Department of Economics

Theoretical and Econometric Analysis of Behaviours Toward Environment

Laurent Meunier

Thesis submitted for assessment with a view to obtaining the degree of
Doctor of Economics of the European University Institute

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Theoretical and Econometric Analysis of Behaviours Toward Environment

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Introduction

As recently as in the 1970s, neither the general public nor policy makers were prepared to listen to those who warned of the damaging effects human behaviour was having upon the environment. However, evidence that environmnent damaging is occuring as a result of human behaviour has now become so manifest that there is almost unamnimous scientific agreement on the subject. As a result it is generally accepted that humans must react to reduce negative impact upon the environement

Economics is the human science which studies the allocation of scarce resources. Thus, as environment is a scarce resource it is logical and necessary that we study the interaction between the productive sphere and the environment. To produce wealth, we need (among others) raw materials and energy. In addition, production often -not to say necessarily- enhances environmental externalities. However, the planet Earth has an ability to recycle, and thus produce new raw materials and treat waste: this is often referred to as Earth's bio-capacity. Problems arise if we overpass this bio-capacity, and it has now occured for two decades[1]. "Over-living" can only be temporary, since we draw in a finite capital.

As a consequence, it seems both interesting and relevant to study the interaction between the environment and production. There are several dimensions in the concept of "production". First, there is a socio-economic dimension, *i.e.* which deals with the organisation of economic relations. Markets and competition are the usual mechanisms in which economic exchanges are performed. This gives rise to the analysis of the consequences of the organisation of economic relations upon the environment. One the one hand, competition stimulates (either to conquere or to survive) innovation and technological progress, which is -*ceteris paribus*- ,

[1] See "Living Planet Report 2006" at http://www.wwf.org

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a good thing and may result in positive environmental outcomes. On the other hand, since it stimulates supply and thus production, it also increases the pressure on environment.
Secondly, what is produced is intended to be consumed. Therefore, examining the determinants of consumption is also relevant. In particular, one would like to know if values are one of these determinants. Changing values might lead to a change in behaviour and then possibly decrease the pressure on the environment.
Finally, technological progress and innovation are important dimensions of production. Moreover, it can be seen as a way to face the environmental challenge. If this is true, should we not observe a decrease in the levels of externality? However, it seems that we observe the contrary, *i.e.* consumption of resources and pollution (emissions, waste, etc...) both increase.

For many scholars, these are fascinating issues that require further analysis. This thesis brings contributions to the following issues. In the first chapter, we will analyse theoretically the conflicts of interest between environmental and competition policy on oligopolistic asymmetric markets. In a following chapter, we will study the empirical link between environmental policy preferences and energy consumption. Finally, we will analyse the empirical relationship between income and energy consumption.

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Chapter 1

Voluntary Agreements and Heterogeneity

1.1 Introduction

A voluntary agreement is one possible tool for dealing with increasingly pressing environmental challenges. It is an agreement between one authority (*e.g* the Ministry of Environment of a given country) and an industry, or some of the firms acting in a given market. One advantage of voluntary agreements is the fact that they allow for the undertaking of policies which take into account the specific nature of a given industry. In such agreements, firms usually have to comply with environmental objectives, in return for economic compensation. Compensation may occur as either a subsidy to encourage investment in clean technologies, or a discount in the tax paid in relation to emissions' levels. An example of this kind of agreement is the Danish agreement on industrial energy efficiency, which is part of a plan aiming at reducing CO_2 emissions[1]. To do so, the Danish government created incentives in order to encourage the concerned firms to behave more environment-friendly: in exchange of a reduction in $CO2$ emissions *a posteriori*, firms get a discount in the per-unit of emission tax rate, through an individual contract proposed by the regulator to the firms. The concerned firms (329 in total) are those from energy intensive production processes (*e.g.*

[1]See the related OECD report. Refer to the bibliography for more details

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paper industry, Iron and steel, milk condensation, etc...) and the authority is the Danish Energy Agency. I will now focus on the main economic issues. Firstly, each firm is proposed an agreement and decides to agree upon it or not. As a consequence, there is no issue of free-riding here because there is no common objective. Secondly, a lot of controls and audits have been undertaken, before and during the agreement. Thus, the Danish Authority has received significant information about the firms, especially those contained in the plan sketched by firms to decrease their emissions. Thirdly, if a firm did not comply with what it had committed to, it simply did not get the tax-rebate, which constitutes a strong incentive. To ensure that firms behaved the way they had to, they were regularly required to provide progress reports, which were later examined for their authenticity. In the case in which a firm failed to meet the terms of the contract, the Danish Authority could simply cancel the agreement. It turned out that this scheme has been effective, although the administrative costs have been quite high (mainly due to controls and audits). The example of the Danish leads to the following issues: how heterogeneity among firms influences an environmental policy, through a given tool, namely the voluntary agreement (hence VA); what are the consequences in terms of competition? From a theoretical viewpoint, VAs are interesting since there are a policy-mix tool[2]: on the one hand, there is a standard to be met (then, we know ex-*ante* the environmental goal reached); on the other hand, there is an economic incentive. Empirically, VAs have been increasingly used for about 20 years[3].

Yet, as far as competition is concerned, VAs create collusion. Brau and Carraro, *1999* survey the literature concerning the relationship between VAs and market structures. The main results are the following: on the one hand, VAs are likely to increase both the industry concentration and the likelihood of collusive behaviour; on the other hand, highly concentrated industries are more likely to favour both the existence of VAs as well as their effectiveness. Thus, there is a clear dilemma between environmental benefits and economic costs. In other words, VAs might enhance a decrease in production greater than the socially optimal one. Here, we plan to explore the consequences of VAs when firms are heterogeneous.

[2] Glachant, 1995

[3] Refer to the report of the OECD 2003

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This will allow us to answer a very simple and practical question such that: should we use VAs as an environmental tool in homogeneous oligopolies or heterogeneous ones?
Intuitively, one can expect VAs to be used in little heterogeneous industries. However, when firms are heterogeneous, it might be a good solution to have an agreement with less firms. This is due to the inefficiency at stake. In the next section, we describe the game. Then, in the following sections, we will solve it stage by stage, inducting backward.

1.2 Model Set-up

This section will consist of a description of the framework in which our analysis will be conducted.

1.2.1 Description Of The Game

In this model, there are three agents: a regulator and 2 firms in oligopolistic competition. The game played is a three-stage one. In the first stage, the regulator -maximising welfare[4]- proposes a VA, which is modeled as a firm-level take-it-or-leave-it offer (d, s), where d is a subsidy a firm receives if it does not emit more than s units of emission. In order to avoid multiple equilibrium issues, we assume that the regulator is able to choose whom to propose the contract to: either to one of the firms, either to both of them (in that case they will be proposed the same contract), or either to none of them. In the second stage, each firm decides whether to agree or not upon the proposal of the regulator. In the third stage, firms compete *à la Cournot*, each firm setting its production in order to maximise its profits.

Figure 1- Game Tree

[4]The welfare function is described in the following subsection

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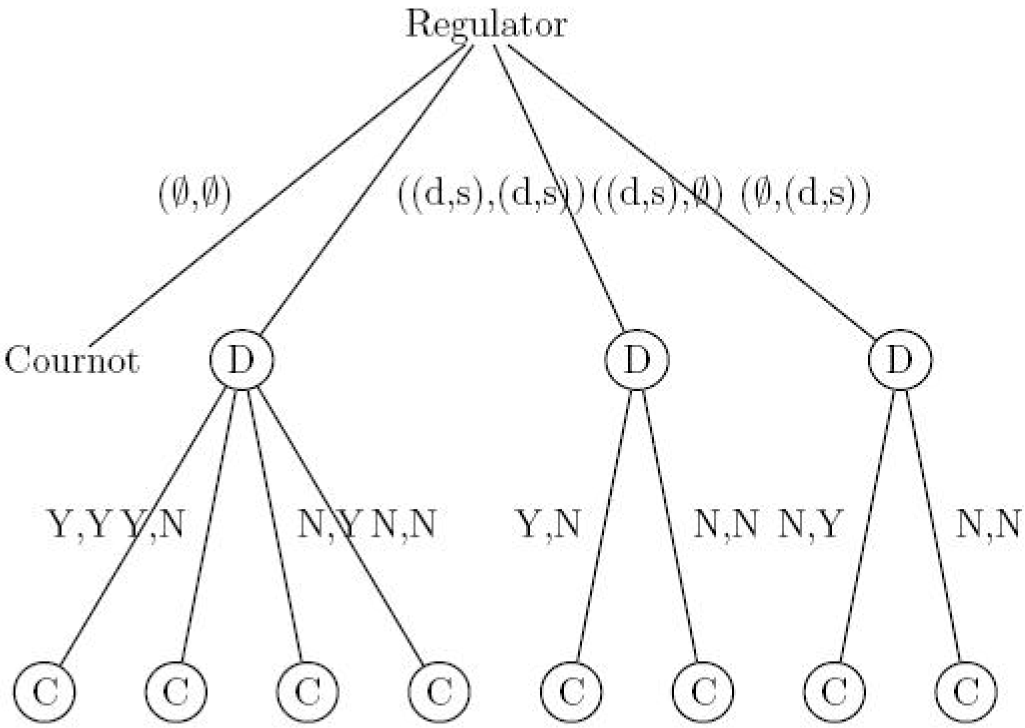

Where:

- $(\emptyset, \emptyset)$ means that the regulator does not propose any contract to any firm
- $((d, s), \emptyset)$ (respectively $(\emptyset, (d, s))$) means that the regulator proposes a contract (d, s) only to the first firm (respectively to the second one)
- $((d, s), (d, s)$ means that the regulator proposes a contract to both firms
- Y (N) means that a firm accepts the agreement (refuses)
- D represents the decision subgame
- C represents the competition subgame

I will now turn to both the objectives and the assumptions on the behaviour of both types of agents.

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1.2.2 Players: Objectives And Behavioural Assumptions

Regulator

The regulator's objective is to maximize welfare, which consists of the consumer surplus, the producer surplus (net of tax revenue), and the disutility which occurs due to the externality damaging the environment. Formally, the objective of the regulator is the following:

$$\max_{(d,s)} W = CS + PS - DU(S)$$

Where:

- S is the total amount of emissions of CO_2 in the industry ($S = \sum_{i=1}^{2} s_i$)
- (d, s) is the contract proposed by the authority
- CS is the consumer surplus
- PS is the producer surplus
- $DU(S)$ is the desutility of the externality ($DU(S) = eS^2$))

Firms

The industry is made up of two firms, competing *à la Cournot*. The constant marginal cost of the most efficient firm is set equal to 0, that of the second one equal to Δ. Furthermore, the emission function is:

$$\forall\ i \in \{1, 2\},\ \ s_i(q_i) = eq_i$$

Where e represents the emission per unit of production, and is strictly positive. Let us notice that we assume that each firm has the same pollution function in order to focus on the heterogeneity of production costs, which is at the very core of the analysis. In case firm i refuses the proposal of the regulator, its profit function is the following:

$$\Pi_i(q_i) = P\left(Q\right) q_i - c_i q_i$$

If it accepts and respects it ($eq_i \leq s$), its profit function is:

$$\Pi_i(q_i) = P\left(Q\right) q_i - c_i q_i + deq_i$$

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Indeed, the profit is made up of the revenue ($P(Q)\,q_i$), minus the total production cost , plus the subsidy[5]. Finally, we assume a linear demand function, in order to simplify the calculations.

Formally, we have:

$$Q(P) = 1 - P$$

Where:

- P is the price
- Q the global quantity, equal to $\sum_{i=1}^{2} q_i$.

After having set-up the model, let us now solve it using backward induction and determine the equilibrium of each of the subgames: first the competition subgame; secondly the decision subgame; finally the contract subgame.

1.3 Competition Subgame Equilibrium

In this section, we will determine the *Nash* equilibria of the competition subgame. It should be noted that there are four different cases to be considered: First the case in which both firms are proposed the agreement; second the case in which only the first one is proposed; third the case in which only the second one is proposed; fourth the one in which no agreement is proposed.

1.3.1 Case 1: Both Firms Participate

If both firms accept the proposal of the regulator, the profit maximisation problem they will have to solve is the following:

$$\forall i = 1,2 \left\{ \begin{array}{c} \max_{q_i \geq 0} \ \Pi_i(q_i) = P\left(\sum_{j=1}^{2} q_j\right) q_i - c_i q_i + deq_i \\ s.t: \ eq_i \leq s \end{array} \right.$$

[5] Actually, it is a discount in the per-unit tax t. However, fixing the latter to 1 turns d into a subsidy

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We can rewrite this program as follows:

$$\forall i = 1,2: \max_{q_i \geq 0} L_i(q_i, \lambda_i^{YY}) = P\left(\sum_{j=1}^{2} q_j\right) q_i - c_i q_i + deq_i + \lambda_i^{YY}(s - eq_i)$$

where λ_i^{YY} is the *Lagrange* multiplier of the firm i associated to the constraint imposed by the agreement when both firms agree.

The first-order conditions[6] of such a problem are, for any $i = 1,2$:

$$\frac{\partial L_i(q_i,\lambda_i^{YY})}{\partial q_i} = 0 \Longleftrightarrow 1 - 2q_i - q_{-i} + de - \lambda_1^{YY} e = 0$$
$$\lambda_i^{YY}(s - q_i e) = 0$$

One can easily observe that there are four cases under consideration, given the fact that we do not want to restrict the analysis.

Case (i): $\lambda_1^{YY} = \lambda_2^{YY} = 0$

In this case, the environmental constraint is not binding for either firm. Setting both Lagrange multiplier equal to 0 in the FOC, we obtain:

$$q_1^{YY,i} = \frac{1+de+\Delta}{3}$$
$$q_2^{YY,i} = \frac{1+de-2\Delta}{3}$$

The *Nash* equilibrium of the competition subgame where both firms participate in the agreement and none of them is constrained is: $(q_1^{YY,i}, q_2^{YY,i}) = (\frac{1+de+\Delta}{3}, \frac{1+de-2\Delta}{3})$. **The payoffs associated are:** $(\Pi_i^{YY,iv})_{i=1,2} = ((\frac{1+de+\Delta}{3})^2, (\frac{1+de-2\Delta}{3})^2)$.

Case (ii): $\lambda_1^{YY} = 0$; $\lambda_2^{YY} > 0$

λ_1^{YY} being equal to 0 implies that $q_1 < \frac{s}{e}$. On the other hand, having λ_2^{YY} being strictly greater than 0 implies that $q_2 > \frac{s}{e}$. These two conditions would imply that q_2 be greater than q_1. This is clearly impossible as the first firm is more efficient than the second one.

[6] The reaction functions are sketched in annex

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Case (iii): $\lambda_1^{YY} > 0$; $\lambda_2^{YY} = 0$

In that case, the constraint of the first firm is binding and thus q_1 is equal to $\frac{s}{e}$. Plugging this value in the FOC of the second firm and taking into account that $\lambda_2^{YY} = 0$, we have:

$$q_1^{YY,iii} = \frac{s}{e}$$
$$q_2^{YY,iii} = \frac{1-\frac{s}{e}+de-\Delta}{2}$$

The *Nash* equilibrium of the competition where both firms participate in the agreement and only the first one is constrained is: $(q_1^{YY,iii}, q_2^{YY,iii}) = (\frac{s}{e}, \frac{1-\frac{s}{e}+de-\Delta}{2})$**.** **The payoffs associated are:** $(\Pi_i^{YY,iii})_{i=1,2} = \left((\frac{1-\frac{s}{e}+de+\Delta}{2})\frac{s}{e}, (\frac{1-\frac{s}{e}+de+\Delta}{2})^2\right)$

Case (iv): $\lambda_1^{YY} > 0$; $\lambda_2^{YY} > 0$

In that case, both firms are constrained and therefore they both produce what the contract allows them to, *i.e.* $\frac{s}{e}$.

The *Nash* equilibrium of the competition subgame where both firms participate in the agreement and are constrained is: $(q_1^{YY,iv}, q_2^{YY,iv}) = (\frac{s}{e}, \frac{s}{e})$**. The payoffs associated are:** $(\Pi_i^{YY,iv})_{i=1,2} = \left((1-\frac{2s}{e}+de)\frac{s}{e}, (1-2\frac{2s}{e}+de-\Delta)\frac{s}{e}\right)$.

