of consumers.

[9]The work of Laffont (1975), reports that economic agents acting on certain morals and which incorporate externalities such as pollution in their choices .We believe that environmental awareness is related to the reflection on the environmental impact of every product on the environment. We can define the sustainable consumption as an ethical practice of consuming related to the object of reducing environmental impact (Evans 2011).

2.3 EPR and policy instruments

Many instruments are used for the implementation of the EPR (Kroepelien 2000; Walls 2006). The main object is to delegate the responsibility of waste management to producers and link effort in the upstream of packaging waste production with the downstream.

We discuss the use of two principles instruments: membership fees to Eco-collect and eco-tax subsidy[10].

2.3.1 Membership fees to eco-organizations

Producers are required to collect and recycle packaging waste related to their production. For this, they have the choice between either, collecting themselves or delegating this task to collective structures. Producers can implement their own system to collect waste, but this first alternative is still very costly. So it is preferable for companies to join a collective organization and share the cost of collection. For the second alternative, the value and the way of calculation of individual producers' membership are important to assure the efficiency of this instrument. In our model, we suppose that each producer pays a fee per unit of product sold in the market and that the fee rate depends on the weight, size and type of each material. So the adhesion offers individual incentives to prevention effort.

However, many questions persist about the extent of this responsibility and it's sharing with municipalities (Fleckinger and Glachant 2010; Milanez and Buhrs 2009). In practice, experiences in many countries like France or Germany are associated to different systems of responsibility transfer.

The model discusses the modality of calculation of the membership fees and if the Eco-collect fixes the fee adhesion before the Firm effort decision (Scenario 1) or if the fee adhesion is integrated in the Firm cost function and based on its overall effort (Scenario 2).

2.3.2 Eco-tax subsidy

The object of this instrument should be the reduction of environmental damage and increasing environmental effort. In this context, public intervention can contribute to achieve priority goals. Therefore, tax policy is thought to enhance producer environmental effort and to be an instrument of "criminalization" or penalization for companies making no environmental effort (Ekins 1999).

The impact of policy instruments in attaining the goals of optimal environmental effort, reducing waste at source or reducing waste going to landfill is assessed in the model. The model answers also the following questions. Should the effort be oriented to waste reduction at the source or to promote the selective collection and the recyclability of packaging? Is there a mix environmental policy that permits the optimization of producer effort? Could policy instruments be applied in all countries and even in developing countries?

The paper supposes complementarities of policy instruments in the task of raising producer's environmental effort. We question the effectiveness of measures taken by the government to ultimately reduce the amount of uncontrolled waste. The eco-tax is associated with membership value to the collective structure for the collection and the valorization of packaging waste.

The impact of government intervention is analyzed in the following sections. The eco-tax can be thought of as a way to encourage companies to reduce the amount of packaging waste. Its unit value is assumed to depend on the level of overall effort[11].

[10]The recycling rate target is also another instrument, which lies under the EPR umbrella. The government may constraint producer to meet a recycling rate goal. The target can apply either to each producer or to the overall industry. The recycling targets is integrated in our model through the recyclability R but the discussion in the value of R and its impact on the global environmental effort will be discussed

Under these conditions, we assume that Firm 1 is subjected to a unit tax denoted by t, which will be imposed on the amount of residual waste (which is not treated). For Firm 2, waste management is delegated to Eco-collect. The firm does not directly pay the eco-tax. Eco-collection supports decreasing tax with higher environmental effort of Firm 2.

We hold the following specification so that:

Eco-tax unit= $t\,(1-k_i)$ (H4)

When we consider that Firm 2 delegates the task of collection to Eco-collect, we suppose that the fee adhesion will serve to cover costs of collection and tax supported by Eco-collect.

$$\eta_2 = \lambda S_2 + t(1-k_2)$$

3. Fixed Adhesion (Static Approach)

The first scenario supposes a partnership between one of the two firms (e.g., Firm 2) and Eco-collection. The aim of the cooperation is to reduce the amount of waste produced through increasing environmental effort in the upstream (source reduction waste) and downstream (waste collection and recycling) of consumption process. Under these terms, Firm 2 adhering to Eco-collect, pays a single adhesion η_2 and agrees for global environmental effort $k_2>0$. It is assumed that this contribution is less than the unit price of innovation so that $\eta_2 < 1$.

Firm 1, is supposed not adhering to Eco-collect and supporting the eco-tax. It makes no effort to reduce packaging $X_1=R_1= S_1=0$. It follows that $k_1=0$.

The analysis proceeds as follows. We first consider that the level of overall environmental effort by Firm 2 is given and we determine the optimal level of each of its variables. This will allow us to express the function of production costs on the global environmental effort.

3.1 Cost function

Now consider the simultaneous choice of three components that define the global dimension k_2. The following program expresses the optimization problem faced by Firm 2:

$$\begin{cases} \min_{S_2,T_2,X_2} S_2 + R_2 + X_2 + \eta_2(1-X_2) \\ S/c \quad k_2 = R_2^a S_2^b X_2^{(1/2)-a-b} \\ R_2 \geq 0, S_2 \geq 0, X_2 \geq 0 \end{cases} \quad (3)$$

Supposing a constant and identical unit price for each component of the effort, Firm 2 seeks to minimize the total cost for the three components and the cost of joining the Eco-collect structure depending only in source waste reductionX_2.

Certainly, the first equation of system (3) represents a total unit cost incurred for each unit produced. It is to be minimized under the constraint given by (H3), the second equation of the system.

The resolution by the Lagrangian of the system (3) allows for the optimal values for k_2 given for the three components (see Appendix 1.A).

These expressions are summarized by the system (4)

[11]This underlies that if the firm adopts a process for better biodegradability of waste not collected, it will be less penalized by the government

$$\begin{cases} R_2 = 2ac(1-\eta_2)^{1-2(a+b)}\, k_2^{\ 2} \\ S_2 = 2bc(1-\eta_2)^{1-2(a+b)}\, k_2^{\ 2} \\ X_2 = (1-2a-2b)c(1-\eta_2)^{-2(a+b)}\, k_2^{\ 2} \end{cases} \qquad (4)$$

With $c = \dfrac{(\frac{1}{2}-a-b)^{-1+2(a+b)}}{2a^{2a}b^{2b}}$

We note that efforts for reduction at the source, collection, or recycling depend on *a* and *b* values that reflect consumers' sensitivity to each type of effort.

Using the system (4), we can easily deduce the unit cost c_2 of Firm 2:

$$c_2 = c(1-\eta_2)^{1-2(a+b)} k_2^2 + \eta_2 .$$

To continue solving the dynamic game defined above and determine the perfect equilibrium, we proceed by backward induction. First, we determine the sub-game perfect Nash equilibrium first in price; the level of overall environmental effort by Firm 2 is considered as given (the level of effort by Firm 1 is assumed to be zero). Next, we determine the overall effort. The last step in the analysis is a discussion of membership prices Eco-collect structure and potential effects of public regulation.

3.2 The price equilibrium

According to (H1) and to Glachant (2005), the amount of potential waste resulted from Firm 1is assumed to correspond to q_1. Firm 1 makes no effort to collect waste so all production is subject to eco-tax, thus its profit becomes $\Pi_1=[p_1- t]q_1$.

We note η_1=t.

Firm 2 waste is equal t o $\alpha_2 q_2$ and cost is $c_2\, q_2$ so its profit becomes $\Pi_2 =[p_2-c_2]\, q_2$

To determine the equilibrium price of this second stage of the game, we solve simultaneously the maximization program of the two firms (each Firm 1 maximizes its profit with respect to its decision variable; *i=1, 2*).

Profit maximization of each firm leads to the following equilibrium price (see Appendix 1.B):

$$\begin{cases} p_1 = \frac{1}{3}[c(1-\eta_2)^{1-2(a+b)}\, k_2^2 + k_2 + 2\eta_1 + \eta_2)] \\ p_2 = \frac{1}{3}[2c(1-\eta_2)^{1-2(a+b)}\, k_2^2 + 2k_2 + \eta_1 + 2\eta_2)] \end{cases} \qquad (5)$$

The prices of both goods 1 and 2 are moving in the same direction with k_2. We also note that the price difference is monotonically increasing. The competitive pressure on the product 2 is relaxed and its price increases.

3.3 The overall optimal effort by Firm 2

Going back to the first stage of the game, the decision by Firm 2 concerns the level of effort required. To do this, it must anticipate the sub-game perfect equilibrium of the second stage and integrate the equilibrium price obtained.

Using equation (5) and injecting optimal prices in the expression of Firm 2 profit, we obtain

$$\Pi_2 = \frac{[k_2^2 c(1-\eta_2)^{1-2(a+b)} - 2k_2 + \eta_2 - \eta_1]^2}{9k_2}$$

(6)

Firm 2 must maximize profit over k_2. Note that the positivity condition for the Firm's 2 demand (which guarantees also the positivity of its margin) requires that parameters meet the following condition: $c(1-\eta_2)^{1-2(a+b)}(\eta_2 - \eta_1) \leq 1$.

In this case, the optimal value of the overall effort must be within the range: $[\dot{k}, \ddot{k}]$ where:

$$\begin{cases} \dot{k} = \dfrac{1-\sqrt{1-c(1-\eta_2)^{1-2(a+b)}(\eta_2-\eta_1)}}{c(1-\eta_2)^{1-2(a+b)}} \\ \ddot{k} = \dfrac{1+\sqrt{1-c(1-\eta_2)^{1-2(a+b)}(\eta_2-\eta_1)}}{c(1-\eta_2)^{1-2(a+b)}} \end{cases}$$

The optimal value for this scenario, denoted, $k_{21}$is

$$k_{21} = \frac{1+\sqrt{1+3c(1-\eta_2)^{1-2(a+b)}(\eta_2-\eta_1)}}{3c(1-\eta_2)^{1-2(a+b)}} \quad (7)$$

Proof: see Appendix 1.C

Proposition 1:

The optimal level of overall effort increases with the membership Eco-collect price. It is the same for its different components but with unequal elasticity's. If R2 and S_2 *admit the same sensitivity to* η_2 *variation*, X_2 *is more elastic.*

Proof: see Appendix 2.1

From this proposition we can note that the raise of the amount of adhesion is required to increase environmental effort. In reality, the amount of adhesion fees is related to the cost of collection and recycling. So the decrease of adhesion reflects that the total cost will not be supported by producers and will be shared with municipalities. Thus, the producer responsibility is partial and not total.

