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Essays on environmental innovation : the role of vertical relations and public policies

Rania Mabrouk

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THÈSE

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Essays on Environmental Innovation: The Role of Vertical Relations and Public Policies

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Contents

Introduction	1
Chapter 1	8
1 The impact of bargaining power within supply chains on Monopolist product variety choice	8
1.1 Introduction	8
1.2 Related Literature	9
1.3 Model	15
1.4 Mussa and Rosen Utility	16
1.4.1 Benchmark case: Vertically integrated market (No supplier powers)	16
1.4.2 Vertically separated markets (With supplier powers)	18
1.4.2.1 Exclusive contracts	18
1.4.2.2 Non-exclusive contracts	19
1.5 Shaked-Sutton utility	22
1.5.1 Benchmark case: Vertically integrated market (No supplier powers)	22
1.5.2 Vertically separated markets (With supplier powers)	24
1.5.2.1 Exclusive contracts	24
1.5.2.2 Non-exclusive contracts	25
1.6 Bowley-Spence-Dixit utility	27
1.6.1 Benchmark case: Vertically integrated market (No supplier powers)	27
1.6.2 Vertically separated markets (With supplier powers)	29
1.6.2.1 Exclusive contracts	29
1.6.2.2 Non-exclusive contracts	30
1.7 Conclusion	32
Chapter 2	34
2 Monopoly and Abatement Technology Choice: The Impact of Environmental Taxes and Bargaining	34
2.1 Introduction	34
2.2 Literature review	37
2.3 The model	40
2.4 Production	43
2.5 Bargaining	44
2.5.1 No technology as the monopoly's outside option	44
2.5.2 Clean technology as the monopoly's outside option	45
2.6 R&D stage	46
2.7 Regulation	47

2.7.1	Optimal taxation under end-of-pipe regime	48
2.7.2	Regulator’s preferences concerning technology choice	49
2.7.3	Alignment of preferences when regulator promotes the end-of-pipe technology	52
2.7.4	Alignment of preferences when regulator promotes the clean tech- nology	54
2.8	Conclusion	55
Chapter 3		59
3	Macroeconomic Determinants of Environmental Innovations in Europe: A Panel Approach	59
3.1	Introduction	59
3.2	Literature review	61
3.2.1	The micro eco-Innovations’ determinants	61
3.2.2	The macro Innovations’ determinants	69
3.3	Data and descriptive analysis	74
3.3.1	Data	74
3.3.1.1	Eco-patents as a proxy of eco-innovation	74
3.3.1.2	Measuring the Innovation Determinants	75
3.3.2	Descriptive analysis	77
3.4	Empirical analysis and results	84
3.4.1	Methodology	84
3.4.2	Estimation results	84
3.5	Concluding remarks	88
Conclusion		91
Appendices		95
A	Appendix Chapter 1	96
A.1	Optimal two-part-tariffs with non-exclusive contracts	96
A.2	Fixed production or contracting costs	96
A.2.1	Exclusive contracts	97
A.2.2	Non-exclusive contracts	97
A.3	Linear costs	98
A.3.0.1	Exclusive contracts	98
A.3.0.2	Non-exclusive contracts	98
A.3.0.2.1	Case 1).	99
A.3.0.2.2	Case 2).	100
A.3.0.2.3	Case 3).	100
A.3.0.3	Equilibrium	101
B	Appendix Chapter 2	103
B.1	Production stage	103
B.1.1	Polluter’s output absent abatement technology	103
B.1.2	Polluter’s output with integrated technology	103
B.1.3	Polluter’s output with end of pipe technology	104
B.2	Bargaining stage	105

B.2.1	No technology as the monopoly's outside option	105
B.2.2	Clean technology as the monopoly's outside option	106
B.3	Different welfares	107
B.4	Optimal tax	108
B.5	Simulations: case of $W_c^* < W_{eop/\emptyset}^*$	109
B.5.1	No Investment in R&D stage	109
B.5.2	Investment in R&D	110
B.5.2.1	Investment: Laisser-faire case	110
B.5.2.2	Investment: lowering taxes and avoiding R&D investment	111
B.5.2.3	Investment: lowering taxes and incurring R&D investment	112
B.5.3	Over-investment in R&D to boost bargaining power	113
B.5.3.1	Over-investment: Laisser-faire case	113
B.5.3.2	Over-investment: Lowering taxes	114
B.6	Simulations: case of $W_{eop/\emptyset}^* < W_c^*$	115
B.6.1	Investment in stage 2	115
B.6.2	No-Investment: highering tax	116
B.6.3	No-Investment: Laisser-faire case	117
C	Appendix Chapter 3	118
C.1	Summary: focus and main results from the literature review	118
C.2	Evolution of the environmental policy stringency	131
C.3	R&D expenditures	131
C.4	Evolution of Government expenditures on education (as% of GDP)	131

List of Figures

2.1	R&D incentives and impact of environmental taxation	47
2.2	Comparison of clean welfare and end-of-pipe welfare	52
2.3	Polluting firm profits under different technology choices when $W_c^* < W_{eop}^*(t^*)$	52
3.1	Structure of the Environmental Policy Stringency Index	76
3.2	Evolution of international Eco-patents	80
3.3	Mean of international Eco-patents per GDP	80
3.4	Evolution of international Eco-patents per GDP	80
3.5	Average of the environmental policy stringency(1990)	81
3.6	Average of the environmental policy stringency (2012)	81
3.7	Mean of R&D expenditures per GDP	82
3.8	Evolution of R&D expenditures per GDP	82
3.9	Demand expenditures per capita	82
3.10	Mean of Government expenditures on education (as% of GDP)	83
3.11	Openness evolution	83
3.12	Mean of Openness	83
C.1	R&D expenditures	131
C.2	Government expenditures on education (as% of GDP)	131

List of Tables

2.1	Summary of notation	42
2.2	Welfare components under different technology choices	51
3.1	Variables list and definition	74
3.2	Summary statistics	78
3.3	Cross-correlation table	79
3.4	OLS and FGLS regressions	86
3.5	FGLS estimation results	87
B.1	No Investment in R&D stage	109
B.2	Investment: laissez-faire case	110
B.3	Investment: lowering taxes and ovoiding R&D investment	111
B.4	Investment: lowering taxes and incurring R&D investment	112
B.5	Over-investment: laissez-faire case	113
B.6	Over investment: lowering taxes	114
B.7	Investment in R&D	115
B.8	No-Investment: highering tax case	116
B.9	No-Investment: Laisser-faire case	117
C.1	Overview of empirical studies on the impact of environmental regulations on eco-innovations	119
C.2	Articles testing the trichotomy of Rennings	123
C.3	Some empirical articles on the drivers of innovation at a country level	126

Introduction

If Sustainable Development is at the heart of the debate on the economic development of industrial economies, making it the object of numerous academic researches since long years ago, its implementation still remains very problematic and current. More particularly, the environmental dimension of an economic development respectful of the present and future generations certainly constitutes the most important challenge. Exhaustion of natural resources (both raw materials and energetic ones), degradation of living environments, disturbance of the biological systems, deterioration of the primary resources (water, air, ground), etc. are all environmental concerns which threaten our industrial society and our way of life as a whole. Beyond the ethical and moral challenges, the Sustainable Development also represents important economic issues. For our industrial societies, it is a question of engaging in new modes of production and consumption, modes leading to the development of new behaviours and a radical evolution of the technological regimes. Indeed, whether for the approach of the “Strong Sustainability” (Daly, 1991), in which the Sustainable Development presupposes a significant limitation of the use of natural resources up to the dematerialization of the economy, or for the approach of the “Weak Sustainability” (Nordhaus, 1992), in which the technological progress will allow to find solutions to the environmental challenges, the technological development and its cohort of innovations will be determining. Thus, the technological progress and the environmental innovations are considered to be the most important means to reach the goals of the XXIst century.

In this context, business managers and public authorities undergo considerable pressures in favour of the promotion of the environmental innovations, which requires a good apprehension of its contents and its characteristics. Indeed, defining the environmental innovations is not easy as long as of the environmental impacts are difficult to measure and evaluate. The concept of innovation itself is dynamic and scalable according to the considered angle of analysis (Gasmi and Grolleau, 2003). In their report to the measure of the environmental innovation (also called eco-innovation terms), Kemp and Pearson (2008) define the latter

by: “*the production, assimilation or exploitation of a product, production process, service or management or business methods that is novel to the organization (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives*”. In other words, an environmental innovation is any action, be it technological, individual or organizational, innovative at the level of the organization, which is undertaken in order to reduce or manage negative environmental impacts or/and to maintain or improve positive environmental impacts (Gasmi and Grolleau, 2003). Unquestionably, the positive effect on the environment is the principal element of these definitions, whether this impact is intentional or not, local or global, more or less important compared to current technologies. It is also worth mentioning that this positive impact is rarely absolute but often related to alternative technologies (Belin et al., 2009). Considering the new environmental dimension in the innovation process places us in the intersection of two fields of the economy: on the one hand the innovation economics – which aims at apprehending the conditions of emergence and diffusion of innovations within the economies and the societies – and on the other hand environmental economics – who’s objective is to develop effective public policies to integrate environmental issues into the strategies of actors. This positioning is not so much a thematic proximity, but rather a necessity to fully and simultaneously understand the two major public policy stakes relating to Sustainable Development.

From the economic point of view, the environmental impacts of economic activities represent negative externalities. Whether it is about exhaustion of natural resources or damages to the ecosystems, these phenomena result from market failures insofar as the economic decisions of agents (of production and/or consumption) do not take into account the full costs - the private and the social- generated by the activities. The major challenge of the public policies is then to develop instruments allowing the internalization of these negative externalities so as to modify the individual behaviours (Baumol and Oates, 1988). Simultaneously, the questions of innovation concern the management of the positive externalities generated by any R&D activity. Indeed, even under intellectual property regime, these R&D innovation activities can generate knowledges that are not appropriable by the economic agent at the source of innovation. Therefore it follows that all profits from these R&D investments are not taken into account in the decisions of private actors. The second challenge of the public policies is then to implement incentive mechanisms strong enough to avoid the underinvest-

ment in R&D and activities of innovation (Dosi et al., 1988, Griliches, 1991). There is thus a need to take this problem of “double externality” into account (Rennings, 2000) in order to determine the “innovating” conditions to implement environmental policies, in the way in which the actors would be brought to develop innovation strategies leading to a double dividend.

However when analysing environmental behaviours of actors, one should not limit the analysis only to the companies forced by the environmental regulations or other external pressures. It is imperative to integrate other stakeholders (firms’ owners, banks, environmental NGOs, consumers, competitors. . .) who influence, directly or indirectly at one moment or another in the decision-making or/and process of firm’s innovation. This idea broke through several academic fields over the last few years, generating numerous studies in different disciplines. In this work, we are more precisely interested in vertically linked actors, that is, belonging to the same supply chain (mainly between suppliers and producers). Indeed, even if early economic approaches have focused on the "horizontal" diffusion of innovations (i.e. all competitive firms operating on the same market) (Milliman and Prince, 1989, Montero, 2002a, 2002b) the issue of environmental innovation and diffusion is increasingly addressed at the "vertical" level (Parry, 1998, David and Sinclair-Desgagné, 2005; 2007, Nimubona and Sinclair-Desgagné, 2010). This interest in the study of vertical relationships arises first from the characteristics of production systems in which the value proposition results from a combination, often complex, of specific inputs from many firms. It also stems, when including environmental concerns, from the characteristics of many environmental issues where the environmental impacts are "diffuse" throughout the supply chain (for example regarding carbon print of products and services offered on final markets). However, the studies related to environmental innovations are often cost/benefit oriented (Requate, 1998, 2003). Our work, in another register, will contribute to environmental literature by examining the strategic use of environmental innovation and technology adoption decisions in vertical chains; as well as the role of public authorities in this context (Heyes and Kapur, 2011). In other words, this essay is more precisely interested in the impact of the bargaining powers between the vertically dependent companies on the division of the added-value created by the total supply-chain. Within such a connection, the environmental innovations can become an extra means used by the companies to increase their economic private profit without taking into consideration the environmental benefits. In this context, the public au-

thorities must take into account the distortions generated by such strategic behaviours during the elaboration of the environmental policies because there could be a divergence between a welfare-maximizing regulator and environmental damage-minimizing one. The public authorities should not neglect the other determinants of the environmental innovation either. In fact, even if the environmental policies are regarded as the main drivers of the environmental innovation, firms' environmental performances are strongly correlated with the more or less favourable macroeconomic conditions are.

To address these questionings, this thesis is composed of three chapters. The first focuses on the impact of bargaining power on firms' strategies in terms of commercial reports and behaviours on the final markets. To do so, we have developed a model in which a monopsony copes with two vertically differentiated suppliers on the intermediate market. All the actors have a power during the negotiation of the contracts. The latter have the form of two-part-tariffs and are negotiated according to the Nash bargaining process. On the final markets, three types of utility functions are tested: Mussa and Rosen (1978), Shaked and Sutton (1982) and Bowley-Spence-Dixit (Bowley, 1924; Spence, 1976; Dixit, 1979). These utility functions are the most used to study the vertically differentiated products demand. We show that the monopsony has always an interest to contract with both suppliers without thereby benefit consumers from a diversification or a fall in the prices of the products on the final market. Indeed, contracting with the second supplier, sometimes without even selling her product, has purely strategic end which is increasing the monopsony's buyer power through the outside option with the main supplier. This makes possible to the monopsony to enhance his share of the profit generated by the sector.

The second chapter, while still focusing on bargaining power stakes, introduces the questioning on the behaviour of a welfare-maximizing regulator. In fact, the regulator faces several problems. From the innovation policies' point of view, the question is to know how to support the development and the diffusion of environmental innovations as well as possible knowing that these innovations, according to the standard approach of the environmental economics, would not be initiated in a spontaneous way by the actors. From the point of view of the environmental policies, the question is to know how to significantly modify the behaviours of economic actors in order to make them compatible with the environmental challenges. In a very stylized way, our reflection falls under a context where the individual decisions are sub-optimal not only from the innovation point of view in the broad sense –

insufficient R&D activities – but also from the environmental point of view – production of polluting activities.

The theoretical model developed in this second chapter analyses a polluting monopoly subject to an environmental tax. Facing such a regulation, the adoption of abatement technology is a result of a competition between different types of technologies, i.e. clean technology developed by the downstream firm (more efficient in abating the pollution but more expensive) and end-of-pipe technology sold by an upstream firm (cheaper but results in lower abatement). As seen in the first chapter, the results show that the pollutant might have an interest to develop its own technology for reasons solely related to bargaining powers. Under some other conditions, the pollutant refrains from innovating for private interests which are not in phase with the public objectives. In such sub-optimal situations, the regulator adjusts its policy according to whether there is a situation of under or over-investment. These adjustments could push the pollutant monopoly to develop clean technology in case of under-investment or force the use of the invented technology or the abstention from investing in an R&D activity in case of over-investment. However under certain conditions, the regulator is unable to effectively act using only one tool of the environmental policy such as taxes. This would cause welfare losses.

This result highlights the fact that neither the environmental policies nor single political tool are sufficient to promote environmental innovations. Indeed, if the internal dynamics of the company represents the essential base for environmental innovation, the implementation of such a dynamic is primarily related to the conditions of firms' inclusion in a favourable macro-economic environment. For this reason, the third chapter considers the question of the macro-economic determinants of the environmental innovations. The chapter starts with a literature review. This section mobilizes in addition to the environmental and innovation economics, cited above and which focus on environmental policy, technology-push and demand-pull determinants; the contributions of “endogenous growth approach” that focuses on the origins and mechanisms of technical progress and “National Innovation System approach” - which underlines the role played by national institutions in the emergence of innovations. A second section, this time empirical, tests the impact of the various drivers pointed in the literature. The results show the importance of the technological and institutional determinants in addition to the public policies. To go further, the analysis of the 3rd chapter should lead to reconsider the nature and the forms of public interventions in innovation and

protection of the environment. Beyond the environmental policies, it is a question of thinking of new means of public actions in favour of the other determinants of the environmental innovation.

To finish with, a general conclusion summarizes the contributions of this thesis and presents the limits and extensions to be developed in future research.

Chapter 1

The impact of bargaining power within supply chains on Monopolist product variety choice¹

1.1 Introduction

A company is in permanent rivalry with the different actors in order to increase its bargaining power which is the key of competitiveness (Porter, 1982). This is the case specially within active negotiations when there are no higher authorities fixing rules, no instructions governing the decision and no markets predetermining the terms of goods and services trades (Zartman 1978, 2004). A multitude of factors are emphasized by the negotiation theory to increase the monopolist power against a supplier². In this chapter, we focus on one in particular that is the increasing of the outside option following the introduction of a new supplier. Indeed, a monopolist may have an interest in introducing competition in the upstream of the supply chain, even with leaving a positive margin to a less efficient supplier, in the sole intention to increase its bargaining power with the efficient producer. The underlying idea is that the introduction of a new supplier reduces the opportunity cost that supports the monopolist in the case of negotiation failure with the principal producer. The latter however, facing the threat of a supplier change, is found in a unilateral dependence situation and agrees to assign greater profit margin to the monopolist.

Our paper, on the one hand, verifies this hypotheses in vertically differentiated market using the most common utility functions studied in the literature on product differentiation: those with Mussa and Rosen (1978), Shaked and Sutton (1982) and Bowley-Spence-Dixit

¹This chapter is based on an article written in collaboration with Emanuele Bacchiega and Olivier Bonroy (2013)

²We define the bargaining power as the part of the industry benefit that an agent can appropriate.

(Bowley, 1924; Spence, 1976; Dixit, 1979) and, on the other hand, wonders if the introduction of a new supplier could be a factor pushing a monopolist to vary his products. Put in another way, can bargaining power stakes explain multi-product strategies? To answer this question, we develop a simple model where a monopolist faces two suppliers on the intermediate market. One sells a conventional low quality product while the second offers an innovative product that improves quality without increasing costs. We show that increasing bargaining power is not a valid reason to change the number of varieties offered at the equilibrium on the final market. However, we show that even if the innovative product covers all the demand on the final market, the low-quality product does not disappear from the intermediate market and the monopolist always signs contracts with both suppliers. This paradox clearly shows that a low-quality product that should disappear after the introduction of an innovation may stay on the market only to assure some competition on the upstream market.

The chapter is organized as follows. Section 2 reviews the existing literature. Section 3 describes the general model. The case with the Mussa and Rosen utility is presented in section 4. Section 5 and 6 deal respectively with the Shaked and Sutton and the Bowley-Spence-Dixit utilities. Section 7 concludes.

1.2 Related Literature

Our chapter is in the intersection of many theoretical frameworks. Three concern us particularly: the private labels literature, the monopolist product variety choice one and finally the innovation economics literature dealing with the drasticness propriety of an innovation.

The private label literature has widely examined the issue of introducing private labels by retailers with the specific objective of exerting competitive pressure on their national-brand manufacturers³. Indeed, private labels are products that compete with the national-brands in the retail market and this competition shifts the balance of power in favour of the retailer. We can divide the theoretical articles on the topic in two categories according to the nature of the contract between the producer and the retailer: those using a linear contract and those using a two-part-tariff contract⁴.

In the first categories, we find the pioneer work of Mills (1995) and that of Bontems et

³This literature focuses on private labels and national brands but the theoretical framework can be easily generalized to any kind of vertically differentiated goods or services.

⁴In what follows, we will focus only on articles studying the case of two vertically related monopolies because it is the most used framework and it is also the one mobilized in our model.

al. (1999). These two articles consider a supplier and producer both in a monopoly situation. The supplier produces a high quality good, national-brand, supporting a constant marginal cost. The retailer buys the product to resell it on the final market. With the linear pricing, we are in a situation of double marginalization that harms consumers and reduces the overall profit of the vertical structure. Under such hypotheses, the retailer could introduce a private label and use it as a weapon to strengthen its bargaining power against the producer. In response, the latter would decrease its prices and thus would limit the effect of double marginalization.

To explain this mechanism, Mills (1995) assumes a model where the production of private label has the same variable cost as the national-brand but a lower fixed cost. According to the consumer perception of the quality difference between private label and national-brand, three situations can occur. If this perception is very high, i.e. consumers consider that the national-brand has a much higher quality than the private label, this latter is not produced at the equilibrium and does not constitute a threat to the producer. However if the perception is low, the private label is introduced and the producer has to drastically lower its prices to accommodate this entry⁵. For intermediate levels of perception, the supplier will adopt a strategy of price limit in order to prevent the introduction of the private label. In this case, even if the private label is not sold, it is still a credible threat to allow the retailer to lower its purchasing costs of the national-brand and in this way increase its profits.

Bontems et al. (1999) meanwhile elaborate a model where the marginal cost is increasing with the quality level and where private label supplier has a cost disadvantage compared to national-brand one. In this case, the private label is introduced only if its quality is low. Indeed, the strong differentiation of the two products allows them to coexist in the market despite the disadvantage cost of the private label. As response to the private label entry on the market, the national-brand supplier reduces its wholesale prices but this price cut is not monotonous with the quality of the private label. In the first instance, the more the quality of private label increases the lower the national-brand supplier price goes down because goods become less differentiated. Reaching a given quality level, private label becomes too expensive compared to the national-brand and so the supplier takes advantage of this situation to increase its price again. For the intermediate levels of quality, national-brand producer adopts the strategy of price limit to prevent the introduction of private label and

⁵Its price will be equal to its marginal cost if the two goods are perceived as similar.

as the private label quality increases, it becomes less expensive to adopt this strategy. For high levels of private label quality, the retailer finds no interest in entering the private label on the market because of the cost disadvantages and we fall back on the situation of two successive monopolies. [Bontems et al. \(1999\)](#) also examine the case when national-brand and private label have the same quadratic function cost. They find that the private label is always introduced and the price of the national-brand decreases with the quality of the private label.

Using linear contracts was widely criticized because in reality the contracts are much more complex which induced the use of the two-part-tariff contracts by many researchers ([Chen, 2003](#); [Rey and Tirole, 2000](#)). [Narasimhan and Wilcox \(1998\)](#) assume a market with consumers divided into two exhaustive and non-overlapping segments: loyal and switchers. They assume a fixed wholesale price. Both segments have the same reservation price for the national-brand and the private label. They find that, under these assumptions, the introduction of the private labels can only lead to a decrease in the national brand wholesale price. [Scott Morton and Zettelmeyer \(2004\)](#) introduced a novelty in this field by adding the notions of shelf space scarcity and strategic positioning of the private labels in their model. They imagine a model where there are two national brands and where the retailer cannot offer more than two products in his shelves. So if the retailer wants to sell a private label, it must be by replacing one of the two national-brands existing on the market. The authors show that the retailer will replace the low quality national brand by a private label with a closest location to the high quality product in the product space. Indeed, by providing a close substitute to the national brand, the retailer may be more threatening during the bargaining with the supplier whom will be forced to lower her profit margin. In this situation, the total rent in the vertical chain will be reduced due to the minimal product differentiation but the retailer gains a larger share of it.

The second framework mobilized concerns the monopolist product variety choice. It starts in the 1970s even if it takes their foundation long before with the pioneering work on the "linear city model" of [Hotelling \(1929\)](#)⁶. In this model, products are inherently homogeneous but differ from each other by their localisations along a $[0, 1]$ interval representing the

⁶The term product variety refers in this work "to the number of variants within a specific product group, corresponding broadly to the number of "brand" as the term is used in the marketing literature or the number of "model" in consumer durable markets. Pure conglomeration, in which firms expand the number of product groups but not the variety within a group, is not considered" ([Lancaster, 1990](#), p189).

length of a street or equivalently the space tastes. Since then, factors impacting the product variety choice have been a long-standing topic of interest to economists. At the beginning, researchers have focused on horizontally different products ⁷ (Eaton and Lipsey, 1975, 1989; Lancaster 1979, 1982; Salop, 1979; Shaked and Sutton, 1982). We had to wait until 1978 when Mussa and Rosen, with an article based on the theory of non-linear pricing and the literature of the self-selection problem ⁸, launched researches relative to quality discrimination strategy in a vertically differentiated market. In this seminal article, authors imagine a monopolist selling a single good at various levels of quality and price combinations to a heterogeneous population of customers. The heterogeneity here means that all customers prefer the high quality to the low quality but differ in how much they are willing to pay for the quality. In other words, the marginal utility from a price and quality combination differs for different consumers. In their model, even though the monopolist knows the aggregate distribution of tastes, he cannot distinguish each consumer type to effectively price discriminate between different consumers. That's why, the monopolist can offer a menu of price-quality pairs to push the self-selection process but this process leads to distortions in the quality offered compared to the first best case⁹.

Twenty years after, Acharyya (1998) shows that this result is deeply dependent on the assumption of the costly quality improvement. If this latter is costless, quality distortion will disappear. The author goes further and explains that, in addition to qualities costs, income disparities (or equivalently taste parameters) are also responsible for the monopolist choice. According to him, with unconstrained income customers (or linear preference structure) and a cost function not sufficiently convex (otherwise costless quality improvement), the only profitable strategy for monopoly is to offer the best available quality on the market whatever the customers' distribution is. This is what he is calling the pooling menu¹⁰.

⁷Two variants of a product are differentiated horizontally when sold at the same price, some consumers prefer to buy the first to the second, while the reverse is true for other consumers. However, two variants of a product are differentiated vertically when sold at the same price, all consumers prefer to buy one variant to the second (Gabszewicz, 2006).

⁸The self-selection constraint consists on "*choosing a pricing scheme that induces consumers of each quality level to prefer their own quality to any other quality*" (Varian, 1989, p640)

⁹The monopolist changes the quality of some of its varieties from the efficient level in order to enhance its profit. Generally the highest consumer type will choose inefficiently low qualities

¹⁰Gabszewicz and Thisse (1979) were the first to assume the income disparities in duopoly model. They explain that since all customers have the same preference ranking for the vertically differentiated varieties, something other than preferences is needed to offer different qualities on the market. Shaked and Sutton (1982) examined the impact of income disparities on monopolistic competitors having the same production cost for the different qualities. Gabszewicz et al. (1986) analyses a model where consumers are identical in tastes but different in income and find that, as the income distribution narrows, a monopolist focuses its production on a

However, [Gabszewicz and Wauthy \(2002\)](#) demonstrate that a separating menu, i.e. providing the two qualities on the market, may occur even with costless quality in the case of multiple demand i.e. consumers can purchase several units of the indivisible good. [Kim and Kim \(1996\)](#), on their part, examine the spill-over effects and show that when there is a positive cost externality between the high and the low quality, a higher marginal willingness to pay does not necessarily generate a higher quality. In that case a monopolist may offer a unique price-quality pair to decrease total production cost and enhance the profit. [Bonnisseau and Lahmandi-Ayed \(2006\)](#), always using the Mussa and Rosen's model ([1978](#)), confirm Acharyya's proposition ([1998](#)) that the only two factors explaining a multi-product strategy are quality costs and income disparities. They do so by proving that deterring entry is not a determinant to push a monopolist to have a separating menu. In contrast, [Ghaz-zai \(2008\)](#) affirms that relative preferences for quality can be the third factor to explain the quality discrimination. Indeed, she shows that when consumers are concerned by the other consumers' choices, due to the "prestige" or "social distinction" effect, a multi-product strategy is feasible. [Deltas and Zacharias \(2012\)](#) arrive to the same multi-product strategy in the presence of status effects or more generally "positional externalities"¹¹.

The third standard of literature is related to the innovation economics and deals with the drasticness propriety of an innovation. This notion is used to qualify innovations, when placed on the market, make old technologies, varieties or production methods obsolete ([Reinganum, 1985](#)). Two types of drastic innovations exist. We speak about drastic process innovation when, as described in the work of [Arrow \(1962\)](#), the monopoly price using the new technology p_m^* is lower than the competitive price c using the old technology $p_m^* < c$. In other terms, the new technology brings down the cost of production so that, even in the monopoly prices, the product is sold below the cost price of potential competitors. However sometimes even a no-drastring process innovation can permit its user to eject other competitors from the market. In this case, the technology lowers the production costs to c' but not so as to have the price of the monopoly lower than production costs with the old technology $c < p'_m$. In some situations, the new technology user sets p'_p called predatory price such as $c' < p'_p < c < p'_m$ to expel existing firms or deter entry of future competitors ([Rey and](#)

single quality level.

¹¹There is a positional externalities when "consumers (...) care about how many consumers have a product that is worse than the one they own, and how many consumers have a product that is better than the one that they own." ([Deltas and Zacharias, 2012, p.2](#))

Tirole, 1997)¹². This strategy is credible when the benefit of new technology user is higher with p'_p than its profit if it had to cope with other competitors.

This absolute power assumed to drastic or quasi-drastring innovations is not infallible. Under certain conditions, firms may continue to use, in parallel, old technologies. Indeed, Lapan and Moschini (2000) show that a superior technology that lowering an input price (or increasing a productivity of one input) can be not fully adopted if the final product is composed of many kinds of other inputs and that the prices of one or more of these inputs are endogenously fixed and correlated to the use of the new technology. Bergès and Chambolle (2009), on the other hand, highlight the effect of a dynamic game on downstream monopsonist's strategy within a vertical relationship. They demonstrate that in the case of linear take-it or leave-it contracts offered by suppliers, a monopsonist may keep on the market a less efficient supplier in the first period in the sole intention to preserve his buying power when bargaining with the more efficient one in the second period.