1.3.2 Case 2: Neither Firm Participates

In this case, firms will simply maximise the profit of both firms without any constraint. Therefore, this case is the one of a simple competition *à la Cournot*, where firms solve for the following program:

$$\forall i = 1,2: \max_{q_i \geq 0} \Pi_i(q_i) = P\left(\sum_{j=1}^{2} q_j\right) q_i - c_i q_i$$

The FOC amounts to:

$$1 - 2q_i - q_{-i} - c_i = 0$$

The *Nash* equilibrium of the competition subgame where neither firm participates in the agreement is: $(q_i^{N,N})_{i=1,2} = (\frac{1+\Delta}{3}, \frac{1-2\Delta}{3})$**. The payoffs associated are:** $(\Pi_i^{N,N})_{i=1,2} = ((\frac{1+\Delta}{3})^2, (\frac{1-2\Delta}{3})^2)$**.**

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Let us turn now to the final case, namely when only one firm signs the agreement.

1.3.3 Case 3: Only The Most Efficient Firm Participates

First, it should be noted that the refusal of one firm to sign the agreement can occur in two cases since there are two firms. Thus, solving for one case amounts by analogy to solve for the second one. Let us take first the case in which 1 accepts and 2 does not. 1 will solve the following program:

$$\max_{q_1 \geq 0} L(q_1, \lambda^{YN}) = P\left(\sum_{j=1}^{2} q_j\right) q_1 + deq_1 + \lambda^{YN}(s - eq_1)$$

The first-order conditions are:

$$\frac{\partial L(q_1, \lambda^{YN})}{\partial q_1} = 0 \Longleftrightarrow 1 - 2q_1 - q_2 + de - \lambda^{YN} e = 0$$

$$\lambda^{YN}(s - q_1 e) = 0$$

On the other hand, the second firm solves the following program:

$$\max_{q_2 \geq 0} \Pi_2(q_2) = P\left(\sum_{j=1}^{2} q_j\right) q_2 - \Delta q_2$$

The FOC is:

$$1 - 2q_2 - q_1 - \Delta = 0$$

Here again we have different cases to consider whether or not the constraint on the first firm is binding.

$$\begin{cases} 1 - 2q_1 - q_2 - c_1 1 + de - \lambda_1^{Y,N} e = 0 \\ 1 - 2q_2 - q_1 - c_2 = 0 \end{cases}$$

Case (i): $\lambda^{YN} > 0$

In that case, firm 1 will bind its constraint and thus produce a quantity equal to $\frac{s}{e}$. The second firm has got no constraint since it does not participate in the VA and will respond according to its reaction function given by the FOC. Plugging in that FOC the value of q_1, we have:

$$\begin{cases} q_1^{YN,i} = \frac{s}{e} \\ q_2^{YN,i} = \frac{1 - \frac{s}{e} - \Delta}{e} \end{cases}$$

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The *Nash* equilibrium of the competition subgame where the most efficient firm participates in the agreement and is constrained is: $(q_1^{YN,i}, q_2^{YN,i}) = (\frac{s}{e}, \frac{1-\frac{s}{e}-\Delta}{e})$**.** **The payoffs associated are:**$(\Pi_i^{YN,i})_{i=1,2} = \left(\left(\frac{1-\frac{s}{e}+2de+\Delta}{2}\right)\frac{s}{e}, \left(\frac{1-\frac{s}{e}-\Delta}{2}\right)^2\right)$.

Case (ii): $\lambda^{YN} = 0$

In this case, setting the value λ^{YN} in the FOC of the firm 1, we get:

$$\begin{cases} q_1^{YN,ii} = \frac{1+2de+\Delta}{3} \\ q_2^{YN,ii} = \frac{1-de-\Delta}{3} \end{cases}$$

The *Nash* equilibrium of the competition subgame where the more efficient firm participates in the agreement without being constrained is: $(q_i^{YN,ii})_{i=1,2} = (\frac{1+\Delta+de}{3}, \frac{1-2\Delta-2de}{3})$**. The payoffs associated are:** $(\Pi_i^{YN,ii})_{i=1,2} = \left(\left(\frac{1+2de+\Delta}{3}\right)^2, \left(\frac{1-de-\Delta}{3}\right)^2\right)$**.**

1.3.4 Case 4: Only Firm 2 Participates

By analogy to the previous case, we have the following equilibria.

The *Nash* equilibrium of the competition subgame where the less efficient firm participates in the agreement and is constrained is: $(q_1^{NY,i}, q_2^{YN,i}) = (\frac{1-\frac{s}{e}}{2}, \frac{s}{e})$**.** **The payoffs associated are:** $(\Pi_i^{NY,i})_{i=1,2} = \left(\left(\frac{1-\frac{s}{e}}{2}\right)^2, \left(\frac{1-\frac{s}{e}+2de-\Delta}{2}\right)\frac{s}{e}\right)$**.**

The *Nash* equilibrium of the competition subgame where the less efficient firm participates in the agreement is: $(q_i^{NY,ii})_{i=1,2} = (\frac{1+\Delta-de}{3}, \frac{1-2\Delta+2de}{3})$**. The payoffs associated are:** $(\Pi_i^{NY,ii})_{i=1,2} = \left(\left(\frac{1+de-\Delta}{3}\right)^2, \left(\frac{1+2de-2\Delta}{3}\right)^2\right)$**.**

Having solved for the competition subgame, let us now proceed in reverse order and solve the decision subgame.

1.4 Decision Subgame

This section will determine the conditions on the terms of the contract in order for the different possible equilibria to be *Nash* equilibria of the decision subgame. To do so, each of the four cases will be analysed with specific focus upon the possible profitable deviations.

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1.4.1 Case 1: Both Firms Participate in the VA

In this section, we have to consider separately each of the different possible cases we determined before.

Case (i): $q_1^c < \frac{s}{e}$ and $q_2^c < \frac{s}{e}$

In order to check whether the participation of both firms is in that case a *Nash* equilibrium, we have to check several conditions. First of all, there has to be no profitable deviation for at least one of the two players, *i.e.* one having an incentive to move from Y to N. Formally, what we have to check is the following:

$$\Pi_1(q_1^c, q_2^c) \geq \Pi_1(BR_1^{\bar{c}}(q_2^c), q_2^c)$$

Where:

- q_1^c is the equilibrium quantity produced by firm 1 if it participates in the agreement;
- $BR_1^{\bar{c}}(q_2^c)$ is the best response of firm 1 to firm 2' decision

We need to determine $\Pi_1(BR_1^{\bar{c}}(q_2^c), q_2^c)$. This profit is obtained maximising the following program:

$$max_{q_1}\Pi_1 = (1 - q_1 - q_2^c)q_1 \Longleftrightarrow BR_1(q_2^c) = \frac{2 + 2\Delta - de}{6}$$

Therefore, we can write the previous conditions as:

$$\left(\frac{1 + \Delta + de}{3}\right)^2 \geq \left(\frac{2 + 2\Delta - de}{6}\right)^2$$

As the set of parameters is such that $(\Delta, e) \in \Re^+ * \Re^{+*}$, this condition always holds. Therefore, firm 1 has no incentive to deviate and refuse the agreement. By analogy[7], we would find that firm 2 neither has no incentive to deviate from Y. These conditions are trivial: if one deviates, it can not take advantage anymore of the subsidy while not being constrained by the agreement.

[7] The condition is: $\left(\frac{1-2\Delta+de}{3}\right)^2 \geq \left(\frac{2-4\Delta-de}{6}\right)^2$

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When both firms participate and none of them is constrained, $\{Y, Y\}$ is an *Nash* equilibrium of the decision subgame for the whole set of the parameter, *i.e.* $\{(\Delta, e)|\Delta \geq 0 \wedge e > 0\}$.

Case (iii): $q_2^c < \frac{s}{e} < q_1^c$

Let us recall that the second case is not possible and therefore we must deal directly with the third case. In this case, we have $q_1^c > \frac{s}{e}$ and $q_2^c \leq \frac{s}{e}$.

We first have to ensure that firm 1 does not want to deviate. This amounts to the following condition:

$$\Pi_1(q_1^c, q_2^c) \geq \Pi_1(BR_1^{\bar{c}}(q_2^c), q_2^c)$$

We need to determine the profit if there is deviation from "Y", which results from the maximisation of the following program:

$$max_{q_1}\Pi_1 = (1 - q_1 - q_2^c)q_1 \Longleftrightarrow BR_1(q_2^c) = \frac{1 + \frac{s}{e} + \Delta - de}{4}$$

Plugging this value in the profit function, we obtain the following condition:

$$\left(\frac{1 - \frac{s}{e} + \Delta + de}{2}\right)\frac{s}{e} \geq \left(\frac{1 + \frac{s}{e} + \Delta - de}{4}\right)^2$$

The second condition to be checked is that the second firm also has no incentive to deviate. Firstly, let us compute its best response to firm 1's action. We have to solve the following program:

$$max_{q_2}\Pi_1 = (1 - q_1^c - q_2)q_2 \Longleftrightarrow BR_2^{\bar{c}}(q_1^c) = \frac{1 - \frac{s}{e} - \Delta}{2}$$

Reacting given the previous equation, we see that the second firm gets the profit $\Pi_2^{\bar{c}}(q_1^c, BR_2^{\bar{c}}(q_1^c))$ which is equal to $\left(\frac{1-\frac{s}{e}-\Delta}{2}\right)^2$. The second firm will not deviate if and only if this profit is lower or equal than the profit it makes if it does not deviate:

$$\Pi_2(q_1^c, q_2^c) \geq \Pi_2(q_1^c, BR_2^c(q_1^c)) \Longleftrightarrow \left(\frac{1 - \frac{s}{e} - \Delta + de}{2}\right)^2 \geq \left(\frac{1 - \frac{s}{e} - \Delta - de}{2}\right)^2$$

Clearly, this condition always holds as e is positive.

What remains to be proved is the monotonicity of the profit function of firm 1 (*i.e.* that it

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has no incentive to produce less than $\frac{s}{e}$). This amounts formally to:

$$\forall q_1 < \frac{s}{e} : \frac{\partial \Pi_1(q_1, BR_2^c(\frac{s}{e}))}{\partial q_1} > 0 \tag{1.1}$$

The condition for this derivative to be positive is q_1 being lower than $\frac{1+\frac{s}{e}+\Delta+de}{4}$. One can easily check that it holds for any $q_1 < \frac{s}{e}$.

When both firms participate and only firm 1 is constrained, $\{Y,Y\}$ is a *Nash* equilibrium of the decision subgame for the following set of parameter values: $\{(\Delta,e)|\left(\frac{1-\frac{s}{e}+\Delta+de}{2}\right)\frac{s}{e} \geq \left(\frac{1+\frac{s}{e}+\Delta-de}{4}\right)^2\}$.

Case (iv): $\frac{s}{e} < q_2^c < q_1^c$

In this case the conditions are: Both firms are constrained by the agreement, *i.e.* $q_1^c > \frac{s}{e}$ and $q_2^c > \frac{s}{e}$. The best response of firm 1 to firm 2's action is derived from the following program:

$$max_{q_1}\Pi_1 = (1-q_1-q_2^c)q_1 \Longleftrightarrow BR_1^{\bar{c}}(q_2^c) = \frac{1-\frac{s}{e}}{2}$$

This deviation would give the firm 1 the following profit: $\Pi_1^{\bar{c}}(BR_1^{\bar{c}}(q_2^c), q_2^c)$ which is equal to $\left(\frac{1-\frac{s}{e}}{2}\right)^2$. The condition for firm 1 not to deviate is:

$$\Pi_1(q_1^c, q_2^c) \geq \Pi_1^c(BR_1^c(q_2^c), q_2^c) \Longleftrightarrow \left(\frac{1-2\frac{s}{e}+de}{2}\right)\frac{s}{e} \geq \left(\frac{1-\frac{s}{e}}{2}\right)^2 \tag{1.2}$$

By analogy, the second firm will not deviate if and only if:

$$\Pi_2(q_1^c, q_2^c) \geq \Pi_2^c(q_1^c, BR_2^c(q_2^c)) \Longleftrightarrow \left(\frac{1-2\frac{s}{e}+de-\Delta}{2}\right)\frac{s}{e} \geq \left(\frac{1-\frac{s}{e}-\Delta}{2}\right)^2 \tag{1.3}$$

When both firms participate and are constrained, $\{Y,Y\}$ is a *Nash* equilibrium of the decision subgame for the following set of values of parameters:$\{(\Delta,e)|(1.2)\wedge(1.3)\}$**.**

1.4.2 Only The Most Efficient Firm Participates

In this case, there are two subcases to be considered, whether q_1^c is or not greater than $\frac{s}{e}$.

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Case (i): $q_1^c < \frac{s}{e}$

We have to compute the profit it gets in case he would move from Y to N, denoted $\Pi_1(q_1^c, q_2^c)$.

$$\Pi_1(q_1^c, q_2^c) \geq \Pi_1(BR_1^{\bar{c}}(q_2^c), q_2^c)$$

We need to determine $\Pi_1(BR_1^{\bar{c}}(q_2^c), q_2^c)$. This profit is obtained by maximising the following program:

$$max_{q_1}\Pi_1 = (1 - q_1 - q_2^c)q_1 \Longleftrightarrow BR_1(q_2^c) = \frac{2 + 2\Delta + de}{6}$$

Therefore, we can write the previous conditions as:

$$\left(\frac{1 + \Delta + de}{3}\right)^2 \geq \left(\frac{1 + 1\Delta + \frac{1}{2}de}{3}\right)^2$$

As the set of parameters is such that $(\Delta, e) \in \Re^+ * \Re^{+*}$, this condition always holds. Therefore, firm 1 has no incentive to deviate and refuse the agreement. Clearly, there is no issue of deviation for firm 2 since it has not been proposed the agreement.

Therefore, $\{Y, N\}$ -when firm 1 is not constrained- is an equilibrium of the the decision subgame for the whole set of parameter, *i.e.* $\{(\Delta, e)|\Delta \geq 0 \wedge e > 0\}$.
In that case, the condition is trivial since the environmental constraint is relatively low to prevent firm 1 to produce what it would produce anyway in the case of a competition *à la Cournot*. Thus, any positive d will ensure its participation in the agreement.

Case (ii): $q_1^c > \frac{s}{e}$

We have to ensure that firm 1 does not want to deviate. This amounts to the following condition:

$$\Pi_1(q_1^c, q_2^c) \geq \Pi_1(BR_1^{\bar{c}}(q_2^c), q_2^c)$$

We need to determine the profit if there is deviation from "Y", which results from the maximisation of the following program:

$$max_{q_1}\Pi_1 = (1 - q_1 - q_2^c)q_1 \Longleftrightarrow BR_1(q_2^c) = \frac{1 + \frac{s}{e} + \Delta}{4}$$

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Plugging this value in the profit function, we obtain the following condition:

$$\left(\frac{1-\frac{s}{e}-\Delta+2de}{2}\right)\frac{s}{e} \geq \left(\frac{1+\frac{s}{e}+\Delta}{4}\right)^2$$

Here again, there is no issue of deviation for the second firm as it has not been proposed the agreement.

$\{Y, N\}$ -firm 1 being constrained- is an equilibrium of the decision subgame for the following set of parameters values: $\{(\Delta, e)| \left(\frac{1-\frac{s}{e}-\Delta+2de}{2}\right)\frac{s}{e} \geq \left(\frac{1+\frac{s}{e}+\Delta}{4}\right)^2\}\ \}$

1.4.3 The Second Firm Participates

In that case, there are two subcases to be considered, whether q_2^c is or not greater than $\frac{s}{e}$.