The impact of these initial findings can be analyzed firstly in a static approach and secondly in dynamic approach.

Firstly, in a static approach, we can deduce that full transfer of responsibility improves producer environmental effort. So, the implication of producer is important to attain the object of an optimal environmental effort. This relationship compares to the German model,[12] through the DSD structure (Dual System Deutschland GmbH), where producer support the total cost and the French eco-packaging model characterized by the participation of municipalities in the process of collection and management of packaging waste. In the French model, the transfers are partial and producers support only 37% of the cost of collection and recycling (Glachant 2005). The German model seems to be more efficient for developing environmental effort.

[12]The regulations enacted in 1991 were accompanied by an innovative initiative from the German producers who formed a private company, the DSD responsible for organizing the collecting and sorting

We can also deduce that total transfer of responsibility enhances reduction at the source. When membership value increases, the firm seeks to reduce the cost of adhesion. For this, it will raise its effort at the source, which leads to an immediate reward of the firm. This explains the distinct consequences of French and German models. The Glachant work (2005) showed that the reduction at the source effort was greater in the German model and almost nonexistent in the French model.

However, we remark that the reduction at the source is accompanied with effort in collection and recycling and question why firms increase collection and recycling efforts?

The rise of η_2 ($\eta_2 < 1-((1-2a-2b)c)^{1/(2(a+b))} k_2^{1/(a+b)}$), imply an increase in the cost of innovation (c_2) and in the Firm 2 price (p_2) and thus a reduction in the margin of profit (p_2-c_2). Firm 2 risks a fall in the demand. To face this situation, it should increases its environmental effort k_2 to assure its quality differentiation and modify the position of a consumer indifferent to its product and thus to Firm1.

So, Firm 2 is led to also increase efforts in collection and recycling. However, if this rise exceeds a certain threshold ($\eta_2 > 1-((1-2a-2b)c)^{1/(2(a+b))} k_2^{1/(a+b)}$), the innovation effort reduces the overall amount membership and leads to a reduction in the cost and price of Firm 2.

It is important to emphasize here that η_2 rises does not entail a simple substitution between the different components of the effort but there was quality differentiation chosen to relax price competition. When the cost of collection is high, the manufacturer uses a trade-off between paying a strong adhesion on the packaging or incurring costs of investing in new technologies and processes that reduce the amount or type of packaging used. If the cost of prevention is less than the cost of adhesion, producers are encouraged to reduce waste at the source.

So incentive mechanisms should assure a full transfer of responsibility for collection and encourage firms to invest in clean technologies and achieve the goal of source reduction.

This alternative should be for producers a profitable strategy in the medium term.

Secondly, in along-term and dynamic approach, we observe a bandwagon effect. If Firm 2 increases its overall effort then the following membership fees are likely to decline. Anticipating this, Firm 2 will have an incentive to continually increase its efforts to reduce Eco-collect costs and thus benefit from a future decline of η_2.

Proposition 2:

The overall optimal efforts is not monotonically increasing with either a or b. An action that aims to strengthen the effort down stream only (collection or recyclability effort) does not achieve high level of optimal overall effort.

Proof: see Appendix 2.2

From proposition 2, it follows that it is not always necessary to increase consumers sensitivity to the collection effort, b, or to the recyclability effort, a, to obtain a high level of overall effort. The raise in sensitivity should be significant to support an increase in overall environmental effort. Acting insensitivity requires strong communication that should be well targeted to a very specific axis to give a significant result and increase environmental effort.

Proposition 3:

When $\eta_2$is constant, the optimal overall effort (and its components) is decreasing with the amount of the tax.

Proof: see Appendix 2.3

Since the tax is supported only by Firm1 and that Eco-collect deducts the tax in product 2 from the membership fees, an increase of the amount of tax helps out Firm1. Firm 2 has a low incentive to provide high effort at all levels.

This section revels that the assumption of a total transfer of responsibility to producer permits the optimal effort. The tax rising should be reflected in η_2 to offer incentives to the firm to increase the overall environmental effort optimal.

There are two contradictory effects. On the one hand, increasing tax affects the cost supported by Firm 1 and enhances price competition. On the other hand, if there is a total transfer charges on η_2, an increase of t affects η_2 and weakens price competition by increasing the incentive to differentiation. This last point requires a new step in the scheme of sequential decisions presented above. Firm 2 level of efforts decision are related to the membership fees to Eco-collect.

In the next section, we assume that Firm 2 correctly anticipates the decision η_2 and integrates it into its optimization program.

4. Dynamic Approach, Variable Adhesion, Model with Delegation

In the static approach, we suppose that adhesion to Eco-collect is fixed before the Firm effort decision k_2 and therefore before collection S_2, recyclability R_2 and reduction at source X_2 efforts. Eco-collect chooses ex post a membership price allowing it to coverall its costs.

In this section, we assume that Eco-collect delegates all of its costs to its partner Firm 2. The model posits that Firm 2 chooses its decisions by anticipating the cost of membership that will be imposed by Eco-collect. The idea is to incorporate cost function adhesion fee, based on its overall environmental effort and its various dimensions.

4.1 Cost function

For Firm 2, the optimization problem becomes

$$\begin{cases} \min\limits_{S_2, T_2, X_2} S_2 + R_2 + X_2 + \lambda\, S_2 + t\,(1-k_2) \\ S/c \quad k_2 = R_2^a\, S_2^b\, X_2^{(1/2)-a-b} \\ \qquad S_2 \le 1 - X_2 \\ R_2 \ge 0, S_2 \ge 0, X_2 \ge 0 \end{cases} \tag{8}$$

The resolution by the Lagrangian of the system (8) allows for the optimal values of k_2 given in three sizes and sets (see Appendix 1.D). These expressions are summarized by the system (9):

$$\begin{cases} R_2 = 2a\,c(1+\lambda)^{2b}\, k_2{}^2 \\ S_2 = 2b\,c\,(1+\lambda)^{2b-1}\, k_2{}^2 \\ X_2 = (1-2a-2b)\,c\,(1+\lambda)^{2b}\, k_2{}^2 \end{cases} \tag{9}$$

with $c = \dfrac{(\frac{1}{2}-a-b)^{-1+2(a+b)}}{2\,a^{2a}\,b^{2b}}$

According to the system (9), we can deduce the unit cost c_2 of Firm 2. We obtain

$$c_2 = c\,(1+\lambda)^{2b}\; k_2^2 + t\;(1-k_2)$$

We continue solving the dynamic game by using backward induction. Firstly, we determine the sub game perfect Nash equilibrium in price. Next, we determine the optimal level of Firm 2 overall environmental effort. Finally, we deduce the value of Eco-collect adhesion.

4.2 The price equilibrium

To determine the equilibrium price of this second stage of the game, we solve simultaneously the maximization program of the two firms (each firm *i* maximizes its profit with respect to its decision variable p_i, $i = 1, 2$).

Profit maximization of each firm leads to the following equilibrium price:

$$\begin{cases} p_1 = \frac{1}{3}[c(1+\lambda)^{2b} k_2^2 + (1-t)\, k_2 + 2\eta_1 + t)] \\ p_2 = \frac{1}{3}[2c(1+\lambda)^{2b} k_2^2 + 2(1-t)\, k_2 + \eta_1 + 2\,t)] \end{cases} \tag{10}$$

4.3 The overall optimal effort by Firm 2

Going back to the first stage of the game, Firm 2 decision concerns its effort level. To do this, it must anticipate sub game perfect equilibrium of the second stage and integrate information on the equilibrium price. Using the relation (10) and injecting the price in the expression of the profit of Firm 2, we get:

$$\Pi_2 = \frac{[k_2^2\, c\,(1+\lambda)^{2b} - (2+t)\, k_2 + t - \eta_1]^2}{9k_2} \tag{11}$$

Firm 2 must maximize profit over the k_2 variable. The optimal value for this scenario, denoted, k_{22} is

$$k_{22} = \frac{2+t}{3c(1+\lambda)^{2b}} \tag{12}$$

Which leads to:

$$\eta_{22} = t + \frac{(2+t)(4b\lambda - t(3+(3-2b)\lambda)}{9c(1+\lambda)^{1+2b}} \tag{13}$$

We now discuss how the equilibrium and results change according to parameters and we identify factors, which increase differentiation of Firm's 2 product. As the analysis is close to the previous game, we highlight the points of difference between fixed and variable adhesion. Proposition 4 summarizes the results.

Proposition 4:

The optimal level of overall effort increases with the tax and decreases with the unit cost of collection. It decreases with recycling sensitivity until reaching a minimum and then rises. It also has a minimum with collecting sensitivity.

Proof: See Appendix 2.4

The cost of collection is the only fixed parameter on which the firm cannot act. So, reducing the cost of collection increases firm environmental effort.

This model reflects a total transfer of responsibility to the producer, which will include the value of membership in the cost function. Economic instruments are efficient because they contribute to increase overall environmental effort. We also note that the sensitivity of consumers to recycling and collection is an important factor for overall optimal effort. The firm should invest in a targeted communication strategy to enhance its collection effort, recycling or source reduction.

However, one may ask what the best scenario is and should priority be given to a fixed or mobile membership scheme?

The following section provides some answers by presenting an analytical framework for comparing two scenarios. The use of simulations permits to report the complexity of the model and highlight the interactions between different variables.

5. Scenarios Comparison and Economic Interpretation

The objective of scenarios comparison is to determine the best environmental impact reduction of packaging waste. If the main target is increasing environmental effort, we show that the effectiveness of each instrument will be in relation with the objectives set for each policy.