The second type of drastic innovation concerns the quality of the final product. In the case of perfect information, an innovation that would increase the quality of a product without increasing costs is considered as a drastic innovation since it excludes the varieties of lower quality from the market. Unless, sometimes market failures like incomplete information hamper such a mechanism. To understand this point, we can go back to the work of Akerlof on "The market of Lemons" (1970) in which the author describes a market where vertically differentiated used cars are priced uniformly. The market price is the only information given to the buyers who can correctly anticipate the average quality but cannot identify the quality level of any particular car. In such a context, the lack of complete information leads to the disappearance of the market, bad products driving out good ones. This informational problem is more or less important according to the nature of the good and the cost of obtaining the information. Three main categories of goods are listed according to when buyers get information on the quality level during the transaction¹³. The "search goods" are those for which a buyer can inspect the various aspects before purchasing. This type includes goods that the quality level can be observed directly, from reliable and inexpensive information easily found, or from signals that can be interpreted as reflecting quality such as

¹²Firms can even set prices $p'_p < c'$ to send erroneous signals to the market but this practice is most of the time prohibited by law and unsustainable in the long term

¹³Stigler (1961), in his information search theory, explained that consumers continue to search for information until the marginal benefit expected of additional information equals the marginal cost of acquiring that information.

guarantees (Tirole, 1988) and advertisements (Nelson, 1970, 1974). The "experience goods" are those for which it is better to acquire information on quality by purchasing and consuming the good than by gathering information before purchasing. The following purchases depend on this first experience (Nelson, 1970). The last category includes "credence goods" i.e. goods whose quality is costly to determine even after purchase and consumption such as organic products (Darby and Karni, 1973). Traditional mechanisms of signal (Caswell and Mojdzuska, 1996) or reputation (Bonroy and Constantatos, 2008) are no longer effective in such a market which gave birth recently to label theory literature that proposes solutions to overcome this informational problem.

1.3 Model

We consider a market where two upstream firms, denoted 1 and 2, produce a vertically differentiated good of quality s_1 and s_2 respectively, with $s_2 > s_1 > 0$. A downstream monopolist purchases the good(s) from one (or both) firm(s) and sells it (them) to the final consumers. The three-stage game is as follows. At stage 1 the downstream monopolist commits to an exclusive relationship with firm $i \in \{1, 2\}$ only, or to a non-exclusive relationship with both firms. At stage 2 the monopolist bargains simultaneously with each of his suppliers over a two-part-tariff contract (v_i, f_i) , where v_i is a per-unit input price and f_i is the fixed fee. The use of the two-part-tariff contract allows the vertically separated channel to replicate the monopoly profit (see Tirole, 1988; Muthoo, 1999; Cachon, 2003 among many others). At stage 3, the monopolist sets the final price(s) for the good(s) purchased.

We solve the sub-games with an exclusive contract and that with non-exclusive ones by backward induction. Then, we compare their outcomes to find the subgame-perfect Nash equilibrium of the whole game. To begin with, it is useful to fix ideas by considering the benchmark case in which there is a vertically integrated market or equivalently that suppliers have no bargaining power on the intermediate market to see if the efficient variety is drastic in this context and demonstrate how the introduction of the bargaining issues with suppliers in the intermediate market affect the monopolist strategy. We use three different utility functions: Mussa and Rosen, Shaked and Sutton and Bowley-Spence-Dixit.

1.4 Mussa and Rosen Utility

Consider a market where consumers are heterogeneous in their quality appreciation θ , which is uniformly distributed with density 1 over $[0, 1]$. A consumer enjoys an indirect **Mussa and Rosen** utility $U(\theta) = \theta s_i - p_i$ with $i \in \{1, 2\}$, if he/she buys a product of quality s_i at price p_i , and zero if he/she abstains from consuming. As a unit mass of consumers exists, the market demands are written as

$$D_1^{MR}(p_1, p_2) = \left(\frac{p_2 - p_1}{s_2 - s_1} - \frac{p_1}{s_1} \right)$$

and

$$D_2^{MR}(p_1, p_2) = 1 - \frac{p_2 - p_1}{s_2 - s_1}$$

when both goods are supplied;

and

$$D_i^{MR}(p_i) = \left(1 - \frac{p_i}{s_i} \right)$$

when variant i only is offered.

1.4.1 Benchmark case: Vertically integrated market (No supplier powers)

As we said above we suppose that the two suppliers haven't any bargaining power or that the two chains are vertically integrated. This hypothesis will be relaxed for the following cases.

Suppose that the monopoly sells the low quality product. The market demand is

$$D_1^{MR}(p_1) = \left(1 - \frac{p_1}{s_1} \right)$$

Monopolist maximizes its profit function with respect to price

$$\Pi_1^{MR} = p_1 D_1$$

yielding:

$$p_1^{MR*} = \frac{s_1}{2},$$

$$D_1^{MR*}(p_1) = \frac{1}{2}$$

and

$$\Pi_1^{MR*} = \frac{s_1}{4}.$$

Suppose now that the monopoly discovers a new method to improve quality without increasing costs. If the monopolist decides to put on the market the both varieties, the market demands become

$$D_1^{MR}(p_1, p_2) = \left(\frac{p_2 - p_1}{s_2 - s_1} - \frac{p_1}{s_1} \right)$$

and

$$D_2^{MR}(p_1, p_2) = 1 - \frac{p_2 - p_1}{s_2 - s_1}$$

Maximizing the profit function with respect to prices

$$\Pi_{1,2}^{MR} = p_1 D_1 + p_2 D_2$$

yields:

$$p_1^{MR*} = \frac{s_1}{2},$$

$$D_1^{MR*}(p_1, p_2) = 0,$$

$$p_2^{MR*} = \frac{s_2}{2},$$

$$D_2^{MR*}(p_1, p_2) = \frac{1}{2}$$

and

$$\Pi_{1,2}^{MR*} = \frac{s_2}{4}.$$

We can easily see that the new high quality product is drastic and ousts out of the market the low quality one (demand of the low quality variety is zero).

1.4.2 Vertically separated markets (With supplier powers)

Here all the game players have a positive bargaining power and both the production and retailer costs are zero.

1.4.2.1 Exclusive contracts

We solve the sub-game by backward induction.

In stage 3, The monopolist commits to an exclusive relationship with producer $i \in \{1, 2\}$.

The monopolist profit is $\Pi_i^{MRa} = (p_i - v_i)D_i(p_i) - f_i$, which is maximized for

$$p_i^{MRa}(v_i) = \frac{s_i + v_i}{2}.$$

By plugging the price back into the profit we find

$$\Pi_i^{MRa}(v_i, f_i) = \frac{(s_i - v_i)^2}{4} - f_i.$$

The profit of supplier i is $\pi_i^{MRa}(v_i, f_i) = v_i D_i(p_i) + f_i$, which, at $p_i^{MRa}(v_i)$, writes

$$\pi_i^{MRa}(v_i, f_i) = \frac{(s_i - v_i)v_i}{2s_i} + f_i.$$

In stage 2, upstream and downstream firms bargain over the contract terms. The optimal two-part-tariff (v_i, f_i) is obtained through the generalized Nash bargaining solution.

Let $\alpha \in]0, 1[$ (respectively $\beta \in]0, 1[$) be the power of the monopolist in the bargaining with the high-(respectively low-)quality producer, and, accordingly, let $(1 - \alpha)$ (respectively $(1 - \beta)$) be the power of the high-(respectively low-)quality producers¹⁴. The outside options for all firms are zero. In other words, if no agreement is reached, no firm has alternative sources of profit. The Nash product is therefore,

$$B_i^{MRa}(v_i, f_i) = [\Pi_i^{MRa}(v_i, f_i)]^\mu [\pi_i^{MRa}(v_i, f_i)]^{1-\mu}$$

with $i = 1, 2$ and $\mu = \alpha$ (respectively β) if $i = 2$ (respectively $i = 1$). Maximization of

¹⁴We let α and β over the open interval $]0, 1[$ to allow for a positive bargaining power for all the firms. We also assume that they are exogenous and fixed parameters i.e. that none of the two firms can influence them.

$B_i^{MRa}(v_i, f_i)$ with respect to v_i^{MRa} and f_i^{MRa} gives

$$v_i^{MRa*} = 0$$

and

$$f_i^{MRa*} = \frac{(1 - \mu)s_i}{4}$$

As expected, the variable part of the tariff is set equal to marginal cost so as to maximize the joint profits of the supply chain. The total profit are apportioned according to the sharing rule determined by the bargaining weights (Muthoo, 1999). By plugging the optimal two-part-tariff back into price, demand and profits, we obtain:

$$p_i^{MRa*} = \frac{s_i}{2} \quad D_i^{MRa*} = \frac{1}{2} \quad (1.1)$$

$$\Pi_i^{MRa*} = \mu \frac{s_i}{4} \quad \pi_i^{MRa*} = (1 - \mu) \frac{s_i}{4} \quad (1.2)$$

with $i = 1, 2$ and $\mu = \alpha$ (respectively $\mu = \beta$) if $i = 2$ (respectively $i = 1$).

If committed to an exclusive relationship, the monopolist signs a contract with the high- (respectively low-)quality producer if, and only if, $\Pi_2^{MRa*} > \Pi_1^{MRa*} \Leftrightarrow \frac{\alpha}{\beta} > \frac{s_1}{s_2}$ (respectively $\Pi_2^{MRa*} < \Pi_1^{MRa*} \Leftrightarrow \frac{\alpha}{\beta} < \frac{s_1}{s_2}$).

1.4.2.2 Non-exclusive contracts

The monopolist may sign a contract with both producers and, thus in stage 3, sell both goods to the final consumers. In this case his profit is written as

$$\Pi_{1,2}^{MRb} = \sum_{i=1}^2 [(p_i - v_i)D_i(p_1, p_2) - f_i].$$

Standard computations yield the optimal prices at this stage:

$$p_i^{MRb}(v_i, f_i) = \frac{s_i + v_i}{2}, \text{ with } i = 1, 2$$

Accordingly, the profits for the monopolist, the high-quality producer and the low-quality producer are respectively

$$\Pi^{MRb}(v_1, v_2, f_1, f_2) = \frac{s_1[\Delta s(s_2 - 2v_2) + v_2^2] + v_1(s_1v_1 - 2s_2v_1)}{4s_1\Delta s} - f_1 - f_2$$

$$\pi_2^{MRb}(v_1, v_2, f_2) = \frac{v_2(\Delta s - v_2 + v_1)}{2\Delta s} + f_2$$

$$\pi_1^{MRb}(v_1, v_2, f_1) = \frac{v_1(s_1v_2 - s_2v_1)}{2s_1\Delta s} + f_1$$

where $\Delta s \equiv s_2 - s_1$.

Under the non-exclusive contracts regime, the monopolist simultaneously bargains over the two-part-tariff with the two producers in stage 2 ¹⁵. The bargaining weights are unchanged compared to the case of exclusive contracts, and they are common knowledge among the firms. The outside options for the upstream firms are still zero: if no agreement is reached they cannot sell their goods. However, the outside option for the monopolist is positive because if the agreement with firm i is not reached, the bargaining with firm j ($i, j \in \{1, 2\}, i \neq j$) continues as in the case of exclusive contract. Thus, the outside option of the monopolist in the bargaining with firm 1 is Π_2^{MRa*} and that with firm 2 is Π_1^{MRa*} . Accordingly, the two Nash products are

$$B_1^{MRb}(v_1, v_2, f_1, f_2) = [\Pi^{MRb}(v_1, v_2, f_1, f_2) - \Pi_2^{MRa*}]^\beta [\pi_1^{MRb}(v_1, v_2, f_1)]^{(1-\beta)} \quad (1.3)$$

$$B_2^{MRb}(v_1, v_2, f_1, f_2) = [\Pi^{MRb}(v_1, v_2, f_1, f_2) - \Pi_1^{MRa*}]^\alpha [\pi_2^{MRb}(v_1, v_2, f_2)]^{(1-\alpha)} \quad (1.4)$$

The joint maximization of (1.3) and (1.4) with respect to (v_i, f_i) , $i \in \{1, 2\}$ yields the equilibrium two-part-tariffs with non-exclusive contract as shown below

$$v_1^{MRb*} = 0, \quad f_1^{MRb*} = \frac{s_1\beta(1-\alpha)(1-\beta)}{4\Phi}$$

and

$$v_2^{MRb*} = 0, \quad f_2^{MRb*} = \frac{(1-\alpha)[\alpha s_2 - \beta s_1 + (1-\alpha)\beta s_2]}{4\Phi} \text{¹⁶}$$

¹⁵The analysis is developed in the case of public contracts i.e. contracts signed between upstream and downstream firms are publicly observed and irreversible. However, since the monopolist knows the terms of both contracts, the distinction between public and secret or unobservable contracts is immaterial here.

¹⁶Proof in the appendix A.1

where $\Phi \equiv \alpha + \beta - \alpha\beta$

By plugging these values back into the equilibrium prices and demands we obtain

$$p_2^{MRb)*} = \frac{s_2}{2}, \quad p_1^{MRb)*} = \frac{s_1}{2}, \quad (1.5)$$

$$D_2^{MRb)*} = \frac{1}{2}, \quad D_1^{MRb)*} = 0. \quad (1.6)$$

Since $v_i^{MRb)*} = 0$, $i \in \{1, 2\}$, the profit of the upstream firms coincide with the fixed fee of the two-part-tariff: $\pi_i^{MRb)*} = f_i^{MRb)*}$. The profit of the downstream monopolist is

$$\Pi_{1,2}^{MRb)*} = \frac{\alpha s_2}{4} + \frac{(1 - \alpha)s_1\beta^2}{4\Phi} \quad (1.7)$$

This expression is nothing but the total industry profit ($\frac{s_2}{4}$) minus the fixed fees that the monopolist pays to the two suppliers ($f_1^{MRb)*} + f_2^{MRb)*} = \frac{(1 - \alpha)s_2}{4} - \frac{(1 - \alpha)s_1\beta^2}{4\Phi}$).

Analysing the equilibrium outputs of the two subsets, we state the following;

Proposition 1. *Let $(\alpha, \beta) \in]0, 1[$, The monopolist*

(i) *always signs contracts with both the high- and low-quality producers*

(ii) *never sells the low-quality good.*

Proof. $\forall (\alpha, \beta) \in]0, 1[$

$$(i) \quad \Pi_{1,2}^{MRb)*} - \Pi_1^{MRa)*} = \frac{\alpha s_2}{4} - \frac{\alpha\beta s_1}{4\Phi} > 0^{17};$$

$$\Pi_{1,2}^{MRb)*} - \Pi_2^{MRa)*} = \frac{s_1(1 - \alpha)\beta^2}{4\Phi} > 0$$

$$(ii) \quad D_1^{MRb)*} = 0 \quad \square$$

The monopolist always finds it optimal to sign non-exclusive contracts with both producers which allows him to dilute the supplier powers between the competitors. Indeed, a single supplier policy removes the other actor from the negotiation in favour of a single producer with strengthened supplying power. In this case, the monopolist cannot rely on a substitute supplier if negotiation fails and will have to concede a larger share of the total profit to the single efficient producer. We also note that the contracts are efficient, as the

¹⁷In order to be more explicite, we can rewrite $\Pi_{1,2}^{MRb)*} - \Pi_1^{MRa)*}$ as follows

$$\frac{\alpha}{4\Phi} [\alpha(1 - \beta)s_1 + \beta(s_2 - s_1)]. \quad (1.8)$$

The three parts of the decomposition are positive so $\Pi_{1,2}^{MRb)*} - \Pi_1^{MRa)*} > 0$.

upstream price equals the upstream marginal production cost. However, despite the positive fee paid to the low-quality supplier, the monopolist sets the downstream prices so that the equilibrium demand for the low-quality good is zero to avoid cannibalization between variants. So comparing to the benchmark case when producers have supplying powers, the contractual relationship with the low-quality producer is only a device to improve the bargaining position of the monopolist over the high-quality producer and has no effect on the final market i.e. the high-quality product is still drastic¹⁸.

1.5 Shaked-Sutton utility

Now, consider a market where consumers have a Shaked-Sutton utility function. In this case, we assume a continuum of consumers identical in tastes but differing in income. Incomes t are uniformly distributed with density 1 as $0 < a \leq t \leq b$. A consumer enjoys an indirect Shaked-Sutton utility $U(t, i) = s_i(t - p_i)$ with $i \in \{1, 2\}$ if he/she buys a product of quality s_i at price p_i . The utility $U(t, 0) = s_0 t$ with $s_0 = 1$ if he/she abstains from consuming and $s_i > s_0$. The market demands are written as

$$D_1^{SS}(p_1, p_2) = \left(\frac{p_2 s_2 - p_1 s_1}{s_2 - s_1} - p_1 \frac{s_1}{s_1 - 1} \right)$$

and

$$D_2^{SS}(p_1, p_2) = b - \frac{p_2 s_2 - p_1 s_1}{s_2 - s_1}$$

when both goods are supplied;

and

$$D_i^{SS}(p_i) = \left(b - p_i \frac{s_i}{s_i - 1} \right)$$

when variant i only is offered.

1.5.1 Benchmark case: Vertically integrated market (No supplier powers)

As the first section, we suppose that both suppliers have no bargaining power. Consider the case that the monopoly sells only one variant of the product.

¹⁸The same results are obtained while introducing fixed (see appendix A.2) or linear (see appendix A.3) costs.

The market demand is

$$D_i^{SS}(p_i) = (b - p_i \frac{s_i}{s_i - 1})$$

Monopolist maximizes his profit function with respect to price

$$\Pi_i^{SS} = p_i D_i$$

yielding:

$$p_i^{SS*} = b \frac{s_i - 1}{2s_i},$$

$$D_i^{SS*} = \frac{b}{2}$$

and

$$\Pi_i^{SS*} = b^2 \frac{s_i - 1}{4s_i}.$$

Simple calculations permit us to confirm that the monopolist sells the high quality in this case because $\Pi_2^{SS*} > \Pi_1^{SS*}$.

If the monopolist decides to put both varieties on the market, maximizing the profit function with respect to prices yields

$$p_1^{SS*} = b \frac{(s_2 + s_1)(s_1 - 1)}{\Upsilon}$$

$$p_2^{SS*} = 2b \frac{s_1(s_2 - 1)}{\Upsilon}$$

$$D_1^{SS*} = b \frac{s_1(s_2 - 1)}{\Upsilon}$$

$$D_2^{SS*} = b \frac{s_2(s_1 + 1)}{\Upsilon}$$

and

$$\Pi_{1,2}^{SS*} = b^2 \frac{s_1(s_2 - 1)}{\Upsilon^2}.$$

where $\Upsilon \equiv s_2 + 3s_2s_1 + (s_1 - 1)s_1$.

Comparison between the profits of the two cases shows that $\Pi_{1,2}^{SS*} > \Pi_2^{SS*}$. As a consequence, the monopoly always offers the tow goods on the market even if there are no supplier powers and the high quality is costless. With a Shaked-Sutton utility function, having a cost advantage is not a reason to offer a pooling menu.

1.5.2 Vertically separated markets (With supplier powers)

Supposing that the monopolist has to enter negotiations with the suppliers if he wants to send the product on the final market. As with the Mussa and Rosen utility function, the cases with exclusive and non-exclusive producers are studied and compared.

1.5.2.1 Exclusive contracts

The equilibrium values at the stage 3 are

$$p_i^{SSa} = \frac{b(s_i - 1) + s_i v_i}{2s_i}$$

$$D_i^{SSa} = \frac{b(s_i - 1) - s_i v_i}{2(s_i - 1)}$$

By plugging the price back into the monopolist and supplier profits respectively we find

$$\Pi_i^{SSa} = \frac{b^2(s_i - 1)^2 - 2b(s_i - 1)s_i v_i + s_i(s_i v_i^2 - 4f_i(s_i - 1))}{4s_i(s_i - 1)}$$

$$\pi_i^{SSa} = f_i - \frac{v_i(b(1 - s_i) + s_i v_i)}{2(s_i - 1)}$$

Resolving the bargaining stage

$$B^{SSa}(v_i, f_i) = [\Pi_i^{SSa}(v_i, f_i)]^\mu [\pi_i^{SSa}(v_i, f_i)]^{(1-\mu)}$$

with respect to v_i and f_i yields

$$v_i^{SSa*} = 0$$

and

$$f_i^{SSa*} = (1 - \mu) \frac{b^2(s_i - 1)}{4s_i}$$

with $i = 1, 2$ and $\mu = \alpha$ (respectively β) is still the bargaining power of the monopolist facing the high(respectively low) quality supplier.

In this case the variable part of the tariff is also set so as the vertically separated firms attain full monopoly profit and that profit is apportioned according to the sharing rule determined by the bargaining weights.

By plugging the optimal two-part-tariff back into price, demand and profits, we obtain:

$$p_i^{SSa*} = p_i^{SS*} \quad D_i^{SSa*} = D_i^{SS*} \quad (1.9)$$

$$\Pi_i^{SSa*} = \mu \Pi_i^{SS*} \quad \pi_i^{SSa*} = (1 - \mu) \Pi_i^{SS*} \quad (1.10)$$

If committed to an exclusive relationship, the monopolist signs a contract with the high quality producer if, and only if:

1) $\alpha > \beta$ i.e. his bargaining power with the high supplier is higher than with the low supplier¹⁹; or

2) $\alpha = \beta$ and $s_2 > \frac{\alpha s_1}{\alpha s_1 + \beta(1 - s_1)}$; or

3) $\alpha < \beta$, $1 < s_1 < \frac{\beta}{\beta - \alpha}$ and $s_2 > \frac{\alpha s_1}{\alpha s_1 + \beta(1 - s_1)}$ i.e. if the quality of the upper product is sufficiently high with respect to the quality of the under product.

1.5.2.2 Non-exclusive contracts

Continuing to use the same framework as in the first case, the monopolist may sign a contract with both producers and, thus in stage 3, sell both goods to the final consumers. In this case his profit is written as $\Pi_{1,2}^{SSb} = \sum_{i=1}^2 [(p_i - v_i)D_i(p_1, p_2) - f_i]$.

Standard computations yield the optimal prices at this stage:

$$p_2^{SSb}(v_2, f_2) = \frac{s_1(2b(s_2 - 1) + (2s_2 + s_1 - 1)v_2 + v_1 - s_2v_1)}{\Upsilon}$$

$$p_1^{SSb}(v_1, f_1) = \frac{b(s_1 - 1)(s_2 + s_1) + s_2((s_1 - 1)v_2 + (s_1 + 1)v_1)}{\Upsilon}$$

In stage 2, the two Nash products are given by

$$B_1^{SSb}(v_1, v_2, f_1, f_2) = [\Pi^{SSb}(v_1, v_2, f_1, f_2) - \Pi_2^{SSa*}]^\beta [\pi_1^{SSb}(v_1, v_2, f_1)]^{(1-\beta)} \quad (1.11)$$

$$B_2^{SSb}(v_1, v_2, f_1, f_2) = [\Pi^{SSb}(v_1, v_2, f_1, f_2) - \Pi_1^{SSa*}]^\alpha [\pi_2^{SSb}(v_1, v_2, f_2)]^{(1-\alpha)} \quad (1.12)$$

The joint maximization of (1.11) and (1.12) with respect to (v_i, f_i) , $i \in \{1, 2\}$ yields the

¹⁹We notice that we also have $\Pi_2^{SS*} > \Pi_1^{SS*}$ as we saw earlier

equilibrium two-part-tariffs with non-exclusive contract as shown below

$$v_1^{SSb*} = 0, \quad f_1^{SSb*} = \frac{b^2(s_1 - 1)(1 - \beta)[\alpha(s_2 - 1)s_1(s_2 - s_1) + (1 - \alpha)\beta s_2 \Upsilon]}{4s_2 s_1 \Upsilon \Phi}$$

and

$$v_2^{SSb*} = 0, \quad f_2^{SSb*} = \frac{b(1 - \alpha)[\alpha(s_2 - 1)s_1 \Upsilon + \beta(s_2(s_2 - s_1)(1 + s_1)^2 - \alpha \Upsilon s_1(s_2 - 1))]}{4s_2 s_1 \Upsilon \Phi}$$

By plugging these values back into the equilibrium prices and demands we obtain

$$p_2^{SSb*} = \frac{2b(s_2 - 1)s_1}{\Upsilon}, \quad p_1^{SSb*} = \frac{b(s_1 - 1)(s_2 + s_1)}{\Upsilon}, \quad (1.13)$$

$$D_2^{SSb*} = \frac{bs_2(1 + s_1)}{\Upsilon}, \quad D_1^{SSb*} = \frac{b(s_2 - 1)s_1}{\Upsilon}. \quad (1.14)$$

Since $v_i^{SSb*} = 0, i \in \{1, 2\}$, the profit of the upstream firms coincide with the fixed fee of the two-part-tariff: $\pi_i^{SSb*} = f_i^{SSb*}$. The profit of the downstream monopolist is

$$\begin{aligned} \Pi_{1,2}^{SSb*} = \\ \frac{b^2[\alpha^2 s_1(s_2 - 1)\Upsilon + \alpha\beta s_1(s_2 - 1)(s_2(s_1(4 - 3\alpha) - \alpha) - \alpha s_1(s_1 - 1)) + (1 - \alpha)\beta^2 s_2(s_1 - 1)\Upsilon]}{4s_2 s_1 \Upsilon \Phi} \end{aligned} \quad (1.15)$$

To summarize the results, we propose the following:

Proposition 2. *Let $(\alpha, \beta) \in]0, 1[$. The monopolist*

- (i) *always signs contracts with both suppliers*
- (ii) *sells the two varieties on the market.*

Proof. $\forall (\alpha, \beta) \in]0, 1[$

$$(i) \quad \Pi_{1,2}^{SSb*} > \max[\Pi_1^{SSa*}, \Pi_2^{SSa*}]$$

$$(ii) \quad D_1^{SSb*} > 0 \quad D_2^{SSb*} > 0 \quad \square$$

With a Shaked-Sutton utility function, the monopolist always finds it optimal to sign non-exclusive contracts and to send both varieties on the final market despite the cost advantage of the high quality good and the costly contract with the second supplier.

To understand the difference between the results obtained in the two first parts, the Mussa and Rosen and the Shaked and Sutton utility functions must be observed in details. The big

divergence between the two functions is that, in the first case (Mussa and Rosen) consumers are distributed according to their taste of the quality and that in the second one (Shaked-Sutton) they are distributed according to their income. If we look deeper, according to Mussa and Rosen (1978), consumers always attribute the same utility to an increase in quality (the marginal rate of substitution MRS is always constant and equal to θ). However, according to the hypotheses of Shaked-Sutton (1982) we can notice two things. First the higher the quality gets, the less the incentive to pay more to increase it becomes. Second, rich consumers are willing to pay more for the quality than poor ones ($MRS = \frac{tp_i}{s_i}$). This implies that the competition between varieties under the Mussa and Rosen utility function is higher and this competition explains the risk of the cannibalization effect. However under the Shaked-Sutton utility function the products are much less in direct competition and the monopoly is able to capture a higher profit by offering a high quality at a high price variety to rich consumers and low quality at low price to poor consumers.

1.6 Bowley-Spence-Dixit utility

Assume a representative consumer characterized by a utility function $U(q_1, q_2) = \lambda_1 q_1 + \lambda_2 q_2 - \frac{1}{2}(q_1^2 + 2\gamma q_1 q_2 + q_2^2)$ with q_i the quantity of the good $i \in \{1, 2\}$ (Bowley, 1924; Spence, 1976; Dixit, 1979). We assume that the goods are substitutes with γ representing the substitutability degree ($0 < \gamma < 1$: higher γ corresponds to higher level of substitutability). We also assume that good 2 has a higher demand intercept than good 1 ($\lambda_2 > \lambda_1 > 0$). The demands are written $D_1(p_1, p_2) = \frac{(\lambda_1 - p_1) - \gamma(\lambda_2 - p_2)}{1 - \gamma^2}$ and $D_2(p_1, p_2) = \frac{(\lambda_2 - p_2) - \gamma(\lambda_1 - p_1)}{1 - \gamma^2}$ when both goods are supplied; and $D_i(p_i) = \lambda_i - p_i$ when variant i only is offered.

1.6.1 Benchmark case: Vertically integrated market (No supplier powers)

The monopolist can put both varieties on the market depending on the level of the substitutability degree γ .

His profit is therefore $\Pi_{1,2}^{BSD}(p_1, p_2) = \sum_{i=1}^2 [p_i D_i(p_1, p_2)]$ and maximizing it with respect to

price yields:

$$p_i^{BSD*} = \frac{\lambda_i}{2}$$

$$D_1^{BSD*} = \frac{\lambda_1 - \gamma\lambda_2}{2(1 - \gamma^2)}$$

$$D_2^{BSD*} = \frac{\lambda_2 - \gamma\lambda_1}{2(1 - \gamma^2)}$$

$$\Pi_{1,2}^{BSD*} = \frac{\lambda_1^2 + \lambda_2^2 - 2\gamma\lambda_1\lambda_2}{4(1 - \gamma^2)}.$$

$D_1^{BSD*} > 0$ if and only if $0 < \gamma < \frac{\lambda_1}{\lambda_2}$. Said another way, the demand of the low quality good is positive if the two products are not strongly substitutable.

If $\frac{\lambda_1}{\lambda_2} < \gamma < 1$ the monopolist sells only the high quality variant of the good at the final market, the demand is as

$$D_2^{BSD}(p_2) = \lambda_2 - p_2$$

Monopolist maximizes his profit function with respect to price

$$\Pi_2^{BSD} = p_2 D_2$$

yielding:

$$p_2^{BSD*} = \frac{\lambda_2}{2},$$

$$D_2^{BSD*} = \frac{\lambda_2}{2}$$

and

$$\Pi_2^{BSD*} = \frac{\lambda_2^2}{4}.$$

Result 1. (i) for $0 < \gamma < \frac{\lambda_1}{\lambda_2}$ i.e. the two products are poor substitutes, the monopolist sells both goods;

(ii) for $\frac{\lambda_1}{\lambda_2} < \gamma < 1$ i.e. the two products are high substitutes, the monopolist sells only the good 2 with the higher demand intercept.

Proof. (i) for $0 < \gamma < \frac{\lambda_1}{\lambda_2}$, $D_1^{BSD*} > 0$ and $\Pi_{1,2}^{BSD*} > \Pi_2^{BSD*}$

(ii) for $\frac{\lambda_1}{\lambda_2} < \gamma < 1$, $D_1^{BSD*} < 0$

□

1.6.2 Vertically separated markets (With supplier powers)

1.6.2.1 Exclusive contracts

Stage 3. The pricing stage profit for the monopolist is $(p_i - v_i)D_i(p_i) - f_i$, which is maximized for $p_i^{BS Da}(v_i) = \frac{\lambda_i + v_i}{2}$.