Case (i): $q_2^c < \frac{s}{e}$

We have to compute the profit it gets in case the firm would move from Y to N, denoted $\Pi_2(q_1^c, q_2^c)$.

$$\Pi_2(q_1^c, q_2^c) \geq \Pi_1(q_2^c, BR_1^{\bar{c}}(q_1^c)$$

We need to determine $\Pi_1(q_2^c, BR_1^{\bar{c}}(q_1^c)$. This profit is obtained by the maximisation of the following program:

$$max_{q_2}\Pi_2 = (1-q_1-q_2^c)q_1 \Longleftrightarrow BR_2(q_1^c) = \frac{1-2\Delta+\frac{1}{2}de}{3}$$

Therefore, we can write the previous conditions as:

$$\left(\frac{1-2\Delta+de}{3}\right)^2 \geq \left(\frac{1-2\Delta+\frac{1}{2}de}{3}\right)^2$$

As the set of parameters is such that $(\Delta, e) \in \Re^+ * \Re^{+*}$, this condition always holds. Therefore, firm 2 has no incentive to deviate and refuse the agreement. Clearly, there is no issue of deviation for firm 1 since it has not been proposed the agreement.

Consequently, $\{N, Y\}$ -when firm 2 is not constrained- is an equilibrium of the decision subgame for the whole set of parameter, *i.e.* $\{(\Delta, e)|\Delta \geq 0 \wedge e > 0\}$.

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Case (ii): $q_2^c > \frac{s}{e}$

We have to ensure that firm 1 does not want to deviate. This amounts to the following condition:

$$\Pi_2(q_1^c, q_2^c) \geq \Pi_2(q_1^c, BR_2^{\bar{c}}(q_1^c))$$

We need to determine the profit if there is deviation from "Y", which results from the maximisation of the following program:

$$max_{q_2}\Pi_2 = (1 - q_1 - q_2^c)q_1 \Longleftrightarrow BR_2(q_1^c) = \frac{1 + \frac{s}{e} - 2\Delta}{4}$$

Plugging this value in the profit function, we obtain the following condition:

$$\left(\frac{1 - \frac{s}{e} - \Delta + 2de}{2}\right)\frac{s}{e} \geq \left(\frac{1 + \frac{s}{e} - 2\Delta}{4}\right)^2$$

Here again, there is no issue of deviation for the second firm as it not been proposed the agreement.

In the end, $\{N, Y\}$ -firm 2 being constrained- is an equilibrium of the decision subgame for the following set of parameters values: $\{(\Delta, e) | \left(\frac{1-\frac{s}{e}-\Delta+2de}{2}\right)\frac{s}{e} \geq \left(\frac{1+\frac{s}{e}-2\Delta}{4}\right)^2\}$

1.5 Optimal Contract

It is important to recall that the welfare function consists of the consumer surplus, the producer surplus and the disutility associated with pollution. Moreover, if one takes into account that the cost of the most efficient firm has been set to 0, we can write the objective function of the regulator as follows[8]:

$$W(d, s) = Q(1 - (\frac{1}{2} + e)Q) - \Delta q_2$$

That expression allows us to clearly see the different effects at stake. On the one hand, one can see that global production has two effects on welfare: it increases it as long as the

[8]This expression is a simplified one of $W(d, s) = \int_0^Q (1 - u)du - \Delta q_2 - e(\sum_{i=1}^2 q_i)^2$

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total surplus has not reached its maximum; it decreases it because of the desutility due to the emissions. On the other hand, the direct effect of the production of the second firm is without ambiguity negative: this is due to the inefficiency of the second firm that needs more resources than the first one to produce the same amount of goods. However, the production of the second firm also has an indirect effect on welfare, via its effects on global production.

What remains to be completed is to determine the best contract for each of the possibilities of participants. Before doing so, we will determine the first-best optimal to have a benchmark situation in mind.

1.5.1 A benchmark case: The First-best optimum

To determine the first-best optimum, we have to solve for the following program:

$$\max_{(q_1 \geq 0, q_2 \geq 0)} W(q_1, q_2) = (q_1 + q_2)(1 - (\frac{1}{2} + e)(q_1 + q_2)) - \Delta q_2$$

The FOC of such a problem are:

$$\begin{aligned} \tfrac{\delta W(q_1+q_2)}{\delta q_1} &= 0 \Longleftrightarrow 1 - 2(\tfrac{1}{2} + e)(q_1 + q_2) = 0 \\ \tfrac{\delta W(q_1+q_2)}{\delta q_2} &= 0 \Longleftrightarrow 1 - 2(\tfrac{1}{2} + e)(q_1 + q_2) - \Delta = 0 \end{aligned}$$

Clearly, both conditions can not hold simultaneously. If the first one holds, then the second one is negative. In particular, the second derivative is negative for $q_2 = 0$. Thus, the production of the second firm is equal to 0 and that of the first firm is equal to 1. Therefore, we have the following optimal quantities:

$$\begin{aligned} q_1^{FB} &= \tfrac{1}{1+2e} \\ q_2^{FB} &= 0 \end{aligned}$$

One can notice that for $e = 0$, i.e. there is no externality, the quantity produced will be equal to 1. Indeed, the cost of the most efficient firm being equal to 0, the best response is to produce everything that is possible, *i.e.* 1.

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1.5.2 Three Particular Cases

No Externality

If there is no externality, *i.e.* $e = 0$, the consequences are twofold: firstly, the regulator does not care anymore about the environment; secondly, firms no longer pollute. Therefore, whatever the contract proposed by the regulator, the competition subgame equilibrium is that of standard *Cournot* duopoly. Indeed, when e is equal to 0, the regulator just maximises the total surplus. Moreover, each firm maximises the following profit function:

$$\Pi_i(q_i, q_{-i}) = q_i(1 - q_i - q_{-i} - c_i)$$

One can see that the subsidy does not appear anymore in the profit function and this explains the response of the firm to any given contract of the regulator. Yet, the externality does not appear anymore in the welfare function and as a consequence, the regulator will not propose any contract to any firm. The equilibrium of the subgame is therefore:

$$\left((\emptyset, \emptyset), (\frac{1+\Delta}{3}, \frac{1-2\Delta}{3})\right)$$

Homogeneous Firms

In that case, $\Delta = 0$. The consequence is that the regulator is able to implement a contract such that the level of welfare is the one of the first best: it sets s so as to enhance the first best production and sets d to force firms' participation. Indeed, since there is no longer asymmetry between firms, there is no issue of efficiency and thus only the global production is relevant. In other words, market share does not matter since each is as efficient as the other. Therefore, the regulator will allow firms to produce a quantity Q_0 such that the total amount of emissions does not overtake the optimal level. Then, any contract enhancing any (q_1, q_2) such that $q_1 + q_2 = Q_0$ will be an equilibrium of the contract subgame equilibrium. Therefore, it will either be $(Y, Y), or (Y, N) or (N, Y)$.

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No Asymmetry, Nor Externality

Following the reasoning of the two previous particular cases, we can now look at the case where both parameters are equal to 0. Clearly, since the there is no externality, there will be no contract. Moreover, firms being as efficient as each other, we end up with the standard symmetric duopoly Cournot equilibrium, *i.e.*. Therefore, the equilibrium of the subgame will be:

$$\left((\emptyset,\emptyset),(\frac{1}{3},\frac{1}{3})\right)$$

1.5.3 Neither Firm Participates

In that case, we just have to compute the level of welfare, plugging in the welfare function the values of the quantities of the competition subgame. This leads to the following level of welfare:

$$W^{NN*} = \frac{1-\Delta}{3}\left(1-\left(\frac{1}{2}+e\right)\left(\frac{1-\Delta}{3}\right)\right)-\Delta\left(\frac{1-2\Delta}{3}\right)$$

1.5.4 Both Firms Are Involved In The Agreement

Both Firms Are Constrained

We deal first with the case in which both firms are constrained. Let us recall that the regulator maximises its welfare function, given that he wants both firms to agree upon the proposal, which amounts to the following program to be solved[9]:

$$\begin{cases} \max_{(d\geq 0,s\geq 0)} W(d,s) = \frac{2s}{e}(1-(\frac{1}{2}+e)\frac{2s}{e})-\Delta\frac{s}{e} \\ s.t\ : \left[\begin{array}{c} \left(1-\frac{2s}{e}+de+\Delta\right)\frac{s}{e} \geq \left(\frac{1-\frac{s}{e}}{2}\right)^2 \\ \left(1-\frac{2s}{e}+de-\Delta\right)\frac{s}{e} \geq \left(\frac{1-\frac{s}{e}\Delta}{2}\right)^2 \\ \frac{s}{e} < \frac{1+de-2\Delta}{3} \end{array}\right. \end{cases}$$

Noticing that the three constraints leads to d being large enough, we can just maximise with respect to s and then find d such that all the constraints are satisfied. The first-order

[9]Having plugged in the values of the quantities obtained from the competition subgame

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condition is:

$$\frac{\partial W(s)}{\partial s} = 0 \Longleftrightarrow 2 - \Delta - 8\frac{s}{e}(\frac{1}{2} + e) = 0$$

Therefore, we obtain:

$$s^{YY,i,*} = \frac{2-\Delta}{8(\frac{1}{2}+e)}$$
$$W^{YY,i,*} = \frac{2-\Delta}{4(\frac{1}{2}+e)}(1 - \frac{2-\Delta}{2}(\frac{1}{2} + e))$$

As far as d is concerned, the optimal value is not that important since it is only a transfer between the regulator and the firms. The important point to ensure is that a value of d exists such that both will participate and this has already been shown. Note otherwise that the optimal value of s is positive for the whole set of values of parameters.

None Is Constrained

In that case, the regulator solve for the following program:

$$\begin{cases} \max_{(d\geq 0, s\geq 0)} W(d,s) = \frac{2+2de-\Delta}{3}(1 - (\frac{1}{2}+e)\frac{2+2de-\Delta}{3}) - (\Delta\frac{1+de-2\Delta}{3}) \\ s.t\ : \left[\begin{array}{c} \left(\frac{1+de+\Delta}{3}\right)^2 \geq \left(\frac{1-\frac{de}{2}+\Delta}{3}\right)^2 \\ \left(\frac{1+de-2\Delta}{3}\right)^2 \geq \left(\frac{1-\frac{de}{2}-2\Delta}{3}\right)^2 \\ \frac{s}{e} > \frac{1+de-2\Delta}{3} \end{array} \right. \end{cases}$$

We see that whatever the values of the parameter, firms will participate for any $d \geq 0$. Moreover, for any d, the regulator will set s such that firms are not constrained. Taking the derivative of the welfare function and setting it equal to 0, we find the following optimal value of d and the optimal value of welfare:

$$d^{YY,iv,*} = (\frac{3(2-\Delta)}{4(\frac{1}{2}+e)} - (2-\Delta))\frac{1}{2}$$
$$W^{YY,iv,*} = \frac{2-\Delta}{4(\frac{1}{2}+e)}(\frac{2+\Delta}{2}) - \Delta(\frac{3(2-\Delta)}{4(\frac{1}{2}+e)} - \Delta)\frac{1}{6}$$

Note that d has to be greater or equal than 0. This holds only if $e < \frac{1}{4}$. Otherwise, the optimal d is 0, and the level of welfare is the one of the case in which there is no agreement.

Only The Most Efficient Firm Is Constrained

This case has no analytic solution, and we will solve it numerically while solving the whole game in the next section. We will turn directly to the next case, where only the most efficient firm is proposed the agreement.

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1.5.5 Only The Most Efficient Firm Partipates

The Most Efficient Firm Is Constrained

The problem to be solved by the regulator is:

$$\max_{(d\geq 0,s\geq 0)} W(d,s) = (\tfrac{1+\frac{s}{e}-2\Delta}{2})(1-(\tfrac{1}{2}+e)(\tfrac{1+\frac{s}{e}-2\Delta}{2})) - \Delta(\tfrac{1-\frac{s}{e}-2\Delta}{2})$$

$$s.t \left[\begin{array}{c} (\frac{1-\frac{s}{e}+2de+\Delta}{2})(\frac{s}{e}) > (\frac{1+\frac{s}{e}+\Delta}{2})^2 \\ \frac{s}{e} < \frac{1+2de+\Delta}{3} \end{array} \right.$$

Here again, a quick look at the constraints reveals that d has to be sufficiently high. Therefore, we just have to find the optimal value of s. The first-order condition is:

$$\frac{\partial W(s)}{\partial s} = 0 \Longleftrightarrow 1 - 2(\frac{1}{2}+e)(\frac{1+\frac{s}{e}-2\Delta}{2}) + \Delta = 0$$

In the end, we have the following optimal value of the maximum level of emissions and welfare when the first firm participates and is constrained:

$$s^{YN,ii,*} = \tfrac{1+\Delta}{\frac{1}{2}+e} - (1-2\Delta)$$

$$W^{YN,ii,*} = (\tfrac{1+\Delta}{2(\frac{1}{2}+e)})(1-(\tfrac{1}{2}+e)(\tfrac{1+\Delta}{2(\frac{1}{2}+e)})) - \Delta((1-2\Delta) - \tfrac{1+\Delta}{2(\frac{1}{2}+e)})$$

One can observe that $s^{Y,N*}$ is increasing with respect to the gap in costs and decreasing with respect to the per-unit of production emission. Note also that s is positive if $\Delta \geq \frac{(\frac{1}{2}+e)-1}{2(\frac{1}{2}+e)+1}$. This condition is restrains the set of parameter if and only if $e > \frac{1}{2}$.

The most efficient firm is not constrained

The problem to be solved by the regulator is:

$$\max_{(d\geq 0,s\geq 0)} W(d,s) = (\tfrac{2+de-\Delta}{3})(1-(\tfrac{1}{2}+e)(\tfrac{2+de-\Delta}{3})) - \Delta(\tfrac{1-de-2\Delta}{3})$$

$$s.t \left[\begin{array}{c} (\frac{1+de+\Delta}{3})^2 \geq \left(\frac{1+\frac{de}{2}+\Delta}{2}\right)^2 \\ \frac{s}{e} > \frac{1+2de+\Delta}{3} \end{array} \right.$$

Here again, a quick look at the constraints reveals that d just needs to be positive to ensure the participation of the first firm. Moreover, for any given value of d, the regulator can set afterward a value of s such that the firm 1 is not constrained. Thus, we have to find the optimal value of d, and the first-order condition is:

$$\frac{\partial W(d)}{\partial d} = 0 \Longleftrightarrow 1 - 2(\frac{1}{2}+e)(\frac{2+de-\Delta}{3}) + \Delta = 0$$

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In the end, we have the following optimal value of subsidy and welfare when the first firm participates and is constrained:

$$d^{YN,ii,*} = \frac{(3(1+\Delta)}{2(\frac{1}{2}+e)} - (2-\Delta)$$
$$W^{YN,ii,*} = (\frac{1+\Delta}{2(\frac{1}{2}+e)})(\frac{1+\Delta}{2}) - \Delta(1-\Delta)$$

Note that d is positive if $\Delta \geq \frac{4(\frac{1}{2}+e)-3}{2(\frac{1}{2}+e)+3}$. This condition restrains the set of parameters if and only if $\frac{1}{4} < e < 1$. If e is lower than one fourth, then this condition is not restraining since Δ just needs to be greater than something negative. On the contrary, if e is above 1, then the optimal d is equal to 0 and the optimal level of welfare is the one obtained in the case inn which there is agreement at all.

1.5.6 Only The Second Firm Participates

Firm 2 is constrained

By analogy to the previous case, we have:

$$s^{NY,ii,*} = \frac{1-2\Delta}{\frac{1}{2}+e} - 1$$
$$W^{NY,ii,*} = (\frac{1-2\Delta}{2(\frac{1}{2}+e)})(1 - (\frac{1}{2}+e)(\frac{1-2\Delta}{2(\frac{1}{2}+e)})) - \Delta(\frac{1-2\Delta}{\frac{1}{2}+e} - 1)$$

Interestingly, one can notice that the optimal quantity determined by the contract will not be 0 (apart from an improbable combination of the values of parameters). This is due to the competition at stake: in case the second firm would produce a 0 quantity, the first one would respond by producing the monopoly quantity(Q^M). This would be optimal only for e being such that $Q^{FB} = Q^M$. In my opinion, that is one highly important illustration of the fact that an environmental policy can not be conducted independently of the competition operating within a given market.