Both scenarios: cost fixed membership model and integrated membership are very close in terms of assumptions, yet they produce equilibrium (and thus results) that are quite different.

On the other hand, the comparison of simulations in both scenarios faces the complexity and the interaction between the different variables in the models, so it is sometimes difficult to separate the simultaneous effects, especially for scenario1, and to define the causality relationship.

Thus, equilibrium with pre-fixing membership is a static equilibrium and needs an adaptation of η_2 following the change of a parameter of the model. The character exogenous in the scenario 1 and endogenous in the scenario 2 of adhesion (η_2), which influences the efficiency of policy instruments. We integrate this complexity assuming that the simulations are performed each time on the basis of a rule defining the value of η_2 in scenario 1.

Simulations cover three situations:

In the first case, we assume that the value of membership adhesion $\eta_{21}= \eta_1+\varepsilon = t+\varepsilon$ (with $\varepsilon>0$). We try to determine the impact of a small increase in membership over the tax on scenario efficiency.

In the second case, we suppose that the value of membership adhesion in scenario1 is defined regarding the value of adhesion in scenario 2.

Finally, scenario 1 simulations are performed assuming that the value of η_2 is defined to cover the Eco-collect costs, through the assumption of ex post zero profit for Eco-collect. Indeed, this assumption assimilates the static game in scenario 1 to a dynamic one.

We compare the effectiveness of scenarios to achieve the following goals: (1)Raise the overall effort, (2) Increase effort at source, (3)Reduce the amount of waste going to landfill, and (4) Spread of environmental effort.

We will not only compare the scenarios in terms of achieving the targets but also we will measure the impact of the instrument of taxation on each scenario. In this sense, we will discuss firstly the effectiveness of each scenario relatively to the achievement of optimal environmental effort and show that consumer awareness is an important factor in choosing the most suitable policy environment.

5.1 Simulations results for $\eta_{21} = t + \varepsilon$

We note that the producer does not pay the same membership fee in the model of fixed (and static) adhesion and in the model of variable (and dynamic) membership. In scenario 1, Firm 2 is required to pay a high adhesion compared to scenario 2 and slightly higher fee membership accession compared to tax supported by Firm1.

The difference between the adhesion values is widening with the tax rise on the one hand and consumer sensitivity to upstream effort on the other. These relationships must be considered in the following analysis.

A higher tax implies a greater adhesion value in scenario 1 which incites Firm 2 to increase its environmental effort. This effort will be more important with increasing tax as well as to the consumer sensitivity to upstream effort. Note that the gap between adhesion values in scenarios 1 and 2 increases with taxes.

Thus, scenario 1 achieves better the first goal of increasing the Firm's effort and the second goal of increasing effort at the source.

Turning next to the purpose of reducing waste going to landfills, this goal is related to effort at the source and the collection effort. In scenario 1, this goal could be achieved as Firm 2 focuses more on a source reduction effort to decrease the amount of membership. However, the scenario 1 does not offer sufficient incitation to increase the collection effort. Figure 4 represents a weakness on downstream effort in scenario 1, which decreases when the tax rises. The gap between the two scenarios will continue to increase as customers sensitive to downstream effort increases.

Scenario 1 allows reaching the goal of reducing waste sent to landfills for consumers sensitive to an upstream effort.

If the environmental effort is greater in scenario 1, the spread of this effort in the overall economy remains limited as shown in Figure 6 (environmental demand). Indeed, by fixing the membership at a very high value, the cost to Firm 2 increases, prices raise and the demand for Firm 2 drops. So, the environmental impact will be marginalized and associated to weak demand.

However, and as shown in Figure 7 (packaging waste), overall environmental effort and specially reducing waste at the source, will effectively reduce the amount of waste in circulation and thus reduce its social impact.

5.2 Simulations for $\eta_{21} = \eta_{22}$

When setting $\eta_{21} = \eta_{22}$, tax rate and membership value increase in the same direction and an emphasis on upstream sensitive increases the gap between them.

Raising the tax more than membership, leads to the eviction of Firm 1. This foreclose effect deters Firm 2 from making a greater environmental effort.

The relationship between tax and adhesion instruments should be considered in the analysis of the efficiency of each scenario.

For **the target 1 of Increasing overall environmental effort** we note that the scenario 2 (variable adhesion) is more efficient and that the eco-tax instrument enhances the efficiency of scenario 2. Moreover, the increase of consumer sensitivity to downstream effort yields to the greatest improvements of scenario 2. This result should be linked with the gap between tax and adhesion in scenario 1 which is a main factor to stimulate firm environmental effort.

For scenario 1, as already demonstrated in section 2, the tax instrument is inefficient to increase the environmental effort, regardless of consumer sensitivity because of the lack of incentives for Firm 2.

Now, with regards to **the target 2**: reducing waste at the source, consumer sensitivity to reduction at the source enhances scenario 2 efficiency. Significant tradeoffs between the two goals (and thus between the two scenarios) depend on consumer sensitivity to the upstream effort relative to that of the downstream effort.

Figure 11 shows that the collection and recycling effort depend on the sensitivity of consumers to the downstream effort. In this regard, scenario 2 will accomplish these goals and the gap between the two scenarios increases with the tax as well as with the sensitivity of consumers to the downstream effort.

For the target 3 of reducing waste going to landfill, the gap between heterogeneous consumer sensitivity is attenuated, so a combination of tax and variable adhesion is an efficient policy to attain the reduction of waste going to landfill.

Scenario 2 also allows propagation of an environmental effort and a reduction in the amount of waste produced in the economy (target 4). For each value of consumer sensitivity, scenario 2 variable adhesion remains more efficient.

Although, Firm 2 is required to pay the same value fees in the two scenarios, economic results are significantly different between the two scenarios. In the dynamic approach (and variable adhesion), Firm 2 will make relatively more effort than in the static approach (and fixed adhesion).

Furthermore, we see that in scenario 1, Firm 2 has no incentive to make efforts and Eco-collect will be required to bear the costs of collection. Thus, producer responsibility is partial and Eco-collect is required to fund part of the cost of collection. This is why its profit is negative.

It is interesting to note that despite the fact that Firm 2 supports the same membership costs in the two scenarios, in scenario1, its responsibility is considered as partial while in scenario 2, its responsibility is total. The total transfer of responsibility provides more incentives to reduce environmental stress and to reduce the social and environmental impact of waste.

5.3 Simulations for Eco-collect profit = 0

We note (figure 15) that in defining the goal of zero profit of Eco-collect as a basis for fixing the membership value, the gap between the tax and the value of membership is not fixed but increases with a rising tax and also with consumer sensitivity to upstream effort. These results should be taken into account in the following economic interpretations.

Note that the variable membership in scenario 2 is more favorable to the promotion of the global environmental effort k_2 (target 1) than the ix adhesion scenario in scenario 1. This result is confirmed when consumers are more sensitive to the effort in the downstream (collection and recyclability). Besides, the increasing tax leads systematically to increased environmental effort.

However, when the consumer is more sensitive to the upstream effort (reduction at source) scenario 2is efficient compared to scenario 1 for low values of the tax. However, beyond threshold level of taxation, the scenario 1 becomes more favorable with regards to environmental effort.

Consumer sensibility is an important factor for the choice of the optimal environmental policy. When the heterogeneity of consumers is important, this influences the effectiveness's of policy instruments. Many works (Panzone *et al*. 2013; Jackson 2006) show that changing household's behaviors contributes to the environmental impact of consumption. In this sense, the concept of sustainable consumption is related to the use of services and products having a minimum environmental impact (OECD 1999). For this, it is not sufficient for an firm to make environmental effort, the communication through logo and label to the consumer of this effort is prerequisite to attain sustainable consumption.

In scenario 1, simulations show that when we suppose that the value of adhesion is based on an Eco-collect profit equal to zero, the rising tax may reduce the overall environmental effort in the case of the less upstream effort sensitive consumer. However, the decline of the effort should not be linked only to the sensitivity of the consumer, but it also reflects the impact of the tax increase on the value of membership. Indeed, as shown in Figure (15), when $e<a+b$, an increasing of the tax value induces a less proportional raise in membership fees so that the gap grows with tax. This situation is unfavorable to Firm 1 and contributes to its foreclosure. As a result, Firm 2 is in a more favorable situation, and not encouraged to higher environmental effort. Note that more the gap between the tax and the membership is reduced the more Firm 2 has an incentive to make a greater effort.

We deduce that the tax and the adhesion fee should rise in the same proportion to encourage further effort.

The scenario 1 is more appropriated to attain the object of waste reduction at source (target 2). This result should be related to the gap between tax and adhesion. Firm 2 tries to reduce the amount of adhesion cost by raising its effort in reduction at source.

The target of reducing the amount of waste going to landfill will be achieved by reducing the amount of waste (X) and increasing the amount of waste collected (S).

The collection effort depends on the value of the sensitivity of the consumer to the collection. It is clear from Figure 18 that the collection effort is much lower in scenario 1 than in scenario 2. The gap grows with the sensitivity of the consumer to downstream effort.

However, the effort of reduction at source exceeds the collection effort, so the scenario 1 is more efficient to attain the target of reducing waste going to landfill.

The discussion on scenarios environmental impact on society depends on consumer sensitivity. So, for sensitive downstream consumer's effort, scenario 2 is more efficient. Though, for a high sensitivity to upstream effort, the scenario 1 becomes increasingly efficient. The amount of waste generated in society follows the same path.

6. Conclusion and Recommendations

This research intends to answer many questions related to policy instruments. How can we establish the responsibility of producers for packaging waste? How to push firms to meet their responsibilities? Is engaging producer responsibility and pushing it to further effort sufficient to achieve social welfare? How should the efficiency of economic instruments for packaging waste management be assessed? Should the regulator interfere to define the modalities for financing collective organizations? What are the conditions needed to ensure the success of economic policy management in the field of packaging waste?