By plugging the price back into profit function we find

$$\Pi_i^{BS Da}(v_i, f_i) = \frac{(\lambda_i - v_i)^2}{4} - f_i$$

The profit of supplier i is

$$\pi_i^{BS Da}(v_i, f_i) = \frac{(\lambda_i - v_i)v_i}{2} + f_i$$

Stage 2. The Nash product is

$$B_i^{BS Da}(v_i, f_i) = [\Pi_i^{BS Da}(v_i, f_i)]^\mu [\pi_i^{BS Da}(v_i, f_i)]^{1-\mu}$$

with $i = 1, 2$ and $\mu = \alpha$ (respectively $\mu = \beta$) if, and only if $i = 2$, (respectively $i = 1$).

Maximization of $B_i^{BS Da}(v_i, f_i)$ with respect to v_i and f_i gives

$$v_i^{BS Da)*} = 0 \quad f_i^{BS Da)*} = \frac{(1 - \mu)\lambda_i^2}{4}$$

By plugging the optimal two-part-tariff back into price, demand and profits we obtain:

$$p_i^{BS Da)*} = D_i^{BS Da)*} = \frac{\lambda_i}{2}$$

$$\Pi_i^{BS Da)*} = \mu \frac{\lambda_i^2}{4}$$

$$\pi_i^{BS Da)*} = (1 - \mu) \frac{\lambda_i^2}{4}$$

If committed to an exclusive relationship, the monopolist signs a contract with the high- (respectively low-)quality producer if, and only if, $\Pi_2^{BS Da)*} > \Pi_1^{BS Da)*} \Leftrightarrow \frac{\alpha}{\beta} > \left(\frac{\lambda_1}{\lambda_2}\right)^2$ (respectively $\Pi_2^{BS Da)*} < \Pi_1^{BS Da)*} \Leftrightarrow \frac{\alpha}{\beta} < \left(\frac{\lambda_1}{\lambda_2}\right)^2$).

1.6.2.2 Non-exclusive contracts

The monopolist's profit is therefore

$$\Pi_{1,2}^{BSDb}(p_1, p_2) = \sum_{i=1}^2 [(p_i - v_i)D_i(p_1, p_2) - f_i], \quad (1.16)$$

Stage 3. Standard computations yield the optimal prices:

$$p_i^{BSDb}(v_i, f_i) = \frac{\lambda_i + v_i}{2} \quad i = 1, 2$$

Accordingly, the profits of the monopolist, the producer of good 2 and the producer of good 1 are

$$\Pi_{1,2}^{BSDb}(v_1, v_2, f_1, f_2) = \frac{(v_2 - \lambda_2)^2 + (v_1 - \lambda_1)(v_1 - \lambda_1 + 2(\lambda_2 - v_2)\gamma)}{4(1 - \gamma^2)} - t_1 - t_2,$$

$$\pi_2^{BSDb}(v_1, v_2, f_2) = \frac{v_2(v_2 - \lambda_2 + (\lambda_1 - v_1)\gamma)}{2(\gamma^2 - 1)} + f_2$$

and

$$\pi_1^{BSDb}(v_1, v_2, f_1) = \frac{v_1(v_1 - \lambda_1 + (\lambda_2 - v_2)\gamma)}{2(\gamma^2 - 1)} + f_1$$

Stage 2. The monopolist simultaneously bargains over the two-part-tariff with the two producers, the two Nash products are

$$B_1(v_1, v_2, f_1, f_2) = [\Pi(v_1, v_2, f_1, f_2) - \alpha \frac{\lambda_2^2}{4}]^\beta [\pi_1(v_1, v_2, f_1)]^{1-\beta}, \quad (1.17)$$

$$B_2(v_1, v_2, f_1, f_2) = [\Pi(v_1, v_2, f_1, f_2) - \beta \frac{\lambda_1^2}{4}]^\alpha [\pi_2(v_1, v_2, f_2)]^{1-\alpha}. \quad (1.18)$$

The joint maximization of (1.17) and (1.18) yields

$$v_1^{BSDb*} = 0 \quad f_1^{BSDb*} = \frac{(1 - \beta)(\alpha(\lambda_1 - \lambda_2\gamma)^2 + \beta\lambda_1^2(1 - \alpha)(1 - \gamma^2))}{4\Phi(1 - \gamma^2)}$$

and

$$v_2^{BSDb*} = 0 \quad f_2^{BSDb*} = \frac{(1 - \alpha)(\beta(\lambda_2 - \lambda_1\gamma)^2 + \alpha\lambda_2^2(1 - \beta)(1 - \gamma^2))}{4\Phi(1 - \gamma^2)}.$$

By plugging these values back into the equilibrium prices and demands we obtain

$$p_1^{BS Db)*} = \frac{\lambda_1}{2} \quad D_1^{BS Db)*} = \frac{\lambda_1 - \lambda_2 \gamma}{2(1 - \gamma^2)}$$

and

$$p_2^{BS Db)*} = \frac{\lambda_2}{2} \quad D_1^{BS Db)*} = \frac{\lambda_2 - \lambda_1 \gamma}{2(1 - \gamma^2)}.$$

Direct inspection of $D_i^{BS Db)*}$, $i \in \{1, 2\}$ reveals that :

Remark 1. With non-exclusive contracts, as in the benchmark case, the demands for the goods are simultaneously positive if, and only if, $0 < \gamma \leq \frac{\lambda_1}{\lambda_2}$ otherwise only good 2 has a positive demand.

Since $v_i^{BS Db)*} = 0$, the profits of the upstream firms coincide with the fixed fee of the two-part-tariff: $\pi_i^{BS Db)*} = f_i^{BS Db)*}$, with $i \in \{1, 2\}$.

The profit of the downstream monopolist

$$\Pi_{1,2}^{BS Db)*} \equiv \frac{(\alpha^2 \lambda_2^2 (1 - \beta) + \lambda_1^2 \beta^2 - \alpha \lambda_1^2 \beta^2)(1 - \gamma^2) + \alpha \beta (\lambda_1^2 + \lambda_2^2 - 2\lambda_1 \lambda_2 \gamma)}{4\Phi(1 - \gamma^2)}. \quad (1.19)$$

Comparing the monopolists profits with exclusive and non-exclusive contracts, we state the following;

Proposition 3. *With the Bowley-Spence-Dixit utility function,*

- (i) *the monopolist always signs contracts with both the high- and low-quality producers*
- (ii) *the degree of substitutability influences the monopolist variety choice on the final market.*

Proof. (i) $\Pi_{1,2}^{BS Db)*} > \Pi_i^{BS Da)*}$
(ii) *for* $\frac{\lambda_1}{\lambda_2} < \gamma < 1$, $D_1^{BS Db)*} = 0$ □

To sum up, the three utility functions give the same result: the introduction of a second supplier on the intermediate market is a means to increase the trading power of the downstream monopoly but this has no impact on the strategy of product diversification in the final market.

1.7 Conclusion

Sometimes we notice behaviours on the market that seem counter-intuitive at the first glance. However, these behaviours meet the basic standard of microeconomics i.e. any action providing a gain greater than its cost must be undertaken. This is the case in our model where a monopolist always contracts with both suppliers regardless whether it sells one or both goods on the final market. It seems comprehensible that the monopoly makes business with both suppliers in the latter case; however it is less obvious when it sells only one good. The reason of such behaviour is purely strategic. Indeed, since the two-part-tariff contracts allow the replication of industry integrated performance without any distortion, the monopoly always finds profitable to choose the market configuration, pooling vs separating, that offers the highest integrated profit (the highest pie to share). However, on the upstream market, the monopoly always finds it profitable to maintain the second supplier on the market even with leaving her a positive margin and not selling her product to final consumers. This is a monopoly strategy to introduce competition in the upstream side and enhance his bargaining power facing the principal supplier. To recap, contracting with both suppliers is a means to get a larger part of the total pie but bargaining power stakes never impact the size of the pie it-self. Interestingly, this result clearly shows that a low-quality product that should disappear after the introduction of an innovation may stay on the market only to assure some competition on the upstream market.

A first route of extending these results, developed in the next chapter, is to explore the applicability of similar two-part-tariff contracts in a model where R&D for abatement technology replace the introduction of a new supplier and the consequences of such behaviour on a welfare-maximizing regulator. Much other possibilities of extending remain to be undertaken like enlarging the setup to allow for oligopolistic competition either on downstream or upstream market (or on both) as well as allowing other contractual designs and other types of beliefs to be accounted for. These tasks, however, are left for future research.

Chapter 2

Monopoly and Abatement Technology Choice: The Impact of Environmental Taxes and Bargaining¹

2.1 Introduction

In response to economic and ecological crises that are becoming increasingly pressing, governments are trying to promote environmental innovations as shown, for example, by the European commission report "Europe 2020" that followed the report of Lisbon (2000a). Environmental innovations are typically divided in two distinct types: end-of-pipe solutions and clean technologies. The former occurs at the end of production process to mitigate environmental impacts of economic activities without changing the production process itself. In contrast, clean innovations, which are generally argued as being preferable in the long run (Fronzel et al., 2008, Porter and Van der Linde, 1995, Yarime, 2007), minimize pollution at source by using cleaner inputs and production methods. However, in most cases they require an intensive change in productive systems and a significant commitment in terms of financial and human resources. More than thirty years after the creation of environmental policies, it is strikingly obvious to note that the majority of technologies used are end-of-pipe solutions (Hammar and Löfgren, 2010).

The purpose of this paper is to contribute to environmental literature by examining the environmental innovation and technology adoption decisions in vertical chains. Indeed, while studies examining the impact of environmental regulations on innovation are widespread², only few papers have tried to address the issue of investment and technology

¹This chapter is written in collaboration with Oliwia Kurtyka

²See the excellent surveys of Jaffe et al. (2003) and Requate (2005).

choice. Our framework challenges the hypothesis that abatement technology is done only by eco-industries and assumes that eco-innovation can be done by the polluter as well. We suppose a monopolist liable to an environmental taxation has a possibility either to buy an end-of-pipe technology from an independent eco-supplier³ or to develop a clean technology on his own. This type of in-house innovation is supported by empirical research. [Lanjouw and Mody \(1996\)](#) estimate that worldwide 20% of patents for pollution control technologies are taken up by polluting firms. So the polluter can develop R&D activities for clean technologies in order to use it or to increase his strategic advantage over an existing supplier of an end-of-pipe solution. In our setting the end-of-pipe supplier has a mature technology and she does not invest in further research.

The contribution of the paper to the literature on strategic use of innovation is twofold. First, we explain that the adoption of abatement technology is a result of a competition between different types of technologies. The clean technology developed by the downstream firm is more efficient in abating the pollution (but more expensive) while the end-of-pipe technology sold by an upstream firm is cheaper but results in lower abatement. Second, we study how environmental policy should be adjusted when innovation is used strategically in vertical chains. To this end, we develop a simple vertical relationship model with three players: 1) the regulator who fixes an environmental tax to mitigate the environmental damage due to the economic activities of the monopoly; 2) a downstream firm generating by-product emissions of a harmful pollutant and facing a price-sensitive consumer demand on the final market; and 3) an upstream eco-industry supplier who develops an end-of-pipe technology that it licenses to the polluting firm. Our primary focus is on a case where the polluter innovates and carries on a bargaining deal with the eco-supplier. However, for completeness we also consider the case when eco-supplier drops out of market or no innovation is undertaken⁴. We discuss the role of regulator in such situations. As expected, we show that the introduction of the environmental tax necessarily involves the use of an environmental abatement technology. However, under certain conditions, the problem of under or over-investment may nevertheless persist. They stem from the misalignment of interests between the regulator and innovating firm.

Industrial choices will have different consequences on welfare depending on R&D in-

³[David and Sinclair-Desgagné \(2005\)](#) launched the literature on the independent eco-industry supplying abatement goods and services to a polluting industry.

⁴Furthermore, the discontinuity in the polluting firm's profit function is considered, but all calculations are relegated to the appendix.

centives. From the welfare point of view, the duplication of R&D expenses is unwarranted in case of purely substitutable nature of innovations. In our model the two types of innovation are not perfect substitutes. The technology developed by the polluting firm is more efficient in terms of emissions abated. This stems from the fact that he has more precise knowledge concerning their production process, materials used and potential for change. Hence duplication of R&D procures the social planner a benefit from higher pollution abatement. Intuitively, this should decrease regulator's incentive to be more complacent when firms innovate. Moreover, investment impacts not only marginal abatement costs but also production cost. The direction of the impact is unknown. In reality, the impact of clean technologies on variable cost can be either positive or negative depending on the technology in question. For example, paper industry in Sweden moved to a closed-loop production process and its variable costs consequently decreased. The same applies to solar electricity production. However, for biological agriculture, moving to no pesticide production increases the costs (or decreases the agricultural yields). Since the clean technology changes production level, this additionally has an impact on the size of the total pie produced in the economy and therefore changes regulator's approach to innovation. We show that the size of the total pie produced in the economy may increase or decrease as a result of innovators' competition; and that even if the impact on production cost is positive (i.e. it becomes more expensive to produce) the polluter and the regulator have interests in developing this option, however the reasons are different.

We derive some surprising results. The polluting firm may have interest in innovating whereas the regulator prefers the end-of-pipe technology to be adopted therefore leading to over-investment. This comes from the fact that innovation does not necessarily imply that the clean technology would prevail. The intuitively convincing reason for this result is that the polluter decides to innovate in order to increase his bargaining power. For the regulator, the resulting solution represents only the transfer of benefits between eco-supplier and polluter, a transfer that is costly from the society's point of view. In such a region of over-investment, the regulator must adapt its taxation in order to deter the polluter from innovating only for bargaining reasons. The regulator may also be opposed to the research even if the resulting technology is used by the innovator when the social cost exceeds the environmental benefit. Sometimes when the clean technology is preferable from the welfare point of view, this preference is not shared by the polluting firm and the regulator has to

intervene to make it profitable. However, in both regions of over and under-investment, under some parameter values, the regulator might not be able to deter or encourage the innovation and suboptimal situations may nevertheless occur.

The paper is organized as follow. Section 2 reviews existing literature, section 3 sets up the model. Section 4 and 5 characterize the production and bargaining stage. Section 6 turns toward R&D incentives. The question of the regulation response is explored in section 7. Finally, a conclusion is drawn.

2.2 Literature review

In empirical field on different types of technology, [Fronzel et al. \(2008\)](#) and [Hammar and Löfgren \(2010\)](#) analyse factors that may enhance firm's propensity to implement clean technologies rather than end-of-pipe ones. [Fronzel et al. \(2008\)](#) use a survey on OECD firms and find that environmental regulations are more likely to lead to the adoption of end-of-the-pipe solutions and that market forces, such as cost savings or environmental management tools lead to the adoption of cleaner production processes. On the other hand, [Hammar and Löfgren \(2010\)](#) use a panel of Swedish firms to test for other explanatory variables. They find that learning by doing and knowledge, measured by expenditures on green R&D, increase the probability of investment in clean technologies. In contrast, the size of firms measured by the revenue and energy prices are important determinants for investing in the end-of-pipe technologies. In theoretical literature few papers have recently begun to investigate the question of abatement technology choice. [Meunier and Nicolai \(2012\)](#) show that, depending on the type of technology used, the impact of environmental regulation on firms' profits can be either positive or negative. In the same logic, [Christin et al. \(2013\)](#) study the effect of a cap-and-trade system on industry profits under imperfect competition and highlight that the abatement technology type is fundamental to answer this question. They show that industries that use process-integrated technologies are more affected than those using end-of-pipe abatement technologies.

Early approaches to environmental innovation assume that a polluter is also an innovator and that a technological discovery results in a downward shift in the marginal abatement curve ([Milliman and Prince, 1989](#); [Montero, 2002a](#)). This initial hypothesis was soon replaced with vertical structure considerations. [Parry \(1998\)](#) models the R&D sector as a

competitive free entry sector where the innovator gets a patent and sells the discovery to polluting firms. At the same time, alternative assumptions on the impact of innovation cost structure appear. [Requate \(1998\)](#) was the first to consider that innovation leads to a lower rate of emissions per output but at the same time imposes a higher marginal cost of production. [Requate \(2003\)](#) models the R&D sector as a monopolistic one with a certain probability of discovery whereas the polluting firms have heterogeneous abatement costs. The innovation decreases those costs but to a different degree i.e. the innovation may be more suitable to some firms and less to others. This kind of modelling is consistent with the end-of-pipe type of abatement.

In majority of papers on environmental innovation in vertical relationships it is assumed that only the upstream firm is responsible for innovation. However, [Nimubona and Sinclair-Desgagné \(2010\)](#) allow for different sourcing of technology to be used: in-house technology and an outsourced one from independent supplier. Moreover, they show that the existence and performance of eco-industry depend on the substitutability or complementarity of technologies. Using a model of vertical relationship between a regulated polluting firm and a specialized eco-industry supplier, [Heyes and Kapur \(2011\)](#) allow both sectors to perform on their own R&D and develop perfectly substitutable abatement technologies. They show that the polluting firm can develop the technology to enhance its bargaining power against the supplier. Equivalently, in our model, the negotiation between the two vertically related firms relies on the adoption of the Nash bargaining solution through a two-part-tariff contract⁵ and the polluting firm can improve his outside option through innovation. This particular point links us to the literature dealing with firms' make-or-buy choices with the related contractual and investment problems that could arise from the latter. For example [Bacchiega and Bonroy \(2015\)](#) show that efficient two-part-tariff contracts can modify the structure of the downstream market by lowering the number of competitors and hence may make the consumers worse-off. [Battigalli et al. \(2007\)](#), using a take-it-or-leave-it process with no restriction on the type of contracts offered, argue that a supplier's incentive to improve quality in vertically-differentiated market is inversely proportional to the buyer power. [Lambertini \(2016\)](#) raise the question about the design of optimal contracts in a dynamic model and demonstrates that the two-part-tariff contract with a linear fixed fee with respect to R&D in-

⁵In the standard literature on vertical relations and supply chain coordination, the two-part-tariffs contracts are widely used since it overcomes the double marginalization problem ([Tirole, 1988](#), [Muthoo, 1999](#), [Cachon, 2003](#))

vestment (or product quality) allow the replication of the vertically integrated monopolist's outputs in terms of profit, R&D investment coordination and product quality.

Our paper addresses the issue of the strategic use of innovation in the supply chain. The literature in this field is abundant, however, few papers study innovation decision taken vis-à-vis suppliers. Most of them study horizontal R&D, i.e. where research is led by firms that are competitors on the product market. In such pure horizontal R&D set-up, a firm's cost-reducing investment results from two effects: a cost minimizing effect and a strategic effect (Montero et al., 2002b). The latter enables the innovator to steal market share from its rivals without affecting their cost structures. Vertical R&D are also studied but to a smaller extent. Banerjee and Lin (2003) analyse R&D decisions in vertically related industries and find that downstream firms have more incentives to innovate if a price adjustment by the input supplier leads to a higher production cost for all rival firms. Biglaiser and Horowitz (1994) examine research and adoption decisions where innovation decreases emissions. They find that standards may discourage innovation as firms may prefer to adopt someone else's technology rather than innovate on their own.

Several papers focus on strategic innovations in order to influence regulatory policy (Puller, 2006; Requate, 2005). This strand of literature relates very much to the timing of the game and commitment issue. Requate (2003) shows, that when the regulator commits to regulation *ex ante* innovation, the optimal adjustment of its policy to overpricing problem by an R&D firm is to adopt taxes rather than permits. Moreover, an optimal policy for the regulator is to think of a menu of instruments conditional on innovation. The earlier the regulator acts, the higher the welfare given some flexibility over instrument setting is reached. When regulation is set *ex post* innovation two countervailing incentives drive firms' innovation decisions. First, when regulator cannot commit to a policy, firms have lower incentives to innovate as they expect the regulator to ratchet up the policy once the innovation developed (Puller, 2006). This may happen in order to expropriate gains that occur to innovators. Second, when rising rival costs becomes possible as well (Salop and Scheffman, 1987), firms may decide to increase their R&D to influence positively the policy and penalize their competitors (Puller, 2006). Note that in presence of rent seeking behaviour unbiased regulator is not welcomed. Heyes and Kapur (2011) show, that there is a need for the social planner to delegate the regulation to an unbiased authority in order to correct for the regulatory influence and the consequent underinvestment.

Literature on the topic of environmental policy in vertical chains is scarce. [David and Sinclair-Desgagné \(2007\)](#) were the first to consider environmental regulation in vertical chains. They show that combining an emission tax to a subsidy to polluters cannot lead to first-best, while the opposite conclusion holds if the subsidy is granted instead to eco-industry. [David et al. \(2011\)](#) point out that when abatement is provided by an oligopolistic eco-industry with free-entry, the optimal emission tax may exceed, fall short or be equal to the Pigouvian rate, depending on its effect on total abatement supply relative to entry in the eco-industry. However, innovation is absent in their framework. [Biglaiser and Horowitz \(1994\)](#) find that technology adoption standards are part of the optimal regulation. They also show that making the adoption standard stricter reduces research. To the best of our knowledge, this paper is the first one to consider innovation with different types of technologies and regulatory attitudes in the same setting. In the empirical field, [Franco and Marin \(2015\)](#) test the impact of environmental taxes within the supply-chain on innovation and productivity. They find that regulation on downstream sectors encourages more the innovation.

2.3 The model

A firm with a monopoly power faces a linear demand function $D(p) = a - bp$ where a and b are positive parameters and p is the price on the final market. Production costs are quadratic $\delta D(p)^2$, with $\delta > 0$. While producing, the firm generates pollution e as a by-product of his business activity. A pollutant e is proportional to output $D(p)$ and given by $e = \theta D(p)$. For simplicity we assume that $\theta = 1$.

An environmental tax t is imposed by a regulator on the polluting firm in order to motivate him to undertake costly abatement. The polluting company has two options to address this regulation: to continue polluting and pay the tax on total emissions or to use a technology to abate some or all emissions. In case the decision to abate is taken, the polluter must decide on the type of technology he will use. The abatement technology stems from two different sources: internal research done by the polluter himself that modifies his production process (and therefore his production costs) or external licensing of an end-of-pipe equipment from an upstream supplier.

In our model, three points render the polluter's investment decision attractive. First, due to innovation, production costs may decrease. This motivates the polluter, other things equal,

to do research. Examples of such innovations can be found in a paper and pulp industry (bleaching technology) (Bergquist and Söderholm, 2015) as well as in metallurgy in quenching process. In case of the increase of production cost, this hampers the polluter's innovation incentives. This clearly applies to organic products where production becomes more expensive. Second, we assume that the internal technology, which is a process-integrated one, results in zero pollution level after adoption while the external end-of-pipe technology has a lower marginal efficiency of depollution and imposes an additional cost of adoption. In other words, the abatement technology efficiencies are different for the polluting firm's and the eco-supplier's technology. Third, the polluter is also motivated by the possibility to obtain a larger share of the profit when bargaining due to a higher outside option created by the new investment (see also Heyes and Kapur, 2011). However, this increase in bargaining position is done at a cost of technology development r . The polluter must incur this cost whether he carries on a deal with the eco-supplier or not. On the other side, total costs borne by the polluter when he uses the end-of-pipe technology are of four different types: production costs δ that remain unchanged with respect to no technology case, a two-part-tariff licence fee (whose value changes with the bargaining position), the adoption costs ω^2 for the technology where ω represents the level of abatement and finally the tax he owes to the regulator. The clean technology generates only two costs: production cost λ and the fixed R&D cost r . As production costs differ depending on the technology choice, this also modifies the output level and consequently the surplus of consumers- the impact that is neglected in literature on end-of-pipe type of equipment. The consequences of industrial choices thus differ from the welfare point of view. The regulator's choice of taxation is based on an evaluation of a welfare function including environmental damage. For the regulator, research and development is not sunk yet. When evaluating welfare, the regulator knows that it can influence the state of technology. From this point of view, we follow the literature on technology forcing regulation (see table 2.1).

For the sake of clarity, let us explicit the timing of the game as follows:

Stage 1) (Regulation) The regulator sets a pollution tax t for each unit of pollutant emitted e .

Stage 2) (R&D stage) The polluting firm decides whether or not to invest in R&D to develop a clean technology at a cost r . Once developed, the technology becomes a common knowledge.

Stage 3) (Bargaining) The polluter decides which option to choose: paying the tax without any abatement, using a process-integrated technology if such technology has been invented in stage 2, or bargaining with external eco-supplier to use the end-of-pipe technology.

Stage 4) (Production) The polluting firm decides on the price on the final market and the abatement level if any. As usual, we solve the model backwards.

Table 2.1: Summary of notation

Notation	Description
c	Subscript c denotes the clean technology
eop	Subscript eop denotes the end-of-pipe technology; "eop/∅" is used in the case where the clean technology is not developed when bargaining; "eop/c" is used when the clean technology is developed when bargaining
TA	Superscript TA denotes the case of total abatement
$D(p) = a - bp$	Linear demand function with a and b positive parameters
p	The price per unit on the final market
$\delta D(p)^2$	Initial production costs with $\delta > 0$
$\lambda D(p)^2$	Production costs using clean technology with $\lambda > 0$
r	R&D investment
ω^2	Adoption costs of the end-of-pipe technology with ω is the performance of the technology
(v, f)	The two-part-tariff contract for end-of-pipe equipment with v the per-unit charge and f the lump-sum fee
$e = \theta D(p)$	Initial polluting emissions θ assumed to be equal to 1 for simplicity
t	Environmental tax
$(e - \omega)^2$	Environmental damage
W	Welfare

In our analysis, we rely on the assumption on r detailed below.

Assumption 2.1: We suppose that R&D cost is as follows:

$$0 \leq r \leq \frac{a^2}{4b(1+b\lambda)} \quad \text{if } \lambda > \delta \quad (2.1)$$

$$\frac{a^2}{4b(1+b\lambda)} - \frac{a^2}{4b(1+b\delta)} \leq r \leq \frac{a^2}{4b(1+b\lambda)} \quad \text{if } \lambda < \delta.$$

These assumptions ensure that the polluter's profit is positive when using clean technology but the use of this technology is never profitable before the introduction of a tax.

2.4 Production

Let p_θ^* , p_c^* , p_{eop}^* denote the equilibrium prices absent abatement technology, with clean technology and with end-of-pipe equipment respectively. ω^* on the other hand, represents the performance of the end-of-pipe technology. These strategic variables result from the following maximization programmes:

$$p_\theta^* = \arg \max_p \pi_\theta(p) = pD(p) - \delta D(p)^2 - tD(p), \quad (2.2)$$

$$p_c^* = \arg \max_p \pi_c(p) = pD(p) - \lambda D(p)^2 - r, \quad (2.3)$$

$$p_{eop}^*, \omega_{eop}^* = \arg \max_{p, \omega} \pi_{eop}^{down}(p, \omega) = pD(p) - \delta D(p)^2 - v\omega - f - \omega^2 - t(D(p) - \omega), \quad (2.4)$$

where r is a fixed R&D cost of clean technology, ω^2 adoption costs of end-of-pipe technology, (v, f) represent the two-part-tariff for end-of-pipe equipment and $\lambda, \delta > 0$ represent variable production costs. As mentioned above the relationship between λ and δ are industry specific.

Easy calculations show that as expected in the benchmark case with no abatement technology environmental, tax increases the price of the monopoly p_θ^* and consequently decreases the total demand $D^*(p_\theta^*)$ and the polluter's profit $\pi_\theta^*(p_\theta^*)$ ⁶. Monopoly decisions with clean technology are independent of environmental regulation as the firm generates no emissions. However, the decision about the development of clean technology is driven by the taxation. Indeed, when the clean technology increases variable cost of production ($\lambda > \delta$), the polluter never adopts this technology without environmental regulation. In addition, the higher R&D cost gets, the less incentivizing the technology development is (see appendix B.1.2). Contrary to the clean technology, taxation does influence the abatement decisions under the end-of-pipe technology. Note that production decisions with partial abatement⁷ are unaltered by the use of the end-of-pipe technology and are equal to the case where abatement technology is absent (see appendix B.1.3).

One element of this model merits some attention. When the polluting company has an access to end-of-pipe equipment, a problem of discontinuity in profit function with respect to abatement effort ω arises. For very strong taxation, the company may decide to abate

⁶All calculations are in the appendix B.1.1

⁷Partial abatement case happen when the polluter decides to not abate all the pollution emitted $e > \omega$

all his emissions. We can talk about a total abatement case. With moderate taxation, the abatement is partial. The threshold taxation is given by $t_{cont} = \frac{a}{1 + b(\delta + 1)} + \frac{v(1 + b\delta)}{1 + b(\delta + 1)}$. This issue is important and gives rise to an interesting result for welfare maximization, a result that is studied in regulation section.

Remark 2. (Production) Output decisions with no technology and with end-of-pipe technology and partial abatement are the same, whereas the production under clean technology differs depending on production cost change induced by innovation.

2.5 Bargaining

To acquire the end-of-pipe technology, the polluting monopoly bargains with an external company over a two-part-tariff contract (v, f) , where v is a per-unit charge and f is a lump-sum fee. We assume that the polluter's bargaining power in negotiations is $\alpha \in [0, 1]$ and $(1 - \alpha)$ is the bargaining power of the external supplier. The Nash product of bargaining is given by:

$$B(v, f) = (\pi_{eop}^{down} - \pi^{down})^\alpha (\pi_{eop}^{up} - \pi^{up})^{(1-\alpha)} \quad (2.5)$$

where π_{eop}^{down} as defined in (2.4) and $\pi_{eop}^{up} = v * \omega + f$ are the profits of the polluter and supplier respectively. The outside options for these companies, i.e. the alternative source of profits if negotiations fail, are given by π^{down} and π^{up} . We assume that the outside option of the supplier is zero. However, π^{down} , the outside option of the monopoly is positive. It is the profit from the clean technology or the profit without any technology if he chooses not to invest in R&D⁸. The results of the bargaining stage depend on which outside option prevails. Below, we solve the negotiation stage for the two cases.