Firm 2 is not constrained

The problem to be solved by the regulator is:

$$\max_{(d\geq 0, s\geq 0)} W(d,s) = (\frac{2+de-\Delta}{3})(1-(\frac{1}{2}+e)(\frac{2+de-\Delta}{3})) - \Delta(\frac{1-de-2\Delta}{3})$$
$$s.t \left[\begin{array}{c} \left(\frac{1+2de-2\Delta}{3}\right)^2 \geq \left(\frac{1-2\Delta+\frac{1}{2}}{3}\right)^2 \\ \frac{s}{e} > \frac{1+2de-2\Delta}{3} \end{array} \right.$$

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Here again, an introductory analysis of the constraints reveals that d just needs to be positive to ensure the participation of the second firm. Moreover, for any given value of d, the regulator can set afterward a value of s such that the firm 1 is not constrained. Thus, we have to find the optimal value of d, and the first-order condition is:

$$\frac{\partial W(d)}{\partial d} = 0 \Longleftrightarrow 1 - 2(\frac{1}{2} + e)(\frac{2 + de - \Delta}{3}) + \Delta = 0$$

In the end, we have the following optimal value of subsidy and welfare when the first firm participates and is constrained:

$$d^{NY,ii,*} = \frac{(3(1+\Delta)}{2(\frac{1}{2}+e)} - (2 - \Delta)$$
$$W^{NY,ii,*} = (\frac{1+\Delta}{2(\frac{1}{2}+e)})(\frac{1+\Delta}{2}) - \Delta(1 - \Delta)$$

Note that d is positive if $\Delta \geq \frac{4(\frac{1}{2}+e)-3}{2(\frac{1}{2}+e)-3}$. This condition tells us that Δ has to be greater than 1 in order for d to be positive. This is impossible since Δ can not[10] be greater than $\frac{1}{2}$. So, the optimal d is equal to 0 and thus we go back to the situation in which there is no agreement. Therefore, the regulator can never perform better than in the case of *Cournot* competition by proposing an agreement to the second firm without any constraint. Such a policy amounts to subsidising the less efficient firm, and that is why it is not worth doing it.

1.6 Numerical Solution of the Model

1.6.1 Welfare Analysis

In this section, we will determine the best policy that the regulator can perform. Since there is no analytic solution (because of the case in which both firms participate and the most efficient is constrained), we will solve for the model numerically.

The argument proceeds in the following way. For any value of the parameters (*i.e.* e and Δ), the set of values of the arguments satisfying the different constraints as defined in the previous section may be determined. Subsequently, for each couple (d, s) satisfying the constraints, the corresponding level of welfare is computed. This allows us to determine the

[10] If it were to be the case, then firm 2 would not be able to produce a positive quantity when competing *à la Cournot* with firm 1

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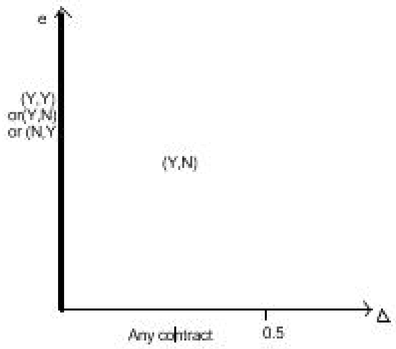
values of d and s [11] such that welfare is maximised for each type of contract. Finally, in order to determine, for each couple of values of the parameters, the best contract that can be implemented by the regulator, the levels of welfare are compared.
Let us first emphasize two things: first, a regulator is always able to make at least as well as if there were no contract; secondly, as the second firm is less efficient, it is always possible to implement a contract where only the more efficient firm is involved and performs at least as well as if only the second firm participates. Consequently, in order to determine the best contract, we just need to compare the level of welfare in the case in which both firms participate and the level obtained when only the most efficient firm participates.

The results of the numerical resolution of the model are sum-up in figure 2.

Figure 2- Results



Several conclusions may be drawn from the above graph. If there is no externality (*i.e.* $e = 0$), then the level of welfare is that of standard Cournot duopoly, regardless of the

[11]Refer to the appendix in which $s^*(\Delta)$ has been sketched for several values of the parameter e. Notice however that given the constraints and the function, there is no continuity in the function $s^*(\Delta)$ since a small change of the value of a parameter can enhance a switch due to a different equilibrium.

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contract if there is even any. Indeed, if there is no externality, the subsidy would be equal to 0. Therefore, firms would behave as if no contract exists and thus produce the Cournot equilibrium quantity. Moreover, the possible subsidy being a transfer, it would have no effect on welfare. Therefore, the equilibrium is that of Cournot with no externality along the horizontal axis. In particular, if there is no asymmetry (*i.e.* $\Delta = 0$), then the outcome of our game is that of Cournot duopoly with no assymmetry. Let us now turn to the case in which there is no asymmetry, but there are externalities (*i.e.* $e > 0$). In such a case, the regulator can involve both firms in an agreement which requires that they produce in such a way that the enhanced level of emissions is obtained at the first-best optimum. In this particular case, the regulator can choose to require that one firm produces more than another: since the latter are perfectly symmetric in all aspects, quantities and thus welfare will be equal to the one when both produce the same amount of good. Concerning the subset of parameters in which $\Delta > 0$ and $e > 0$, the conclusions are different. Indeed, in such a case, an agreement involving only the most efficient firm will be the best to be implemented. Although it appears a little extreme as a result, it will be shown that it is not that surprising. It is necessary to remember that the per-unit emission is the same for both firm. It should also be taken into consideration that firm 1 is more efficient. Consider the case in which an agreement leads to a global number of unit of production equal to, Q_1, and individual production equal to q_1 and q_2. If the regulator implements an agreement where only the first firm participates, then she can find an agreement in which the global production will be equal to Q_1, thus the level of production is the same as in the case of two firms participating. However, since the production of firm 1 will be greater than q_1 -and thus that the production the second firm will be lower than q_2, the total cost of production will necessarily be lower than in the previous case (remember that $\Delta > 0$). That is why it is always better, when both parameters are stricly positive, to have an agreement involving only the most efficient firm.

Even if it can appear somehow obvious, notice first that it is not obvious that an agreement necessarily reaches an equilibrium *a priori*. In other words, this result was expected,

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but given the complexity of the constraints, it was necessary to check that the equilibria were *effectively* equilibria.

1.6.2 Competition And Economic Policy Issues

Economic Policy

This section we will study the implications in terms of competition issues. It first describes the trade-off at stake, and then proceeds to analyse the consumer surplus with and without agreement.

Let us first underline the two main conflicts of interest at stake between the action of the regulator and competition: firstly, involving the most efficient firm in an agreement strengthens its dominant position on the market; secondly, involving both of them in an agreement is *de facto* collusive in the sense that the equilibrium is more symmetric. Clearly, this second remark is due to the nature of the contract proposed by the regulator (recall that there is no discrimination in terms of allowed levels of emissions). Therefore, we see that the implementation of an agreement in our model raises competition issues: either strengthening the dominant firm's position; or resulting in a more collusive equilibrium, having in addition a less efficient firm producing.

Consumer Surplus

I will now turn to the analysis of consumer surplus. The following graphs represents, for given values of externality, the difference in consumer surplus when there is an agreement and when there is no agreement as a function of asymmetry between firms.

Figure 3- Differences in Consumer Surplus

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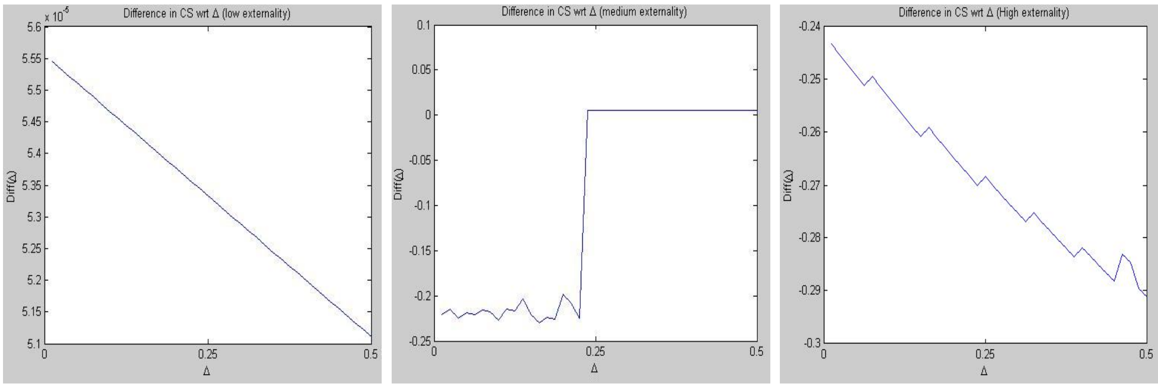

Let us first remark that the graphs represent the difference in consumer surplus in the case of a VA and in absence of VA. Therefore, if the difference is positive, it means that the consumer surplus in the case of a VA is greater than in case there is no VA.

As one may observe in the first graph, when the per-unit emission e is low, the consumer surplus obtained with a VA is greater than the one obtained under standard Cournot competition. This holds whatever the value of Δ. Thus, if the objective of a competition authority is to maximise the consumer surplus, then there is no conflict of interest between competition policy on the one hand, and environmental policy on the other. In other words, damages due to the externality (generating a loss of welfare) are not great enough to compensate for the gain in welfare due to an increase in production enhanced by the agreement. (Recall that in the standard Cournot duopoly model, a regulator would like to subsidise firms to make them produce at their marginal cost.)

The second graph exhibits a different result: we take an intermediate value of e and the consumer surplus when there is a VA is greater than the consumer surplus when there is no VA only if the level of assymmetry between firms is high enough. When externality is higher, so is the loss related to it for a given level of production. However, involving the most efficient firm in an agreement merits completion for high values of Δ since production of firm 2 induces a high level of inefficiency. Therefore, competition and environmental policy are in conflicts when there is little assymmetry between firms. This is not surprising: when assymmetry is high, then it is worth subsidising firm 1 to reduce productive inefficiency, and this outweighs the loss of welfare due to the externality if the inefficiency is sufficiently large. These most recent results confirm the previous results: when externality is relatively high,

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then competition and environmental policy exist in conflict. Indeed, the difference in consumer surplus is negative regardless of the value of Δ. This means that it is better in competition policy terms not to implement an agreement. The reason is that the externality pulls production downward in the case of an agreement (since e is relatively high and the constraint in the agreement is $\frac{s}{e}$).

Concerning the question raised in the introduction, it may be concluded that VAs will not raise competition issues as long as the externality is relatively low.

1.7 Conclusion

This chapter has investigated the implementation of VAs (take-it-or-leave-it-offers in our model) from an authority aiming at regulating a polluting oligopolistic industry. In this industry, two firms compete *à la Cournot* and produce a good enhancing emissions of a pollutant. The regulator wants to limit these emissions and thus proposes to them (or to one of them) a contract. If the latter is accepted and respected, firms get a discount on the per-emission tax. The main feature of the industry is that the firms are heterogeneous as concerns their cost. As a consequence, an agreement involving both firms, since it is the same for both of them, enhances loss due to productive inefficiency. When an externality exists , then it is better to propose a contract only to the most efficient firm.

We have seen that, in terms of competition policy, the role of efficiency is very important and raises risks of abuse of dominance since it increases the dominance of the most efficient firm.

Moreover, as concerns consumer surplus, the chapter has shown that a conflict of interest between competition and environmental policy occurs, especially when the externality is high. In economic policy terms, these results would suggest that in highly polluting oligopolistic industries, regulation is likely to be better than competition. This is a partial answer to the question asked in the general introduction, concerning the link between competition and environment. The other part of the question could be investigated by looking at the positive effect of competition on environment, either through efficiency gains or preferences changes.

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Chapter 2

Environmental Policy Preferences vs Behaviours

2.1 Introduction

Environmental issues concern an increasing number of people, and this might first enhance a change in their preferences and eventually, a possible change in their behaviour. Indeed, it might be the case that people who feel concerned about the environment are likely to care more about it than others. In particular, they might want to limit their environmental cost (henceforth footprint), and thus reduce their consumption of goods that enhance externalities. Investigating the possible existence of a link between what people declare to care about and their consumption behaviour is the purpose of this chapter.

There are many ways to investigate how people feel concerned by environmental issues, and how they actually behave. One method of analysing this relationship is to explore the willingness-to-pay (hence WTP) to protect the environment. Usually, people are asked general questions about what they would pay to protect the environment. For example, in the World Values Survey, people are asked: "Would you accept an increase in tax to protect the environment?". From that survey, Torgler and Garcia-Valinas (2005), studying the environmental preferences in Spain, created a model to explain the WTP with a set of socio-economic and demographic variables. One problem usually mentioned concerning the

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WTP is that the content of such survey is of such a vague nature that it is hard for people to give an accurate answer. Returning to the question asked in the World Values Survey, one could of course ask how the respondents understood the level of the increase in tax contained in the question. Moreover, BULTE AND AL, 2004 have found some evidence that the cause of environmental damages affects the WTP. From a field study, they found in particular that people are more willing to pay when problems are believed to be human-related. From the same survey, we know that socio-demographic variables are highly correlated with both environmental preferences and behaviors(see DUROY (2003)). In this paper, we want to go a step further and look at the link between environmental policy preferences (*i.e.* regardless whether or not a person would prefer a government aiming at protecting the environment rather than a government aiming at maintaining the current standards of living and behaviours.

This issue deserves to be investigated. In order to give an answer, this chapter will compare environmental policy preferences (*i.e.* what should the government's priority be? maintaining the standards of living or protecting the environment) of people and their ecological footprint. In particular, we will look at what people think about environmental policy and their consumption of energy. The latter is certainly one formidable environmental challenge: there are some issues of emissions (in particular greenhouse gas emissions) [1] and fantastic issues of resources depletion (in particular concerning fossil energy). In the British Household Panel Survey, we have information on both values and consumption. Therefore, it seems adequate to investigate the link between both. The next section will present the determinants of domestic energy consumption. After this section the chapter will describe the data and the model to be estimated. In a following section, the results are presented and discussed. Finally, the last section concludes and suggests some paths for further research.

[1] see the EU Environmental Report 2003

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2.2 Determinants of Energy Consumption

This section aims at describing the theoretical determinants of household energy consumption. Firstly, it shows that energy consumption is mainly linked to physical and socio-economic determinants. Secondly, the chapter shows why environmental policy preferences might be related to energy consumption and as a consequence, how these preferences can explain part of the differences in energy consumption among households.

2.2.1 Physical and Socio-economic Determinants

Physical and Environmental Constraints

Clearly, domestic energy consumption crucially depends on physical variables. Among these, the main one is the weather. Indeed, the energy consumed for heating one's house crucially depends on temperatures: the higher the temperatures, the lower the energy consumption. This holds of course for reasonable temperatures. Clearly, if temperatures are very high, then people will start to use air-conditioning, which consumes energy. However, we will use data from the first half of the nineties and relative to the UK. This mitigates the possible "air-conditioning" effect.

Besides temperatures, there are other physical variables that make energy consumption varying across individuals. Firstly, the size of accommodation plays a clear role in household energy consumption, especially in relation to heating. Indeed, one can expect that the greater the size of the accommodation, the greater the need for heating. In the same way, the type of accommodation should matter theoretically: households living in apartments or terraced- or semi-detached housing are expected to heat less than people living in houses.
Thirdly, the number and the type of domestic appliances should also matter as concerns energy consumption. A household that uses any possible domestic appliance is expected to consume more energy than a household that, for example, just uses a fridge.
Lastly, the type of heating is a crucial determinant of energy consumption. Indeed, there are differences in both prices and efficiency among different types of energy (namely oil, gas,

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electricity and solid fuel or other fuel).

Socio-economic Variables

Besides the physical determinants, there are also some socio-economic determinants.
First of all, income plays a clear role in the energy consumption (see BLUNDELL (1989) and REDHANZ (2005). We will take the log of the annual income and expect the coefficient to be positive.
Besides houshold income, the relationship of the houshold to the ownership of the property is *a priori* crucial in determining the energy consumption of households. Indeed, it is easier for owners than tenants to invest in better insulation, purchase more efficient durable goods such as washing-machine, tumble dryer, etc...Consequently, we expect tenants to consume more energy and to heat their accommodation more than owners do.
We will also examine the age of people even though the effect is not clear *a priori*.
Another important variable is the number of children in the household. Indeed, a household where there are many children is expected to heat more in the sense that it might have to heat a greater number of rooms. Moreover, the probability that there somebody is almost all the time in a given accommodation is much higher for households where there are children. Finally, a higher number of children increases the probability of having young children and thus the necessity to heat more to offer the child good living conditions. To sum up, we expect the number of children to influence positively energy consumption.
Finally, another determinant of energy consumption deserves to be taken into account: the status of people. Pensioners, unemployed people, self-employed people can reasonably be expected to be heat more since that they are likely to spend more time in their accommodation.