Table 1 shows a comparison of the effectiveness of the combination of two economic instruments: membership (fixed or variable) and the eco-tax on achieving priority objectives of management of packaging waste and implementing EPR principles.

Move towards mix -policy instruments in packaging waste: The two instruments are complementary in the task of reducing the environmental impact of packaging waste. In the various simulations we have shown that the difference between the tax and membership is an important stimulus for boosting effort. Tax increases contribute to favor Firms making an environmental effort. However, a significant increase in the tax can oust the firm not making an environmental effort by increasing prices. This can cause a decrease in incentive to make further efforts to quality differentiation.

On the other hand an increase in membership not proportionate to the tax may further stimulate the environmental effort of the firm, however, in terms of market share; the effort may remain marginalized and affects only a small demand when the cost of quality differentiation is higher.

The paper considers two-policy instruments eco-tax and the membership value. The integration of new instruments such as recycling norms is an extension of this research and provides new opportunities for interaction between variables in the model.

Assessment of policy instruments with regard to environmental targets: How we can attain the best overall environmental effort? The firm should invest in reduction at source, collection effort or in recycling. We argue that optimal effort will be obtained by an optimal combination of all three components.

We argue the idea advanced by several authors such as Wall (2004) that the effectiveness of economic instruments in the field of packaging waste depends on the objectives.

In our simulations, we try to assess results through different objectives: increasing environmental stress, waste reduction at the source, reduction of waste going to landfill, spread of environmental effort and reducing the volume of waste in economy. We have shown that certain objectives can be better achieved with scenario 1 and that scenario 2 is more effective in achieving other objectives. In this sense, when setting the membership to a higher level than the tax in scenario1, firms are encouraged to increase environmental effort, but this effort remains marginalized and cannot attract strong demand.

Consumer sensitivity and economic instruments Consumer sensitivity is an important factor in the effectiveness of economic instruments. It is not sufficient to make an environmental effort, but the producer should communicate about this effort. Increasing consumer's sensitivity about concern for the environment is prerequisite for a successful economic policy of waste management. The information may relate to the awareness effort upstream or the downstream effort. We remark that, the effectiveness of the scenarios depends on whether the consumer is more sensitive to the upstream or downstream effort. The firm must keep in its communication strategy.

One can also ask about the role of the regulator in raising consumer awareness and the question of the effectiveness of economic instruments in developing countries. In countries where firms and the government do not invest in consumer environmental awareness, the effectiveness of economic instruments will be restricted.

Total responsibility transfer: The transfer of responsibility must be total and not partial. In this context, experiences in countries like France and Germany tell us about distinct systems of responsibility transfer of collection through eco-organizations.

We argue that when we encourage individual environmental responsibility, the impact of policy instrument should be more efficient (Lifset and Lindhqvist 2008). In reality, the amount of adhesion fees is linked to the cost of collection and recycling. So, exogenous change of adhesion in scenario 1 reflects if the total cost will be supported by producers or shared with municipalities. The model of variable adhesion offers more incitation for firm to make effort and the simulations show that for the same amount of adhesion, the effort is highly when firm knows that its implication can reduce the value of adhesion.

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Figure 1: Simulations 1: Value Adhesion Gap (η_{22}-η_{21})