2.5.1 No technology as the monopoly's outside option

When the polluter decides to not develop the clean technology, the Nash product of bargaining is given by

$$B_\emptyset(v, f) = (\pi_{eop}^{down} - \pi_\emptyset^*)^\alpha (\pi_{eop}^{up})^{(1-\alpha)} \quad (2.6)$$

⁸The outside option can be zero if the monopolist decides to not develop the clean technology and the tax imposed by the regulator is higher than $\frac{a}{b}$. However, like we will see later, this case never occurs since the regulator can put the tax higher than $\frac{a}{b}$ only to push the monopolist to use the clean technology.

where π_0^* is defined in (2.2). Maximizing $B_0(v, f)$ with respect to v and f gives $v^* = 0$ and $f^* = (1 - \alpha)(\Pi_{eop}^{Ind*} - \pi_0^*)$ where Π_{eop}^{Ind} is the profit generated by the integrated industry using the end-of-pipe technology and defined as follows:

$$\Pi_{eop}^{Ind*} = \max_{p, \omega} pD(p) - \delta D(p)^2 - \omega^2 - t(D(p) - \omega). \quad (2.7)$$

The total size of Π^{Ind} increases as the end-of-pipe technology is introduced. The reason is the following. The polluting company no longer pays the environmental tax as a part of its emissions are abated. The cost of adoption being lower than tax savings, this profits the industry. Remark that the double marginalisation problem is absent in our framework. The eco-supplier is licensing the technology at a zero marginal cost and extracting a part of the total gains in the form of a lump sum payment. The polluter's profit in this case is $\pi_{eop/\emptyset}^{down*} = \pi_0^* + \alpha(\Pi_{eop}^{Ind*} - \pi_0^*)$ and reflects the well-known result of the bargaining game. As the polluting monopoly has a positive outside option, this is the minimum amount it must receive from negotiations, the rest of the pie being shared with the eco-supplier according to bargaining powers (calculations are in the appendix B.2.1). The situation is slightly more complicated when the clean technology becomes an outside option.

2.5.2 Clean technology as the monopoly's outside option

When the polluter decides to develop the clean technology, the Nash product of bargaining is given by:

$$B_c(v, f) = (\pi_{eop}^{down} - \pi_c^*)^\alpha (\pi_{eop}^{up})^{(1-\alpha)}, \quad (2.8)$$

where the polluter's outside option $\pi_c^*(p)$ is equal to $\frac{a^2}{4b(1+b\lambda)} - r$.

Solving the maximization stage of $B_c(v, f)$ with respect to v and f yields $v^* = 0$ and $\pi_{eop/c}^{up*} = f^* = (1 - \alpha)[(\Pi_{eop}^{Ind*} - r) - \pi_c^*]$ for the eco-supplier and $\pi_{eop/c}^{down*} = \pi_c^* + \alpha[(\Pi_{eop}^{Ind*} - r) - \pi_c^*]$ for the polluting firm. Whenever $(\Pi_{eop}^{Ind*} - r)$ is higher (lower) than the outside option π_c^* of the polluting firm, this latter adopts the end-of-pipe (clean) technology.

Two points deserve particular scrutiny. First of all, the polluter's and eco-supplier's payoff can be expressed in the following way:

$$\pi_{eop/c}^{down*} = \pi_c^* + \alpha(\Pi_{eop}^{Ind*} - \pi_c^*) - \alpha r$$

and

$$\pi_{eop/c}^{up*} = (1 - \alpha)(\Pi_{eop}^{Ind*} - \pi_c^*) - (1 - \alpha)r$$

The first two elements follow the standard rules of equilibrium partition of the profit in the bargaining literature. They represent the need to compensate the parties for their outside options and the sharing rule for the remaining surplus (as for the case where no technology was available) (see [Muthoo, 1999](#)). Nevertheless, since the polluting firm undertakes a costly investment to increase its bargaining position, a part of the integrated industry profit is lost due to unnecessary innovation. The polluter's payoff decreases in consequence as shown by the third element of the profit $\pi_{eop/c}^{down*}$. Interestingly, the innovator does not cover all his investment costs. A part of these costs are passed on to the eco-supplier. In other words, the investment in new technology represents a loss for the integrated industry and therefore decreases the total size of industry profits available to both firms in bargaining process. However, the loss is shared by both downstream and upstream firm according to their bargaining powers.

Secondly, environmental taxation influences the integrated industry profits, Π_{eop}^{Ind} . Recall that the outside option π_c^* is independent of taxation. Whereas, the polluter's and eco-supplier's payoffs depend on taxation only through their impact on integrated industry profit. To sum up, the integrated industry profit, polluter's and eco-supplier's payoffs, and hence the incentive for bargain, decrease as taxation gets stronger (see the appendix [B.2.2](#)).

2.6 R&D stage

We turn now to R&D choices of the polluting company. This latter decides to undertake research for two reasons. First, it may innovate purely for bargaining considerations: this increases its negotiating position and hence the clean technology is not used once negotiations are concluded. This happens when two conditions are verified: the end-of-pipe technology is preferred to the clean one, $(\Pi_{eop}^{Ind} - r) > \pi_c^*$ and the clean technology is preferred as the outside option when bargaining, $\pi_c^* > \pi_0^* + \frac{\alpha}{1 - \alpha}r$. Second, the clean technology may be interesting in itself and the firm decides to innovate and to use it. This happens when $\pi_c^* > \max\{(\Pi_{eop}^{Ind*} - r); (\Pi_{eop}^{Ind} - (1 - \alpha)(\Pi_{eop}^{Ind} - \pi_0^*))\}$ ⁹. The above conditions are equivalent

⁹It means that the profit with clean technology is higher than the profit with end-of-pipe technology whatever the outside option.

to saying that as long as the clean profit lies within the $[\pi_\emptyset^* + \frac{\alpha}{1-\alpha}r, \Pi_{eop}^{Ind*} - r]$ range, the company undertakes research in order to boost its bargaining position (Figure 2.1). Once the profit obtained through the clean technology increases further, the polluting firm uses this technology and hence eliminates the eco-supplier from the market.

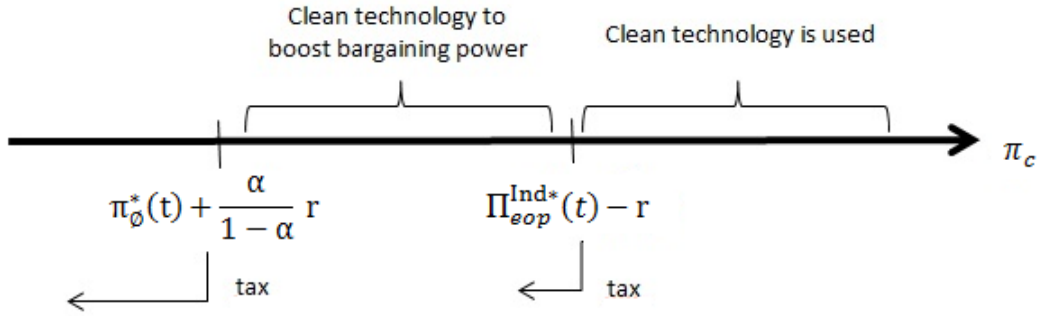


Figure 2.1: R&D incentives and impact of environmental taxation

Consider again the Figure 2.1. Environmental regulation changes both threshold levels for the case where the clean technology is used and where the technology is developed to boost the bargaining power only but not in the same rhythm. Taxation increases the incentive to develop the clean technology for its own use (the threshold $\Pi_{eop}^{Ind*}(t) - r$ decreases). This is due to the fact already mentioned above that integrated industry profits shrink with taxation, therefore there are less and less profit to share in bargaining. Furthermore, a close look at derivatives of $\Pi_{eop}^{Ind*}(t)$ and $\pi_\emptyset^*(t)$ with respect to taxation¹⁰ reveals that the lower threshold $(\pi_\emptyset^*(t) + \frac{\alpha}{1-\alpha}r)$ decreases faster than the upper threshold $(\Pi_{eop}^{Ind*}(t) - r)$. In other words, environmental policy, other things equal, makes the firm undertake innovation sooner but paradoxically, at the same time increases the polluting firm's likelihood to innovate but for the bargaining reasons only.

2.7 Regulation

We begin by examining the regulator's problem. Social welfare is the sum of consumers' surplus, profits of both (or just one) companies, tax revenue and environmental damage. As we have already mentioned in the introduction, environmental damage depends on technology choice in equilibrium. Note that the tax revenue for the government and taxes paid by

¹⁰ $\frac{\partial \Pi_{eop}^{Ind*}(t)}{\partial t} = -[D(p^*) - w^*]$ and $\frac{\partial \pi_\emptyset^*(t)}{\partial t} = -D(p^*)$.

Given that for both cases price and output are the same, the first impact will be smaller in absolute value due to abatement activity.

the polluting firm cancel out in the welfare formula. Under clean technology there are no emissions, so that taxation generates no revenues for the government. However, the level of environmental tax plays an important role as explained above. It makes the polluter undertake research and also decides for which purpose this technology is developed.

Recall that the main interest of the paper is to study firm's strategic use of innovation and regulator's optimal response to it. To this aim, we shall consider only two welfare functions: one resulting from the use of the clean technology and second resulting from the use of the end-of-pipe technology. We will first study the tax rule chosen by the regulator to maximize welfare under the end-of-pipe technology, then we will compare polluting firm's and regulator's preferences for the technology. Finally, we will discuss the regulator's options for reconciliation of interests of both parties.

2.7.1 Optimal taxation under end-of-pipe regime

Let W_c^* , $W_{eop}^*(t)$ denote welfare functions under clean and end-of-pipe technology respectively¹¹. These functions are given by the following equations:

$$W_c^* = \int_{p_c^*}^{a/b} D_c(p) dp + D_c^*(p_c^*) p_c^* - \lambda D_c^*(p_c^*)^2 - r, \quad (2.9)$$

$$W_{eop/\emptyset}^*(t) = \int_{p_{eop}^*}^{a/b} D_{eop}(p(t)) dp + p_{eop}^* D_{eop}(p^*(t)) - \delta D_{eop}(p^*(t))^2 - w^*(t)^2 - (D_{eop}(p^*(t)) - w^*(t))^2. \quad (2.10)$$

Note that we consider here only the case where end-of-pipe technology results in partial abatement¹². In addition, we consider only the welfare $W_{eop}^*(t)$ where profit with no technology is used as an outside option in negotiations. The reason for that is straightforward. From the welfare point of view, using clean technology in the bargaining process serves only to redistribute the industry profit in favour of the polluter. Consequently, the welfare decreases by the amount of the level of R&D expenses r . Maximization of the welfare function $W_{eop}^*(t)$ implies the maximization of the same welfare under different outside options.

Under the end-of-pipe solution, a tax must be imposed so as to force the polluter to buy

¹¹We showed earlier in appendix B.2.1 that the end-of-pipe regime always dominates the no-technology used one. Therefore, in the rest of the paper the latter regime is excluded from the study.

¹²The case of total abatement is available in appendix B.3.

abatement equipment. The regulator maximizes the welfare function $W_{ep}^*(t)$ with respect to a tax that yields the formula for the optimal tax (appendix B.4)

$$t^* = 2E + \frac{D(p^*(t))D_p(p^*(t))p_t(t^*)}{[D_p(p(t^*))p_t(t^*) - w_t(t^*)]} - \frac{w_t(t^*)v}{[D_p(p(t^*))p_t(t^*) - w_t(t^*)]}, \quad (2.11)$$

where $E = D(p(t)) - w(t)$ are emissions. First part of the above expression is the marginal damage - Pigouvian part of taxation. This has to be adjusted for the monopoly power of the polluting firm (second part of the expression) as in [Barnett \(1980\)](#). The third part comes from the existence of upstream supplier. Since the supplier charges a price higher than marginal cost, a part of the regulator's effort to induce abatement is hindered by a higher price of equipment. This needs to be corrected by an even higher tax (see [Sinclair-Desgagné et al., 2008](#)). Note that the third expression is proportionate to the price v the upstream firm charges. In our case, thanks to the two-part-tariff, the contract is efficient and hence $v = 0$.

Lemma 1. *The optimal tax rate is*

$$t^* = 2E + \frac{D(p^*(t))D_p(p^*(t))p_t(t^*)}{[D_p(p(t^*))p_t(t^*) - w_t(t^*)]} - \frac{w_t(t^*)v}{[D_p(p(t^*))p_t(t^*) - w_t(t^*)]}.$$

It accounts for the external damage, market power of polluter and a higher price of abatement equipment set by a supplier.

2.7.2 Regulator's preferences concerning technology choice

To remind you, in this section, we study how each component of welfare function varies with polluting firm's technology choice, thus giving a first hint at the reasons the government may prefer certain technologies. In the following section, we compare the regulator's preferences with the firm's choices. The suggestions for the regulator's response follow.

Consider again the two welfare functions $W_{ep}^*(t)$ and W_c^* . Table 2.2 allows better understanding of different components that stimulate welfare under each technology choice. Let us start with consumers' surplus. The surplus is the same under no technology regime and under bargaining solution whatever the outside option used. This is due to the fact that end-of-pipe technology has no impact on production decisions. However, the clean technology modifies the production costs, and therefore the impact on consumers is ambiguous¹³. Envi-

¹³Production decision under no technology is defined by first order condition: $D(p) + pD'(p) =$

ronmental tax plays an important role in determining the preferences concerning technology choice from the consumers' point of view. Whenever the clean technology decreases costs, no matter how low the tax is (as long as it stays positive), the clean technology is always preferred. When production costs are higher with clean technology, as the taxation increases but stays at moderate levels, the resulting consumers' surplus shifts the preferences towards the end-of-pipe type of equipment. Only very strong taxation encourages the clean technology from the consumers' point of view.

The impact of technology choice on profits was studied in details in production and bargaining sections. One issue however merits some attention. Taxation has an important impact on the total industry profits as shown in third column of Table 2.2. The gains in integrated industry profits under the end-of-pipe equipment stem from the savings companies make in taxes less adoption costs, $(tw^* - w^{*2})$. The higher the tax, the higher potential gain for the whole industry with respect to no technology. Moreover, the clean outside option negatively influences the industry profits. It results in a pure loss r . We will return to the profits issue once again in section below when studying alignment of preferences between the polluter and the regulator. Furthermore, welfare under clean technology yields no pollution and therefore necessitates no tax and the environmental damage is the lowest.

Note that for some levels of production cost λ , the end-of-pipe solution prevails in equilibrium even though it leads to higher pollution. This is due to several reasons. Firstly, when clean technology leads to higher variable cost of production, the end-of-pipe technology will most probably prevail. The probability of clean technology imposing itself decreases with cost difference¹⁴. In other words, welfare difference between clean solution and end-of-pipe one in optimum gets higher with cost difference. Secondly, as cost of R&D gets higher, clean technology loses its advantage and it becomes more difficult to make the firm choose this technology on its own. At optimum, the clean technology can only be chosen for low R&D cost.

$2\delta D(p)D'(p) + tD'(p)$ whereas the clean technology optimization yields: $D(p) + pD'(p) = 2\lambda D(p)D'(p)$. The comparison of outputs depends on the relative value of the right hand sides of both equations.

¹⁴The probability being defined as a range of taxes leading to a higher clean welfare than end-of-pipe welfare.

Table 2.2: Welfare components under different technology choices

	Consumers' surplus	Downstream profit	Upstream profit	Industry profit	Emissions	Environmental damage
No technology	CS_{\emptyset}	π_{\emptyset}^*	-	π_{\emptyset}^*	D_{\emptyset}	$(D_{\emptyset})^2$
Clean technology	CS_c	π_c^*	-	π_c^*	0	0
End-of-pipe with no technology as outside option	CS_{\emptyset}	$\pi_{\emptyset}^* + \alpha(\Pi_{eop}^{Ind*} - \pi_{\emptyset}^*)$	$(1 - \alpha)(\Pi_{eop}^{Ind*} - \pi_{\emptyset}^*)$	$\Pi_{eop}^{Ind*} = \pi_{\emptyset}^* + (t\omega^* - \omega^{*2})$	$D_{\emptyset} - \omega^*$	$(D_{\emptyset} - \omega^*)^2$
End-of-pipe with clean technology as outside option	CS_{\emptyset}	$\pi_c^* + \alpha(\Pi_{eop}^{Ind*} - \pi_c^* - r)$	$(1 - \alpha)(\Pi_{eop}^{Ind*} - \pi_c^* - r)$	$\Pi_{eop}^{Ind*} = \pi_{\emptyset}^* + (t\omega^* - \omega^{*2}) - r$	$D_{\emptyset} - \omega^*$	$(D_{\emptyset} - \omega^*)^2$

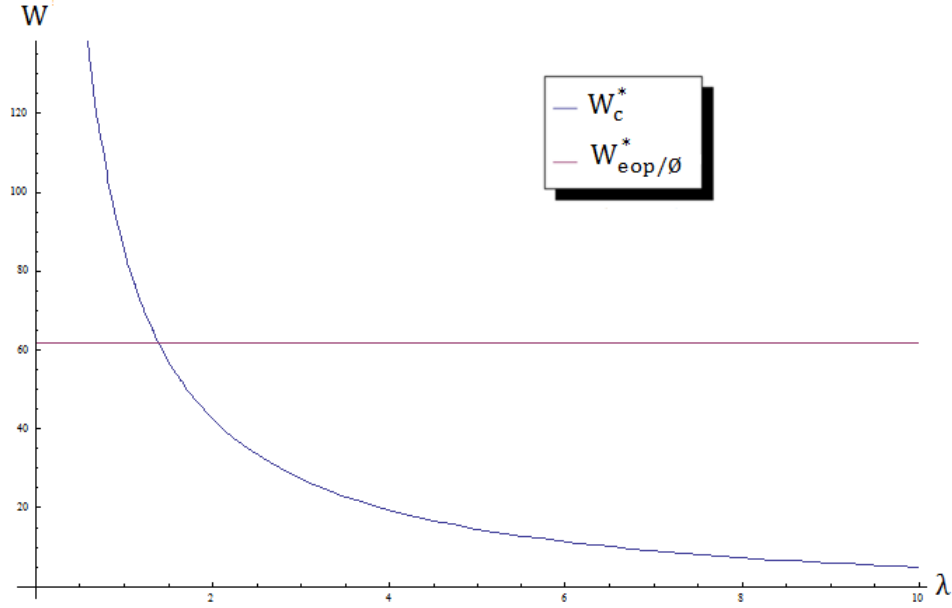


Figure 2.2: Comparison of clean welfare and end-of-pipe welfare (for $a = 100$, $b = 5$, $\delta = 1$, $r = 5$ and $t = 5$)

So, welfare with partial abatement can be higher or lower than the welfare with clean technology as we can see on Figure 2.2.

2.7.3 Alignment of preferences when regulator promotes the end-of-pipe technology

Let us consider the first case where $W_c^* < W_{eop}^*(t^*)$. While the regulator sets the tax equal to t^* , the polluting firm reacts to this tax in three different ways. Depending on a value of λ , we can find three regions of investment as seen below in Figure 2.3:

First, a zone where R&D is undertaken and technology developed in order to use it. Second, a region of over-investment, where the R&D is undertaken only to boost the bargaining power of the polluter, that represents a pure loss from the welfare point of view. Finally a region where no R&D is undertaken and the polluting company uses the end-of-pipe equipment in line with regulator's desire.

As mentioned above, the region of no investment in R&D in the second stage, $\pi_c^* < \pi_{eop/c}^*(t^*) < \pi_{eop/\theta}^*(t^*)$, poses no problem to the regulator. The best response of the regulation to maximize the welfare and set the optimal tax t^* (See Appendix B.5.1).

In the region of R&D investment where $\max\{\pi_{eop/\theta}^*(t^*); \pi_{eop/c}^*(t^*)\} < \pi_c^*$, the monopoly

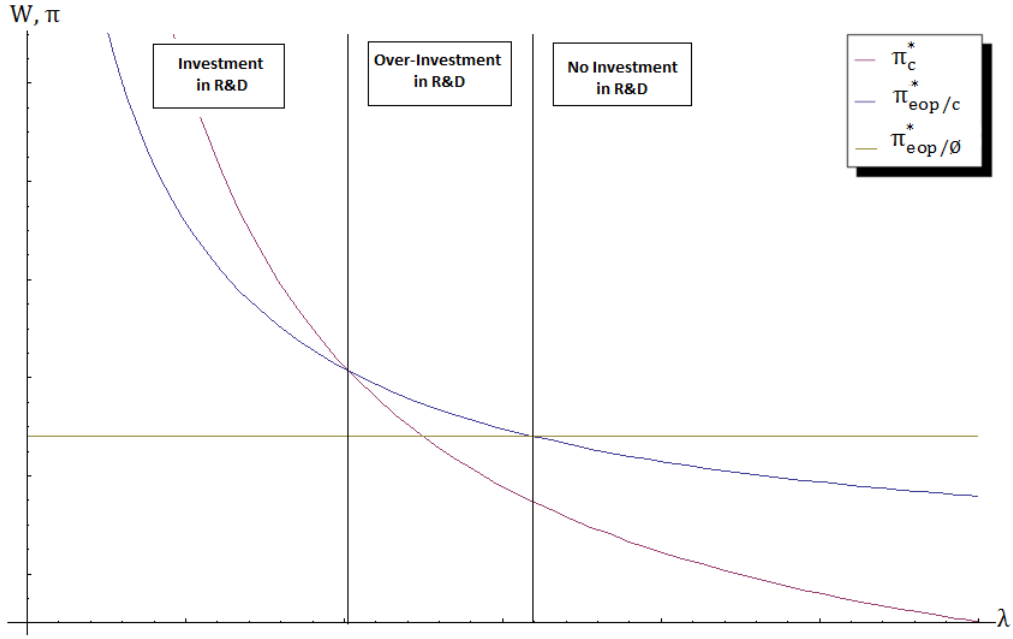


Figure 2.3: Polluting firm profits under different technology choices when $W_c^* < W_{eop}^*(t^*)$ (for $a = 100, b = 5, \delta = 0.2, \alpha = 0.5$ and $r = 5$)

profit is higher with clean technology than with end-of-pipe. Confronted with this situation, the regulator can keep the optimal tax unchanged and undergoes a net welfare loss, i.e. a loss from consumers and industry components but a gain from environmental point of view (See Appendix B.5.2.1 for a simulation case).

Since $W_c^* < W_{eop}^*(t^*)$, the regulator may also modify its policy and set a tax such that:

$$\begin{aligned} \max_t W_{eop}(t), \\ s.t. \pi_c^* < \max\{\pi_{eop/\theta}(t), \pi_{eop/c}(t)\}. \end{aligned} \quad (2.12)$$

In either case, compared to the optimal situation, the resulting tax is lower and so is the welfare. When $\pi_{eop/\theta}(t') > \pi_{eop/c}(t')$ the regulator manages to deter the monopoly from R&D investment (Appendix B.5.2.2). In the contrary case, the research nevertheless takes place ($\pi_{eop/\theta}(\hat{t}) < \pi_{eop/c}(\hat{t})$) (Appendix B.5.2.3).

Proposition 4. *In a case where the end-of-pipe regime dominates the clean regime in terms of welfare, under certain parameter values, the polluting industry invests in R&D and environmentally innovates. Paradoxically, the regulator may oppose such an effort and sets environmental policy so as to make the firm adopt existing end-of-pipe solution. Unfortu-*

nately, even by doing so, it might not prevent the polluting firm from useless innovation if $\pi_{eop/\emptyset}(\hat{t}) < \pi_c^* < \pi_{eop/c}(\hat{t})$. The welfare results in the third best.

In the third region where *investment* in the second stage is undertaken to *boost bargaining power*, i.e. where $\max\{\pi_{eop/\emptyset}^*(t^*); \pi_c^*\} < \pi_{eop/c}^*(t^*)$, the society incurs the investment cost decreasing the welfare. Indeed, the polluting monopoly invests in R&D in order not to use the clean technology in the production process, but only to enhance its outside option when bargaining with the end-of-pipe technology supplier. From this point of view, there is an over-investment in R&D which lowers the total welfare. Similarly to the preceding case, facing this situation, the regulator must adjust its policy. The regulator may sustain the level of taxation and undergoes a loss equal to R&D cost ($W_{eop}^*(t^*) - r$) (appendix B.5.3.1) or set the tax according to the following program:

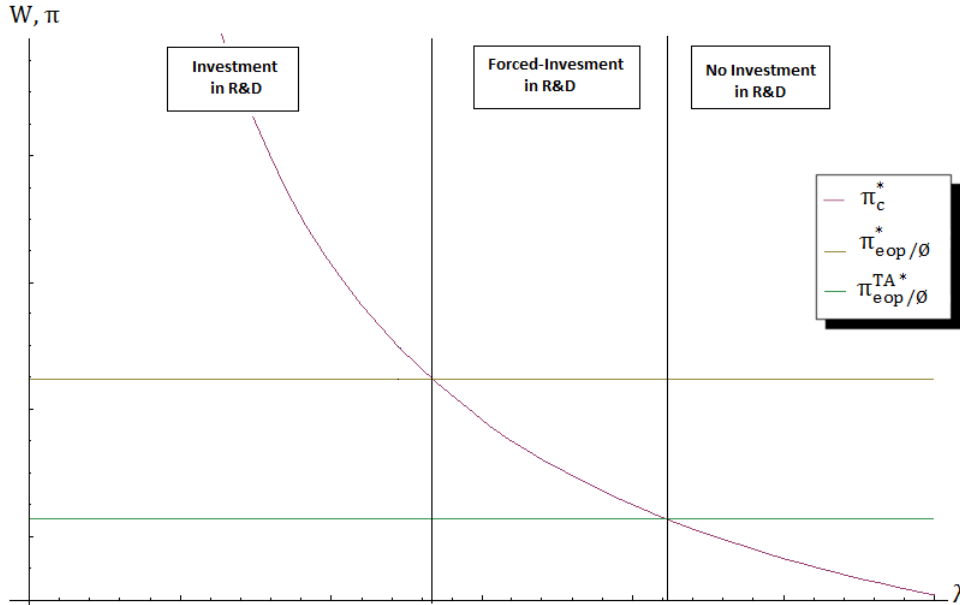
$$\begin{aligned} & \max_t W_{eop}(t), \\ & s.t. \max\{\pi_{eop/c}(t); \pi_c\} < \pi_{eop/\emptyset}(t) \end{aligned} \quad (2.13)$$

If the profit from bargaining with the clean technology as an outside option dominates the profit of end-of-pipe with no technology as well as the clean technology profit, $\pi_{eop/c}^*(t^*) > \pi_{eop/\emptyset}(t) > \pi_c^*$, a tax $\underline{t} < t^*$ can be chosen such that $\pi_{eop/\emptyset}^*(\underline{t}) = \pi_{eop/c}^*(\underline{t}) + \varepsilon$; and thus, the regulator prevents the monopoly from R&D investment. Recall Figure 2.1 to see how taxation influences technology choices. In this case, the regulator certainly avoids the deadweight loss r but, on the other side it loses on environmental quality (as tax gets lower and so does abatement). The resulting welfare is equal to $W_{eop/\emptyset}(\underline{t})$. Whenever $W_c^* < \max\{W_{eop}(t^*) - r; W_{eop/\emptyset}(\underline{t})\}$ the regulator sticks to end-of-pipe technology (appendix B.5.3.2).

Proposition 5. *In a case where the end-of-pipe regime dominates the clean regime in terms of welfare, under certain parameter values, the polluting industry overinvests in R&D just to boost its bargaining power resulting in a decrease in total welfare. This forces the regulator to adapt its taxation policy and either to support the consequences of the firm's choice, or to change the level of taxation to incentivize the firm to change its behaviour. Unusually, the option to develop a clean technology may make the regulator become laxer when it comes to taxation. The welfare however always results in the third best.*

2.7.4 Alignment of preferences when regulator promotes the clean technology

Let us now consider the next case where $W_{eop}^*(t^*) < W_c^*$. Assuming partial abatement, three situations can occur.



First, investment in stage 2, $\max\{\pi_{eop/\theta}^*(t^*); \pi_{eop/c}^*(t^*)\} < \pi_c^*$, where the monopoly profit with clean technology is higher than with end-of-pipe technology. In this case, the regulator can set t^* since $t^* \in [\tilde{t}, +\infty[$. It is the clean technology that is used (appendix B.6.1)¹⁵.

Second, a region of forced investment in stage 2, $\pi_{eop/\theta}^{TA*} < \pi_c^* < \pi_{eop/\theta}^*$ implying that the monopoly's profit with clean technology is lower than the one with end-of-pipe technology. In this case the regulator sets any tax $t \in [\bar{t}, +\infty[$ with \bar{t} defined as $\pi_c^* = \pi_{eop/\theta}^*(\bar{t})$ and thus encourages monopoly to use clean technology. There are no welfare losses since we end up with a clean technology and welfare independent of the tax (appendix B.6.2).

Proposition 6. *In a case where the end-of-pipe regime is dominated by the clean regime in terms of welfare, under certain parameter values, the polluting industry does not want to innovate. The regulator must set a higher tax in order incentivize the firm to undertake the research and use the free emission technology. The welfare is at its optimum.*

¹⁵ Actually, the regulator can set any tax higher than \tilde{t} , the tax that equals $\max\{\pi_{eop/\theta}(\tilde{t}); \pi_{eop/c}(\tilde{t})\}$ and π_c^* .

Finally, as mentioned in the beginning of the paper, an interesting case of laissez-faire situation appears where

$$\pi_c^* < \pi_{eop/\emptyset}^{TA*}.$$

The monopoly profit with clean technology is lower than the one with end-of-pipe technology with total abatement. In this case, setting any tax higher than t^* decreases the welfare. Indeed, since $\pi_c^* < \pi_{eop/\emptyset}^{TA*}$, when the tax increases, the monopoly abates the pollution using the end-of-pipe technology so the welfare goes down to W_{eop}^{TA*} instead of increasing to W_c^* (recall that $W_{eop/\emptyset}^{TA*} < W_{eop}^*(t^*)$). In what follows, the regulator prefers fixing t^* to leave the firm do the partial abatement. So the regulator can never reach W_c^* in this situation (simulations in appendix B.6.3).