After having described the physical and socio-economic variables, we will now explain why environmental policy preferences might play a role in explaining part of the observed heterogeneity among households as concerns their energy consumption.

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2.2.2 Environmental Policy Preferences and Their Link With Energy Consumption

Economic Policy Issues

The main reason for studying the relationship between the environmental policy preferences and the actual behaviour of people is related to economic policy implementation. If the protection of the environment is an important objective of a given government, there are many ways to act aiming at reaching such a goal. First, there are economic incentives: taxation for example is one way to increase the price of a good, in our case energy. This is supposed to make people consume less energy following the increase in prices. Conversely, subsidies can be used to promote more efficient use of energy. An alternative way is coercion: a regulator can simply prohibit the use or production of a given good, considered as dangerous. An example of this kind of prohibition occurred with chemicals such as DDT. A less radical way to implement environmental policies is to set some norms, for example on emissions. An example of such a regulation is to set the level of emission of new vehicles at $120gCO_2.km^{-1}$ by 2012. A third way is to inform or educate people in order for them to understand better the complex relationship between their behaviour and the related environmental impact. The best policy might be a mix of those mentioned obove, but the one that is interesting for this analysis is the third one. Indeed, if a link exists between what people think and what people do, then implementing a policy aiming at informing people and consequently changing their attitudes towards energy use might be worth being performed. As a consequence, if a part of the heterogeneity of energy consumption may be explained by the heterogeneity in environmental policy preferences, then a policy aiming at influencing those preferences might be considered for implementation.[2]

After having described the motivations of our analysis, we will study the theoretical foundations of the existence of a relationship between the environmental policy preferences and the actual behaviour of people.

[2]Clearly, this paper is a first step. A proper causality analysis should then be performed.

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Theoretical Foundations

The following postulate is at the core of the theoretical foundations: the more people are aware of a negative externality, the more they will try to decrease their consumption of externality-enhancing goods. Note that the awareness of the externality can enter in two ways in the utility function: by simple altruism, people might consume less of a given good; alternatively, people will be willing to decrease their consumption if they begin to pay the price of the externality associated to the good. In any case, a given person will be aware if it arms at least somebody in a sufficient extent. In a way, the awareness of the externality allows its "internalisation". What we need to assume at that point is that environmental policy preferences are a useful measure of the awareness of people concerning environmental issues. In particular, it can be taken as a measure of their awareness of the negative externality enhanced by the consumption of a given good. In our case, this would simply mean that people declaring to be sensitive to the state of environment knows that producing and consuming energy deplete resources and generate emissions of greenhouse gas(mainly (CO_2) or nuclear waste[3]. As a consequence, self-declared green people are expected to consume less energy.

The main reasons for which people have a different awareness of environmental concerns can be the following ones:

- information asymmetry
- idiosyncratic heterogeneity in sensitivity toward environment
- cultural capital heterogeneity

Having observed these theoretical foundations of the analysis, the following section will describe the data used and the model to be estimated.

[3] We clearly assume that energy consuming is environmental damaging. This seems reasonable given the small share of renewable energies, *i.e.* about 6.3% in average in the EU-25 in 2004, European Environment Agency.

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2.3 Data and Model

2.3.1 Data set and frame of analysis

To conduct our research, we have used the British Household Panel Survey. This survey has been conducted annually since 1991 and its gives detailed information about a broad range of both economic and social variables of British households. This chapter uses 3 waves of the panel, namely the first, the third and the fifth. These three particular waves have been chosen because information related to environmental policy preferences was available only in these latter cases. In particular, we know if people would prefer a government aiming at protecting the environment or rather maintaining the standards of living. The actual question in the survey is:

"If the government had to choose between maintaining living standards and protecting the environment, to which do you think it should give the highest priority? Should it be..."

- *Living standards*
- *The environment*
- *Neither*
- *Don't know*

Information about values and environmental policy preferences, life conditions and consumption is available[4]. On the one hand, we know how much households spend in energy, how many domestic appliances they own, the type of accommodation, income, the number of children, etc...[5]. On the other hand, we have some information about values of people. In my opinion, this data is highly valuable because we have on the one hand data related to the values toward environment; on the other hand, we have information on what households

[4]See http:
www.eds.uk

[5]We will review completely the variables used in the next subsection.

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consume, *i.e.* and how they behave. This will allow us to investigate -partly at least- the already mentioned link.

Concerning temperatures, the chapter uses regional monthly temperature from Weatherbase data set.

Finally, the Retail Price Index is used to compute both income and energy spendings in 1993-pounds. Note that we have used two type of price index: one for income (the global consumption price index); one for energy prices. Note that both case use the average annual growth rate. The data used is from the (UK) Office for National Statistics (see Economic Trends 626, January 2006).

2.3.2 Variables

This section defines a set of variables that have to be taken into account in order to explain heterogeneity in energy consumption. People in the panel were asked precise questions about their consumption and what they own, and above all about their energy consumption. This question is of primary interest for us.

Its importance is due to the fact that energy issues encompass several dimensions of environmental concerns, namely resource depletion and pollution. In Europe, energy use is a major contributor to greenhouse gas emissions. [6]. Otherwise, the last report of the WWF "Living Planet 2006" indicates that energy accounts for an important part of the global ecological footprint.

The available information concerning energy consumption is the monthly fuel expenditures of households, *i.e.* the bills of oil, gas and electricity. This energy consumption is our measure of households's footprint. The underlying idea is that, taking into account a broad range of demographic variables, the higher the energy expenditures, the less environmental friendly the behaviour. Clearly, this is far from perfect nor complete, but it offers an important dimension of environment damage for the reasons mentioned above. Moreover, there is a clear incentive to decrease one's energy expenditures for economic reasons. This means

[6] See the report of the EEA "The EU Environment Report 2003"

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that people who pay attention not to use too much energy might do so in order to save on money rather than to protect the environment. Clearly, this is a limitation of the empirical investigation.

We regress the households' monthly energy spendings on a set of socio-economic and physical variables, and check the significance of the already defined intentional variable. The following section takes different sets of regressors into account. Inspired in particular by what used REDHANZ (2005) - see also BAKER AND BLUNDELL (1989)-, I have taken into account a set of demographic, socio-economic variables, and also some physical variables complying as much as possible with the theoretical determinants of energy consumption previously defined. The variables are described in annex 2, table 1.

2.3.3 Model to be estimated

Following the description of the independent variables, it still remains to describe the dependant variable. As mentioned above, the monthly energy spendings of the household will be taken as a dependant variable or rather the log of it(y). This variable takes into account the expenditures of all types of fuel for the house (*i.e.* heating, lighting and domestic appliances using). Clearly, this is only one dimension of the total footprint of a household. Ideally, we would like to have information on all types of consumption and emissions. However, as already mentioned, energy accounts for a large part of one's ecological footprint. The fuel bill is therefore a good proxy for the household's ecological footprint. The underlying idea is that, taking into account economic and physical variables, people who use more fuel cost more in environmental terms.

The equation to be estimated is:

$$y_i = \beta x_i + \alpha env_i + u_i \tag{2.1}$$

Where:

- y_i is the log of the fuel bill
- x_i is the set of socio-economic and physical variables, plus time dummies

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- *env* is the political preferences variable

- u_i is $N(0, \sigma^2)$ distributed

One simple way to know if environmental policy preferences can explain a part of heterogeneity in energy consumption is to estimate this equation and then test the significance of the coefficient α. That is the purpose of the next section.

2.3.4 Econometric Issues

The Issue of Prices

Prices in general can vary in several dimensions: first, prices vary in location; secondly, prices vary in time; thirdly, in the case of energy consumption, prices vary by type of energy; finally, prices can vary by type of contract.
We know already know that we control for the type of energy. Moreover, taking into account temperatures allows us to control the influence of the location. Indeed, it should be recalled that the analysis uses regional temperature. Furthermore, time is control by taking inflation into account. The only assumption which is made is that households are rational and choose the best contract. In so doing, possible variations in prices are taken into consideration.

Endogeneity

One could raise some endogeneity concerns in the model. In particular, one could think that the causality link between environment policy preferences and energy consumption is valid in both senses. In particular, there could be a causality link from energy spending to environmental policy preferences. If it was the case, then our estimates would be biased and thus not reliable. However, in my opinion, this link is not obvious: I do not see any reason why people who spend more in energy should *consequently* be less (or more) environmental friendly, especially in such a reduced amount of time.

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2.4 Results

The equation (2.1) will be estimated in several ways. First, the equation is estimated pooling the data of the three waves. Then, we run the regressions separately for each year. Subsequently, we estimate the model using panel data analysis. Finally, we perform the same regressions, discriminating by type of central heating.

2.4.1 Pooled Regression

As already mentioned, three different waves are available in the BHPS in which there is the environmental policy preference variable. Table 3.1 exhibits the result of such a pooled regression (9967 observations), using robust OLS. One can notice that apart from the year of birth of the household reference person and time dummies, all the regressors are significantly -and in the right sense- correlated with the dependent variable. The temperature and the type of accommodation are negatively correlated: people living in hotter areas and living in flats or terraced houses spend less on heating. Clearly, households that pay a rent including some heating and lighting costs spend then less on heating. As we already said, the interpretation of the coefficients concerning the type of heating is hard to interpret since it controls for both prices and efficiency. However, this is not important: what is important is that the type of fuel is taken into consideration. Otherwise, one can see that all the other variables are significantly and positively correlated with the fuel bill. Indeed, households consume more energy as the number of children, the size of their accommodation, their income, and the number of appliances increase. Moreover, those renting accommodation spend more than those living in their own property. When one of the partners[7] stays at home, it increases significantly the level of household income spent on energy. More interestingly, environment policy preferences are *negatively* and *significantly*correlated with energy spendings at a 95% level. Indeed, households, the reference person of which declared that the government should give priority to the protection of the environment consume in average 2.4% less than other households.

[7]Or the only person the household is made up of in the case in which the number of a single person.

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These first results would confirm empirically the theoretical existence of a link between the environmental policy preferences of people and their energy consumption. The next step is to investigate the question by running separate regression to study better the evolution in time of the effectiveness of preferences.

2.4.2 Separate regressions by wave

From table 3.3, several conclusions can be drawn. First, we see that the model of energy consumption is rather stable and robust across the three different years considered (*i.e.* 1991, 1993, and 1995). Indeed, the results obtained are similar to the previous -in terms of sign and significance- as far as physical and socio-economic variables are concerned. However, environmental policy preferences do not exhibit the same significance across years. In the first wave, the latter, though negatively correlated, are not significantly correlated. The value of the t-statistic is equal to -0.74. Thus, the hypothesis according to which the coefficient α is equal to 0 for the first wave can *not* be rejected. As concerns the second wave, the environment political preferences turned out not be significant neither, though the t-statistic is equal to -1.34. The nullity of the coefficient α is accepted for the second wave too. Notice that the coefficient is negative. As far as the third wave is concerned, we do not accept anymore the nullity of α, since the t-test is equal to -2.44. We can interpret this result in the following way: the effectiveness of environmental policy preferences is growing over time. This might mean that time is necessary for people to translate their political preferences into actions. Assuming that the awareness of environmental concerns is growing over time, this effectiveness might become stronger and stronger over time. These results seem to confirm the existence of a correlation between environmental policy preferences and energy consumption.

One limitation of a pooled regression is that individuals observed in several years are not considered to be the same across these years. Therefore, some individual effect might not be taken into account. Consequently, the estimates might be biased and it is therefore necessary to turn to panel analysis.

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2.4.3 Panel Analysis

In order to take into account individual effects, we regress the same equation (2.1), using a GLS random-effect panel model estimation. It is first performed on the balanced panel, and then on the unbalanced panel. Equation (2.1) may be rewritten in the following way:

$$y_{i,t} = \beta x_{i,t} + \alpha env_{i,t} + u_{i,t} \tag{2.2}$$

Where:

- $y_{i,t}$ is the log of the fuel bill of individual i at year t
- $x_{i,t}$ is the set of socio-economic and physical variables of individual i at year t, plus time dummies
- $env_{i,t}$ is the political preferences of individual i at time t
- $u_{i,t}$ is $N(0, \sigma^2)$ distributed

The crucial assumption of the model considered is that the individual effect is random across years, *i.e.* $u_{i,t}$ is iid across time for a given individual. This is a standard assumption when one deals with individuals: it seems rather logical to consider that the idiosyncratic part of the heterogeneity among individuals is random rather than fixed over time. That is why we use a random-effect model random instead of a fixed-effect model. However, there could be some correlation between independent variables and residuals. We check this assumption by a Hausman'specification test.

Table 3.2 exhibits the results of the regression considered. One can see that apart from the year of birth, all our regressors are significant -most of them at a 1% level-, and correlated in the expected way. Interestingly, the coefficient α is significantly negatively correlated to the fuel bill, though at a 10% level. People declaring that the priority of the government should be to protect the environment spend 2.3% less than those who do not make the same declaration.

This panel analysis therefore allows the conclusion that environmenatal politicy preferences matter and explain some of the heterogeneity in energy consumption amongst households.

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It is an interesting result because the previous results still hold, having taken into account individual effects.

Considering the unbalanced panel, table 7 exhibits different results. As far as demographic variables are concerned, the results remain very much the same. However, one can see that a t-test on the environmental policy preference variable would reject its significance at a 10% level, but accept it at an 11% level. Using the unbalanced panel, we actually use all the information available (9967 observations) and in that respect results are more reliable.

This mitigates the results obtained when we pooled individuals: we can not clearly reject the negative effect of environmental preferences, yet neither are we able to conclude that the effect is clearly significant. However, this significance seems to grow over time. The same econometric analysis is performed in the following section, discriminating by type of central heating.

2.4.4 Separating by type of energy

One problem that could be raised with this type of analysis is that the type of energy does not play on the intercept term (as it does when using a dummy variable), but on the slope, and that therefore the model is structurally different. Therefore, it is worth performing the analysis differentiating observations by type of energy use.

We will focus on gas and electricity users, because they represent 8999 observations among 9967 (gas:7772 observations and electricity: 1227). The results are shown in tables 3.4 3.5. First, one can see that the general model is robust for the considered subsamples: the coefficients are roughly the same in terms of both significance and sign. Yet, there are some differences in magnitude. What is more important for us is the sign and the significance of the coefficient related to the variable accounting for environmental policy preferences. As concerns households that use gas to heat their accommodation, the environmental policy preferences are not significant, be they pool or panel regressions, even though once again the coefficients are negative. On the contrary, the environmental policy preferences do have a negative and significant effect on levels of energy spending. When undertaking pooled regression, the coefficient is significant at a 1% level, while it is significant at a 5% level when

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we perform a panel regression. This analysis may proceed a step further and try to regress separately by waves. This has been undertaken for both, but given the number of observations, separating for electricity users only permits the analysis of small subsamples (about 400 hundreds per wave)[8]. Therefore the following focuses upon gas users. As concerns the latter, one can see in the three last tables that the coefficients of the environmental policy preferences are always negative, though not significant. However, we observe the same trend as the one observed in the first regressions: the significance increases over time. As concerns the first wave, the t-stat is equal to $-.35$; in the second wave, it is equal to -0.55; in the last wave, it is equal to -1.61, *i.e.* almost significant at a 10% level. These latter results occur with the result of the first set fo analysis, where an increasing significance of environmental policy preferences was observed, yet they fail to confirm the existence of an empirical correlation between environmental policy preferences and energy consumption. Although the coefficient associated to the variable "env" is always negative, it is not significant.

To conclude, the empirical investigation undertaken here reveals no evidence of a robust relationship between environmental policy preferences and energy consumption.