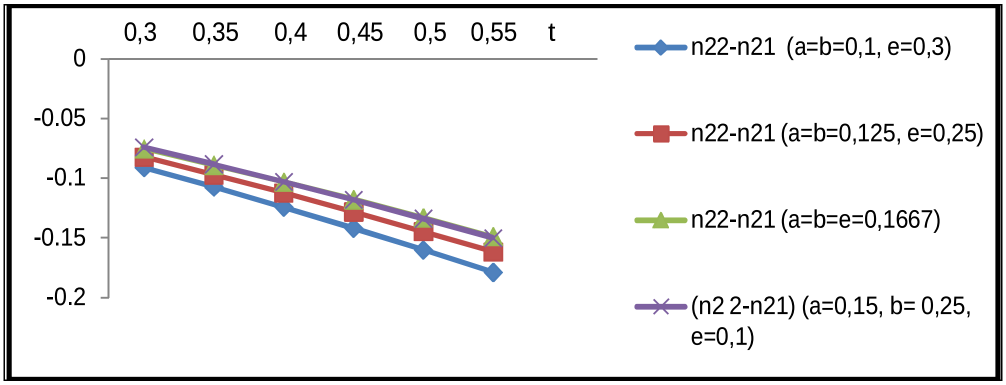

Figure 2: Overall Environmental Effort

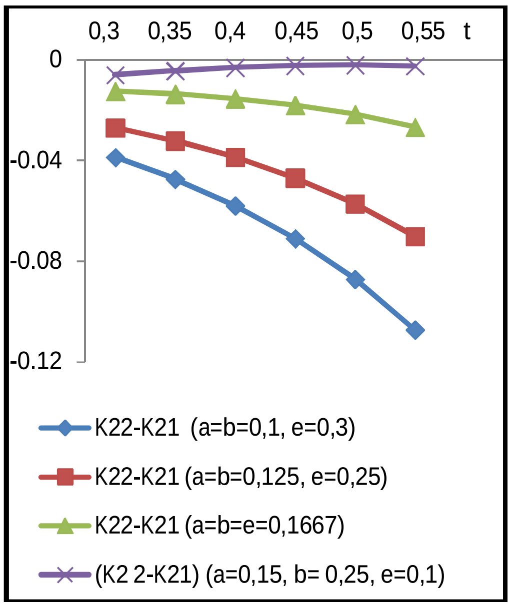

Figure 3: Waste Reduction at the Source

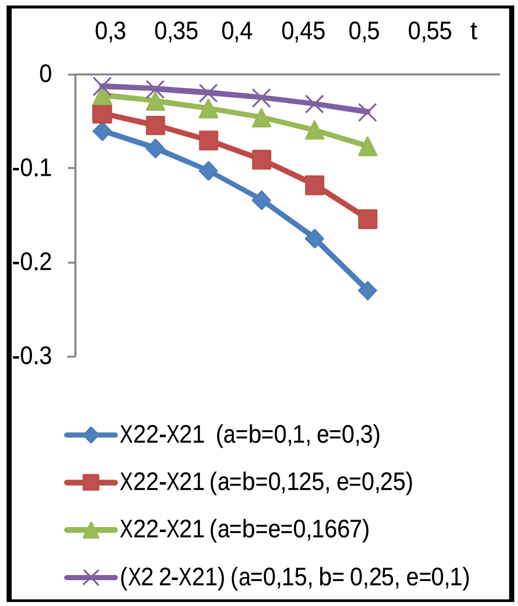

Figure 4: Collection Effort

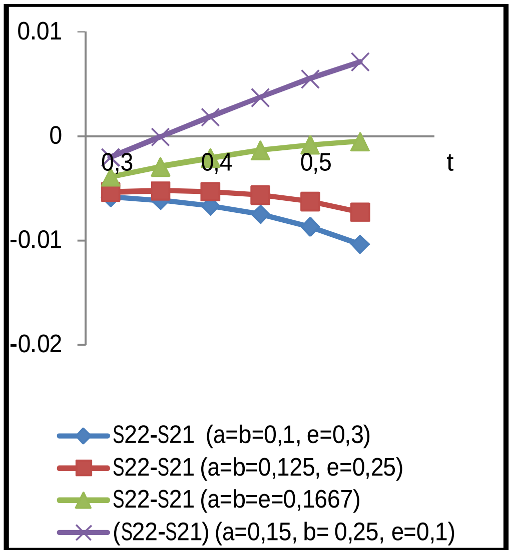

Figure 5 Waste Going to Landfill

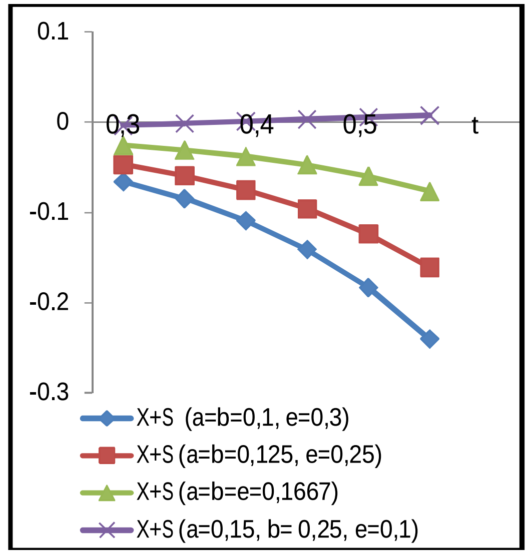

Figure 6: Environmental Demand

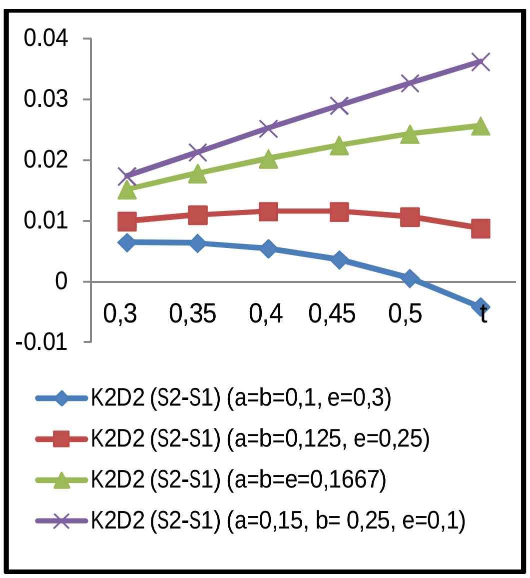

Figure 7 Total Packaging Waste

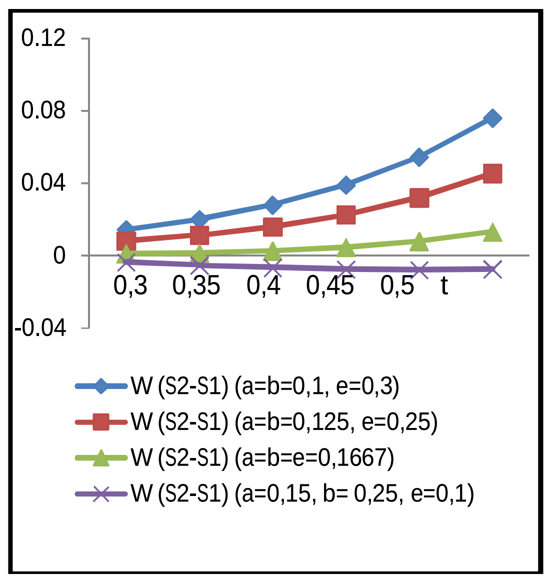

Figure 8 Gap Between Tax and Fixed Adhesion for Scenario 1

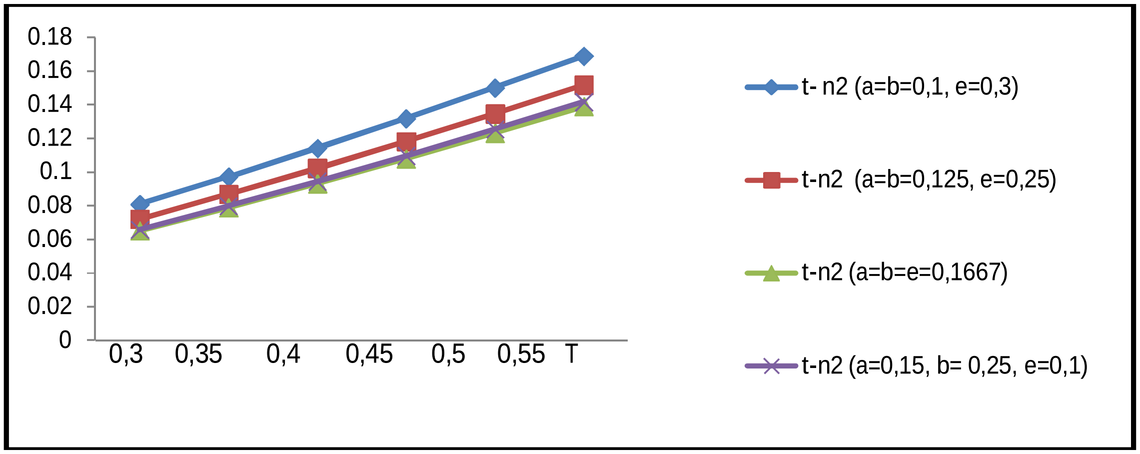

Figure 9: Environmental Effort

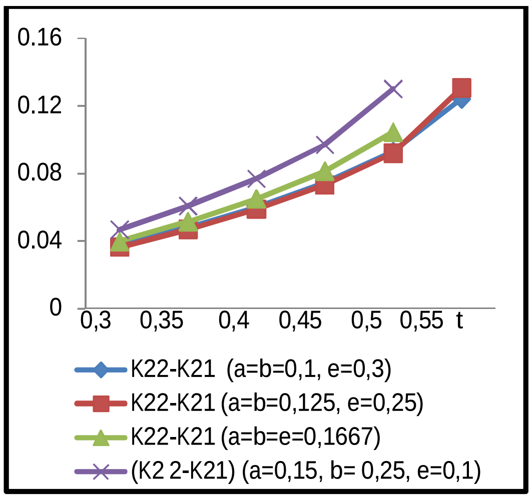

Figure 10: Reduction at the Source Effort

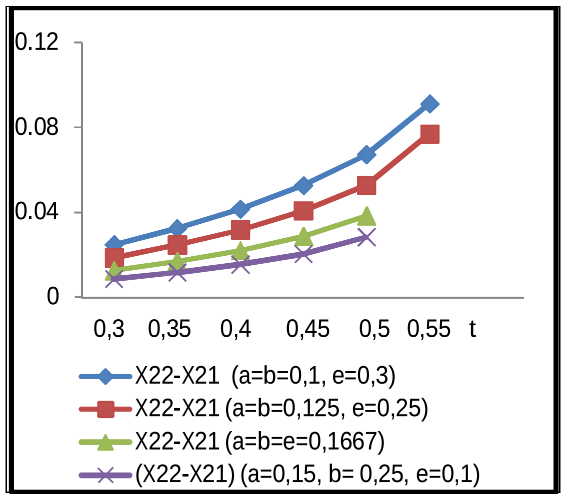

Figure 11: Collection Effort

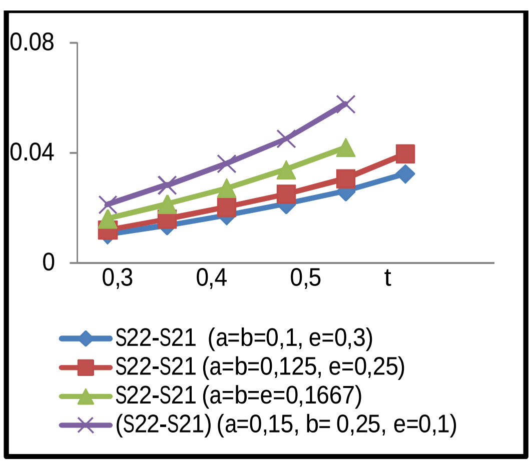

Figure 12: Waste Going to Landfill

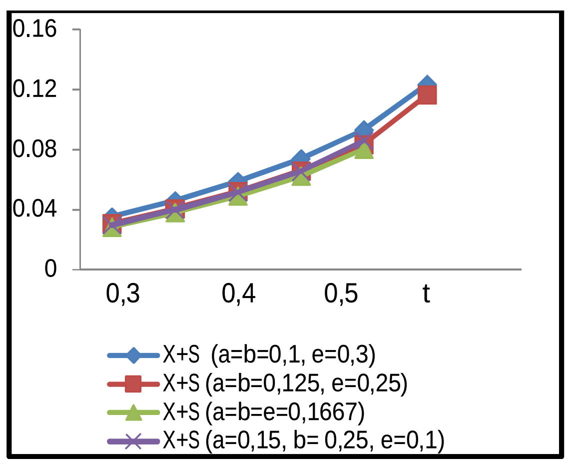

Figure 13: Environmental Demand

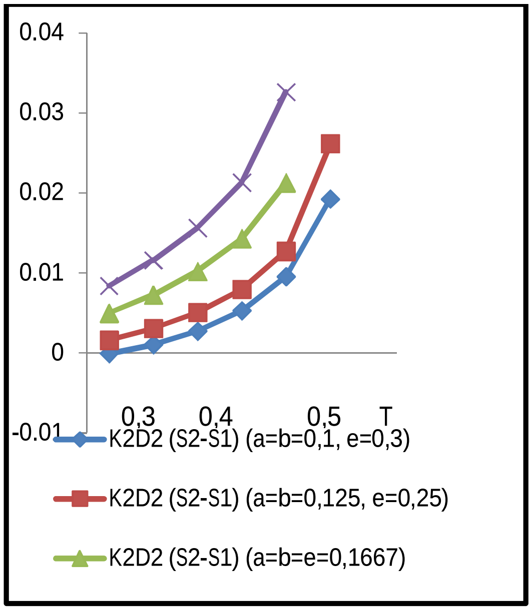

Figure 14: Total Waste Packaging

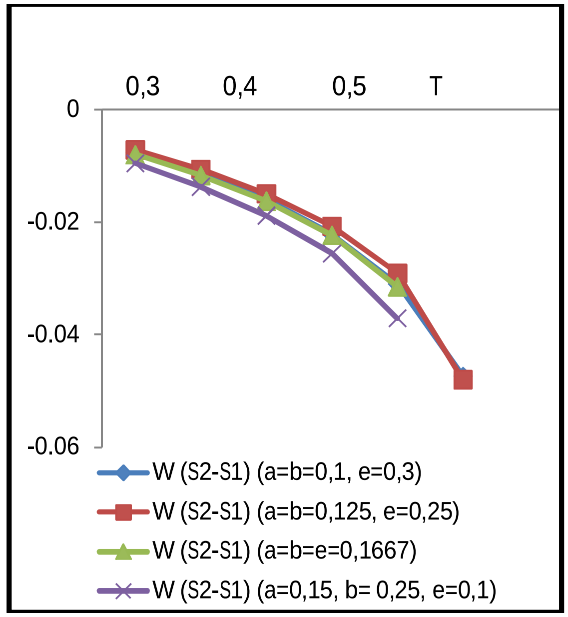

Figure 15: Relationship between Tax And Adhesion

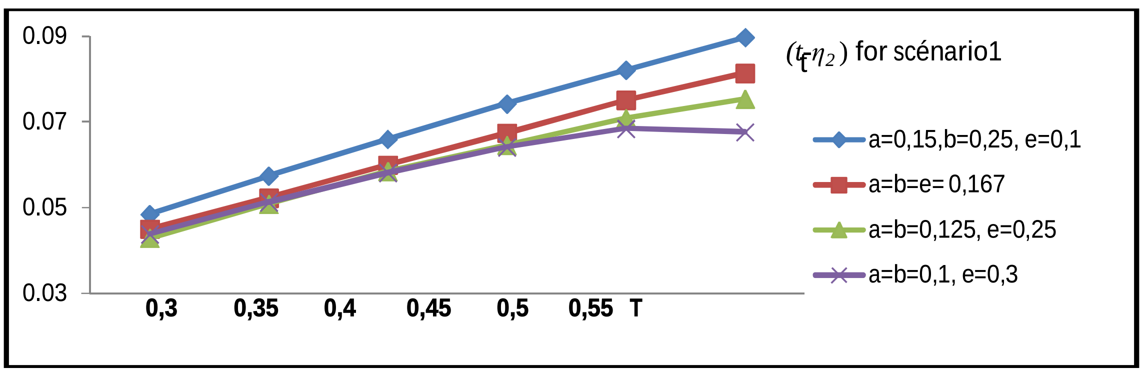

Figure 16: Overall Environmental Effort

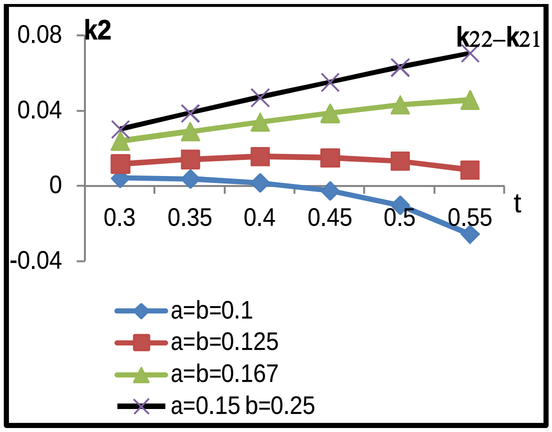

Figure 17: Reduction at Source Effort

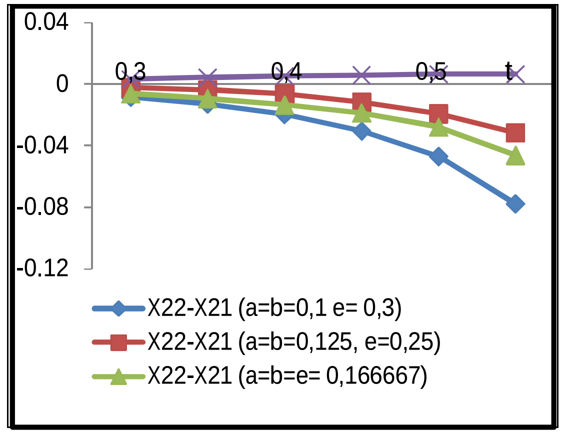

Figure 18: Collection Effort

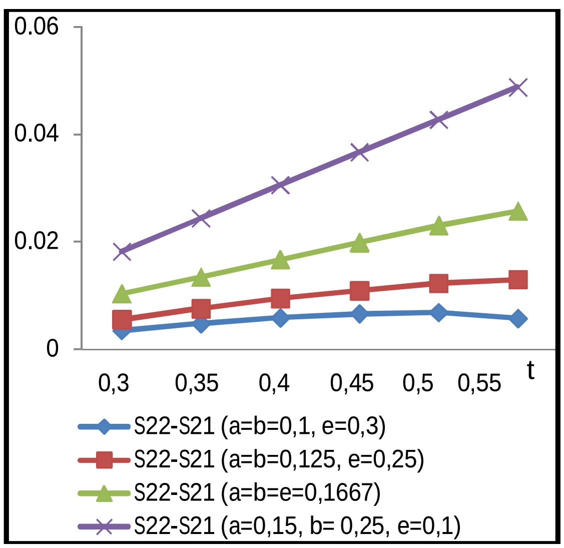

Figure 19: Waste Going to Landfill

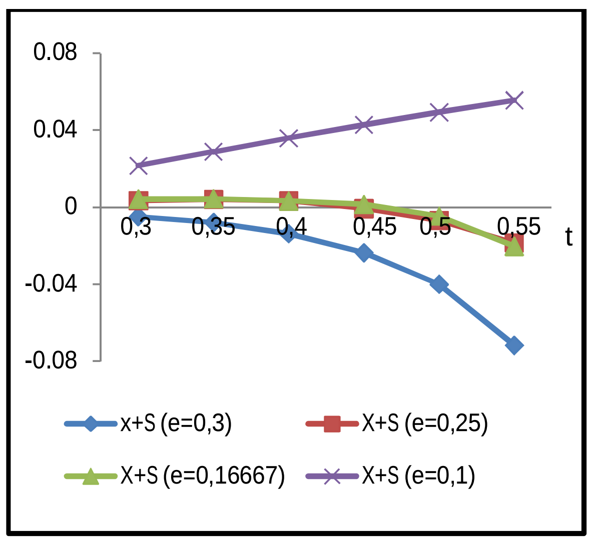

Figure 20 Environmental Demand

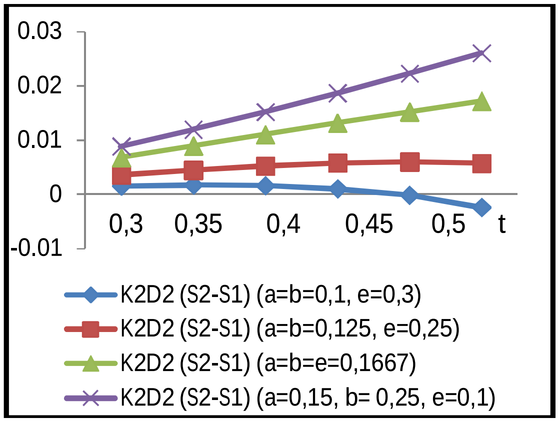

Figure 21: Total Packaging Waste

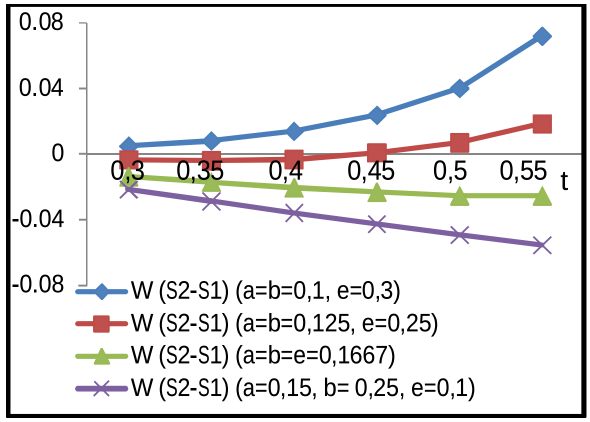

Table 1: Simulations Summary

	$\eta_2 = \eta_1 = t + \varepsilon$						$\eta_{21} = \eta_{22}$						Ecocollect Profit equals to zero					
	Target 1 increasing overall effort	**Target 2 reducing waste at source**	**Target 3 reducing waste going to landfill**		**Target 4 health cost**		**Target 1 increasing overal effort**	**Target 2 reducing waste at source**	**Target 3 reducing waste going to landfill**		**Target 4 health cost**		**Target 1 increasing overal effort**	**Target 2 reducing waste at source**	**Target 3 reducing waste going to landfill**		**Target 4 health cost**	