Proposition 7. *In the case where the end-of-pipe regime is dominated by the clean regime in terms of welfare, under certain parameter values, the regulator cannot do anything to make firm undertake R&D as the further tax increases make firm abate all emissions with end-of-pipe equipment resulting in even lower welfare.*

2.8 Conclusion

The principal goal of environmental regulation is to correct the market failures due to negative externalities. Nowadays, it is common to measure their efficiency by the incentives they give to spur both R&D and adoption of better abatement technologies. In this article, we examined the role that environmental taxation can play in reducing environmental pollution and inducing the choice of greener technology by a profit-maximizing monopoly. We showed that, the strategic interaction between a monopoly and an upstream industry can alter the adoption of the best available abatement technology. Indeed, after the introduction of an emission tax, the polluter can, under some conditions, invest in R&D to develop a free emission technology not to use it but only to have a better outside option while bargaining with the end-of-pipe technology supplier. In such a way he obtains a more profitable license contract. This effect may give rise to conflicts between a regulator and the innovator. The regulator has no other choice but to set the environmental tax so that the polluter chooses the technology preferred by the policymaker. This results in a lower welfare as the level of

taxation needs to be modified in order to influence adoption decisions. Damages from environment get higher than what could be attained if the preferences of regulator and polluter were aligned. We also showed that sometimes the regulator cannot influence innovation and decision adoption and therefore needs to incur unavoidable welfare loss.

Several questions are not treated in this paper and merit some further studies. First, we assume that the two technologies are substitutable. However, our results do not repose on this assumption. Recent research of [Hammar and Löfgren \(2010\)](#) shows that companies using end-of-pipe equipment engage also in clean (in-house) innovation. Unfortunately, the research does not show either the timing of adoption of these technologies or whom they were developed by. This alternative assumption can also be incorporated in our framework. The issue concerning the quality improvement of a product in vertically differentiated market and optimal coordination of supply chain could be developed as well ([Lambertini 2014, 2016](#)). The complementarity of technologies could be explained by increased capability of polluter to undertake research or to perceive other opportunities as a result of getting accustomed to environmental technology. In-house research could lead to a decreased need for the end-of-pipe equipment and would allow renegotiation of existing contracts with upstream suppliers. A potential example could come from metallurgy industry where substantial amounts of water are used in production process. Quenching¹⁶ in the past was associated with the use of oils in hardening process. Production of ball bearing for automobile and aerospace industry requires fast cooling of steel. In certain industries till 80's it was done using oil as a coolant. However, the steel had to be quenched in water immediately afterwards, giving need to waste water purifying station to filter out inter alia the oil. In the following years a substantial research has been performed by the polluting industry and oil has been replaced directly by water as coolant. Empirical validation of this hypothesis would necessitate a close study of contracts between polluters and the associated independent end-of-pipe producers. Another avenue for future research would be to look more closely at the impact of different types of contracts and their efficiency on the optimal innovation decision ([Bacchiega and Bonroy, 2015](#); [Lambertini, 2014](#); [Wang and Shin, 2013](#)). Our results suggest some tensions between a regulator that maximizes welfare and a regulator that minimizes environmental damage. If there are two principals, one responsible for industrial policy and the other for environmen-

¹⁶In materials science, quenching is the rapid cooling of a workpiece to obtain certain material properties. Many variables influence the quality and mechanical properties of hardened steel and they are all important to control: the quenching temperature; the soaking time; the cooling rate (cooling rate); the chemical composition of the material.

tal one, their efforts should be coordinated. The industrial policy may call for increasing innovation efforts that may be unwarranted from the other principal point of view. These points are left for further research.

Chapter 3

Macroeconomic Determinants of Environmental Innovations in Europe: A Panel Approach

3.1 Introduction

An environmental public awareness has emerged these last decades as a result of major technological accidents, ecological disasters and environmental damages caused by the daily human activities and wastes. Therefore, lessening the environmental impact of economic and human activities while maintaining the economic growth has become the major challenge of the 21st century. To realize this objective, policymakers and scholars try to give substance to the concept of green economic growth and sustainable development by clearly defining the means to achieve them. Within this framework, environmental innovation is regarded as one of the key elements to ensure the transition to green economy ¹. Public authorities have a fundamental role to promote them by developing social structures, implementing financial schemes, supporting programs for green R&D, fostering eco-markets and introducing environmental regulations (Jang et al., 2015).

It is in this context that studies on the determinants of eco-innovation exploded in recent years. Academic research, done so far, mostly focused on micro and meso-economics levels. The authors wanted to find out what factors push companies or industries to eco-innovate. It is important to have this kind of studies to go deeper in details at different levels (micro, meso, regional, technological, specific clusters) (Miettinen, 2002). However, if we want to build a comprehensive and coherent project and "[a]s long as nation states exist as political

¹The terms "environmental innovation" and "eco-innovation" are used interchangeably throughout this article even though some researchers differentiate them by considering the eco-innovation as an environmental innovation that improve simultaneously environmental and economic performances (Ekins, 2010).

entities with their own agendas related to innovation, it is useful to work with national systems as analytical objects" (Lundvall et al., 2002, p 215). This is particularly true for eco-innovation which necessitates in addition a coordination between countries due to the nature of the environmental problems that are global and have absolute limits and possible solutions only at a global level.

So the aim of this article is to identify the determinants of eco-innovation at macro-level in European countries. Because of their sensitivity to the environmental concerns, these latter represent an interesting analytical framework. They were the first to put quantitative objectives in their European environmental policy agenda i.e. a 20% reduction in greenhouse gas emissions, with a 20% share of renewable energy source used in final energy consumption, and a 20% reduction of final energy consumption for the year 2020 compared to 1990 levels. They fixed new objectives of a 40% reduction in greenhouse gas emissions for 2030 and longer term targets to decarbonize the European energy system and cut EU's greenhouse gas emissions by 80 to 95% by 2050. They also implemented the European Trading Scheme, established under the Directive 2003/87/EC, which is the largest available cap-and-trade system in the world and considered as the cornerstone of EU's strategy for addressing climate change.

This chapter identifies in the first step, theoretically macroeconomic determinants of eco-innovations. It connects on the one hand, the findings of the environmental and innovation economics and on the other hand, the findings of the endogenous growth theory and the National Innovation System approach. The two first fields focus on micro determinants. The environmental economics stresses the fundamental role of the environmental regulations to boost eco-innovations while the innovation economics added technology-push and demand-pull drivers. These last categories of drivers are studied at aggregate level by the endogenous growth theory. Meanwhile, National Innovation System approach focuses on the role of national institutions. In the second step of the chapter, inspired by the empirical works evoked in the previous part, the study analyses the drivers of eco-innovation by evaluating different variables belonging to the categories cited above (technology-push, demand-pull and institutions with a special focus on regulation) using a panel approach for 12 European countries over the period 1990-2012.

The remainder of the paper is organized as follows. Next section reviews the existing literature and provides an overview of empirical works dealing with this issue. Section 3

introduces the model and the dataset employed. Empirical analysis and result discussions are presented in section 4. Section 5 concludes.

3.2 Literature review

In order to understand the determinants of eco-innovations at the macroeconomic level, this paper mobilizes different streams of research with two study objects. The first group of streams addresses the determinants at the micro (firms) and meso (industrial) levels. Meanwhile, the second has the macroeconomic determinants of innovation in general as a study object.

3.2.1 The micro eco-Innovations' determinants

From a conceptual point of view, this section matches together the environmental and the innovation economics.

Environmental economics

Traditionally the majority of theoretical and empirical works in Environmental economics focus on the role of policy instruments to induce eco-innovation. The term "induced innovation" is inherited from [Hicks' work \(1932\)](#), which states that changes in the relative prices of production factors, such as labour or capital, stimulate the development and diffusion of new technologies in order to save the use of these factors. So the environmental economics highlights the environmental externality generated by the agents' activities ([Pigou, 1920](#)) and postulates the existence of an "optimal level of pollution". Regulation is considered, implicitly, as the sole instrument to reach this optimal level by making environmental goods costly whereas previously they were considered to be abundant and cheap goods. Subject to these public policy interventions, manufacturers must make a trade-off between economic gains and environmental benefits when adopting eco-innovations.

[Porter \(1991\)](#) and [Porter and van der Linde \(1995, 1999\)](#) challenge the assumption of "trade-off" and argue that strict but flexible environmental regulations not only promote the environmental performance of companies, but also can improve their economic performance. The regulation must no longer be seen as an additional burden on businesses but as an effective way to address market failures. From an empirical point of view, three versions

of the Porter Hypothesis have been tested: the 'weak', the 'strong' and the 'narrow' version (Jaffe and Palmer, 1997). The first one takes up the idea that environmental regulations induce eco-innovations but that their opportunity cost is greater than the net profit obtained. The 'strong' version, is the dynamic one and claims that environmental regulations can foster competitiveness and productivity but in a medium/long term. The last version argues that only flexible environmental regulations, notably market-based ones, can improve competitiveness through the induced innovation.

The huge amount of literature developed in this area is far from being homogenous whether in term of methodology or results. Table C.1 summarizes results of some empirical articles². These latter are classified according to the version of the hypothesis tested (weak VS strong and narrow version) and in each category they are classified according to the level of analysis. As shown in the table, the majority of earlier studies is driven at firm and industry level and mainly uses "pollution abatement cost expenditures" (PACE) as a proxy of the environmental regulation stringency. Nevertheless, several problems have been identified in the literature concerning the use of this measure. The first problem concerns the interpretation of PACE. In fact, the idea behind the use of this proxy is that a higher spending in PACE reflects tighter regulation. However this can be one interpretation among others (Jaffe and Palmer, 1997). Inefficiency of polluting firms can also cause high environmental compliance costs and it cannot in this circumstance be interpreted as stringency. At aggregate level, countries with several polluting industries will also have relatively high expenses in PACE regardless of the stringency of their policies (Levinson, 1999; Brunel and Levinson, 2013). The second problem relates to the impact of PACE on innovations. Even if assuming the positive correlation between PACE and regulation stringency, polluters can devote resources towards pollution abatement rather than eco-innovations. In addition, firms can reduce their environmental effect through decisions that do not require expenditures i.e. outsourcing or offshore agreements (Koźluk and Zipperer, 2015). Thirdly, in a cross-country context, *"such a variable is inappropriate due to the heterogeneity in the definitions used and sampling strategies. For instance, in some countries the expenditures of 'specialized' firms in the environmental goods and services sector are included, while in other countries this is not the case"* (Johnstone et al., 2012, p9). For these reasons other measures have started to be used in recent years like environmental taxes revenues, standards, perceived

²Table inspired and completed from Ambec and Lanoie (2007)

stringency but they are imperfect measures of regulatory stringency as well. For example concerning the environmental taxes, the European countries do not have a widespread application of them. The EEA report (2014) confirms that the EU-27 environmental taxes as a percentage of total tax revenues fell from 6.9% in 1999 to 5.9% in 2008 and as a percentage of GDP fell from 2.8% to 2.3%. In addition in Europe, the largest share of European environmental taxes is held by energy ones. Those taxes are not usually introduced to tackle environmental issues. Among other purposes, "[they] are introduced as a relatively efficient source of tax revenue (due to the inelastic nature of energy demand) or they may act as strategic fiscal tools to improve energy security (relevant for countries with limited natural and mineral resources) or to translate part of the fiscal burden on foreign producers of energy" (Franco and Marin, 2015, p13). Moreover, the environmental taxes, as the other policy instruments, are usually very context-specific while many scholarships highlight the inducement effect of environmental policy mix on the innovation path and not only the use of a unique instrument (Hemmelskamp, 1997; Leone and Hemmelskamp, 1998; Requate, 2005; Requate and Unold, 2003; Roediger-Schluga, 2004; Goulder and Parry, 2008; Afif and Spaeter, 2009; Afif, 2012; Brouillat and Oltra, 2012; Klewitz et al., 2012; Veugelers, 2012; Williamson and Lynch-Wood, 2012). Due to these drawbacks and since this paper deals with a broadly-defined eco-innovation and hence covers multiple environmental impacts we will use a newly-released environmental policy stringency (EPS) index as it will be explained later.

Finding an adequate measure of innovation is still an unsolved issue despite the progress made in recent decades (Freeman and Soete, 2009; Blind, 2012). Empirical studies proxy innovation, generally, in one of two ways: R&D expenditures and number of (eco-)patent grants. The main shortcoming with the use the R&D expenditures is that it represents the resources devoted to the input of the innovation process rather than the innovation realized (Kemp and Pearson, 2008). In this chapter we use the number of eco-patents even that this measure also has some known weaknesses especially under a deeper understanding of the innovation's notion including non-technological aspects (Blind, 2012). As pointed out by Griliches (1990, p.1669) "*Not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in "quality", in the magnitude of inventive output associated with them*". Moreover, patents are neither the only nor even the most common form to protect innovations. Cohen et al. (2000b) point out the industrial secrecy,

marketing strategies and lead times as more widespread strategies. However, the use of patent data has been considered as one of the best technological innovations proxy for many reasons. First, it focuses on outputs of inventive process rather than inputs as it is the case for R&D expenditures (Griliches, 1990; Furman et al., 2002; Johnstone et al., 2012). Second, the majority of economically important inventions have been patented (Van Pottelsberghe et al., 2001). Finally, patent data related to environment are easily available nowadays.

Among the most known studies we find the article of Jaffe and Palmer (1997) which distinguishes theoretically the three types of the Porter hypothesis but tests only the "weak" version, i.e. the relationship between stringency and innovation, due to the data restriction³. The authors used a panel data set of U.S. manufacturing industry from 1973 to 1991. The regulation stringency is measured by PACE and the innovation is expressed in two ways, R&D expenditures and patents. The empirical results verify that there is a positive link between PACE and R&D expenditures but the link is insignificant using patents. Hence their suggestion to improve the study by looking for better classification of patents into industries, finding more disaggregated data and using other measure of regulation stringency. Brunnermeier and Cohen (2003) extended the analysis of Jaffe and Palmer (1997) by using, for the first time, the number of environmental patent applications granted instead of all patents as a measure of eco-innovation. They also added monitoring and enforcement activities related to existing policies as a second proxy of stringency. They find that environmental innovation occurs in industries with very competitive international markets and conclude that PACE have positive influence on eco-patents, however, it is not the case of monitoring and enforcement activities that provide no additional incentive. To overpass some of the above mentioned PACE drawbacks, Lanoie et al. (2008) use the changes in the ratio of the value of investment in pollution control equipment to the total cost and add regulation on safety in the workplace index. They find that environmental regulation has a positive impact but only in a medium term (using until three-year lagged regulation) on the productivity of 17 Quebec manufacturing industries and that effect is greater when industries are more exposed to international competition which is in line with the "strong" version of the PH. Another article of Lanoie et al. (2011) tested simultaneously the three versions of the PH using a survey of over 4000 manufacturing facilities in seven OECD countries. It looks to the impact of more stringent regulations on R&D (weak), environmental result (narrow) and

³For example, market instruments have not been widely used so far to conduct a direct test of the "narrow" version of PH.

business results (strong). It finds strong support to the weak, positive one to the narrow but no support to the strong version. Focusing on European countries, the works of [Rubashkina et al. \(2015\)](#) and [Franco and Marin \(2015\)](#) test the "weak" and the "strong" versions of PH. Rubashkina and her co-authors (2015) find a positive impact of the PACE on the number of patents (the "weak" version) but find no evidence in favour or against the impact of PACE on productivity (the "strong" version). [Franco and Marin \(2015\)](#) tested the impact of environmental taxes on innovation and productivity not only in one same sector but also in the upstream and downstream sectors in terms of input-output relationship. They find that the strongest effects on the "weak" and "strong" version come from the downstream sectors. They also test the indirect effect of the tax on productivity by using patents as mediators and find no impact of the innovations' proxy on productivity⁴.

Recently, few empirical works involve macroeconomic level analysis were conducted⁵. [Albrizio et al. \(2014\)](#) is among the first studies that used EPS index and tested its impact at the three levels: macro, meso and micro. They affirm that, at the macro level, productivity growth undergoes an announcement effect of the policy stringency change but this negative affect is offset three years after. [De Santis and Jona-Lasinio \(2015\)](#) studied a panel of 11 EU countries over the period 1995-2008 and used a multitude of environmental stringency measures. They found that the market based instruments are more likely to positively affect production growth than non-market instruments. In a very recent working-paper, [Morales-Lage et al. \(2016\)](#) test the "weak" and the "strong" versions of the PH using the EPS index and two different econometric models i.e. panel models and quantile regression techniques. They confirm the positive impact of the regulation stringency on innovation and productivity. They then demonstrate that EPS index has a greater impact on the lower quantile of the R&D distribution and on the highest quantiles of patents and total factor productivity distributions.

Innovation economics

Innovation economics awards an important role to regulation as a determinant of eco-innovation as well. According to this literature, regulation can resolve the "double external-

⁴Still focusing on European countries and on supply chains but using a qualitative method, [Barsoumian et al. \(2011\)](#) argue that industries which build narrow networks can benefit from highly integrated supply chains to reduce costs. In such a case, industries remain competitive on a global scale while reducing their energy consumption and carbon footprint.

⁵There is a literature at the macro level, not developed in this work, that focused on the impact of environmental stringency on international trade flows see for example [Tobey \(1990\)](#), [Low and Yeats \(1992\)](#), [Van Beers and Van Den Bergh \(1997\)](#), [Xu and Song \(2000\)](#), [De Santis \(2012\)](#), [Sauvage \(2014\)](#).

ity" problem related to eco-innovation. Indeed, this latter generates two types of positive externalities in both the "*research and innovation*" phase, and the "*adoption and diffusion*" phase. For the first phase the positive externalities are usual and the private underinvestment can be compensated by classical instruments like for example patents. In contrast, the positive externality upon environment in the "*adoption and diffusion*" phase is fairly new. Thus, the private return on eco-innovation is lower than its social return as only the innovator bears the R&D costs whereas the whole society benefits from the environmental improvement that has a public good character. These double market failures reduce private incentives to invest in environmental R&D and justify the need for the "*regulatory push-pull*" effect proposed by the seminal article of [Rennings \(2000\)](#). However, in spite of the incentivizing role of regulation, eco-innovation cannot be considered to be a systematic response to regulation. [Rennings \(2000\)](#) says: "*it can be concluded that contributions on eco-innovation from environmental economics suffer from a simple, mechanistic stimulus-response model of regulation, neglecting the complexity of determinants influencing innovation decision in firms.*" (p. 325) "*While environmental economics tells how to assess environmental policy instruments, innovation economics has led to insights about the complexity of factors influencing innovation decisions.*" (p. 324). This is why, innovation economists have tried to answer the question to whether eco-innovations can be treated as normal innovations or if a specific theoretical frame is needed. Since the 1990's⁶, they have begun to study the impact of the traditional determinants, the "*demand-pull*" and "*technology-push*" ones, on the eco-innovations⁷.

The "*technology-push*" determinants, also called supply-side determinants, are stemmed from the famous Schumpeter's works (1934, 1950) and considered as the first generation of the innovation models ([Bush, 1945](#)). According to this view rather linear, innovations are driven by scientific and technological progress ([Freeman, 1982](#); [Mowery and Rosenberg, 1979](#); [Baumol, 2002](#)). The more we accumulate the knowledge, the more we innovate. These innovations can increase the differentiation between products and thus reduce competition, improve firm's reputation and/or increase performance through cost reduction. We can note that the "*technology-push*" category also includes the organizational innovations (the adoption of environmental management systems, extended producer responsibility) and

⁶Even if articles were published during the 1990s ([Green et al., 1994](#); [Cleff and Rennings, 1999](#)), it is [Rennings \(2000\)](#) who will interest innovation economists to the subject which will accelerate the work in this area.

⁷For a literature review on eco-innovation determinants at firm level see [Pereira and Vence \(2012\)](#)

industrial relationships (supply chain pressure, networking activities) (Oltra et al., 2008; Doran and Ryan, 2012).

The "*demand pull*" approach highlights the market demand roles in the technical change process (Griliches, 1957)⁸. Users represent a key element of the selection environment for innovations and have a deep understanding of the requirements that innovation must meet (Fagerberg et al., 2015). One first role is the level of the demand, as such, on the market or future markets of the innovation (Schmookler, 1962, 1966). The more important the demand or the expected benefices are, the more we are encouraged to innovate. The second role that can be played is associated with the dimension of "*learning by using*". Indeed, an innovation often encounters limits following its use and in general, users make some feedbacks to improve this innovation or to express some other needs which can be satisfied with new inventions. Users are considered as the pioneers of a new trend based on two criteria: experience and intensity of their needs. In this field, we can note the contribution of von Hippel (1986, 2001, 2005) who is considered as the main supporter of the "*bottom-up innovation*" notion where users are in the heart of the design of technical devices. He proposed the notion of "*lead users*" 1986 to qualify these consumers that develop their own inventions to resolve their own problems where there are no solutions on the market; and the "*self-manufacturers*" 2005 those who reGENCY the use of available tools to adapt them to specific needs.

Concerning the empirical studies, the majority of analyses confirm the positive impact of the environmental regulation on the eco-innovation measured essentially by existing and/or anticipated regulations and subsidies. For example, Cleff and Rennings (1999) using Mannheim Innovation Panel (1996) and telephone survey, establish a causality effect between regulation and process eco-innovation. Product-integrated eco-innovation however are determined by 'soft' regulation (e.g. labels, eco-audits). Frondel et al. (2008) analyse a variety of factors impacting the firm's choice between "*cleaner products and production technologies*" and "*end-of-pipe technologies*" in 7 OECD countries and find that regulation has a significant impact only on the "*end-of-pipe technologies*". Horbach et al. (2013) compare the determinants in two different countries France and Germany and find, inter alia, that there is a significant impact of the regulation but no significant one of the subsidies. Cuerva et al. (2014) arrive to same conclusion concerning the role of subsidies on Spanish agri-

⁸This is the second generation of the innovation models.

foods SMEs. Analysing European SMEs dataset, [Triguero et al. \(2013\)](#) confirm the positive effect of regulation on organizational eco-innovations. [Mazzanti and Zoboli \(2005\)](#), [Rehfeld et al. \(2007\)](#), [Horbach \(2008\)](#), among others, confirm the positive effect of the compliance with (future) environmental regulation.

Many papers tested the impact of "*technology-push*" determinants on the eco-innovation. For example concerning the R&D role, [Mazzanti and Zoboli \(2005\)](#) revealed that environmental R&D is one of the most important drivers for eco-innovation in manufacturing Italian firms. [Horbach \(2008\)](#) and [Rehfeld et al. \(2007\)](#) also find positive impact using data derived from German firms contrary to [Kammerer \(2009\)](#) who did not find a significant correlation. [Cuerva et al. \(2014\)](#) indicate that technological capabilities measured by R&D and human capital, foster the conventional innovation but not the eco-innovation in low-tech Spanish SMEs. [Frondelet al. \(2008\)](#) show, in contrast with their conclusion about regulation, that there is a significant positive effect of R&D only on clean technologies. This result is confirmed by [Hammar and Löfgren \(2010\)](#) when they analysed the impact of R&D on the investment in end-of-pipe technology in Swedish firms. Reducing costs, and subsequently increasing profit margins, is a key element to environmental innovation too. This statement is supported by [Green et al. \(1994\)](#) for British companies and [Horbach \(2008\)](#) for German ones. [Horbach et al. \(2013\)](#) also confirm this effect for innovations reducing energy consumption, inputs use and CO₂ emissions. These findings are very close to those of [Rave et al. \(2011\)](#). [Frondelet al. \(2008\)](#) reveal a positive correlation with eco-innovation process while [Demirel and Kesidou \(2011\)](#) point out the positive link between R&D expenditures and saving costs.

It is hard to find adequate measures to test all the nuanced notions of the "*demand pull*" category. Many articles used the expected customer demand and find positive impact especially on product eco-innovation even under greatly different conditions. Indeed, product innovation allows firms to differentiate their product on final market and hence increase their competitive advantage ([Reinhardt, 1998](#)). Using UK dataset, [Green et al. \(1994\)](#) demonstrate that the prospect of expanding market share consist an important factor impacting the product eco-innovation. Market goals play a determinant role only on product eco-innovation in [Cleff and Rennings \(1999\)](#) and [Triguero et al. \(2013\)](#) papers. [Horbach \(2008\)](#) however, find a positive impact of the expected increase in customer demand on overall eco-innovation. [Rehfeld et al. \(2007\)](#) and [Kammerer \(2009\)](#) introduce the consumer satis-

faction or benefits in their studies. Rehfeld and her co-authors (2007) note that satisfying customer's private needs have strongly significant positive effect on product eco-innovation but not to process eco-innovation. Kammerer (2009) studies the impact of the private benefits of customers such as "*cost/energy savings through more efficient appliances, improved product quality and durability, better repair, upgrade, and disposal possibilities, as well as reduced health impacts*" (p4) . From then on, these benefits have been emphasized in the eco-marketing literature as a prominent element to generate stronger consumer demand (Ottman and Books, 1998, Reinhardt, 1998). The results show that firms concerned by customers benefits are more likely to implement product eco-innovation⁹.

The literature of the innovation and environmental economics propose a large number of drivers. These latter belong mainly to one of the following three categories, "*environmental regulation*", "*technology-push*" and "*demand-pull*" one. The analyses developed concern essentially firm and industry level studies. Nonetheless, the transition from a micro to a macro level cannot be done by a simple aggregation i.e. the efficiency of the national system as a whole is not only the juxtaposition of productive units' performances. We must take into account the capacity to promote a favourable environment and ensure coordination between the individual components. This is why it's important to understand what the macroeconomic determinants of innovations are and check if these determinants are also valid for the eco-innovation and/or if others are needed.

3.2.2 The macro Innovations' determinants

The important role of innovation as a driver of growth has enabled it to occupy a privileged place in the macro-economic theory from the 1950s (Solow, 1956, Romer, 1986, Lucas, 1988). It is the theory of exogenous growth, initiated by Solow (1956), which states that innovation (or what he called technical progress) is at the origin of a sustained productivity growth but remains silent on the origins and mechanisms of this technical progress. It took 30 years, with the article of Romer (1986)¹⁰, to elaborate the endogenous growth models, i.e. growth models where technical change is treated as an endogenous determinant of economic growth. According to Romer (1986), innovation is an increasing return activity that generates knowledges. These knowledges have a positive spillover, "*positive external-*

⁹The articles testing the trichotomy proposed by Rennings (2000) are summarized in Table C.2.

¹⁰We can also quote the contribution of Lucas (1988).

ity", which benefits not only to the innovative firms but also to all the society. So innovation relies on economic agents behaviours and it is at the origin of the economic growth.

New growth theories and thereafter international trade theories emphasize the virtues of trade liberalization on the efficiency of the firms at the micro scale and the technology diffusion at the macro level. In their view, liberalization has two positive effects: a static effect generated by the transfer of resources, and a dynamic effect resulting from the growth in factor productivity through increased technology imports and increasing competition between firms (Rodrik, 1993). In this context of openness, States play an important role through two actions. The first one seeks to protect domestic firms from competition through non-tariff barriers, i.e. establishment of strict standards on working conditions, product quality or environmental criteria. The second action influences the creation of a comparative advantage through the incentives given to firms to innovate. Environmental regulations within the European Union (EU), for example, could partially protect European firms from the competition of foreign firms not complying with these standards on the European soil and also could guide local firms towards eco-innovation which will give them a first mover advantage in the way environmental standards are adopted in other countries.

Endogenous growth and international trade theories introduce finer assumptions into neo-classical models but don't break with this mainstream. Some researchers however, not satisfied by the basic premises and features of neoclassical economics, proposed the "National Innovation Systems" (NIS) approach to understand competitiveness at the country level and to identify determinants of innovation (Edquist, 2001)¹¹. The NIS is defined as a "set of institutions that (jointly and individually) contribute to the development and diffusion of new technologies. These institutions provide the framework within which governments form and implement policies to influence the innovation process. As such, it is a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artefacts which define new technologies" (Metcalf, 1995, p.24). We attribute the origin of the NIS concept to the economists Freeman (1982, 1989) and Lundvall (1985, 1988). This approach emerged at a specific moment in history "precisely when economic globalization was accelerating during the 1980s and when international competition among companies

¹¹"I have always been annoyed by how, in spite of its limited relevance and validity, neo-classical economics has pursued the pretentious intention to colonize all thinking about the economy. One important motivation for my interest in innovation and innovation systems is actually that when you focus on innovation it becomes absolutely clear that the neoclassical assumption about agents making choices between well-defined alternatives cannot apply. (Lundvall interview, 20 October 03)" (Sharif, 2006, p.754).

was intensifying. In particular, Japan was emerging as a new global economic powerhouse, dominating a variety of industrial sectors and moving up through the league tables as measured by gross national product" (Sharif, 2006, p.761) ¹².

This approach is based on three main theoretical contributions. First, Lundvall asserts that learning is the most important process and knowledge is the most important resource of innovation. The interactive learning theory (1988; 1998; 2002b; 2010; Lundvall and Johnson, 1994) emphasize the role played by interactions between individuals belonging to different social and economic structures and institutions to facilitate the learning process and the knowledge accumulation. Second, the evolutionary theory of technological change puts the light on the strategic role played by the knowledge and learning to explain the heterogeneity between agents (2007). Indeed, economic agents cannot be treated as homogenous through a "representative agent", but we have to consider their behavioural differences due to differences in the used technologies, internal sources, administrative organizations, external environment, etc. According to this literature, innovation improves the performance of firms to face the natural selection at micro level and it is the driving force of long-run economic development (Nelson and Winter, 1982; Dosi and Nelson, 1994; Mulder et al., 2001; Nelson and Winter, 2002). That's why in the evolutionary theory, institutions whose interactions determine the performance and innovative capabilities of domestic firms are considered as important objects of study. The last theoretical field is the institutional theory (Freeman, 1989, Freeman, 1995; Edquist, 1997). It seeks, amongst others things, to understand the impact of institutions on individual behaviour of economic agents; on differences of national orientations in terms of accumulation of physical and human capitals and on the capacity of countries to use them. For the new institutional economics, institutions are intended to reduce uncertainties which decrease transaction costs, ensure stability, favour the clusters' emergency and counter market imperfections. This mechanism has a great importance on economic performance (North, 1990, 2003). We must then integrate institutional elements in the analysis of technological change and consider the crucial role of institutions to generate and strengthen innovation capacity at national level. To sum up, NIS stresses the importance of firms as individual entities, the importance of their interactions with each other (competition, cooperation, etc.) as well as the prominent role of institutions in the

¹²We are also living a similar hectic period with the emergence of China as a new economic power, the advent of the global financial and economic crises and the acceleration of the environmental concerns. That can justify, in our point of view, the need to theoretical and empirical framework to develop and understand a "National Eco-Innovation System".

innovation system¹³.