2.5 Conclusion

Finally, it is important to highlight how the conclusion from this empirical investigation remains somehow ambiguous. On the one hand, the coefficient related to the environmental policy preferences is always negative. Moreover, there seems to be an increase of the effect over time. Finally, the effect is observed significantly at a general level (see first results). On the other hand, those results obtained when separating by wave and by type of energy, clearly mitigate the previous results. This robustness check rather suggests that this effect of environmental preferences can not be generalised: therefore, the model *not* including the

[8]Actually, performing these regressions turned out not to be satisfactory: some coefficients, because of their significance, their magnitude, or even their signs do not really make sense. Therefore no conclusion may be drawn from them.

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environmental policy preferences seems to be closer to the ”truth”. However, this empirical investigation deserves to be extended. Indeed, environmental values have spread a lot since the early nineties and the same kind of econometric analysis might reveal what we failed to reveal in that paper.

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Chapter 3

Income and Energy Consumption

3.1 Introduction

Although the existence of environmental KUZNETS curve has been subject to considerable empirical investigation, there is still no clear evidence that proves the existence of such a curve. According to the theory, one should observe a bell-shaped relationship between income and environmental damage at the aggregate level; however, this seems not to be observed empirically. At best, it is observed for some local pollutants. This means that either technological progress does not outweigh the growth human needs; or that the top of the bell has yet not been reached. We will in the next section give more details about Environmental KUZNET Curve theory.

Up to now, this existence has just been investigated at an aggregate (country) level, but it has never been investigated at the micro level (households). It seems interesting to investigate it at the individual level: indeed, if we do not observe it at the individual level, then one can seriously wonder how it is be supposed to be observed at the aggregate level.

Therefore the purpose of this chapter is to interpret Environmental KUZNETS Curve (henceforth EKC) theory at a disaggregated level and then to examine if empirical evidence supporting such a theory is available. Both income and energy consumption still increase at the

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aggregate level in rich west European countries[1]. In particular, domestic energy consumption increased by 19% in the UK, whereas the population increased by 4% from 1990 to 2004. Given this problematic it is necessary to explore what occurs at the individual level: does energy consumption just increase in relation to income or is there a threshold from which the latter stabilises, or -even better for the environment- decreases? The main argument is that there should be a threshold in our needs for heating, lighting and thus energy consuming. If this is true, then we should observe a threshold of energy consumption from which individual consumption stabilises. Furthermore, if technological progress has the effects it is supposed to have, then consumption actually decrease.

The chapter begins with a presentation of the EKC theory and the related empirical literature. Following this introduction it interprets it at the microeconomic level. Finally, using panel data from the British Households Panel Survey, the empirical relevance of this theory will be investigated.

3.2 Environmental Kuznets Curve Theory

3.2.1 Theoretical Foundations

This section will discuss the most important features of the Environmental Kuznets Curve (from now, EKC).

At first, Kuznets observed, at a country level, an inverted U-shaped relationship between the level of per capita income and the level of income inequalities (see Kuznets, 1955). In the early nineties the idea that this theory could be transposed to the level of income and environmental externalities emerged. (see Grossman and Krueger (1991) and Shafik and Bandyopadhyway (1992)).

The explanation of the observation of an inverse U-shaped relationship relates ot the following. For low levels of income, consequences of human activities are limited because the economy is based on subsistence production. Indeed, the only need to be satisfied is mainly

[1]Their total energy consumption has increased by 8% between 1992 and 1999. Refer to the report of the European Environment Agency, 2003

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to feed oneself. Therefore, the level of externality is low. Subsequently as agriculture and industry develop, natural resources extraction and pollutants rejection together increase the pressure on the environment. Switching from fruit gathering to agriculture enhances a clear resource depletion. Then, the massive use of chemicals clearly contributes to reject and spread pollutants in the soil, underground water and the atmosphere. Development of industry obviously entails the depletion of resources and above all the generation of pollutants. That is why the level of environmental externality increases in line with increases in income. However, as a population becomes richer, it can sacrifice an increasing part of its capital to develop clean technologies and as a result obtains gains from technological progress. It is for this reason that the level of externality still increases, but does so at a lower pace. Eventually, the invested capital results in a degree of technological progress such that the society affected is able to increase its income, and reduce the level of externality. That is why the curve is eventually down-sloped.

To understand better the effects at stake, we will describe them in the next section.

Effects at Stake

There are three main effects on the production process that are of particular importance. Firstly, there is a **scale effect**: *ceteris paribus* the larger the production, the higher the consumption of raw materials, natural and energetic resources, but also the higher the pollution. In other words, for a given good, any increase in production will *mechanically* result in an increase in the consumption of the resources that are needed to produce it. Moreover, if a given number n of produced units generated a level l of pollutant, a number $n' > n$ of produced unit will generate a level $l' > l$ of pollutants. The scale effect is clear: it is positive on the externality.

Secondly, there is a **composition effect**, namely the fact that the shares of different sectors evolve. To understand the extent of this effect, it is only necessary to take into consideration the differences between developed countries and third-world countries concerning the share of agriculture in their respective GDP. In other words, as they grow, economies switch from

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agriculture, to industry and eventually to services. Yet, the sense of this composition effect is ambiguous: even if an economy produces *relatively* less agricultural goods, it does not mean that it produces less agricultural goods in *absolute terms*.

Last but not least, there is a **technological progress effect**: as a country becomes richer, it can invest more in R&D, in particular to develop clean technologies. This is an effect that is -*ceteris paribus*- clearly negative with respect to the level of externality. Clearly, we are not considering any new technology, but only the ones that enhance decreases in environmental damage. Indeed, **for a given production**, if we find a new process that saves on energy, or reduces CO_2 emissions, the externality decreases and so does the pressure on the environment.

Therefore, if the inverted U-shaped relationship between income and pollution exists, the latter effect must outweigh the first one, or the two first ones if the second is also positive with respect to the level of externality. This summarises the core of the EKC theory: from a given threshold of income (*i.e.* the top of the bell), technological progress will allow us to produce increasingly more, though destroying the environment increasingly less. In front of such a prediction[2], many attempts have been performed to confirm it or contest it. That is what we will see in the next section.

3.2.2 Empirical Evidence

In the empirical literature, results do not seem to be consistent with the existence of a EKC. One has to recall that the externality considered by EKC theory is a **global** index that measures the **total** amount of environmental externality. The main conclusion that one can draw from the empirical literature is that some evidence supporting the EKC has been provided, but only for some local pollutants. In Grossman and Krueger, 1994, the authors estimated the EKC for different types of pollutants. They used data of the GEMS[3] and of

[2]Going further reasoning that way leads to an absurd result: either we would be able to produce an infinite amount of goods with a finite amount of resources; or we would be able to produce a finite amount of goods from nothing...

[3]Global Environmental Monitoring System

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SUMMERS AND HESTON (1991) for income which provided them with information on about 50 countries over a period of approximately 10 years. It is important to remember that as this project was interested in some pollutants, it did not really test for the complete existence of an ECK, but rather had the more limited empirical goal of simply testing whether a bell-shaped relationship between the level of *one* given pollutant and per-capita income exists. They regress several indexes which represent levels of a given environmental externality (on both water and air) on a set of variables, among which income, its square and its cube (to have some flexibility in the estimation of the relationship). The coefficient of interest is the one associated to the squared income: finding a negative and significant coefficient is a condition to have a bell-shaped relationship between income and environmental externality. It worked for SO_2. The only conclusion that can be drawn from this work is that for some pollutants, the relationship between income and the quantity of the pollutant is bell-shaped, but in no way that the *global* pressure on the environment decreases. Moreover, their results have been contested by HARBAUG AND AL. (2000). They used an upgraded version (10 years more and 3 more countries) of the same database and did not find the same results: the bell-shaped relationship between income and level of SO_2 in the air is not observed anymore. Using data from 30 countries over 10 years from the World Resources Institute, SELDEN AND SONG (1994) obtained some similar results to those of GROSSMAN AND KRUEGER for some specific air pollutants. SHAFIK AND BANDYOPDHYAY (1992) found the same kind of results for SO_2 on a sample of 149 countries for the period 1960-1990, but not as concerned the CO_2 and municipal waste: they both increase with respect to the level of income. DE BRUYN AND AL. (1998) even found only increasing monotone relationships between income and some pollutants, and the composition of the sample is of crucial importance (see STERN AND COMMON, 2001). GRIMES AND ROBERTS found some empirical evidence that the divergence between developing countries and industrialized countries explains more the shape of the curve than a "Kuznets effect".

Otherwise, MAGNANI (2000) shows that the *intra*-national income distribution matters: when there are inequalities, the gap between the willingness-to-pay and the actual possibility to pay might enhance a decrease in R&D spending. STERN(2003) shows that developing

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countries address some environmental issues, and sometimes perform even better than richer countries. Clearly, this does not confirm the existence of an EKC.

In the end, the main conclusion that can be drawn from this empirical literature is that there is no clear empirical evidence which conclusively supports the existence of a EKC. However, desptite their differences what all of these empirical studies share in common is there focus upon the aggregated level. In the next section of this chapter the focus is upon the individual level.

3.3 Microeconomic Interpretation of EKC Theory

In this section, we will first reinterpret the ECK at a microeconomic level and then look at the ways to test its empirical relevance.

3.3.1 Theoretical Arguments

Why reinterpreting Kuznets'theory at the individual level?

At the origin of the paper and the reformulation of the EKC theory is the fact that the latter is a macroeconomic theory and that it does not take into account the possible importance of individual behaviours. This is the problem raised by any analysis based on aggregation. One considers countries that have completely different cultures, economic systems: the main criterion of heterogeneity being the per-capita income. It is likely to be an important limitation, and might be the reason for the absence of an empirically observable ECK. Moreover, the timing in the ECK theory is vague: we do not know when the society -or country- will achieve the top of the bell and then the virtuous path of "sustainable growth", if it exists[4]. This is a problem because the theory can never really be tested empirically. Indeed, one can always say that we do not observe it because no country has yet passed over the top of the bell.

On the contrary, the notion of time is different at the individual level: time is much shorter.

[4]Indeed, can something grow endlessly in a finite physical world? See Georgescu, 1971

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Indeed, we need to observe people for a couple of years to gather information upon all the effects which are at stake. This is particularly relevant as far as the technological progress is concerned. Moreover, understanding the specificities of a given good might allow us to draw conclusions in terms of economic policy. This motivation is really important if one looks at the consumption of energy in the UK since the 70's: it has just been increasing, which raises some obvious political and in particular environmental issues. As already mentioned, energy consumption accounts for a large part (about 30%) of the global footprint (mainly because we use fossil fuels) and if we look at its evolution, one can see that it just increases over time. In particular, the energy consumption for domestic needs[5]in the UK increased by between 1970 and 2000. Even though British people exerted a massive effort to improve insulation, it has not prevented people from consuming more energy. The report of the DTI "Energy Consumption in the UK"(2000) explains this increase by referring among other to the profusion of electric appliances. This would go in the sense of the existence of a growing path in energy consumption. Thus, we want to know what happens at the individual level. The chapter now turns to present and describe the microeconomic interpretation of the ECK theory.

Microeconomic effects

We will describe the already mentioned three effects at stake and reinterpret it at the microeconomic level.

- The scale-effect

  The basic idea is that as households become richer, their energy consumption increases *ceteris paribus*. Indeed, becoming richer allows people to consume more and so do they. In particular, they can heat more and thus consume more energy. They can also have better lighting and more domestic appliances. They can finally have a larger accommodation. This effect is clearly positive *vis-à-vis* energy consumption.

[5]Heating, lighting, cooking, etc...

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- The composition-effect

  As people get richer, there is a transformation of the bundle of goods they purchase: the share of necessary goods is growing smaller and smaller because they will consume an increasing number of comfort and superfluous goods. As far as energy consumption is concerned, necessary goods would be lighting and heating (both air and water). Superfluous goods can be any type of appliances that possibly makes life more comfortable and that uses energy. A tumble dryer is a classical example. It is noteworthy that this effect is not as ambiguous as in the aggregated case: the bundle of energy-consuming goods seems to transform because other goods are added in the bundle rather than because of substitutions. Thus, this effect is somehow related to the scale-effect and should go in the same sense.

- The Technological progress effect

  As they get richer, households become increasingly more able to buy environmental-friendly goods which are usually more expensive. For example, they can buy less polluting cars, or organic food. More interestingly for our purpose, they can insulate better (*e.g.* double-gazing) their house and as a consequence they should consume less energy. They can simply invest and install heating systems that consume less energy, or even better, that use renewable energy. Insulating better and having more efficient system of heating will make households consume less energy.

Having described the effects, the question to be answered now is the following: does the technological progress effect outweigh the first two effects? If the answer is yes, then we should observe a bell-shaped relationship between the level of income and the level of energy consumption. If we do not observe it, then the answer is no. Intuitively, there might be a threshold from which one does not want to heat more and owes any possible appliance. What we want to know is whether such a threshold exists, and if the consumption of energy then decreases thanks to technological progress.

Having described both the motivations and the arguments of a reinterpretation of Kuznets' theory at the microeconomic level, we will now explain how we will proceed to test its

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empirical relevance.

3.3.2 Testing its existence

Concerning energy consumption and its relationship with respect to the income, there are three possible scenarios: it can first increase, then reach a maximum and finally decrease; alternatively, it can first increase, then reach a maximum and stabilises; or the final alternative, it may just increase.

Clearly, the scenario consistent with the above theoretical arguments is the first one. We will first estimate the energy consumption of households, controlling for a broad range of physical and socio-economic variables. In particular, we include income among the set of regressors , but also its square and eventually its cube to give more flexibility to the functional form. Several conditions are required to conclude that there actually exits a bell-shaped relationship between income and energy consumption. The first condition is to have a coefficient of the square of income that is negative and significant. The second condition is that which occurs when the level of income from which the energy consumption decreases makes sense, *i.e.* the mass of people being richer than that level of income should represent a substantial part of the sample. If not, then we will have to find another functional form of the relationship between income and energy consumption.

3.3.3 Data

The data used for the following analysis is drawn from the British Household Panel Survey. It uses 8 waves, namely from wave 7 to wave 14[6]. As seen in the previous chapter, this survey is conducted yearly and gather information about social and economic variables. The data we use concern about 2,500 households observed during 8 years. Concerning price indexes, the dataset used the Retail Price Index of the Office of National Statistics. Note that we have used one index for income and a different index for energy spending. Finally, it should be noted that the average annual growth rate has been computed since we have had

[6]From 1997 to 2004

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prices indexes of 1990, 2000 and 2004. From the Weatherbase data set, the regional average monthly temperatures have been used. Additionally, the standard-error of these monthly temperatures has been computde for each region.

3.3.4 Variables

In this section, a set of variables that we have to take into account in order to explain the heterogeneity in energy consumption is defined. Energy consumption is the measure of a household's footprint. The underlying idea is that, taking into account a broad range of demographic variables, the higher the energy consumption of households, the less environmentally friendly they are. Implicitly, we assume that energy consumption enhances environmental externality. We will regress the energy spendings of households on a set of socio-economic and physical variables and then estimate the relationship between income and energy consumption. We have taken into account a set of demographic, socio-economic variables , and also some physical variables in order to comply as much as possible with the theoretical determinants of energy consumption found for example in REDHANZ (2005) or see also BAKER AND BLUNDELL (1989). We will describe them now.

Physical variables

The physical variables we use are the following ones:

- Temperatures

  I have used the regional monthly average and its standard-error[7]. For each household, we have the regional average temperature, and also the standard-error of the monthly temperatures. It is clearly expected that the coefficient associated with the first should be negative, and that of the second should be positive. Clearly, if the temperature is too high, the relationship is inverted because of the possible use of air-conditioning.

[7]The information relative to the temperatures was found in http: www.weatherbase.com

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This is one limitation of the analysis; however, given the location of the UK, this bias might not be that important.

- Type of Accommodation

  People living in flat or terraced house are expected to heat less, thus the coefficient of this regressor should be negative. Our variable is equal to 1 if people live in a terrace house or a flat.

- Type of Central Heating

  We construct dummy variables for each type of fuel (*e.g.* "gas" is equal to 1 if the household uses gas to heat its accommodation). Since this variable captures both differences in prices among fuels and differences in efficiency among type of central heating, signs of coefficients are ambiguous.