	K	***X***	***S***	***X+S***	***KD***	***W***	***K***	***X***	***S***	***X+S***	***KD***	***W***	***K***	***X***	***S***	***X+S***	***KD***	***W***
(a=b=0,1 e=0,3)	S1+++ T+++	S1+++ T+++	S1+++ T+++	S1+++ T+++	S2++ T-	S1+++ T+++	S2++ T+++	S2+++ T+++	S2+ T+++	S2+++ T+++	S2+++ T+++	S2+++ T+++	S1++ T++	S1+ T+	S2+ T+++	S1+++ T+++	S2+++ T+++	S2+++ T+++
a=b= 0.125 e=0.25	S1+++ T+++	S1+++ T+++	S1++ T++	S1+++ T+++	S2+ T+	S1++ T+++	S2++ T+++	S2++ T+++	S2++ T+++	S2+++ T+++	S2+++ T+++	S2+++ T+++	S2+ T++	S2++ T+++	S2++ T+++	S1++ T++	S2++ T+++	S2++ T+++
a=b= 1/6 e=1/6	S1++ T++	S1++ T++	S1+ T--	S1++ T+	S2+++ T+++	S1+ T+	S2+++ T+++	S2++ T+++	S2++ T+++	S2+++ T+++	S2+++ T+++	S2+++ T+++	S2++ T+++	S2++ T+++	S2+++ T+++	S2++ T++	S2+ T++	S2+ T++
a=0.15, b= 0.25 e=0.1	S2+ T+	S1+ T++	S2+++ T+++	S2+ T+	S2 +++ T+++	S1++ T++	S2+++ T+++	S2+ T+++	S2+++ T+++	S2+++ T+++	S2+++ T+++	S2+++ T+++	S2+++ T+++	S2+++ T+++	S2+++ T+++	S2+++ T+++	S1+ T+++	S1+ T+++

Notes: 2: sceanrio2 is more efficient compared to scenario 1, the gap between scenario 2 and scenario 1 is (+) low significant, (++) moderately significant, (+++) very significant
T: The impact of tax is (+) low significant, (++) moderately significant, (+++) very significant

Appendix 1

Appendix 1.A

The optimization programs given by the system:

$$\begin{cases} \min\limits_{R_2,S_2,X_2} S_2 + R_2 + X_2 + \eta_2(1-X_2) \\ S/c \quad k_2 = R_2^a\, S_2^b\, X_2^{(1/2)-a-b} \\ R_2 \geq 0, S_2 \geq 0, X_2 \geq 0 \end{cases} \tag{A1}$$

The corresponding Lagrange function can be written as:

$$L(R_2, S_2, X_2, g) = S_2 + R_2 + X_2 + \eta_2(1-X_2) - g(k_2 - R_2^a\, S_2^b\, X_2^{(1/2)-a-b}) \tag{A2}$$

Where g represents Lagrange's multiplier. The critical values of L occur where its gradient is zero. The partial derivatives are:

$$\begin{cases} \partial L / \partial R_2 = 0 \Leftrightarrow 1 = -agR_2^{\,a-1} S_2^{\,b} X_2^{(1/2)-a-b} \\ \partial L / \partial S_2 = 0 \Leftrightarrow 1 = -bgR_2^{\,a} S_2^{\,b-1} X_2^{(1/2)-a-b} \\ \partial L / \partial X_2 = 0 \Leftrightarrow 1-\eta_2 = -((1/2)-a-b)gR_2^{\,a} S_2^{\,b} X_2^{-(1/2)-a-b} \\ \partial L / \partial g = 0 \Leftrightarrow k_2 = R_2^a\, S_2^b\, X_2^{(1/2)-a-b} \end{cases} \tag{A3}$$