More recently, [Furman et al. \(2002\)](#) proposed the concept of National Innovation Capacity (NIC) that combines the NIS concept with the endogenous growth theory and the cluster-based theory of national industrial competitive advantage ([Porter, 1990](#)). This concept provides a more comprehensive view of national innovation capabilities by considering local, regional and national elements through the study of three building blocks: the common innovation infrastructure, the country's industrial clusters and the strength of linkages between them.

All these fieldworks inspired a countless number of empirical researchers to detect the determinants of innovation at macro level. Many of them are based on the endogenous growth model. Among the most recent papers, [Bayar \(2015\)](#) studied a sample of 10 European countries from 1999 to 2012 and found that innovation, proxied by the number of patents grants, is 1) positively impacted by R&D expenditures, economic growth, financial development, domestic savings and high-technology exports, 2) not impacted by foreign direct investment and 3) negatively or not impacted by inflation (depending on the econometric method used). [Guloglu et al. \(2012\)](#) examined the rate of patents on the G7 countries over the period 1991-2009 and conclude that R&D, high technology exports, and FDI have a positive effect on technological progress, the rate of interest have a negative one, whereas the trade openness seems to not impact the technological progress. In contrast, [Khan and Roy \(2011\)](#) found, comparing OECD and BRICS countries, that trade openness may have a positive effect on innovation. They also found that productivity of R&D expenditures in terms of increased innovation activities is significantly higher in the OECD countries than in the BRICS. The enrolment in tertiary education, however, has a positive impact on the BRICS but no significant one for the OECD countries. [Krammer \(2009\)](#) examined 16 Eastern European countries over the period 1991-2011 using a range of economic methods and control variables. He highlighted the positive role of R&D commitments, existing national knowledge, as well as the policy measures and globalization. Measures of transitional

¹³There are two different scales to study institutions in the NIS fieldwork. A narrow scale which is limited to the consideration of organizations and institutions involved directly in the process of generating knowledge, research, exploration (research centres, R&D departments, technical institutes, universities, etc.) and a larger scale which explains that institutions regarded in the narrow vision are embedded in a broader socio-political-economic system and that all these institutions indirectly involved must be taken into consideration. This article considers the determinants of the narrow vision since that it focuses on the European countries which are developed ones and so the indirect institutions are supposed rather equivalent, stable and favourable to innovations.

downturn and industrial restructuring decrease the propensity to patent. [Eyraud et al. \(2011\)](#) explored empirically the drivers of the renewable green investment using a variety of control variables. They found, among others, that public policy such as high fuel prices, and macroeconomic factors such as economic growth and interest rates, are important factors. [Coe et al. \(2009\)](#) took back the article of [Coe and Helpman \(1995\)](#) on the "International R&D Spillovers" and extended it by including institutional variables. They also revisited it by using newer panel co-integration estimation techniques and expanded data set. The results confirm the positive impact of domestic and foreign R&D capital stock and highlight the impact of human capital about the national productivity. They also give strong evidences on the role of institutions on the degree of R&D spillovers and to explain the differences between the national productivity. [Varsakelis \(2006\)](#) gave evidences to the NIS theory as well by examining the role of education (such as scores and number of students related to scientific subjects) and political institutions (for example civil liberties and press freedom) on innovation activity (number of patents) in 29 countries during the period 1995-2000. [Furman and Hayes \(2004\)](#) and [Hu and Mathews \(2005\)](#) extended the empirical study concerning the 17 OECD countries of [Furman et al. \(2002\)](#) on the NIC to, respectively, 29 OECD countries and East Asian "tigers". They showed more or less the same results.

To recap, this first section gives an overview about the economic fields dealing with the drivers of (eco)innovations. Certainly, each one of them could serve as a theoretical framework to analyse the determinants of the eco-innovation at macro level. However, it may be good to have a view of most, if not all, of the related theories developed so far since they can all shed light on the issue. In what follows, an empirical study will be conducted to test the influence of different determinants on the eco-innovation.

3.3 Data and descriptive analysis

3.3.1 Data

Several data source have been used to construct our final dataset. Further details on definition and data sources are available in [Table 3.1¹⁴](#).

¹⁴Updated data for the last time in November 2016

Table 3.1: Variables list and definition

Symbol	Definition/Measures	Source
ECOPAT	Environmental innovations: Green and inventive technologies	OECD
R&D	Research and Development expenditures (constant 2010 PPP US dollar, per Millions)	OECD
DM	Household final consumption expenditure (constant 2010 PPP US dollar, per Millions)	OECD
EDU _{gdp}	Government expenditures on education (as % of GDP)	World Development Indicators
OPENNESS	Sum of exports and imports over GDP	World Development Indicators
EPS	Environmental Policy Stringency Index	OECD
EPS _{market}	Environmental Policy Stringency Index of market-based instruments	OECD
EPS _{nonmarket}	Environmental Policy Stringency Index of non-market-based instruments	OECD

3.3.1.1 Eco-patents as a proxy of eco-innovation

This study uses a variable based on the number of environmental patents taken out from the OECD (ECOPAT here after). *"The patent statistics presented here are constructed using data extracted from the Worldwide Patent Statistical Database (PATSTAT) of the European Patent Office (EPO) using algorithms developed by the OECD. (...) The relevant patent documents are identified using search strategies for environment-related technologies (ENV-TECH) which were developed specifically for this purpose. They allow identifying technologies relevant to environmental management, water-related adaptation and climate change mitigation. An aggregate category labelled "selected environment-related technologies" includes all of the environmental domains presented here"*¹⁵.

Since we are interested in international comparisons and in order to avoid some of the abovementioned problems in the literature review section, the patent grants are taken according to inventor's country of residence, focusing on those having sought patent protection in at least two jurisdictions and all patents are taken according to their priority date. Indeed, we chose the inventor's country of residence rather than applicant's country to focus on determinants that drive the innovation and not the place where this latter is used or diffused. Secondly, the patent family is a set of the equivalent patent applications corresponding to a

¹⁵http://stats.oecd.org/OECDStat_Metadata/ShowMetadata.ashx?Dataset=PAT_COL_RATES&Lang=en&backtodotstat=false

single invention listed in several patent offices. It has been argued that using data based on the "claimed priorities", i.e. family size comprising at least two offices, is the most appropriate level when we are in analysis across countries since it takes only high-value patents without placing an excessive constraint on narrow technological fields¹⁶. Finally, the use of priority date, which is the earliest year of application and so the nearest date to the inventive activity, also facilitates the comparison of innovation across countries since it gives uniformity in measuring innovation because it does not depend on any differences in application rules set by the different patent offices (De Vries and Withagen, 2005). We have also to notice that the use of patent accounts as a dependent variable may raise concerns about a scale effect since larger and wealthier countries may increase the number of patent applications (Krammer, 2009). To correct this scale problem, we choose to normalize it by GDP (ECOPAT_{GDP}).

3.3.1.2 Measuring the Innovation Determinants

The most serious problem that a cross-country study meets is to find reliable, commensurable measures of the stringency of environmental policies. Stringency can be defined as the explicit or implicit cost imposed on any environmentally harmful comportment (Albrizio et al., 2014; Botta and Koźluk, 2014; Brunel and Levinson, 2013; Koźluk and Zipperer, 2015)¹⁷. Over the last twenty years, EU countries have implemented a wide range of policy instruments that can be grouped into four categories: "Market-based instruments", "Command and Control regulation instruments", "Voluntary agreements" and "Information-based instruments" (Zuniga et al., 2009, Crespi et al., 2015)¹⁸. It is easy to imagine the difficulty of measuring the stringency of these elusive instruments across countries and time to make feasible empirical research at a macro, cross-country level.

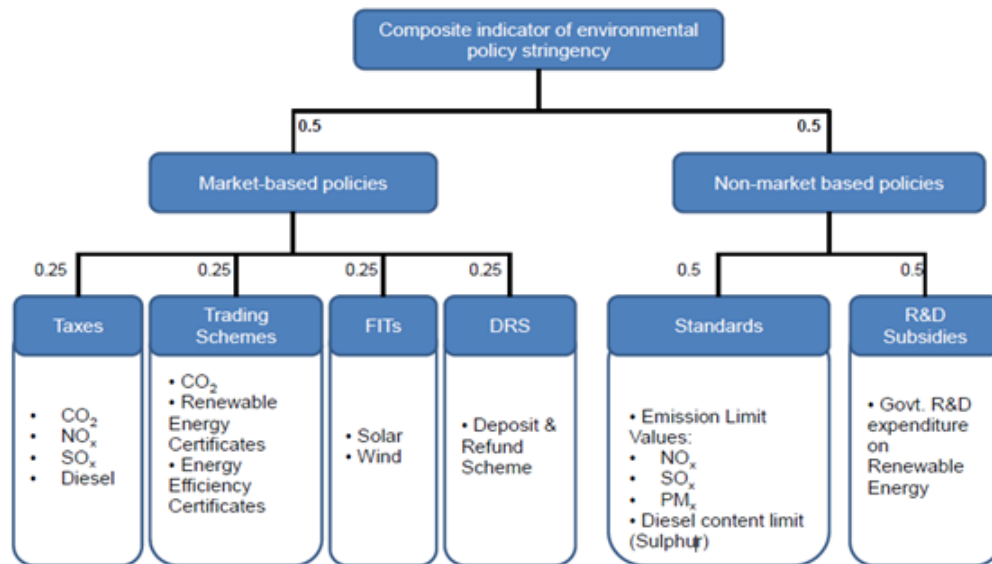
This study uses the new environmental policy stringency (EPS) index of Botta and Koźluk (2014). The index transforms quantitative and qualitative information contained in normative policy instruments into a comparable country-specific measure. To do so, Botta

¹⁶See Hašičič and Migotto (2015) and Martinez (2010) for more arguments.

¹⁷For example taxes, subsidies, stricter emission limit values have all the same interpretation i.e. implying higher stringency. They increase the opportunity costs of polluting or enforce environmental standards and therefore provide advantages to environment-friendly activities (Botta and Koźluk, 2014).

¹⁸This paper focus, as almost all previous works on the determinants of environmental innovation, on the first two categories because they represent the vast majority of policy instruments used, they are easier to observe and quantify and they are more restrictive since they impose explicit obligations. The two last instruments, also called "soft regulations" are very context-specific and look for stimulating discretionary activities.

and Koźluk (2014) rely on the taxonomy developed by De Serres et al. (2010) and weight equally the sub-components of each category as shown in (Figure 3.1). The EPS index ranges from 0 to 6, where 0 translates a nonexistence of any environmental regulation and 6 is, in contrast, a very high level of stringency.



Source: Botta and Koźluk (2014)

Figure 3.1: Structure of the Environmental Policy Stringency Index

Since there is a large consensus in literature considering that market-based instruments are more likely to induce innovation than command and control ones (Malueg, 1989; Jaffe et al., 2002; Fischer et al., 2003; Popp et al., 2010), we will distinguish between the two kinds of regulation to test their relative impacts (EPS_{market} and $EPS_{nonmarket}$).

In the "technology-push drivers" category, it is commonly used in empirical analysis to take the R&D expenditures as proxy of technological capabilities. Data on gross domestic expenditure on R&D were obtained from the OECD database. As for patent data, we normalize the R&D expenditures by GDP to avoid the scale problem ($R\&D_{GDP}$). For the "demand-pull drivers" category, the demand per capita (DM_{PC}) and government expenditures on education as percentage of GDP (EDU_{GDP}) are taken as proxies. The idea behind this is that richer and more highly educated populations are more sensitive to environmental concerns and put more pressure on the demand side.

The government expenditures on education may also give an idea about the "institutional determinants" since higher education sector (university, etc.) gives an indication of the relationship between the scientific sphere and the rest of the innovation system. Concerning the "institutional determinants", it is also important to capture the openness of the national

system to the international trade. Due to the globalization, a national's performance depends not only on its own competences but also on its trade partners' competences (Coe et al., 2009). So States are putting more and more measures in place to promote this exchange. To capture this aspect, we built a variable called OPENNESS that computes the foreign trade as a proportion of GDP (Coe et al., 2009; Khan and Roy, 2011; Guloglu et al., 2012, Huňady and Orviská, 2014) i.e.,

$$\text{Openness} = \frac{\text{Value of import} + \text{Value of export}}{\text{GDP}}$$

This measure gives an idea about the degree of competitiveness that local firms face. It correlates with the ability of local firms to target larger international markets and with the ability of foreign firms to exploit their innovations in the local economy (Furman and Hayes, 2004). This international trade also increases technological imitation and the foreign advanced knowledge diffusion.

Some last points concerning the data have to be explained. To begin with, we have to note that our data are strongly balanced but there are some missing values concerning the non-annual census of some data (representing less than 5%) that were fulfilled by interpolating the average of the two values existing before and after the missing value. We also used lagged variables to allow sufficient time for economic agents to respond to determinants by innovating. A 2-year moving average has been chosen (Furman and Hayes, 2004; Krammer, 2009).

3.3.2 Descriptive analysis

Our sample covers 12 European countries (Austria, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Spain, Sweden and United-Kingdom (UK)), over a time period of 1990-2012 which makes a total of 276 observations. Mean and standard deviations of the employed variables are reported in Table 3.2, while pairwise correlations appear in Table 3.3.

Table 3.2: Summary statistics

Variable label	Mean	Std. Dev.	Min.	Max.
ECOPAT _{gdp} ^(*)	4.45	3.38	0.24	19.96
EPS	1.87	0.82	0.48	4.41
EPS _{market}	1.23	0.84	0.08	4.05
EPS _{nonmarket}	2.50	1.08	0.63	5.50
R&D _{gdp}	0.02	0.01	0.004	0.04
DM _{pc} ^(**)	1.89	0.59	1.156	10.06
EDU _{gdp}	5.53	1.15	3.64	8.62
OPENNESS	74.33	31.10	33.98	190.11

(*) Values are multiplied by 10^4 (**) Values are multiplied by 10^{-4}

Table 3.3: Cross-correlation table

Variables	ECOPAT _{gdp}	EPS	EPS _{market}	EPS _{nonmarket}	R&D _{gdp}	R&Dpr _{gdp}	R&Dpu _{gdp}	DM _{pc}	EDU _{gdp}	OPENNESS
ECOPAT _{gdp}	1.00									
EPS	0.51 (0.00)	1.00								
EPS _{market}	0.22 (0.00)	0.81 (0.00)	1.00							
EPS _{nonmarket}	0.60 (0.00)	0.89 (0.00)	0.46 (0.00)	1.00						
R&D _{gdp}	0.77 (0.00)	0.37 (0.00)	0.10 (0.10)	0.48 (0.00)	1.00					
DM _{pc}	0.09 (0.17)	0.22 (0.00)	0.17 (0.01)	0.20 (0.00)	-0.10 (0.10)	1.00				
EDU _{gdp}	0.49 (0.00)	0.23 (0.00)	0.00 (0.98)	0.35 (0.00)	0.44 (0.00)	-0.05 (0.45)	1.00			
OPENNESS	0.03 (0.61)	0.09 (0.17)	-0.11 (0.09)	0.21 (0.00)	0.01 (0.89)	-0.01 (0.92)	0.07 (0.27)	1.00		

Standard errors in parenthesis

For the countries under analysis, on average, 463.97 patents are granted per country and per year in at least two different offices. This type of patents represents 9.36% of the total patents and have increased by 213% from 2995 in 1990 to 9371 in 2012. In this race for environmental patents, Germany is far ahead with an average of 2739.5 followed by France and the United Kingdom with 745.5 and 585 eco-patents granted respectively. At the bottom of the scale we find Norway (65) and Ireland (24) (see Figure 3.2).

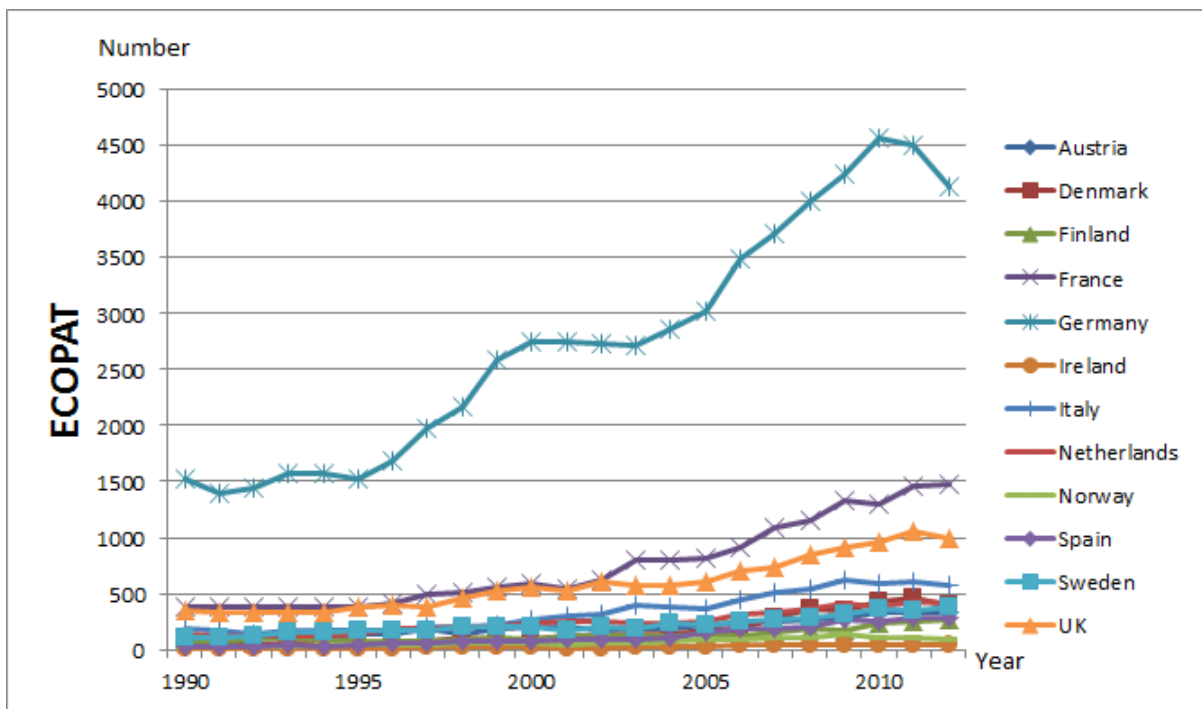


Figure 3.2: Evolution of international Eco-patents

When normalized by GDP, the average number of $ECOPATENT_{GDP}$ becomes 0.0004 and the standard deviation is 0.0003 with a cross country difference ranging from a minimum of 0.000024 for the Spain in 1991 and a maximum of 0.002 for the Denmark in 2011 (Table 3.2). On average over the 23 years, Germany remains ahead (0.0009), followed by Denmark (0.0008), Finland (0.0007), Austria (0.000639) and Sweden (0.000637) (Figure 3.3).

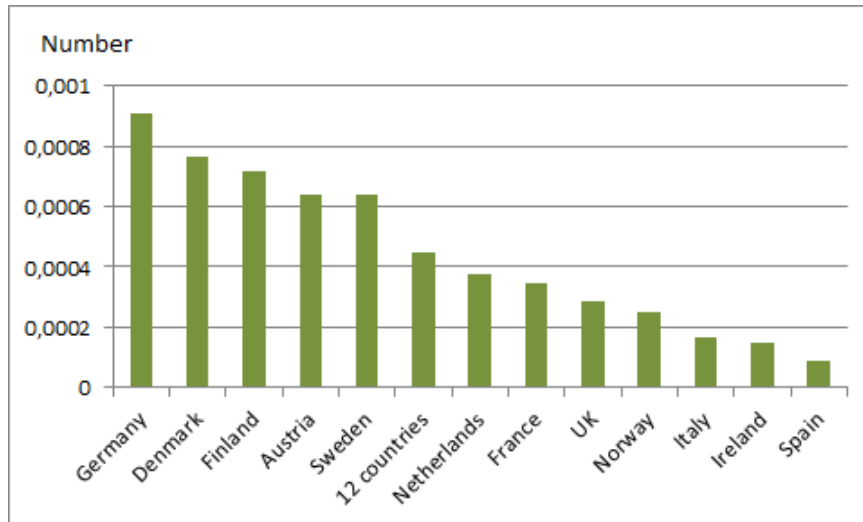


Figure 3.3: Mean of international Eco-patents per GDP

It is interesting to mention the sharp increase of the Danish and Finnish environmental patenting activity which places the two countries in first (0.0017) and second position (0.0013) in 2012 in front of Germany (0.0012). At the bottom of the ranking we find Norway (0.00025) and Italy (0.00017) followed very closely by Ireland (0.00015) and Spain (0.00009) (Figure 3.4).

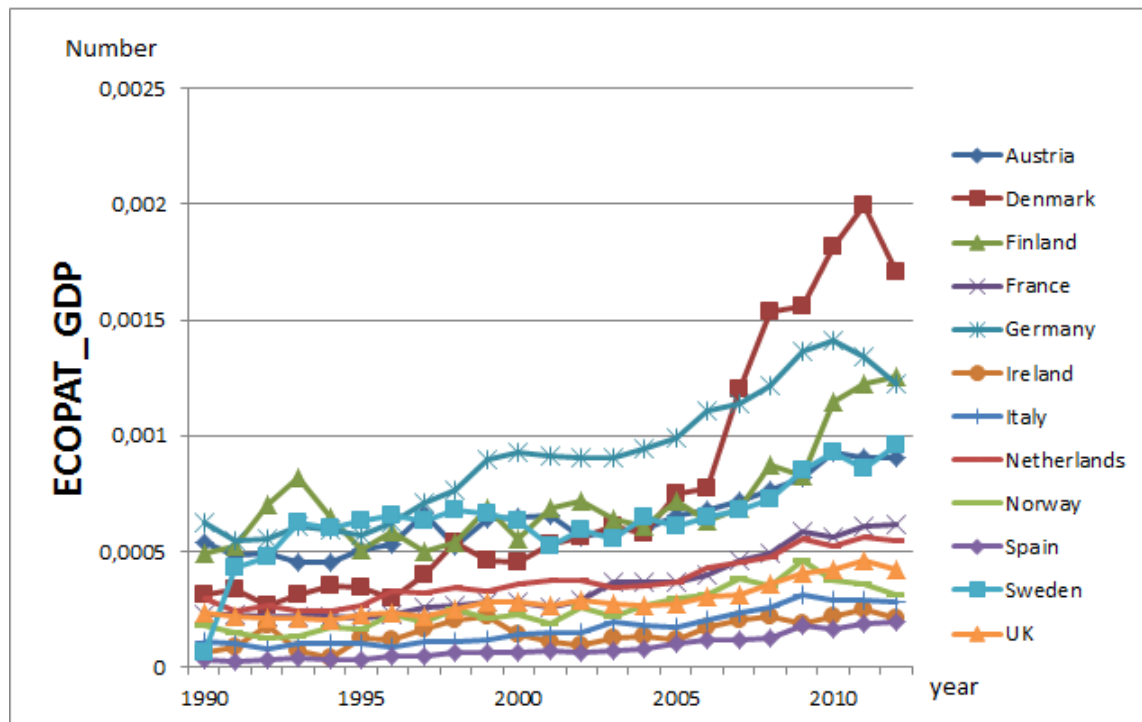


Figure 3.4: Evolution of international Eco-patents per GDP

In order to explain these findings, if we look at the policy stringency, we generally perceive that regulation was more restrictive in 2012 (3.08 on average on a scale of 6) than it

was in 1990 (0.93). Market-based instruments were very uncommon during 1990 not exceeding a stringency threshold of 0.42 exaequo for Finland, France, Germany, Ireland and Italy. For non-market instruments Netherlands was well ahead with a score of 3 followed by Austria and Germany (with a score of 2). Denmark and Sweden were in 3rd place (1.625). In 2012, Denmark took the lead with 4.18 followed by Finland with 3.345 and UK with 3.325. At the bottom of the standings were Ireland (2.05), Spain (2.21) and Austria (2.945). Market-based instruments also rose from 0.33 on average in 1990 to 2.04 but remained far behind non-market instruments with 4.13 (1.54 in 1990). In 2012, regarding these instruments, the UK was leading with 3.40 followed by Denmark (3.12) and France (2.63). The lowest countries were Ireland (0.85), Finland (1.32) and Germany (1.52). The podium for non-market included Finland (5.38) Denmark (5.25) and Netherlands (5). The lowest countries were Ireland, Italy and UK sharing the same position with 3.25 and Spain with 2.75. The UK was the only country where Market Based Instruments were more stringent than non-market ones (see Figure 3.5 and 3.6). Evolution of the environmental policy stringency by country is in Appendix C.2.

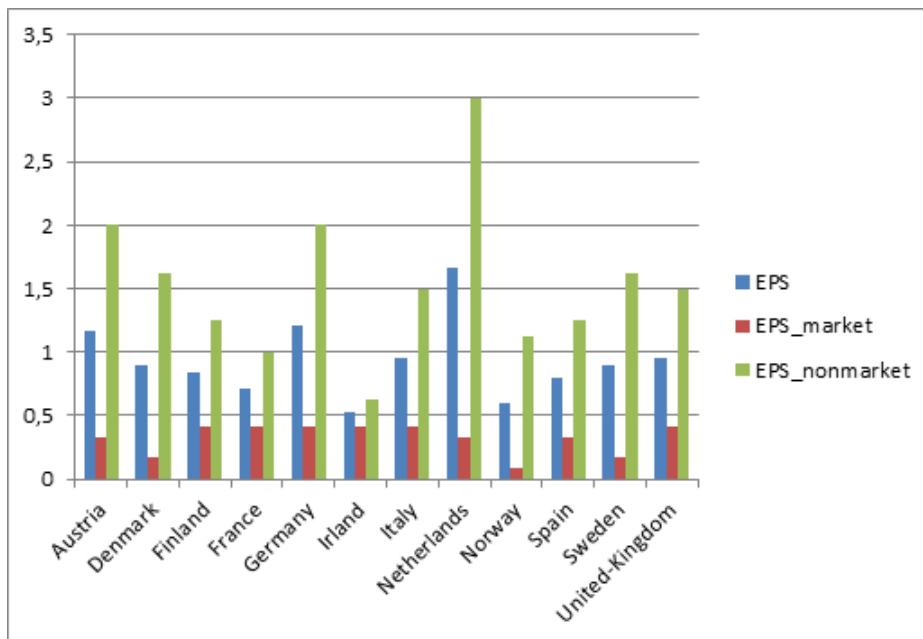


Figure 3.5: Average of the environmental policy stringency(1990)
(EPS index ranges from 0 to 6)

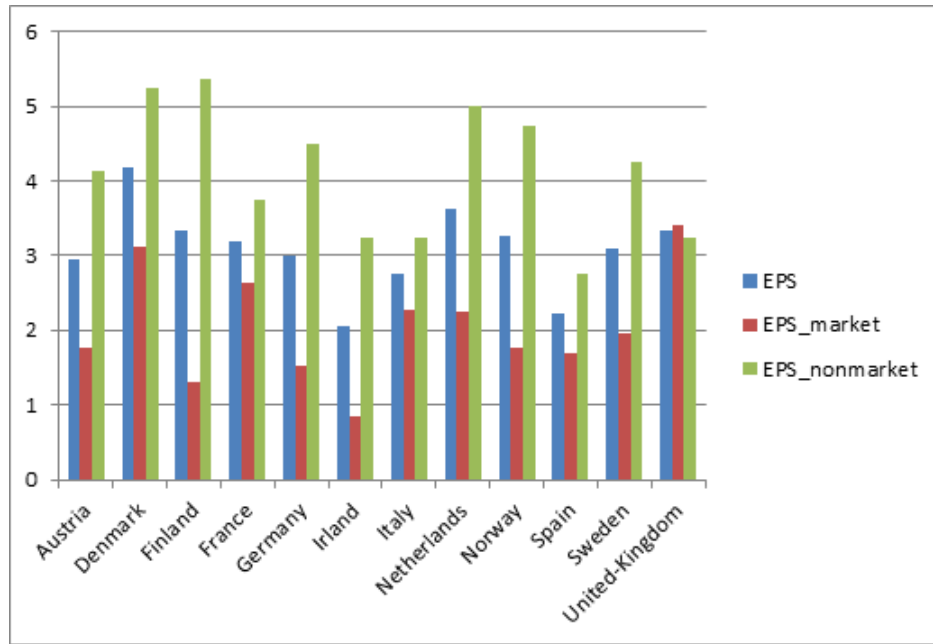


Figure 3.6: Average of the environmental policy stringency (2012)
(EPS index ranges from 0 to 6)

Concerning the *technology-push* determinants, if we look at the behaviour of the different countries in terms of R&D we notice that Finland, Sweden and Denmark are the ones with the strongest growth and which earned them the first three places. Germany started the race at the top but had known a slight increase compared to the other countries, hence its position in 5th place (0.287) in 2012 and 3rd place on average over the 23 years (behind Sweden and Finland but before Denmark) (Figure 3.7). France has not experienced strong growth and even declined from 1990 (0.023) until 2007, when it reached its lowest level (0.020) before realizing a slight increase in 2009 without however returning to its 1990 level in 2012 (0.022). A surprise about the UK which occupied only the 8th position on average over the 23 years and the 10th position in 2012 even though it was in 3rd position if we only look at the amounts spent in R&D (Figure C.1 in the Appendix C.3). Austria is the country with the most stable growth, which earned it the 4th place ahead of Germany in 2012 (0.0289). To finish with, we find Ireland, Italy and Spain at the bottom of the scale. Interestingly, the groups remain more or less the same as those of the $ECOPAT_{GDP}$, with the group of leaders (Austria, Denmark, Finland, Germany and Sweden), the group of latecomers (Ireland, Italy and Spain), France, Netherlands, Norway and United Kingdom are in the intermediate group. This brings us to assume that R&D strongly impacts eco-innovations.