Socio-economic variables

As concerns the socio-economic variables, the following variables have been taken into account:

- Income

  This is the core of the chapter. Both the income and its square, but then also its cube will be used as regressors. In an alternative specification, we will use the *log* of the income.

- Number of Children

  Clearly, as this number increases, the fuel bill is expected to grow.

- Employment Status

  We know whether the reference person (and its possible partner) is employed (*i.e.* does not stay at home) or is a pensioner, unemployed or self-employed (and thus spend more time at more). Our variable is a dummy equal to one if at least one of the partners is not employed. We expect the sign of the coefficient associated to it to be positive.

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- Renter vs Owner

  Our variable is a dummy equal to 1 if the household does not rent its accommodation. As renters might be less willing to invest in better insulation or system of heating and landlords also may no invest in properties they view just as sources of rent income, this might bias upwards the renters' fuel bill.

- Rent includes some heating or lighting spendings

  Concerning renters, whether or not some heating bills are included in the rent is a crucial variable, since it controls for the ”hidden part” of the fuel consumption. This is still a dummy equal to 1 if the rent includes some spending on heating.

- Environmental preferences

  As the effect is not clear (see previous chapter), the environmental policy preferences are taken into account. The same variables are used as in the previous chapter. However, as the information is not available for the waves we use here, we have taken the answer given at the third wave of the second chapter. Implicitly, we assume that preferences have not changed over time.

The Issue of Prices

Prices in general can vary in several dimensions: first, prices vary in location; secondly, prices vary in time; thirdly, in the case of energy consumption, prices vary by type of energy; finally, prices can vary by type of contract.

It has already been shown that the type of energy ahs been controlled. Moreover, taking into account temperatures allows us to control for the location. Indeed, recall that we use regional temperature. Furthermore, we control for time by taking into account inflation. The only thing we have to assume is that households are rational and choose the best contract. In so doing, we control for variations in prices.

Notice that according to Hotelling theory on exhaustible resources (see Hotelling, 1935), prices of energy are expected to grow exponentially. According to that theory, not taking

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into account this "depletion" effect on prices will lead us to *overestimate* energy consumption. However, this hidden increase is price is not observable and therefore it is quite a difficult issue to settle. We are clearly aware that this might be a limitation of the robustness of our results.

3.3.5 Model to be estimated

The dependent variable in our model is household energy spending. This variable takes into account the expenditure of all types of energy for the house (*i.e.* heating, lighting and domestic appliances using). Clearly, this is only one dimension of the total footprint of a household. Ideally, we would like to have information on all types of consumption and emissions. However, as already mentioned, energy accounts for a large part of one's ecological footprint. Energy spending is therefore a good proxy for the household's ecological footprint. The underlying idea of this analysis is that, taking into account economic and physical variables, a household that uses more energy costs more in environmental terms.
Using GLS random-effect estimator, we will estimate the following equation:

$$y_{i,t} = \beta x_{i,t} + \alpha_1 inc_{i,t} + \alpha_2 inc^2_{i,t} + u_{i,t} \tag{3.1}$$

Where:

- $y_{i,t}$ is energy spendings of household i at time t, in pounds
- $x_{i,t}$ is the set of socio-economic and physical variables of household i at time t, plus yearly time dummies
- $inc_{i,t}$ is the annual income of household i at time t, in pounds
- $inc^2_{i,t}$ is the squared annual income of household i at time t, in pounds
- u_i is $N(0, \sigma^2)$ distributed

Issue of Endogeneity As mentioned in the second chapter, one could raise some concerns due to the possible endogeneity problem. In particular, one could say that income and

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energy consumption are somehow jointly determined. Think for example of people having more children: they will want to earn more and consume more energy. If that is true, the consequences for our estimations would be dramatic as we know that estimates would be biased. Yet, two objections can be made to respond to such a possible objection.

Firstly, I think that a causality relationship between income and energy consumption is likely to be one sense directed: in our case, income determines consumption. A converse relationship, *i.e.* energy determines income does not seem to exist to me. I believe that -at least in a short run- people consume more because they have more income, rather than people get more money because they want to consume more energy, although this could be true within a couple of years. Secondly, we use a random individual effect panel model and we know that it is the best estimator if there is no correlation between residuals and regressors. If not, estimates are not consistent and within estimator obtained using a fixed effect panel model is to be used instead of the former one. Thanks to the Hausman specification test, we are able to know which model we should choose. In our case, we will see that the test will allow us to accept H_0, *i.e.* as there is no correlation between residuals and regressors.

3.4 Relationship between income and energy spendings

We first have run 4 panel regressions: two including the income and its square (see tables 8 and 9 in appendix 3: Panel I does not include environmental policy preferences, whereas Panel II does); two others including both of the latter and the cube income(Panel III does not include environmental policy preferences, whereas Panel IV does). This has been performed in order to give more flexibility to the relationship we wanted to determine and therefore more robustness to the results. After having estimated the two models, we have determined the estimated value of income for which the energy spending is maximum.

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Estimated Model Having a look at the tables of results (see annex 3), one can first see that the model of energy consumption used is a good one. First, a HAUSMAN specification test confirms the choice of random effects rather fixed-effect model[8]. Moreover, there is no nonsensical sign for any coefficient, and most of them (apart from "norent") are highly significant. In addition, this is true taking or not environmental preferences into account (which turned out to be significantly and negatively linked to the energy consumption[9]). It is noteworthy that when we include the cube income, both coefficients related to the square income and cube income turned out not to be significant, regardless of whether the environmental preferences are taken into account. The first conclusion is therefore that the first functional form is better(when we do *not* include the cube income) than the second one (when we do include it).

Relationship Income-Energy Consumption First of all, one can see that for all regressions, the coefficient of the square income is negative and significant at a 1% level.
We will focus on the first specification since it turned out to be a better one. When we do not take into account the environmental preferences, the estimated model is (panel I):

$$\hat{y_{i,t}} = \hat{\beta}x_{i,t} + .0022781 * inc_{i,t} - 5.17 * 10^{-9} * inc_{i,t}^2 \tag{3.2}$$

Therefore, the marginal effect of income on energy spendings is:

$$\frac{\partial y}{\partial inc} = .0022781 - 2 * 5.17 * 10^{-9} * inc \tag{3.3}$$

Equalising it to 0 gives us the value of the level income -denoted t_1- from which energy spending decreases: $t_1 = 220,319$ pounds. The number of observations above this value represents about 0.061% of the total number of observations. When we include the environmental policy preferences, the result is pretty much the same given that the threshold t_2 we obtain is: $t_2 = 220,532$. At that point, it would be tempting not to accept the existence of EKC; however, we should go one step further given the small number of observations we

[8]The statistic is equal to 0.28, which is far below $\chi^2_{(21)}$ at a 5% level (equal to 41.40)

[9]This would go in the sense of the time effect, suggesting consequently that people need time to translate preferences into actions.

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have above the thresholds and therefore the huge uncertainty concerning any inference.
What we will do now is to try another functional form and see if the confidence intervals are smaller, *i.e.* estimation is better.
Instead of specification (1), we will try the following one:

$$y_{i,t} = \beta x_{i,t} + \alpha_1 log(inc_{i,t}) + u_{i,t} \tag{3.4}$$

Where:

- $y_{i,t}$ is energy spending of household i at time t, in pounds
- $x_{i,t}$ is the set of socio-economic and physical variables of household i at time t, plus yearly time dummies
- $inc_{i,t}$ is the annual income of household i at time t, in pounds
- u_i is $N(0, \sigma^2)$ distributed

One can observe the implications of such a change in specification: we assume that energy spending *monotonically* increases with respect to income. The results of the estimated model are given in table 9 (Panel V *not* including environmental preferences and Panel VI including them). One can see that all the coefficients are significant (apart from "norent") and with the right sign. Both models seem rather good and what we can do now is to look at the confidence intervals of the relationship between income and energy spendings in the latter case and in the case where income and its square is considered. Figure 1 shows the estimated values of energy spending and the .95 confidence interval: fs is the estimated energy spending with the quadratic functional form ($fsinf$ and $fssup$ are the bounds of the confidence interval); fl is the estimated energy spending with the logarithmic functional form ($flinf$ and $flsup$ are the bounds of the confidence interval).

Figure 3

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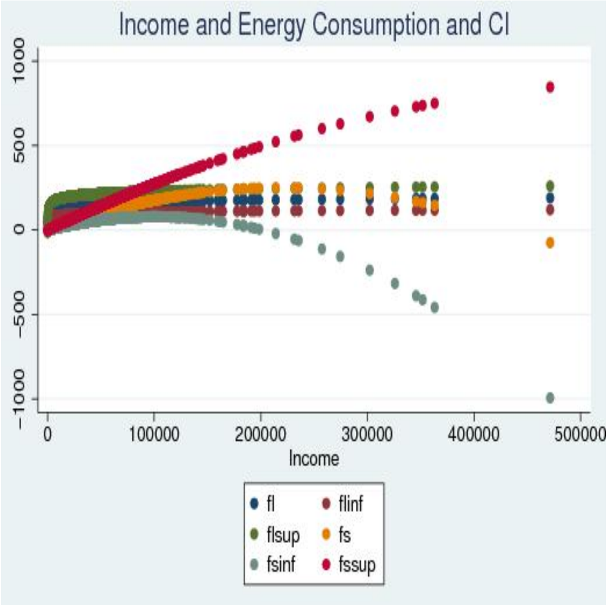

Clearly, the second specification is more precise than the first one. This evidence would rather *contest* the ECK theory. To conclude, a monotone increasing relationship between income and energy spending seems to exist, rather than an inverted U-shaped relationship.

Last but not least, we have considered a good -*i.e. energy*- households pay a part of the externality for. Indeed, they might want to decrease their energy consumption for economic reasons among others. Moreover, we have taken into account the size of the accommodation, which could have also been considered as part of the scale effect. Thus, this was in a way the most favourable case which could be found to look at the existence of EKC. Therefore, one can be pessimistic concerning goods for which people do not pay any part of the externality they create. However, the growing use of green energy might mitigate this result since it *might* decrease the environmental impact of energy use.

If our results reject the existence of a bell-shaped relationship between income and energy consumption, then there are two possible scenarios left: either the energy consumption just increases with the level of income, the technological effect not outweighing the scale scale-effect; alternatively, energy consumption stabilises after a certain threshold. If the latter assertion is true, then we should not observe a big gap between energy consumption growth

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and population growth. However, since 1990, domestic energy consumption in the UK has increased by 19%, whereas the population increase has been at 4% over the same period. This suggests that the individual consumption increased, and that the former scenario is more probable. This deserves to be investigated in order to better understand the relationship between technological progress and energy consumption.

Measuring Technology Effect

We will try a last specification to understand better the possible time effect at stake. To do so, we will include in our set of regressors the average yearly income, and substitute time dummies by a time trend. The coefficients associated to these two variables will tell us more about the pure income effect on the one hand; any time effect (like technology or preferences changes) on the other hand. We will perform this estimation for both the model with the income and its square, and then using the log of income. The results are shown in table A.10. We notice that, for both models, the conclusion is the same: the coefficient associated to the income effect, though negative, is not significant even at a 10% level. Interestingly, this would suggest that there is no income effect in time. Relating these results to the previous ones, we can say that income matters for a given year rather than between years: for a given year rich people consume more energy than poor people. However, when household gets richer, they do not necessarily consume more controlling for all the other variables.
The second conclusion that can be drawn is that there seems to be a downwards time trend: as time runs out, households consume less energy. Indeed, the coefficient in front of the variable time trend is negative and significant. Recall that this time trend measures the effect of changes in time, controlling for all the other variables. The fact that the coefficient associated to that variable is negative could be due to the existence of technological effect. Interestingly, this goes in the sense of the previous results. Indeed, we see that, after having controlled for all the variables, an effect of time on consumption exists. However, we know that consumption has not decreased in the mean time. This means that the possible technological effect discussed previously is likely not to outweigh the scale effect. As a consequence, this second result goes as well as the first clearly against the existence of an

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EKC at the microeconomic level.

3.5 Conclusion

This chapter has investigated, we have investigated the existence of an EKC at the microeconomic level. To sum up, it began by posing the question whether possible technological progress outweighed the scale effect, *i.e.* the fact that richer households consume more energy than less rich ones. Using data from the British Household Panel Survey, it has estimated the relationship between income and energy consumption using panel data techniques. Two results emerged from that investigation. Firstly, the relationship between income and consumption seems not to be bell-shaped. Secondly, we identify a possible technology effect, that, even if it exists, is not strong enough to make energy consumption decrease with time. These two results rather contest the existence of an EKC at the microeconomic level.

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Conclusion

This thesis has centred on the interactions between economic agents and environment. The main reason for having conducted a research related to these issues is the concern raised by the increasingly evidence of the pressure exerted by humans on the planet. The latter seems increasingly smaller and fragile, and I feel as I could not have conducted research not related to environmental issues. The reason is that, as already mentioned in the general introduction, economists deal with scarce resources issues and resources drawn from Earth are becoming increasingly scarce. obvious examples includes high quality air or water, or edible food. I mean that economic issues are *necessarily* related to an environment we draw *everything* from.

First, the thesis has emphasized the possible conflict of interest at stake between competition and environmental policy. This particularly true in highly polluting oligopolistic industries. In such industries, it has been shown that competition objectives and environmental objectives are antagonist. Notice at that point that it seems relevant to study the circumstances under which competition is actually good for the environment. On the one hand, competition leads to greater global production. On the other hand, it might stimulate more environmental-friendly products.

The second chapter has investigated the empirical link between environmental policy preferences and actions. However, it failed to find a clear (expected) negative link between those preferences and people's actions. In other words, people declaring to be in favour of the protection of environment do not *significantly* consume less energy for domestic use. Nevertheless, preferences are likely to change over time. This might be particularly true as concerns environmental issues as humans will increasingly pay for the consequences of our

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behaviour.

Finally, we have investigated the relationship between income and energy consumption in order to confirm or contest the existence of an ECK at a microeconomic level. The results suggest that such an ECK does not exist. In my opinion, this result is not to be taken for granted, but rather gives us a piece of the answer to a thrilling question: does technological progress actually enhance less environmental damage?