Using the two first equations of system (A3), we can obtain the relation:

$$1 = \frac{-agR_2^{\,a-1} S_2^{\,b} X_2^{(1/2)-a-b}}{-bgR_2^{\,a} S_2^{\,b-1} X_2^{(1/2)-a-b}}$$

Which leads simply to:

$$1 = \frac{aS_2}{bR_2} \Leftrightarrow S_2 = \frac{b}{a} R_2 \,. \tag{A4}$$

Substituting this expression into the first equation of (A3) equation (A4) induces the expression of Lagrangien multiplier:

$$1 = -agR_2^{\,a-1} (\frac{b}{a} R_2)^b\, X_2^{(1/2)-a-b}$$

Then:

$$g = -a^{-1+b} R_2^{\,1-a-b} b^{-b} X_2^{(-1/2)+a+b} \tag{A5}$$

Given the above relation and from the third equation of (A3), we obtain:

$$1-\eta_2 = ((1/2)-a-b)a^{-1} R_2 X_2^{-1} \Leftrightarrow R_2 = \frac{(1-\eta_2)a}{((1/2)-a-b)} X_2 \tag{A6}$$

Thus:

$$S_2 = \frac{b(1-\eta_2)}{((1/2)-a-b)} X_2 \tag{A7}$$

Next, we express the last equation of (A3) according to X_2. As a result:

$$k_2 = (\frac{a(1-\eta_2)}{((1/2)-a-b)} X_2)^a (\frac{b(1-\eta_2)}{((1/2)-a-b)} X_2)^b X_2^{(1/2)-a-b} = \frac{a^a b^b (1-\eta_2)^{a+b}}{((1/2)-a-b)^{a+b}} X_2^{1/2}$$

Thus, we deduce:

$$X_2 = \frac{a^{-2a} b^{-2b}}{((1/2)-a-b)^{-2(a+b)}} (1-\eta_2)^{-2(a+b)} k_2^2 \quad \text{(A8)}$$

Re-written as:

$$X_2 = (1-2a-2b) \frac{((1/2)-a-b)^{-1+2(a+b)}}{2a^{2a} b^{2b}} (1-\eta_2)^{-2(a+b)} k_2^2 \quad \text{(A9)}$$

Then, it is straightforward to deduce values of R_2 et S_2as presented by system (4).

Appendix 1.B

We determine the price equilibrium by simultaneously solving the maximization program for both firms (each firm i maximizes its profit with respect to its decision variable p_i, where i =1, 2).

Demand functions defined by system (2) lead to the following profit functions:

$$\begin{cases} \Pi_1 = \dfrac{(p_1 - \eta_1)(p_2 - p_1)}{k_2} \\ \Pi_2 = \dfrac{(p_2 - c_2)(p_2 - p_1)}{k_2} \end{cases} \quad \text{(A10)}$$

The profit maximization program leads to the following price equilibrium:

$$\begin{cases} \partial\Pi_1 / \partial p_1 = 0 \Leftrightarrow p_1 = \dfrac{p_2 + \eta_1}{2} \\ \partial\Pi_2 / \partial p_2 = 0 \Leftrightarrow p_2 = \dfrac{p_1 + c_2 + k_2}{2} \end{cases} \quad \text{(A11)}$$

Second-order conditions are satisfied. Using the relation $c_2 = c(1-\eta_2)^{1-2(a+b)} k_2^2 + \eta_2$, system (5) is obtained.

Appendix 1.C

We solve the quality stage; decision is taken by firm 2. First-order condition is obtained only when the partial derivative of the margin is positive. This is the case when $k_2 < \tilde{k}_2 = 1/(c(1-\eta_2)^{1-2(a+b)})$. In the contrary case, the profit is monotonous decreasing, so that $k_2 = \tilde{k}_2$ is a maximum.

After arrangement of the condition of the first order, we have

$$\partial\Pi_2 / \partial k_2 = \frac{[2k_2 - 3k_2^2\, c(1-\eta_2)^{1-2(a+b)} + \eta_2 - \eta_1]M_2}{3k_2{}^2} = 0 \qquad \text{(A12)}$$

Where M_2 denoted the firm's 2 which is positive by hypothesis.

Two extrema are deduced from (A12) defined when $1+3c(1-\eta_2)^{1-2(a+b)}(\eta_2-\eta_1)>0$. We check the second-order conditions to select the maximum. We show that: $k_{21} = \dfrac{1+\sqrt{1+3c(1-\eta_2)^{1-2(a+b)}(\eta_2-\eta_1)}}{3c(1-\eta_2)^{1-2(a+b)}}$ is the maximum[13].

Indeed, using the Envelope Theorem and given the fact that the first derivative of its profits is zero for the maximum, the sign of $\partial^2\Pi_2 / \partial k_2{}^2$ is reduced to:

$$\partial^2\Pi_2 / \partial k_2{}^2 = \frac{2(1-3k_2\, c(1-\eta_2)^{1-2(a+b)})M_2}{3} < 0 \ \ when \quad k_2 > 1/(3k_2\, c(1-\eta_2)^{1-2(a+b)})$$

Which is the case of k_{21}.

Besides, we can easily verify that the optimal valuek_{21} satisfies as well as the condition of positivity of the margin: $k_{21} < \tilde{k}_2 = 1/(c(1-\eta_2)^{1-2(a+b)})$

[13] The second extreme of firm's 2 profit is obtained for $k_2 = \dfrac{1-\sqrt{1+3c(1-\eta_2)^{1-2(a+b)}(\eta_2-\eta_1)}}{3c(1-\eta_2)^{1-2(a+b)}}$

By applying the same approach, we easily check that it doesn't satisfy second-order condition.

Appendix 1.D

The optimization program is given by the system:

$$\begin{cases} \min\limits_{S_2,T_2,X_2} S_2 + R_2 + X_2 + \lambda\, S_2 + t\,(1-k_2) \\ \textit{Subject to} \quad k_2 = R_2^a\, S_2^b\, X_2^{(1/2)-a-b} \\ \qquad\qquad\quad S_2 \le 1 - X_2 \\ \qquad\qquad\quad R_2 \ge 0, S_2 \ge 0, X_2 \ge 0 \end{cases} \tag{A13}$$

Where g is the Lagrange multiplier associated with the equality constraint and h with the inequality one.

The corresponding Lagrange function can be written as:

$$L(R_2, S_2, X_2, g, h) = S_2 + R_2 + X_2 + \lambda\, S_2 + t\,(1-k_2) - g(k_2 - R_2^a\, S_2^b\, X_2^{(1/2)-a-b}) - h(S_2 - 1 + X_2) \tag{A14}$$

This gives optimality conditions:

$$\begin{cases} \partial L / \partial R_2 = 0 \Leftrightarrow 1 = -agR_2^{\;a-1} S_2^{\;b} X_2^{(1/2)-a-b} \\ \partial L / \partial S_2 = 0 \Leftrightarrow 1 + \lambda - h = -bgR_2^{\;a} S_2^{\;b-1} X_2^{(1/2)-a-b} \\ \partial L / \partial X_2 = 0 \Leftrightarrow 1 - h = -((1/2) - a - b)gR_2^{\;a} S_2^{\;b} X_2^{-(1/2)-a-b} \\ \partial L / \partial g = 0 \Leftrightarrow k_2 = R_2^a\, S_2^b\, X_2^{(1/2)-a-b} \\ h(S_2 - 1 + X_2) = 0 \end{cases} \tag{A15}$$

Since we suppose that $S_2+X_2< 1$ we consider, for the complementary condition, only the case h=0.

Using the two first equations of system (A15), we can obtain the relation:

$$\frac{1}{1+\lambda} = \frac{-agR_2^{\;a-1} S_2^{\;b} X_2^{(1/2)-a-b}}{-bgR_2^{\;a} S_2^{\;b-1} X_2^{(1/2)-a-b}}$$

Which leads simply to:

$$\frac{1}{1+\lambda} = \frac{aS_2}{bR_2} \Leftrightarrow S_2 = \frac{b}{a(1+\lambda)} R_2 \,. \tag{A16}$$

Substituting this expression into the first equation of (A15) equation (A16) induces the expression of Lagrangien multiplier:

$$1 = -agR_2^{\;a-1} \left(\frac{b}{a(1+\lambda)} R_2\right)^b X_2^{(1/2)-a-b}$$

Then:

$$g = -(1+\lambda)^b\, a^{-1+b} R_2^{\;1-a-b} b^{-b} X_2^{(-1/2)+a+b} \tag{A17}$$

Given the above relation and from the third equation of (A3), we obtain:

$$1 = ((1/2) - a - b)a^{-1} R_2 X_2^{-1} \Leftrightarrow R_2 = \frac{a}{((1/2) - a - b)} X_2 \tag{A18}$$

Thus:

$$S_2 = \frac{b}{(1+\lambda)((1/2)-a-b)} X_2 \qquad \text{(A19)}$$

Next, we express the last equation of (A15) according to X_2. As a result:

$$k_2 = \left(\frac{a}{((1/2)-a-b)} X_2\right)^a \left(\frac{b}{(1+\lambda)((1/2)-a-b)} X_2\right)^b X_2^{(1/2)-a-b} = \frac{a^a b^b}{(1+\lambda)^b ((1/2)-a-b)^{a+b}} X_2^{1/2}$$

Thus, we deduce:

$$X_2 = \frac{a^{-2a} b^{-2b}}{((1/2)-a-b)^{-2(a+b)}} (1+\lambda)^{2b} k_2^{\,2}$$

Re-written as:

$$X_2 = (1-2a-2b)c(1+\lambda)^{2b} k_2^{\,2}$$

Where $c = \dfrac{(\frac{1}{2}-a-b)^{-1+2(a+b)}}{2\,a^{2a}\,b^{2b}}$

So that

$$S_2 = 2bc(1+\lambda)^{2b-1} k_2^{\,2}$$

$$R_2 = 2ac(1+\lambda)^{2b} k_2^{\,2}$$

Appendix 2

1. Proof of Proposition1:

First, as k_{21} is the maximum of the firm 2's profit, it verifies: $\partial \Pi_2 / \partial k_2 = 0$.