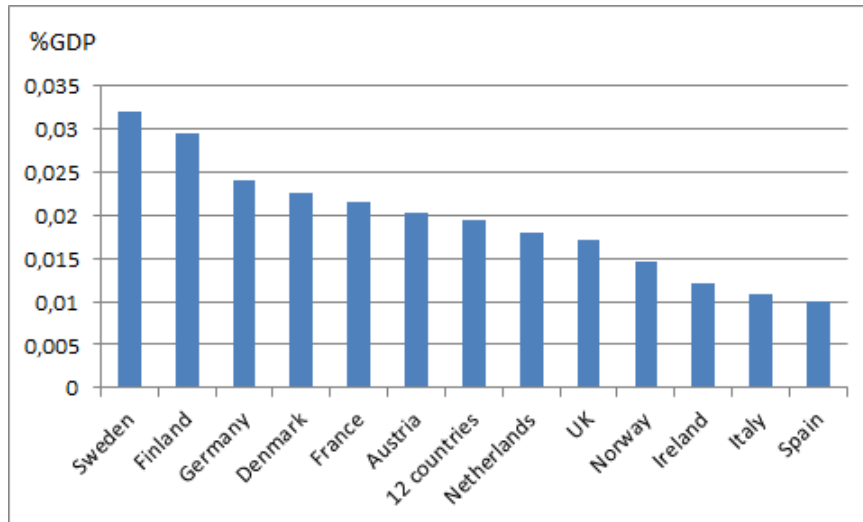


Figure 3.7: Mean of R&D expenditures per GDP

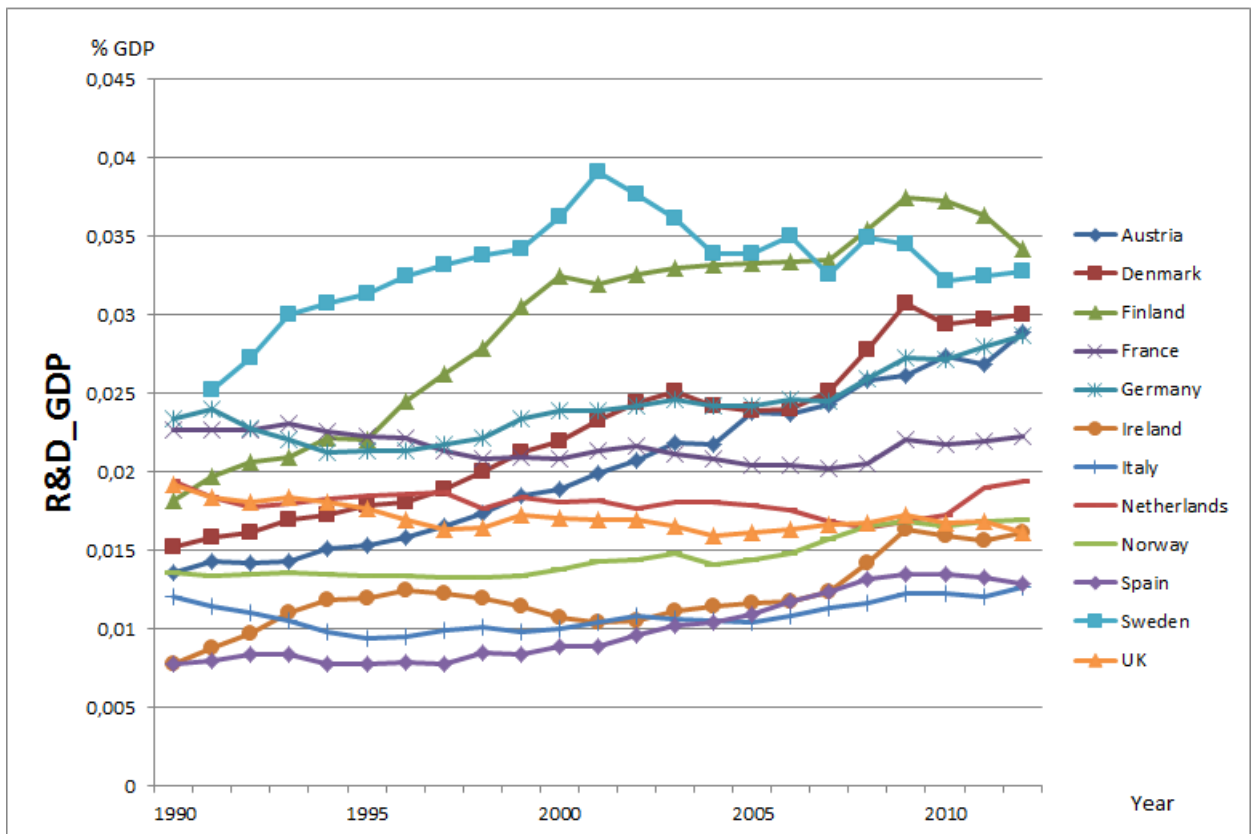


Figure 3.8: Evolution of R&D expenditures per GDP

Figure 3.9 gives an idea about the evolution of the demand expenditures per capita. Roughly speaking, demand has been increasing with a decline around 2009. This decline can be reasonably explained by the global economic crisis of 2008. The demand expenditures resumed their growth thereafter mainly for Austria, Germany, Finland, Sweden. Countries that stabilized their demands are Denmark, France and the UK. In contrast, in Spain, the

Netherlands, Italy and Ireland the demand continued to fall until 2012. We can therefore say that the countries that have maintained their demand expenditures per capita are those that perform better in eco-innovation, while those that have continued to decline are the ones that have innovated the least.

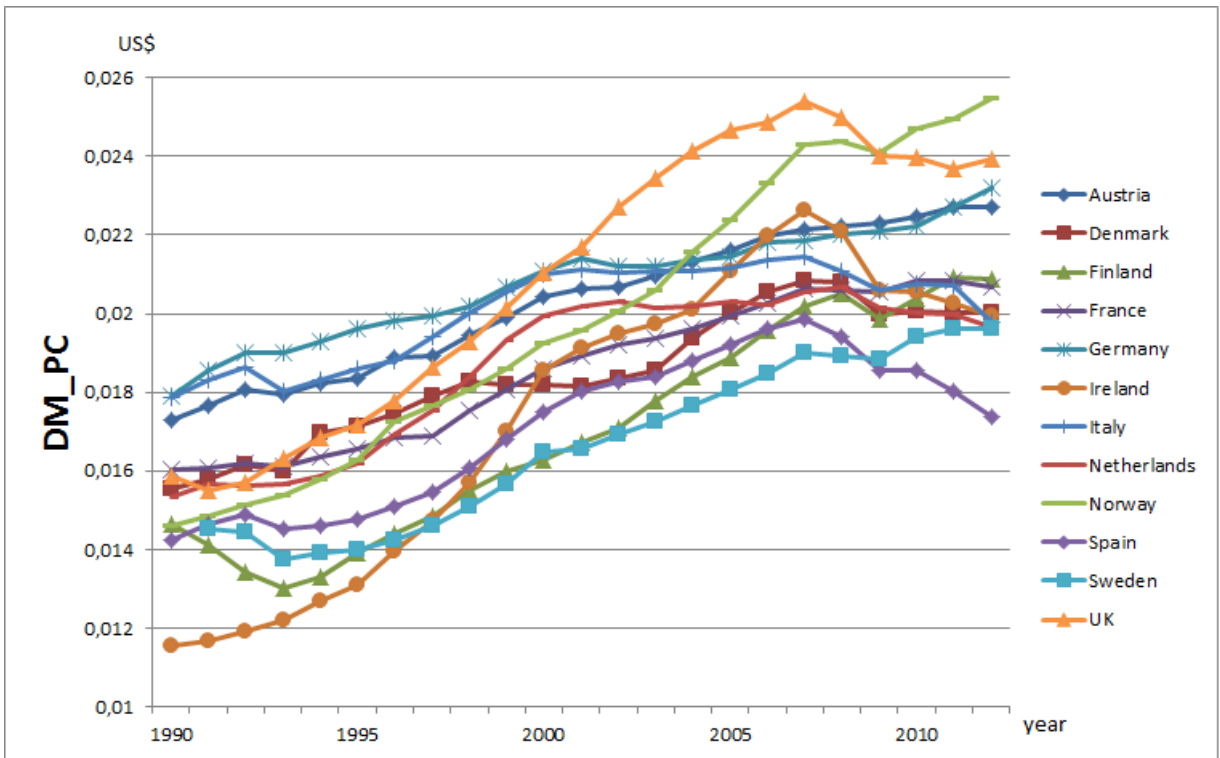


Figure 3.9: Demand expenditures per capita

Regarding expenditures on education, the ranking generally follows the other determinants with Denmark, Sweden, Finland and Austria which are among the top 5. Italy and Spain are the last two countries (Figure 3.10). Nevertheless, there are a few surprises with Norway in second position and Ireland ahead of the UK and Germany, which are respectively in 9th and 10th positions (Evolution of the Government expenditures on education by country is in Appendix C.4)¹⁹.

¹⁹We have to note that data of EDU_{GDP} may refer to spending by the ministry of education only (excluding spending on educational activities by other ministries) and that government expenditure appears lower in some countries where the private sector and/or households have a large share in total funding for education (The world bank). For example in Germany, the apprenticeship rate is very high and apprenticeship is the responsibility of the Länder and not the federal state that spends nothing in educational matters.

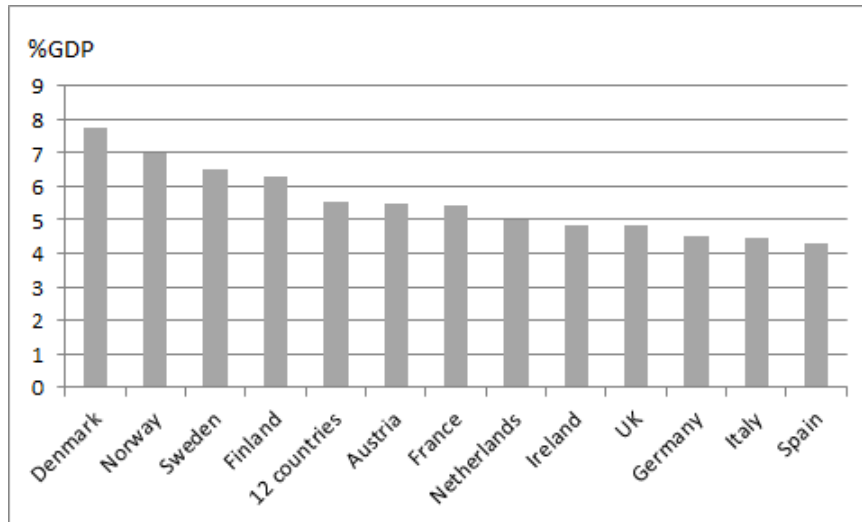


Figure 3.10: Mean of Government expenditures on education (as% of GDP)

By analysing the openness variable, we observe that countries follow more or less the same trend with a first decrease around 2002/2003 following the internet bubble and a second in 2009 following the subprime crisis in 2007 and the economic crisis in 2008 (the decline occurred in 2011 in Ireland) (Figure 3.11). This shows that the trade relations of countries are interconnected and that a shock impacting one or more countries spreads more or less quickly to the others.

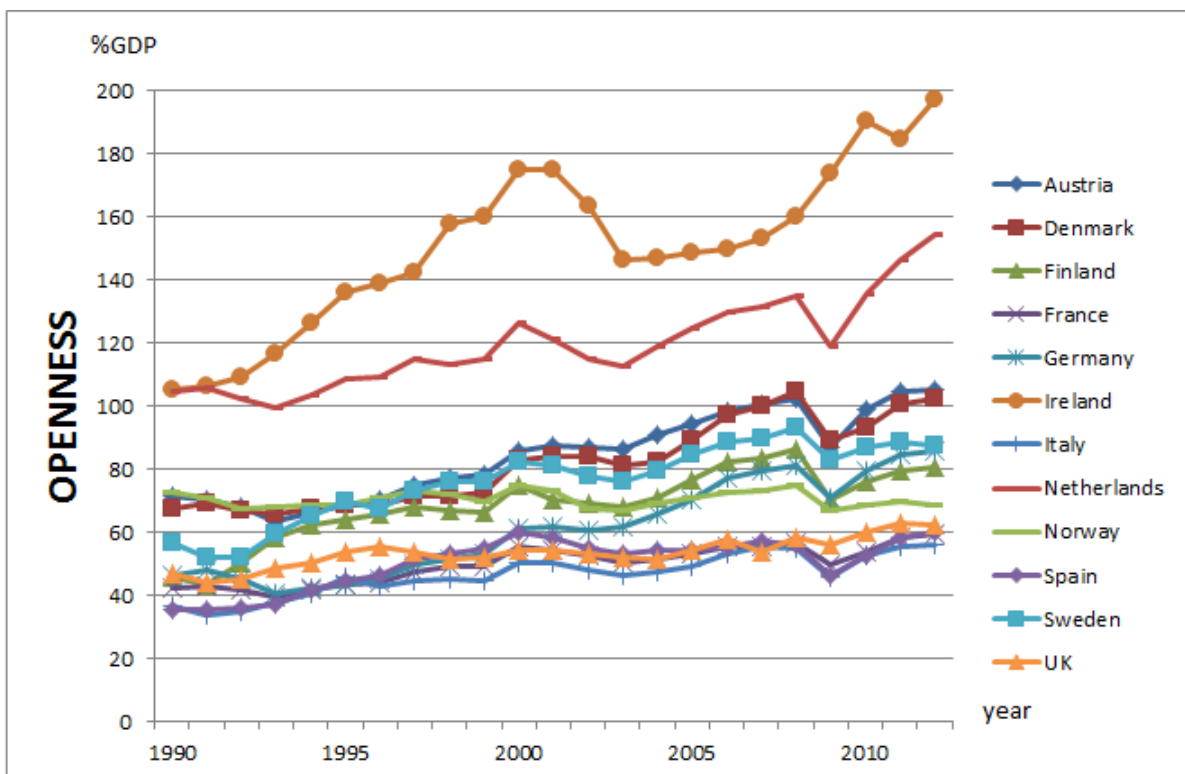


Figure 3.11: Openness evolution

However, when looking at the ranking of countries it is quite surprising to find the 5 largest European economies occupying the 5 places at the bottom and Ireland and the Netherlands occupy largely the first two places at the top (Figure 3.12).

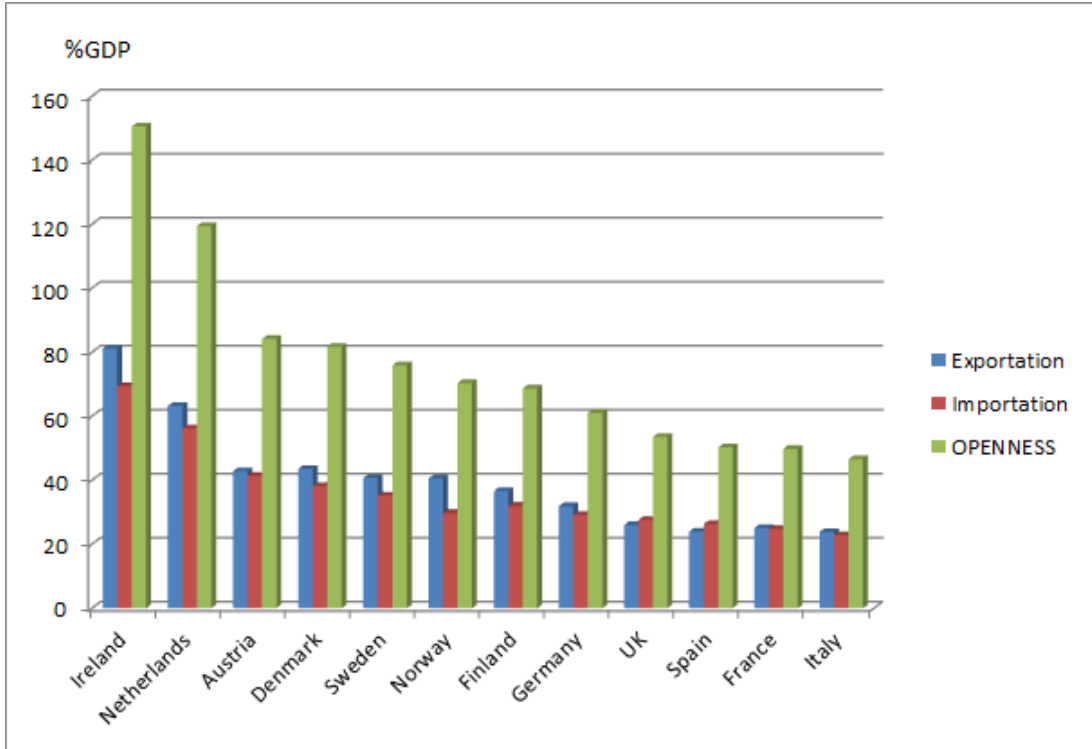


Figure 3.12: Mean of Openness

3.4 Empirical analysis and results

3.4.1 Methodology

In this study, the econometric method of panel data is used in order to exploit the extra information provided by the panel data framework. To do so, the following linear reduced form equation is estimated. This builds on a simple generalization of [Romer \(1986\)](#) and [Jones \(1995\)](#)' specification.

$$\log y_{i,t+2} = \beta_0 + \sum_{k=1}^K \beta_k \log x_{k,it} + \epsilon_{it} \quad (3.1)$$

where i indicates countries $i = 1, \dots, N$, t represents time $t = 1990, \dots, 2010$. k refers to explanatory variable k and $y_{i,t+2}$ and $x_{k,it}$ are respectively the dependent and independent variables for country i and time t . β_0 and β_k refer, respectively, to the intercept and the slope parameters to be estimated. ϵ_{it} is a random error term. Given the nature of the data, estimat-

ing this model using the OLS method could bias the results. Indeed, since we study European countries which share several similarities and which are economically and culturally linked, we assume that there is potentially heteroscedasticity and correlation across-sections. ϵ_{it} is then assumed to be equal to

$$\epsilon_{it} = \rho_i \epsilon_{i,t-1} + \mu_{it}$$

where the autoregressive parameter can vary across countries with $|\rho_i| < 1$. For these reasons, feasible generalized least squares (FGLS) estimator that is robust to first-order panel-specific autocorrelation and panel heteroscedasticity is used (Baltagi, 2008)²⁰.

3.4.2 Estimation results

All variables, except the EPS index, are in log form this way the slope parameters can be interpreted in terms of elasticities, are less sensitive to outliers and are consistent with work in this area (Furman et al., 2002; Krammer, 2009). To choose the most suitable estimation method, we run a couple of diagnostic tests²¹. Through the Breusch-Pagan test (1979) a problem of heteroscedasticity is detected. Theoretically, the presence of heteroscedasticity does not bias the estimated coefficients, but it biases the matrix of variance-covariance of these latter. Our data also reveals correlation problems: a contemporaneous correlation, is detected using CDLM (Cross-sectional Dependence Lagrange Multiplier) test and serial correlation problem using the Wooldridge test (2002). These two types of correlation mean that any shock in any year or to any country affects the following years and the other countries. As it is said earlier, we use FGLS to take into consideration these problems detected. We also include year dummies to capture some of the unobserved heterogeneity (Wooldridge, 2002). Wald statistics show that overall significance of all regressions presented is quite high.

Table 3.4 illustrates the regression results. As it is said earlier, the OLS outcome (column (1)) is biased due to the heteroscedasticity and autocorrelation problems. According to the FGLS regression (column (2)), all the explanatory variables have positive and significant effects at a threshold of 5%. A closer look at findings reveals that R&D seems to be the most

²⁰Beck and Katz (1995) explain that if the sample size is finite or small, the panel must be "temporal dominant" i.e. the total number of temporal observations must be larger than, or at least as large as, the number cross-section units to be able to use the FGLS method. This is the case in this study.

²¹The results for all the tests are significant at 1%

important element in stimulating national eco-innovation. An increase of 1% in $R\&D_{GDP}$ increases the $ECOPAT_{GDP}$ by 1.18%. This is in line with the findings of the innovation economics - at micro-level- and of the Endogenous growth theory and the NIS - at macro-level - that emphasize the role of knowledge as the most important resource of innovation. This is also consistent with our analysis in the descriptive statistics section which shows that R&D expenditures were broadly in line with eco-innovation's evolution. Another finding that confirms our pronouncement concerns the demand side in which the demand per capita and the educational system seem to have an essential role to play as it is the case for standard innovations (elasticities of 0.84% and 0.31% respectively) (Furman et al., 2002; Varsakelis, 2006; Coe et al., 2009; Krammer, 2009; Khan and Roy, 2011). The international trade (Khan and Roy, 2011) has less important coefficient but still positive and significant (0.11%). Finally our findings support the weak version of the Porter Hypothesis since we find a significant positive impact of the regulation stringency on the environmental innovation. A one point increase in stringency enhances the innovation of 12% (Albrizio et al., 2014; De Santis and Jona-Lasinio, 2015). In addition, the literature related to the PH widely emphasized the different impacts that can have market based and command and control instruments noting that the first category gives more incentives to eco-innovate. The result reported in column (3) confirms this purpose since that both instruments have a significant effect but that market based regulations have a higher positive one (8%) than non-market based instruments (5%).

Table 3.4: OLS and FGLS regressions

	(1) OLS Log(ECOPAT _{GDP}) _{t+2}	(2) FGLS Log(ECOPAT _{GDP}) _{t+2}	(3) FGLS Log(ECOPAT _{GDP}) _{t+2}
EPS	0.10*** (0.04)	0.12*** (0.02)	
EPS _{market}			0.08*** (0.02)
EPS _{nonmarket}			0.05*** (0.02)
Log(R&D _{GDP})	1.54*** (0.07)	1.18*** (0.07)	1.19*** (0.07)
Log(DM _{PC})	1.24*** (0.14)	0.84*** (0.08)	0.85*** (0.08)
Log(EDU _{GDP})	0.31** (0.21)	0.31*** (0.10)	0.31*** (0.09)
Log(OPENNESS)	0.16** (0.06)	0.11** (0.04)	0.12*** (0.05)
_cons	-15.31*** (1.40)	-12.60*** (0.66)	-12.70*** (0.66)
Wald Chi square		2546.76***	2533.97***
Observations	252	252	252

* p<0.1, ** p<0.05, *** p<0.01 (Standard errors in parenthesis)

To check the robustness, Table 3.5 unveils the results of FGLS regressions using alternative variables. We use full time equivalent of R&D personal instead of R&D expenditures (columns 1 and 2); enrolment in tertiary education (SCHOOL) instead of Government expenditures on education (columns 3 and 4) and foreign direct investment (FDI) as another measure of the openness of countries (columns 5 and 6). Always with a view of avoiding the scale effect, we divided the two variables of R&D personal and FDI by the GDP, SCHOOL being already a percentage. Overall, results remain unchanged except for OPENNESS and EPS_{nonmarket} that become non-significant at 10%. The FDI_{GDP} does not have a significant impact on environmental innovation as well. By contrast Personal_{GDP} has a strong significant effect (an increase of 1.44% is obtained following an increase of 1% in the R&D personal). Enrolment in tertiary education, even when it is hardly significant, has a too small

impact close to zero.

Table 3.5: FGLS estimation results

	Log(ECOPAT _{GDP}) _{t+2}					
	(1)	(2)	(3)	(4)	(5)	(6)
EPS	0.05* (0.03)		0.12*** (0.02)		0.13*** (0.02)	
EPS _{market}		0.03* (0.02)		0.08*** (0.01)		0.07*** (0.01)
EPS _{nonmarket}		0.02 (0.02)		0.05*** (0.01)		0.05*** (0.01)
Log(R&D _{GDP})			1.21*** (0.08)	1.23*** (0.08)	1.16*** (0.07)	1.17*** (0.07)
Log(Personal _{GDP})	1.44*** (0.09)	1.45*** (0.09)				
Log(DM _{PC})	1.20*** (0.10)	1.22*** (0.10)	0.84*** (0.08)	0.86*** (0.08)	0.84*** (0.07)	0.87*** (0.07)
Log(EDU _{GDP})	0.31** (0.12)	0.29** (0.12)			0.33*** (0.09)	0.37*** (0.09)
SCHOOL			0.003 (0.00)	0.003* (0.00)		
Log(OPENNESS)	0.04 (0.09)	0.04 (0.09)	0.11*** (0.04)	0.13*** (0.04)		
FDI _{GDP}					-0.001 (0.00)	-0.001 (0.00)
_cons	-17.71*** (1.12)	-17.76*** (1.13)	-12.10*** (0.67)	-12.32*** (0.68)	-12.30*** (0.51)	-12.56*** (0.50)
Wald Chi square	2415.58	2497.86	2533.97***	2341.92***	3200.65***	3577.96
Observations	252	252	252	252	252	252

* p<0.1, ** p<0.05, *** p<0.01 (Standard errors in parenthesis)

3.5 Concluding remarks

This study contributes to eco-innovation determinants literature by exploring two aspects. Firstly, concerning the theoretical side, it matches together drivers from different eco-

nomics fields to propose an analytical framework for further researches at a cross-country level. This first part highlights the singularity of eco-innovation with regard to standard innovation that consists in its favourable impact on the environment. This specific positive effect improves the social well-being and is particularly important due to the fact that the future life on earth depends on it. One central objective is then to make the private economic benefits of firms in line with this social benefit by promoting eco-innovations. In this context, economic literature emphasizes several drivers of environmental innovation that can be gathered into three groups "*technology-push*", "*demand-pull*" and "*institutional*" determinants with the particular focus on the environmental *regulation*. Secondly, our study empirically investigates the eco-innovation determinants highlighted. To do so, we analysed panel data belonging to 12 European countries from 1990 to 2012 representing the three categories of determinants cited. The results confirm the theoretical findings. Indeed, the descriptive analysis of the data clearly shows the role of R&D and household demand, the two proxies of *technology push* and *demand pull*. An estimate using the FGLS confirms these results and shows that institutions do have a positive and significant role in eco-innovation as well. In addition to the empirical results, the most important is their implications for policymaker interventions. Globally the key recommendations of our work would be to promote and reinforce a European environmental plan by: 1) encouraging action in favour of the R&D and orienting it towards ecological solutions; 2) promoting the awareness activities in order to push the demand for green products; 3) implementing better regulations to be more effective; 4) creating a beneficial national environment.

For future research, it would be interesting to add other proxies representing the institutional performance of a country. They could be proxies or other variables on administrations, education system performance and so on. It would also be interesting to refine the data by studying data specific to eco-innovations and not broad ones such as environmental R&D, demand for green products and trends in environmental markets. Such research will be feasible in a few years through initiatives like the Eco-Innovation Observatory which is a European Union platform for the structured collection of eco-innovation information. Finally, and maybe the most important, is how to find a way to make all the above-cited recommendations possible.

Conclusion

Innovation has always been considered as the cornerstone of development. Faced with relatively new environmental concerns, innovation must in turn be renewed in order to take into account new challenges i.e. ensure Sustainable development. Up to now, initiatives for eco-innovation were nothing but simple measures juxtaposed to each other that we tried, albeit not exactly successfully, to stick together without actually a great originality nor great consistency. We did a bit of everything: a little bit of economic profit, some social activities, some environmental protection, with tools and resources that we commonly use ([Vivien, 2007](#)). Nevertheless, ensure a green growth through green innovations is not the conceptualization of a lived reality. It is in itself an innovation. It is a notion that comes to break with what was before, the expression of a suction whose content is inverted compared to the most common experience ([Godard, 2004](#)). This thesis falls within this general framework. The ambition is to examine how, on a microeconomic level, the dynamics of inter-firm relationships in supply-chains affect the emergence and diffusion of environmental innovations; and what are the main macroeconomic determinants behind the green technical progress. This is especially important when focusing on environmental innovation since public authorities play a crucial role and need lighting to target interventions, make them more effective and thus increase the reactivity of different key players.

To reach this objective, the dissertation is structured in three chapters. The first one put the attention on the strategic behaviour of a monopolist against his suppliers. We show that in a vertically related market, even when a drastic innovation occurs - in our case one of the two suppliers present on the market provides a costless higher-quality innovation - the monopoly always contract with both suppliers, not to diversify the products on the final market, but only to exert additional pressure on the innovator. In other words, because of the strategic behaviour of firms, an innovation that is supposed to be drastic may no longer be considered as such. This observation, combined with other factors, could explain

that pollutant or lower environmental quality products still exist on the market whereas alternative solutions exist according to experts (Yarime, 2007).

Based on these findings, we show that the monopoly may have an interest in developing an integrated-clean technology for only strategic reasons. Indeed, in the second chapter we targeted to analyse the impact of vertical relationships specificities on the adoption of environmental innovations. To do so, we developed a three-player game: a monopoly who generates by-product emissions when producing, a regulator who fixes an environmental tax to reduce these harmful emissions and a supplier of an end-of-pipe technology. Facing the environmental tax, the monopoly has the possibility to buy the end-of-pipe technology or to develop his own integrated-clean technology. The two technologies are not perfect substitutes. The integrated-clean one is environmentally more efficient since that it does not generate pollution. However, it can be more expensive. The resolution of the game indicates that the clean innovation can be undertaken only to give the monopoly further leverage when dealing with the end-of-pipe technology supplier. Such a strategy is sub-optimal in terms of environmental and economic welfare. To cope with the situation, the regulator must adapt its tax in order to push the monopoly to choose the technology that maximizes total welfare. However, sometimes, the regulator fails to influence the monopoly behaviour and hence inevitable welfare loss occurs.