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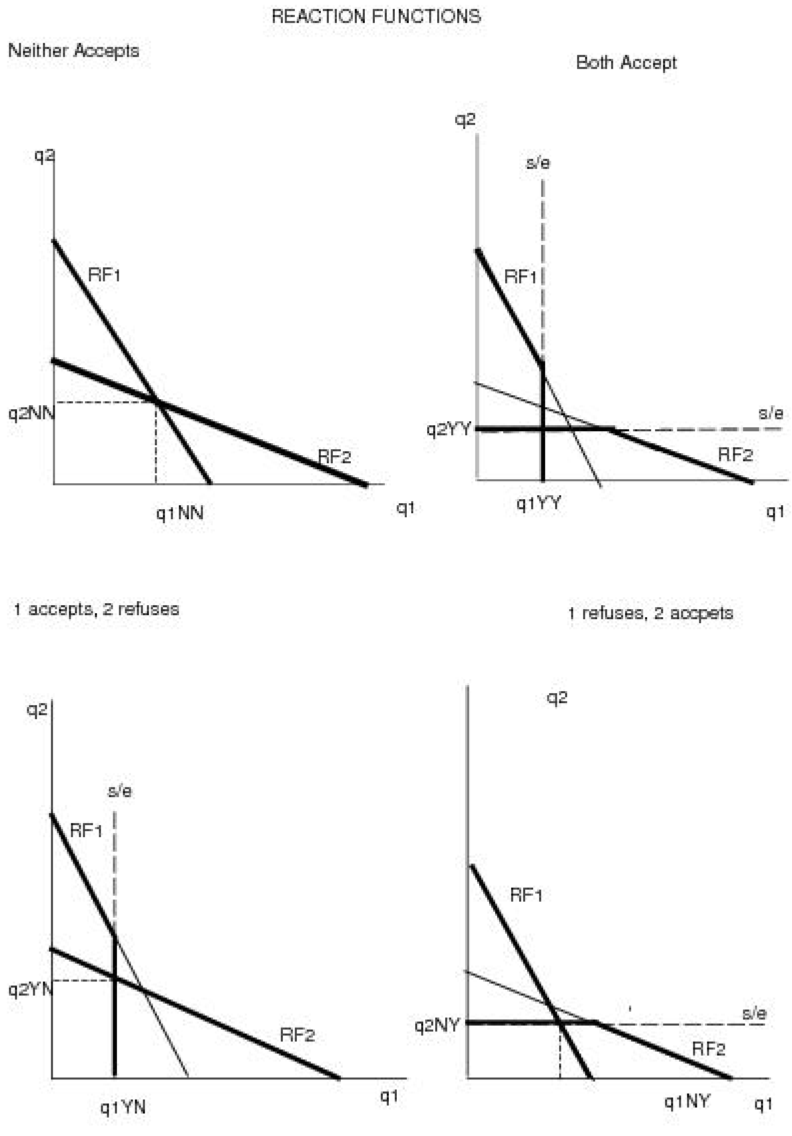
Appendix

.1 Appendix 1



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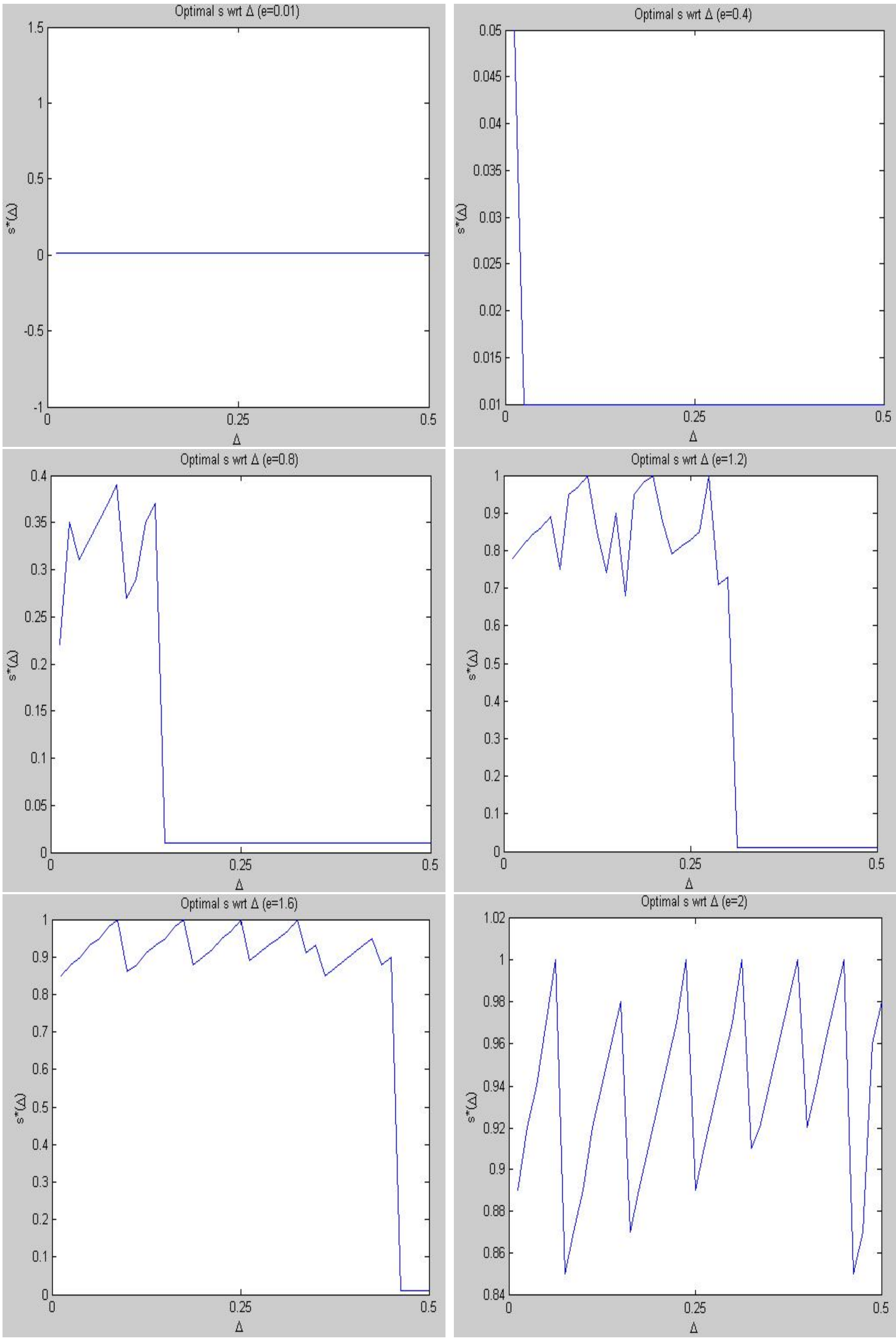
.2 Appendix 1-bis



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.3 Appendix 2-Results of Chapter 2

Table 1: Variables

Variable	definition
y	dependent variable: log of monthly energy spendings
timea	equal to 1 if observed in the first wave
timec	equal to 1 if observed in the third wave
env	equal to 1 if people answers ”3” to question (A)
hgby	year of birth of reference person
alo	equal to 1 if at least one people (ref. pers. or his partner) is not employee
hsroom	number of rooms in accommodation
nkids	number of children
linc	log of annual income
dd	regional monthly average temperature
terf	equal to one if accomodation is a flat or a terraced-house
elec	equal to one if household uses electricity to heat
solid	equal to one if household uses solid fuel to heat
oil	equal to one if household uses oil to heat
nap	number of domestic appliances
renter	equal to one if household rents
bilin	equal to one if some spendings are included in rent

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Table 2: Pool and Panel Regressions

Variable	Pool	Bal.Panel	Unb.Panel
timea	-0.016	-0.046**	-0.038**
timec	-0.012	-0.019**	-0.026**
env	-0.024*	-0.023†	-0.015
hgby	-0.001	0.001	-0.001
alo	0.085**	0.057**	0.058**
hsroom	0.080**	0.062**	0.077**
nkids	0.086**	0.066**	0.087**
linc	0.059**	0.053**	0.042**
dd	-0.006**	-0.002**	-0.004**
terf	-0.016	-0.028†	-0.022†
elec	-0.154**	-0.144**	-0.155**
solid	-0.457**	-0.445**	-0.466**
oil	0.142**	0.137**	0.162**
nap	0.070**	0.059**	0.062**
renter	0.132**	0.070**	0.089**
bilin	-0.175**	-0.127*	-0.124**
Intercept	3.992**	1.210	3.873**
N	9967	5700	9967
R^2	0.3	.	.
$F_{(16,9950)}$	241.861	.	.
$\chi^2_{(17)}$	.	248695.198	2635.502

Significance levels : † : 10% * : 5% ** : 1%

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Table 3: Separate Regressions

Variable	**Wave A**	**Wave B**	**Wave C**
env	-0.011	-0.024	-0.042*
hgby	0.000	-0.001†	-0.001
alo	0.106**	0.070**	0.080**
hsroom	0.097**	0.078**	0.066**
nkids	0.075**	0.076**	0.105**
linc	0.050**	0.057**	0.074**
dd	-0.003†	-0.008**	-0.007**
terf	-0.008	0.005	-0.039†
elec	-0.160**	-0.140**	-0.163**
solid	-0.522**	-0.412**	-0.394**
oil	0.135**	0.171**	0.123**
nap	0.065**	0.068**	0.071**
renter	0.122**	0.133**	0.145**
bilin	-0.243**	-0.176	-0.125*
Intercept	2.068	5.364**	4.520**
N	3409	3213	3345
R^2	0.331	0.286	0.277
$F_{(14,3394)}$	111.772	80.431	82.512

Significance levels : $\dagger$: 10% $*$: 5% $**$: 1%

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Table 4: Gas Pool and Panel

Variable	**Pool**	**Panel**
timea	-0.014	-0.040**
timec	-0.022†	-0.036**
env	-0.010	-0.001
hgby	-0.001*	-0.001
alo	0.078**	0.049**
hsroom	0.077**	0.072**
nkids	0.088**	O.089**
linc	0.064**	0.046**
dd	-0.006**	-0.003**
terf	-0.008	-0.015
elec	0.000	.
solid	0.000	.
oil	0.000	.
nap	0.068**	0.059**
renter	0.146**	0.100**
bilin	-0.090†	-0.078
Intercept	4.559**	4.542**
N	7772	7772
R^2	0.235	.
$F_{(13,7758)}$	171.057	.
$\chi^2_{(13)}$	.	1419.187

Significance levels : $\dagger$: 10% $*$: 5% $**$: 1%

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Table 5: Electricity

Variable	**Pool**	**Panel**
timea	0.003	-0.013
timec	0.025	0.011
env	-0.084**	-0.067*
hgby	0.001	0.001
alo	0.120*	0.103*
hsroom	0.116**	0.121**
nkids	0.117**	0.118**
linc	0.061*	0.049†
dd	-0.011**	-0.008*
terf	-0.047	-0.043
elec	0.000	.
solid	0.000	.
oil	0.000	.
nap	0.077**	0.072**
renter	0.119**	0.106**
bilin	-0.297**	-0.272**
Intercept	1.586	1.237
N	1227	1227
R^2	0.264	.
$F_{(13,1213)}$	36.417	.
$\chi^2_{(13)}$	.	374.97

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

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Table 6: Gas-Separate regressions

Variable	**Wave A**	**Wave B**	**Wave C**
timea	.	.	.
timec	.	.	.
env	0.006	-0.010	-0.029
hgby	0.000	-0.001†	-0.001
alo	0.116**	0.066**	0.058*
hsroom	0.092**	0.081**	0.062**
nkids	0.077**	0.079**	0.106**
linc	0.054**	0.060**	0.078**
dd	-0.005*	-0.006**	-0.006**
terf	0.004	0.009	-0.034
elec	.	.	.
solid	.	.	.
oil	.	.	.
nap	0.068**	0.071**	0.067**
renter	0.137**	0.150**	0.154**
bilin	-0.147	0.059	-0.092
Intercept	3.063*	5.516**	4.799**
N	2572	2522	2678
R^2	0.245	0.228	0.227
$F_{(11,2560)}$	71.581	61.933	67.295

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

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.4 Appendix 3: Results of Chapter 3

Table 7: Variables

Variable	definition
y	dependent variable: energy spendings, in pounds
time(i)	equal to 1 if observed in the wave i
env	equal to 1 if people answers ”3” to question (A) in wave 5
alo	equal to 1 if at least one people (ref. pers. or his partner) is not employee
hsroom	number of rooms in accommodation
nkids	number of children
inc	annual income, in pounds
inc2	square of inc
inc3	cube of inc
ndesi	number of days of energy spendings
dd	regional monthly average temperature
dds	standard-error of monthly temperatures
terf	equal to one if accomodation is a flat or a terraced-house
elec	equal to one if household uses electricity to heat
solid	equal to one if household uses solid fuel to heat
oil	equal to one if household uses oil to heat
norenter	equal to one if household rents
bilin	equal to one if some spendings are included in rent

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Table 8: Results

Variable	Panel I	Panel II	Panel III
inc	0.00228^{**}	0.00232^{**}	0.00326^{**}
inc2	$-5.17*10^{-9**}$	$-5.26*10^{-9**}$	$-1.60*10^{-9*}$
inc3	-	-	$2.04*10^{-14}$
linc	-	-	-
ddm	-3.37723^{**}	-3.34723^{**}	-3.37138^{**}
dds	15.86226^{*}	15.96179^{*}	16.05030^{*}
norent	1.39467	2.90201	-0.92909
alo	$10.63870^{\dagger}$	$10.88424^{\dagger}$	$9.85600^{\dagger}$
nkids	40.82555^{**}	41.30856^{**}	40.34521^{**}
ndesi	0.23600^{*}	0.23738^{*}	0.22729^{*}
hsroom	43.73784^{**}	43.98467^{**}	43.67492^{**}
terhouse	-33.21205^{**}	-33.65999^{**}	43.67492^{**}
flat	-60.62268^{**}	-60.20153^{**}	-59.88548^{**}
gas	-19.77673	-20.35813	-19.66795
elec	7.60892	7.20818	8.17547
solid	113.06763^{**}	112.67397^{**}	113.94897^{**}
oil	173.25757^{**}	173.85525^{**}	173.91641^{**}
bilin	-34.12828^{*}	-33.41217^{*}	-34.58742^{*}
env	-	-22.85772^{*}	-
tim1	50.70236^{**}	50.73485^{**}	49.58997^{**}
tim2	$11.24429^{\dagger}$	11.26331	$10.72188^{\dagger}$
tim3	-7.68706	-7.83136	-6.89089
tim5	-3.34263	-3.34698	-2.55506
tim6	-10.05157	-9.94465	-7.72339
tim7	-11.91419^{*}	-11.91315	$-9.88056^{\dagger}$
tim8	6.14706	6.19610	9.11544
Intercept	316.59986^{**}	320.45260^{**}	306.59396^{**}
N	16497	16497	16497
$\chi^2_{(k)}$	871.20648	877.7599	911.66564

Significance levels : $\dagger$: 10% $*$: 5% $**$: 1%

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Table 9: Results

Variable	**Panel IV**	**Panel V**	**Panel VI**
inc	0.00333^{**}	-	-
inc2	$-1.63*10^{-9*}$	-	-
inc3	$2.09*10^{-14}$	-	-
linc	-	14.56786^{**}	14.79433^{**}
ddm	-3.33943^{**}	-3.44782^{**}	-3.42653^{**}
dds	16.16027^{*}	15.75870^{*}	15.83722^{*}
norent	0.61178	8.59445	9.84508
alo	$10.09293^{\dagger}$	12.97315^{*}	13.19897^{*}
nkids	40.84132^{**}	40.96891^{**}	41.34651^{**}
ndesi	0.22850^{*}	0.26514^{**}	0.26672^{**}
hsroom	43.92827^{**}	46.01392^{**}	46.24821^{**}
terhouse	-33.72618^{**}	-34.58985^{**}	-34.95234^{**}
flat	-59.42277^{**}	-60.98618^{**}	-60.66025^{**}
gas	-20.27202	-19.63714	-20.08888
elec	7.77683	6.11680	5.77348
solid	113.56288^{**}	111.01972^{**}	110.67413^{**}
oil	174.56123^{**}	175.28920^{**}	175.78286^{**}
bilin	-33.83811^{*}	-32.96272^{*}	-32.40010^{*}
env	-24.13864^{*}	-	$-17.63277^{\dagger}$
tim1	49.59546^{**}	51.97102^{**}	52.01576^{**}
tim2	$10.72806^{\dagger}$	12.06239^{*}	12.09035^{*}
tim3	-7.02194	-8.07353	-8.19113
tim5	-2.53970	-2.26648	-2.25308
tim6	-7.55309	-9.07370	-8.96988
tim7	-9.82781	$-11.33802^{\dagger}$	$-11.32876^{\dagger}$
tim8	9.24202	6.33918	6.38059
Intercept	310.44806^{**}	198.29848^{**}	199.33357^{**}
N	16497	16497	16497
$\chi^2_{(k)}$	917.10279	865.02281	871.2942

Significance levels : $\dagger$: 10% $*$: 5% $**$: 1%

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Table 10: Trend and Average Income

Variable	Panel VII	Panel VIII
inc	0.00234**	.
inc2	0.00000**	.
linc	.	15.35821**
minc	-0.00028	-0.00028
time	-5.45290**	-5.50109**
ddm	-3.42956**	-3.50524**
dds	15.58321*	15.46489*
norent	1.95753	9.29550
alo	1.81104	3.58745
nkids	41.05344**	41.21182**
ndesi	0.24584*	0.27378**
hsroom	43.63625**	45.96414**
terhouse	-33.05458**	-34.50213**
flat	-61.17664**	-61.58898**
gas	-17.94556	-17.74148
elec	10.12193	8.70004
solid	115.10048**	113.06223**
oil	174.56180**	176.67865**
bilin	-34.82690*	-33.60022*
Intercept	351.43108**	228.24386**
N	16497	16497
$\chi^2_{(18)}$	724.02818	711.02818

Significance levels : † : 10% ∗ : 5% ∗∗ : 1%

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