This derivative is a two-variable function: η_2 and k_{21}. Let *f* denotes this relation such as: $f(\eta_2, k_{21}) = 0$

According to the implicit function theorem, there exists a function, which expresses $k_{21}$with respect ofη_2. Moreover, we have: $\frac{dk_{21}}{d\eta_2} = -\frac{\partial f / \partial \eta_2}{\partial f / \partial k_{21}}$

Yet, the sign of $\partial f / \partial \eta_2 = \frac{1}{3}[1 + 3c(1-2(a+b))(1-\eta_2)^{-2(a+b)} k_{21}^2] > 0$

Let us consider now $\partial f / \partial k_{21} = \frac{2}{3}[1 - 3c(1-\eta_2)^{1-2(a+b)} k_{21}^2] < 0$, always true for k_{21}. We deduce that:

$$\frac{dk_{21}}{d\eta_2} = -\frac{\partial f / \partial \eta_2}{\partial f / \partial k_{21}} > 0$$

Turning next to different dimensions of the overall effort. To show results of the propostion1, we have to consider their derivative with respect to cost of adhesion η_2. From expressions (4) and (7), we obtain the system (A20):

$$\left| \begin{array}{l} \dfrac{\partial k_{21} / \partial \eta_2}{k_{21}} = \dfrac{(1-\eta_1) - 2(\eta_2 - \eta_1)(a+b) - \dfrac{(1-\eta_2)^{a+b}[(1-\eta_2) - (\eta_2 - \eta_1)(1-2(a+b))]}{\sqrt{(1-\eta_2)^{2(a+b)} + 3c(1-\eta_2)(\eta_2 - \eta_1)}}}{2(1-\eta_2)(\eta_2 - \eta_1)} \\ \dfrac{\partial S_2 / \partial \eta_2}{S_2} = \dfrac{\partial R_2 / \partial \eta_2}{R_2} = \dfrac{1 - \dfrac{(1-\eta_2)^{-1+a+b}[(1-\eta_2) - (\eta_2 - \eta_1)(1-2(a+b))]}{\sqrt{(1-\eta_2)^{2(a+b)} + 3c(1-\eta_2)(\eta_2 - \eta_1)}}}{(\eta_2 - \eta_1)} \\ \dfrac{\partial X_2 / \partial \eta_2}{X_2} = \dfrac{(1-\eta_1) - \dfrac{(1-\eta_2)^{a+b}[(1-\eta_2) - (\eta_2 - \eta_1)(1-2(a+b))]}{\sqrt{(1-\eta_2)^{2(a+b)} + 3c(1-\eta_2)(\eta_2 - \eta_1)}}}{2(1-\eta_2)(\eta_2 - \eta_1)} \end{array} \right. \quad \text{(A20)}$$

Let us examine the sign of different derivatives of the system (A20). It is straightforward to show that if $\eta_2 > \frac{1+\eta_1(1-2(a+b))}{2(1-a-b)}$ then the derivatives are always positives. Next, we examine the contrary case: $\eta_2 < \frac{1+\eta_1(1-2(a+b))}{2(1-a-b)}$

<u>The condition for positivity of the second equation can be written as:</u>

$$(1-\eta_2)^{2(a+b)} + 3c(1-\eta_2)(\eta_2 - \eta_1) > (1-\eta_2)^{2(-1+a+b)}[(1-\eta_2) - (\eta_2 - \eta_1)(1-2(a+b))]^2$$

Case1: If $\eta_2 \geq \eta_1$, We can limit the comparison to

$$(1-\eta_2)^{2(a+b)} > (1-\eta_2)^{2(-1+a+b)}[(1-\eta_2)-(\eta_2-\eta_1)(1-2(a+b))]^2$$ so that,

$$(1-\eta_2)^2 > [(1-\eta_2)-(\eta_2-\eta_1)(1-2(a+b))]^2$$

After simplification, the condition is such as: $\eta_2 < \frac{2+\eta_1(1-2(a+b))}{3-2a-2b}$

Yet, $\eta_2 < \frac{1+\eta_1(1-2(a+b))}{2-2a-2b} < \frac{2+\eta_1(1-2(a+b))}{3-2a-2b}$ so that the positivity of the two derivatives is always verified.

Case 2: If $\eta_2 < \eta_1$,

The positivity condition is verified when:

$$1-\frac{(1-\eta_2)^{-1+a+b}[(1-\eta_2)-(\eta_2-\eta_1)(1-2(a+b))]}{\sqrt{(1-\eta_2)^{2(a+b)}+3c(1-\eta_2)(\eta_2-\eta_1)}} < 0$$

Which is true as soon as:

$$\sqrt{(1-\eta_2)^{2(a+b)}+3c(1-\eta_2)(\eta_2-\eta_1)} < (1-\eta_2)^{-1+a+b}[(1-\eta_2)-(\eta_2-\eta_1)(1-2(a+b))]$$

Or

$$3c(1-\eta_2)(\eta_2-\eta_1)+(1-\eta_2)^{2(a+b)}-(1-\eta_2)^{2(-1+a+b)}[(1-\eta_2)-(\eta_2-\eta_1)(1-2(a+b))]^2 < 0$$

After arrangement, we obtain:

$$3c(1-\eta_2)(\eta_2-\eta_1)+(1-\eta_2)^{2(a+b)}[1-[\frac{(1-\eta_2)-(\eta_2-\eta_1)(1-2(a+b))}{(1-\eta_2)}]^2 < 0 \Leftrightarrow$$

$$3c(1-\eta_2)(\eta_2-\eta_1)+(1-\eta_2)^{2(a+b)}[1-\frac{(1-\eta_2)-(\eta_2-\eta_1)(1-2(a+b))}{(1-\eta_2)}][1+\frac{(1-\eta_2)-(\eta_2-\eta_1)(1-2(a+b))}{(1-\eta_2)}] < 0 \Leftrightarrow$$

$$-3c(1-\eta_2)(\eta_1-\eta_2)+(1-\eta_2)^{2(a+b)}[\frac{2(1-\eta_2)+(\eta_1-\eta_2)(1-2(a+b))}{(1-\eta_2)}][\frac{-(\eta_1-\eta_2)(1-2(a+b))}{(1-\eta_2)}] < 0$$

Which show the positivity of the two derivatives.

<u>The condition of positivity of the first derivative is written as:</u>

From the system (A20), we can deduce the following relation:

$$\frac{\partial k_2/\partial\eta_2}{X_2} = \frac{\partial X_2/\partial\eta_2}{X_2} - \frac{(a+b)}{2(1-\eta_2)} \qquad \text{(A21)}$$

Accordingly to previous proof k_{21} is an increasing function with respect to η_2, which leads to an increasing of X_2 with respect of η_2.

2. Proof of Proposition2:

To show the results, let us calculate partial derivatives of the overall effort k_{21} with respect to a and to b. From expression (7), we determine the following system:

$$\begin{cases} \dfrac{\partial k_{21}/\partial a}{k_{21}^{\;2}} = \dfrac{3a^{-2a}b^{-2b}\,(\frac{1}{2}-a-b)^{2(a+b)}(1-\eta_2)^{1-a-b}\,Log[\frac{a+2-2\eta_2}{1-2a-2b}]}{(1-2a-2b)\sqrt{(1-\eta_2)^{2(a+b)}+\frac{3}{2}a^{-2a}b^{-2b}\,(\frac{1}{2}-a-b)^{-1+2(a+b)}(1-\eta_2)(\eta_2-\eta_1)}} \\ \dfrac{\partial k_{21}/\partial b}{k_{21}^{\;2}} = \dfrac{3a^{-2a}b^{-2b}\,(\frac{1}{2}-a-b)^{2(a+b)}(1-\eta_2)^{1-a-b}\,Log[\frac{b+2-2\eta_2}{1-2a-2b}]}{(1-2a-2b)\sqrt{(1-\eta_2)^{2(a+b)}+\frac{3}{2}a^{-2a}b^{-2b}\,(\frac{1}{2}-a-b)^{-1+2(a+b)}(1-\eta_2)(\eta_2-\eta_1)}} \end{cases} \qquad \text{(A22)}$$

The sign of the first derivative depends of the sign of $Log[\frac{a+2-2\eta_2}{1-2a-2b}]$. The derivative is positive when $\frac{a+2-2\eta_2}{1-2a-2b}>1$ which leads to $a>\frac{2\eta_2-1-2b}{3}$ and negative, otherwise. It's the same for the second by-product. It is positive when $b>\frac{2\eta_2-1-2a}{3}$ and negative, otherwise.

3. Proof of Proposition 3:

The proof is immediate. The derivative of k_{21} with respect to t is expressed by:

$$\partial k_{21}/\partial t = -\frac{(1-\eta_2)^{a+b}}{2\sqrt{(1-\eta_2)^{2(a+b)}+3c\,(1-\eta_2)(\eta_2-\eta_1)}}<0 \qquad \text{(A23)}$$

4. Proof of Proposition 4:

We determine the partial derivatives of k_{22} with respects to his arguments t, a and b, we obtain:

$$\begin{cases} \dfrac{\partial k_{22}/\partial t}{k_{22}} = \dfrac{1}{3c\,(1+\lambda)^{2b}} \\ \dfrac{\partial k_{22}/\partial \lambda}{k_{22}} = -\dfrac{b}{1+\lambda} \\ \dfrac{\partial k_{22}/\partial a}{k_{22}} = 2Log[\dfrac{a}{1/2-a-b}]\geq 0 \quad \Leftrightarrow \quad a\geq 1/4-b/2 \\ \dfrac{\partial k_{22}/\partial b}{k_{22}b} = 2Log[\dfrac{b}{(1/2-a-b)(1+\lambda)}]\geq 0 \quad \Leftrightarrow \quad b\geq \dfrac{(1+\lambda)(1/2-a)}{2+\lambda} \end{cases} \qquad \text{(A24)}$$