This postulate led us to question the role of the regulator in promoting environmental innovations and the most effective way to operate. However, in order to promote environmental innovations, it is imperative to clearly identify their drivers. To do so, the third chapter theoretically and empirically identifies the macro-determinants on environmental innovations. Indeed, in the first part we relied on a literature review that makes emerge national institutions, with a privileged role of environmental policies, “technology-push” and “demand-pull” as the driving force of eco-innovative activities. Then in the second part, we adopted an econometric model of panel data that cover 12 European countries over a time period of 1990-2012. Using descriptive statistics and FGLS regression, results broadly confirm the contributions of the literature review by revealing a positive impact of “technology-push” (proxied by R&D expenditure per GDP), “demand-pull” (proxied by the demand per capita and expenditures on education as a percentage of GDP) and institutions that are measured by the degree of openness of a nation to the international trade and regulation stringency (captured by the EPS index).

In addition to the directions outlined in the conclusions of the different chapters, there are several ways in which the analysis of the environmental innovation in the supply-chain can be extended. First, on the theoretical level, it would be interesting to have a look at the modes of cooperation between vertically linked companies around the development and implementation of environmental innovations. Indeed, technological change is often based on the reactivity, not of a single firm, but of the entire supply-chain. This is due to the characteristics of production systems where final added value results from a combination, often complex, of specific inputs from many firms. This is all the more true if we introduce in addition the environmental issues that have led to the emergence of notions such as the “sustainable life cycle” of products and the need to “green supply chains”. The development and diffusion of environmental innovations is therefore highly dependent on the ability of vertically related firms to coordinate around environmental issues (Vachon and Klassen 2007; 2008). Beyond questions relating to the development of collaborative environmental solutions, a second perspective would be to examine the modes inciting the collaboration between firms. It would be important to reconsider the nature and forms of public intervention in environmental protection. In particular, it is interesting to examine the interactions between different public policies, for example the potential synergies between instruments supporting innovation (intellectual protection, subsidies, education, clusters, etc.) and environmental regulations (standards and certification, etc.) within an approach that explicitly integrates the vertical relationships of the actors. On the empirical level, it would be equally important to continue this dynamic and to focus on the effectiveness of political incentives within supply-chains like Franco and Marin (2015). This will permit not only to target the most effective policy instruments to use, but also to see to what level they should be introduced into the chain.

Appendices

Appendix A

Appendix Chapter 1

A.1 Optimal two-part-tariffs with non-exclusive contracts

Consider first the maximization of (1.3) and (1.4) with respect to t_i . By solving $\frac{\partial \log[B_1^{MRb}(\cdot)]}{\partial t_1} = 0$ and $\frac{\partial \log[B_2^{MRb}(\cdot)]}{\partial t_2} = 0$ for f_1 and f_2 we obtain, respectively:

$$\begin{aligned} f_1(v_1, v_2, f_2) &= \\ &= \frac{(1-\alpha)(1-\beta)s_2^2s_1 + s_2[s_1^2(\alpha+\beta-\alpha\beta-1) - 2(1-\beta)s_1v_2 + (1+\beta)v_1^2] + s_1v_2[2s_1 + v_2 - 2v_1 - \beta(2s_1 + v_2)]}{4s_1(s_2 - s_1)} + \\ &\quad - (1 - \beta)f_2, \quad (\text{A.1}) \end{aligned}$$

$$\begin{aligned} f_2(v_1, v_2, f_1) &= \\ &= \frac{s_1s_2^2(1-\alpha) + s_2[(1-\alpha)v_1^2 - 2s_1v_2 - (1-\alpha)(1+\beta)s_1^2] - (\alpha-1)\beta s_1^3 + s_1v_2(2s_1 + \alpha v_2 + v_2 - 2v_1)}{4s_1(s_2 - s_1)} + \\ &\quad - (1 - \alpha)f_1. \quad (\text{A.2}) \end{aligned}$$

We now use (A.1) (res. (A.2)) as a constraint in the problem of maximizing $B_1^{MRb}(\cdot)$ (res. $B_2^{MRb}(\cdot)$) with respect to v_1 (res. v_2). The solution to these programs is:

$$v_1^{MRb} = 0, \quad v_2^{MRb} = 0. \quad (\text{A.3})$$

By plugging (A.3) into (A.1) and (A.2) and solving the system so defined we obtain the optimal fixed fees:

$$f_1^{MRb} = \frac{s_1\beta(1-\alpha)(1-\beta)}{4(\alpha+\beta-\alpha\beta)}, \quad f_2^{MRb} = \frac{(1-\alpha)[\alpha s_2 - \beta s_1 + (1-\alpha)\beta s_2]}{4(\alpha+\beta-\alpha\beta)}. \quad (\text{A.4})$$

Second-order conditions are locally satisfied. This, together with the uniqueness of the maximizers of $B_i^{MRb}(\cdot)$, $i \in \{1, 2\}$, completes the proof.

A.2 Fixed production or contracting costs

We assume that a fixed cost $F_i < \frac{s_i}{4}$, $i = 1, 2$, $F_2 \geq F_1 \geq 0$ has to be borne by the monopolist¹ in case of successful negotiation either to sell good i or when signing the contract for its provision.

¹This hypothesis is set for simplicity. Assuming that fixed costs are borne by upstream producers does not change the equilibrium outcome and so is the conclusion addressed.

A.2.1 Exclusive contracts

Adding a fixed cost in the profit function of the monopolist does not change neither the optimal downstream prices at stage three, $p_i(v_i) = \frac{s_i + v_i}{2}$, nor the variable part of the two-part-tariff at stage two compared to the main text: $v_i = 0, i = 1, 2$. However, profits of the monopolist and the supplier are now impacted by F_i ².

$$\Pi_i^I = \frac{s_i - 4F_i}{4} \mu$$

$$\pi_i^I = f_i^I = \frac{s_i - 4F_i}{4} (1 - \mu)$$

with $\mu = \alpha$ (res. $\mu = \beta$) if $i = 2$ (res. $i = 1$)³.

A.2.2 Non-exclusive contracts

As in the previous case, the fixed cost does not affect neither monopoly pricing nor the optimal variable part of the two-part-tariff, which is $v_i = 0, i = 1, 2$. In turn, this entails that, if non-exclusive contracts are signed, prices are such that the equilibrium demand for the low-quality good is zero. The fixed parts of the tariff are

$$f_1^{II} = \frac{\beta(1-\alpha)(1-\beta)s_1}{4\Phi} + \beta F_1$$

and

$$f_2^{II} = \frac{1}{4} \left[(1 - \alpha)s_2 - \left(1 - \frac{\alpha}{\Phi}\right)s_1 \right] + \alpha F_2$$

corresponding to the profits of the upstream firms.

The monopolist profit is

$$\Pi^{II} = \frac{\alpha s_2}{4} + \frac{\beta^2(1-\alpha)s_1}{4\Phi} - \alpha F_2 - \beta F_1$$

Comparing these outcomes yields us to state

Result 2. *Let a fixed cost $F_i < \frac{s_i}{4}, i = 1, 2, F_2 \geq F_1$ be borne by the downstream monopolist for each contract it signs, and let $F_2 < \frac{\alpha(1-\beta)s_2 + \beta\Delta s}{4\Phi}$ and $F_1 < \frac{\beta(1-\alpha)s_1}{4\Phi}$. Then the monopolist always (i) signs non-exclusive contracts, and (ii) sells the high-quality good only.*

Proof. For all $(\alpha, \beta) \in]0, 1[^2$

- (i) a) $\Pi^{II} > \Pi_2^I \Leftrightarrow F_1 < \frac{\beta(1-\alpha)s_1}{4\Phi} \equiv \bar{F}_1 < \frac{s_1}{4}$;
- b) $\Pi^{II} > \Pi_1^I \Leftrightarrow F_2 < \frac{\alpha(1-\beta)s_2 + \beta\Delta s}{4\Phi} \equiv \bar{F}_2 < \frac{s_2}{4}$.
- (ii) $D_1^{II} = 0$.

□

It is worth noticing that if $F_1 < \bar{F}_1$ but $F_2 > \bar{F}_2$ (res. $F_1 > \bar{F}_1$ but $F_2 < \bar{F}_2$) the monopolist signs an exclusive contract for good 1 (res. good 2).

²In the following of the appendices, for the sake of readability, we shall not introduce further notation to distinguish among the cases, unless necessary to avoid confusion in the comparisons.

³Even if the fixed cost is supposed to be borne by only one firm, this latter use its bargaining power to pass a part of this loss to the other firm. This explains the remark in footnote 1.

A.3 Linear costs

In this section, we analyse the case where the downstream firm bears a linear cost $C_i(q_i) = c_i q_i$ to retail the goods, with $c_2 \geq c_1 \geq 0$, $s_i > c_i$ and $i \in \{1, 2\}$ (Bester and Petrakis, 1993; Bonanno and Haworth, 1998)⁴.

A.3.0.1 Exclusive contracts

Stage 3. (Pricing)

The monopolist commits to an exclusive relationship with producer $i \in \{1, 2\}$. The pricing stage profit for the monopolist is $(p_i - v_i - c_i)D_i(p_i) - f_i$, which is maximized for

$$p_i(v_i) = \frac{s_i + v_i + c_i}{2}.$$

By plugging the price back into the profit we find that this profit is

$$\Pi_i(v_i, f_i) = \frac{(s_i - v_i - c_i)^2}{4s_i} - f_i.$$

The profit of supplier i at $p_i(v_i)$, writes

$$\pi_i(v_i, f_i) = \frac{v_i(s_i - c_i - v_i)}{2s_i} + f_i.$$

Stage 2. (Bargaining)

The Nash product is,

$$B(v_i, f_i) = [\Pi(v_i, f_i)]^\mu [\pi(v_i, f_i)]^{1-\mu},$$

with $i \in \{1, 2\}$ and $\mu = \alpha$ (res. $\mu = \beta$) if, and only if $i = 2$ (res. $i = 1$). Maximization of $B_i(v_i, f_i)$ with respect to v_i and f_i gives

$$v_i = 0, \quad f_i = \frac{(s_i - c_i)^2(1-\mu)}{4s_i}.$$

By plugging the optimal two-part-tariff back into the price, demand and profits we obtain

$$p_i^I = \frac{s_i + c_i}{2}, \quad D_i^I = \frac{s_i - c_i}{2s_i}$$

$$\Pi_i^I = \mu \frac{(s_i - c_i)^2}{4s_i}, \quad \pi_i^I = (1 - \mu) \frac{(s_i - c_i)^2}{4s_i},$$

with $i = 1, 2$ and $\mu = \alpha$ (res. $\mu = \beta$) if, and only if $i = 2$ (res. $i = 1$). If committed to an exclusive relationship, the monopolist signs a contract with the high-(res. low-)quality producer if, and only if $\Pi_2^I > \Pi_1^I \Leftrightarrow \frac{\alpha}{\beta} > \left(\frac{s_1 - c_1}{s_2 - c_2}\right)^2 \frac{s_2}{s_1}$ (res. $\Pi_2^I < \Pi_1^I \Leftrightarrow \frac{\alpha}{\beta} < \left(\frac{s_1 - c_1}{s_2 - c_2}\right)^2 \frac{s_2}{s_1}$).

A.3.0.2 Non-exclusive contracts

Depending on the level of the marginal costs, the monopolist may decide to set prices so as to sell one good only, as in the case with no costs, or to actually sell two goods. The monopolist profits are, therefore

$$\Pi(p_1, p_2) = \sum_{i=1}^2 [(p_i - v_i - c_i)D_i(p_1, p_2) - f_i], \quad (\text{A.5})$$

Where p_1 and p_2 may be set such that one of the two demands is zero.

⁴As for the upper case of fixed costs, the assumption that upstream firms bear the linear costs yields to the same results.

A.3.0.2.1 Case 1). The monopolist may sign a contract with both producers and, thus, sell both goods to the final consumers.

Stage 3. (Pricing)

The optimal prices at this stage: $p_i = \frac{s_i + v_i + c_i}{2}$, for $i = 1, 2$.

Accordingly, the profits for the monopolist, the high-quality producer and the low-quality producer are

$$\Pi(v_1, v_2, f_1, f_2) = \frac{s_2(c_1^2 + v_1^2) + s_1[c_2^2 + s_2^2 - s_2s_1 - v_2(2s_2 - 2s_1 + 2v_1 - v_2) - 2c_2(\Delta s - v_2 + v_1)] - 2c_1(s_1c_2 + s_1v_2 - s_2v_1)}{4s_1\Delta s} - f_1 - f_2.$$

$$\pi_1(v_1, v_2, f_1) = \frac{v_1(s_1v_2 - s_2v_1 - s_2c_1 + s_1c_2)}{2s_1\Delta s} + f_1,$$

$$\pi_2(v_1, v_2, f_2) = \frac{v_2(\Delta s - c_2 + c_1 - v_2 + v_1)}{2\Delta s} + f_2$$

Stage 2. (Bargaining)

The two Nash products are

$$B_1(v_1, v_2, f_1, f_2) = [\Pi(v_1, v_2, f_1, f_2) - \frac{\alpha(s_2 - c_2)^2}{4s_2}]^\beta [\pi_1(v_1, v_2, f_1)]^{1-\beta}, \quad (\text{A.6})$$

$$B_2(v_1, v_2, f_1, f_2) = [\Pi(v_1, v_2, f_1, f_2) - \frac{\beta(s_1 - c_1)^2}{4s_1}]^\alpha [\pi_2(v_1, v_2, f_2)]^{1-\alpha}. \quad (\text{A.7})$$

The joint maximization of (A.6) and (A.7) yields

$$v_i^H = 0, i = 1, 2,$$

$$f_1^H = \frac{(1-\beta)[\alpha(s_2c_1 - s_1c_2)^2 + (1-\alpha)\beta s_2\Delta s(s_1 - c_1)^2]}{4s_1s_2\Delta s\Phi},$$

$$f_2^H = \frac{(1-\alpha)\{\alpha\Delta s(s_2 - c_2)^2 + [s_2(\Delta s - c_2 + c_1)^2 - \alpha\Delta s(s_2 - c_2)^2]\}\beta}{4s_2\Delta s\Phi}.$$

By plugging these values back into the equilibrium prices and demands we obtain

$$p_1^H = \frac{s_1 + c_1}{2}, \quad D_1^H = \frac{s_1c_2 - s_2c_1}{2s_1\Delta s}.$$

$$p_2^H = \frac{s_2 + c_2}{2}, \quad D_2^H = \frac{\Delta s - c_2 + c_1}{2\Delta s}.$$

Direct inspection of D_i^H , $i = 1, 2$ reveals yields

Remark 3. With non-exclusive contracts, the demands for the goods are simultaneously positive if, and only if, $\frac{s_2c_1}{s_1} < c_2 < c_1 + \Delta s$.

Within this region the profit of the monopolist is

$$\Pi_{1) }^H \equiv \frac{\alpha^2 s_1 \Delta s (c_2 - s_2)^2 + (1 - \alpha) \beta^2 s_2 \Delta s (c_1 - s_1)^2 - \alpha \beta \Theta}{4s_1s_2\Delta s\Phi} \quad (\text{A.8})$$

with $\Theta \equiv \alpha s_1 \Delta s (c_2 - s_2)^2 - c_1^2 s_2^2 + 2c_1c_2s_1s_2 + s_1s_2 [s_1(s_2 - 2c_2) - (c_2 - s_2)^2]$.

The profit of the upstream producers coincides with the fixed part of the fees.

We now move to the cases where the monopolist, as in our main model, sets the prices of the goods so as to sell one variant only. We start with the case of a zero demand for the low quality good.

A.3.0.2.2 Case 2). In this case the downstream monopolist signs a contract with both upstream producers, but sells the high-quality good only ($D_2 > 0, D_1 = 0$).

Stage 3. (Pricing)

The price of the high-quality good is set to maximize the profit, whereas the price of the low-quality good is set so as to make the demand of that good equal to zero. The optimal prices at this stage are therefore obtained as the solution of the system defined by the equations

$$\begin{cases} \frac{\partial \Pi(p_1, p_2)}{\partial p_2} = 0 \\ D_1(p_1, p_2) = 0 \end{cases}$$

and are

$$p_1(v_1, v_2) = \frac{s_1(\Delta s + c_2 - c_1 + v_2 - v_1)}{2\Delta s}$$

and

$$p_2(v_1, v_2) = \frac{s_2(\Delta s + c_2 - c_1 + v_2 - v_1)}{2\Delta s},$$

which lead to profits

$$\pi_1(f_1) = f_1,$$

$$\pi_2(v_1, v_2, f_2) = \frac{v_2(\Delta s - c_2 + c_1 - v_2 + v_1)}{2\Delta s} + f_2$$

$$\Pi(v_1, v_2, f_1, f_2) = \frac{s_2\Lambda + s_1(2c_1v_2 - 2s_1v_2 - 2v_2^2) + c_2(s_2 - 2s_1) - 2c_2\Gamma - 2c_1s_2v_1 + 2s_1v_2v_1 - s_2v_1^2}{4\Delta s^2} - f_1 - f_2,$$

with $\Lambda \equiv (s_2^2c_1^2 - 2s_2s_1 + s_1^2 - 2s_2w_2 + 4s_1w_2 + w_2^2)$
and $\Gamma \equiv s_2^2 - s_2(2s_1 + w_2) + s_1(2w_2 - w_1 + s_1 - c_1)$.

Stage 2. (Bargaining)

The profits under non-exclusive contracts, together with the monopolist's profits from exclusive contracts are used to write Nash products as (A.6) and (A.7), whose maximization yields

$$\begin{aligned} v_1^{II} &= \frac{s_1c_2}{s_2} - c_1, & f_1^{II} &= \frac{\beta(1-\alpha)(1-\beta)(s_1-c_1)^2}{4s_1\Phi} \\ v_2^{II} &= 0, & f_2^{II} &= \frac{(1-\alpha)\{-2c_2s_2s_1\Phi + c_2^2s_1\Phi - s_2[\beta(s_1-c_1)^2 - s_1s_2\Phi]\}}{4s_1s_2\Phi} \end{aligned}$$

Accordingly, prices and demands are written

$$\begin{aligned} p_1^{II} &= \frac{(s_2+c_2)s_1}{2s_2}, & D_1^{II} &= 0 \\ p_2^{II} &= \frac{s_2+c_2}{2}, & D_2^{II} &= \frac{s_2-c_2}{2s_2} \end{aligned}$$

Finally, the profit accruing to the monopolist is

$$\Pi_2^{II} \equiv \frac{s_2(s_1 - c_1)^2(1 - \alpha)\beta^2 + s_1(s_2 - c_2)^2\alpha\Phi}{4s_1s_2\Phi}, \quad (\text{A.9})$$

and those to the upstream firms coincide with the fixed fee.

A.3.0.2.3 Case 3). Let us now consider the symmetric case, namely that where the downstream monopolist sets the prices so as to sell the low-quality good only.

Stage 3. (Pricing)

Similarly to Case 2), the price for the low-quality good maximizes the profit of the monopolist, whereas that of the high-quality one serves to make the demand for this good equal to zero. The solution to the system defined by the equations

$$\begin{cases} \frac{\partial \Pi(p_1, p_2)}{\partial p_1} = 0 \\ D_2(p_1, p_2) = 0 \end{cases}$$

is

$$\begin{aligned} p_1(v_1, v_2) &= \frac{2s_2\Delta s + s_2(c_1 + v_1) - s_1(c_2 + v_2)}{2\Delta s} \\ p_2(v_1, v_2) &= \frac{2s_2\Delta s + s_2(c_1 + v_1) - s_1(c_2 + v_2)}{2\Delta s} \end{aligned}$$

Substitution into the profit functions returns

$$\begin{aligned} \pi_1(v_1, v_2, f_1) &= \frac{v_1[s_1(v_2 + c_2) - s_2(v_1 + c_1)]}{2s_1\Delta s} + f_1, \\ \pi_2(f_2) &= f_2 \\ \Pi(v_1, v_2, f_1, f_2) &= \frac{c_1^2 s_2 (s_2 - 2s_1) - s_1^2 \Omega - 2s_2^2 s_1 v_1 + s_2^2 v_1^2 - 2s_2 s_1 v_1^2 + 2c_1 \Xi}{4s_1 \Delta s^2} - t_1 - t_2, \end{aligned}$$

with $\Omega \equiv c_2^2 - 2c_2 s_2 + 2c_2 s_1 + 2c_2 v_2 - 2s_2 v_2 + 2s_1 v_2 + v_2^2 - 2c_2 v_1 - 2s_2 v_1 - 2v_2 v_1$ and $\Xi \equiv s_2^2 (v_2 + c_2) + s_1 s_2 (s_1 - 2v_1) - s_2^2 (s_1 - v_1)$.

Stage 2. (Bargaining)

As before, the maximization of the Nash products with respect to the contractual terms yields

$$\begin{aligned} v_1^{II} &= 0, & f_1^{II} &= \frac{(1-\beta)\{\alpha[s_2 c_1 (c_1 - 2s_1) - s_1((s_2 - c_2)^2 - s_1 s_2)] + (1-\alpha)\beta s_2 (s_1 - c_1)^2\}}{4s_1 s_2 \Phi} \\ v_2^{II} &= c_1 + \Delta s - c_2, & f_2^{II} &= \frac{\alpha(1-\alpha)(1-\beta)(s_2 - c_2)^2}{4s_2 \Phi} \end{aligned}$$

The prices and demands are

$$\begin{aligned} p_1^{II} &= \frac{s_1 + c_1}{2}, & D_1^{II} &= \frac{s_1 - c_1}{2s_1} \\ p_2^{II} &= \frac{2s_2 - s_1 + c_1}{2}, & D_2^{II} &= 0. \end{aligned}$$

As in the previous cases, f_1^{II} and f_2^{II} are the profits of the upstream producers, and

$$\Pi_3^{II} \equiv \frac{\beta(s_1 - c_1)^2 s_2 \Phi + (1 - \beta)\alpha^2 s_1 (s_2 - c_2)^2}{4s_1 s_2 \Phi}. \quad (\text{A.10})$$

A.3.0.3 Equilibrium

We summarize our findings in the following

Result 3. *Let a downstream retailing cost $C_i(q_i) = c_i q_i$, with $s_i > c_i \geq 0$, $i = 1, 2$ and $c_2 \geq c_1$, then*

- (i) *for $0 \leq c_2 \leq \frac{s_2 c_1}{s_1}$ the monopolists signs non-exclusive contracts but sells the high-quality good only;*
- (ii) *for $\frac{s_2 c_1}{s_1} < c_2 < c_1 + \Delta s$ the monopolist signs non-exclusive contracts and sells both goods;*

(iii) for $c_2 \geq c_1 + \Delta s$ the monopolist signs non-exclusive contracts but sells the low-quality good only.

Proof. (i) Assume $0 \leq c_2 \leq \frac{s_2 c_1}{s_1}$. From Remark 3 we know that, in this region, in case of non-exclusive contracts the monopolist does not sell two goods. Thus, we compare the profits from non-exclusive contracts with one good only actually sold, namely $\Pi_{2)''}$ and $\Pi_{3)''}$. It is easy to ascertain that, for $0 \leq c_2 \leq \frac{s_2 c_1}{s_1}$, $\Pi_{3)''} - \Pi_{2)''} < 0$. As a consequence, in this region, if the monopolist signs non-exclusive contracts, it offers the high-quality good only. To complete the proof it is enough to observe that, in this region, $\Pi_{2)''} > \Pi_i^I, i = 1, 2$, the monopolist always prefers non-exclusive contracts with positive sales of the high-quality good only to exclusive contracts.

(ii) Assume $\frac{s_2 c_1}{s_1} < c_2 < c_1 + \Delta s$. From Remark 3 we know that, in this region, in case of non-exclusive contracts the monopolist maximizes his profit by setting the prices so as to sell two goods. To complete the proof it is then enough to observe that $\Pi_{1)''} > \Pi_i^I, i = 1, 2$, signing exclusive contracts is always a dominated move in this region.⁵

(iii) Assume $c_2 \geq c_1 + \Delta s$. From Remark 3 we know that, in this region, in case of non-exclusive contracts the monopolist does not sell two goods. Thus, we compare the profits from non-exclusive contracts with one good only actually sold, It is easy to ascertain that, for $c_2 \geq c_1 + \Delta s$, $\Pi_{3)''} - \Pi_{2)''} > 0$. As a consequence, in this region, if the monopolist signs non-exclusive contracts, it offers the low-quality good only. To complete the proof it is enough to observe that, in this region, $\Pi_{3)''} > \Pi_i^I, i = 1, 2$, the monopolist always prefers non-exclusive contracts with positive sales of the high-quality good only to exclusive contracts.⁶

□

⁵It is worth noticing that, in this case, $v_1'' < c_1$, namely the equilibrium contract for the low-quality good contemplates that the unit price paid to the upstream firm is lower than the unit cost to produce that good. To explain this apparently counter-intuitive finding notice that, although the low-quality good is not sold by assumption by the monopolist (the value of p_1 is deliberately set to that end), its price enters the demand of the high-quality good. Accordingly, w_1 , and therefore c_1 affect the demand of this good as well. Thus, in order to replicate the outcome of the sale of good 2 only (the one obtained in the case of exclusive contracts), the optimal bargained v_1 is such that $D_2''(v_1, v_2) = 1 - \frac{p_2(v_1, v_2) - p_1(v_1, v_2)}{s_2 - s_1} = 1 - \frac{p_2^I}{s_2} = D_2^I$, for $v_2 = c_2$. Finally, notice that, since the low-quality good is not sold along the equilibrium path, $v_1'' < c_1$ does not affect the equilibrium profit of the low-quality producer, which is uniquely defined by the fixed fee f_1 .

⁶Similarly to Case 2) above, the equilibrium v_2 is lower than c_2 . As before, this serves to replicate the outcome of the sale of the low-quality good under exclusive contracts in the case of non-exclusive contracts with $D_2(\cdot) = 0$ by assumption. See the preceding footnote 5.

Appendix B

Appendix Chapter 2

B.1 Production stage

B.1.1 Polluter's output absent abatement technology

Absent abatement technology, polluter maximizes his profit function with respect to price:

$$\pi_0(p) = pD(p) - \delta D(p)^2 - tD(p),$$

yielding

$$p_0^* = \frac{a(1 + 2b\delta) + bt}{2b(1 + b\delta)},$$

$$D_0^* = \frac{a - bt}{2(1 + b\delta)},$$

$$\pi_0^* = \frac{(a - bt)^2}{4b(1 + b\delta)}.$$

Demand (and therefore polluting firm profit) is positive for all $0 < t < \frac{a}{b}$.

B.1.2 Polluter's output with integrated technology

With clean technology, polluter maximizes his profit function with respect to price:

$$\pi_c(p) = pD(p) - \lambda D(p)^2 - r$$

yielding:

$$p_c^* = \frac{a(1 + 2b\lambda)}{2b(1 + b\lambda)},$$

$$D_c^*(p_c^*) = \frac{a}{2(1 + b\lambda)},$$

$$\pi_c^*(p_c^*) = \frac{a^2}{4b(1 + b\lambda)} - r.$$

The profit $\pi_c^*(p_c^*) > 0$ if and only if $0 < r < \frac{a^2}{4b(1 + b\lambda)}$

The clean technology is never used without the regulation intervention if and only if $\pi_c^*(p_c^*) < 0$

$\pi^*(p^*)$ as $\pi = pD(p) - \delta D(p)^2$ is the profit of the polluter before taxation and $\pi^*(p^*) = \frac{a^2}{4b(1+b\delta)}$.

$$\pi_c^*(p_c^*) < \pi^*(p^*) \text{ is verified if } \begin{cases} \lambda > \delta \\ \text{or} \\ \lambda < \delta \end{cases} \frac{a^2}{4b(1+b\lambda)} - \frac{a^2}{4b(1+b\delta)} \leq r$$

B.1.3 Polluter's output with end of pipe technology

The profit of the polluting firm using end of pipe technology $\pi_{eop}^{down}(p, \omega)$ is equal to:

$$\begin{cases} pD(p) - \delta D(p)^2 - v\omega - f - \omega^2 - t(D(p) - \omega) & \text{partial abatement} \\ pD(p) - \delta D(p)^2 - v\omega - f - \omega^2, & \text{total abatement} \end{cases}$$

Respecting this discontinuity and solving the forth stage of the game yields

Outputs	Partial abatement	Total abatement
	$t < t_{cont}$	$t \geq t_{cont}$
P_{eop}^*	$\frac{a(1+2b\delta) + bt}{2b(1+b\delta)}$	$\frac{a(1+2b(1+\delta)) + bv}{2b(1+b(1+\delta))}$
D_{eop}^*	$\frac{a - bt}{2(1+b\delta)}$	$\frac{a - bv}{2(1+b(1+\delta))}$
ω_{eop}^*	$\frac{t - v}{2}$	$D_{eop}^* = \frac{a - bv}{2(1+b(1+\delta))}$

The thershold $t_{cont} = \frac{a}{1+b(1+\delta)} + v\frac{1+b\delta}{1+b(1+\delta)}$ is giving by the fact that the polluting firm can not abate more than his emissions i.e. $\omega_{eop}^{PA*} < D_{eop}^{PA*}$ with $\omega_{eop}^{PA*} = \frac{t-v}{2}$ and $D_{eop}^{PA*} = \frac{a-bt}{2(1+b\delta)}$ as calculated in the table.

Note that production decisons with partial abatement are unaltered by the use of the end of pipe technology and are equal to the case absent abatement technology. This is because the end-of-pipe technology doesn't change the production process and so the polluter sets, in one hand the marginal return on output equal to the marginal cost and, in the other hand the marginal cost of abatement equal the marginal benefit of abatement as if it wants to maximize two independant activities. However, if the tax is very high, the polluter couldn't reach the interior solution of the abatement activity and it will abate, in this case, all the pollution generated.

B.2 Bargaining stage

B.2.1 No technology as the monopoly's outside option

When the polluter decides to not develop the integrated technology, his outside option π_0^* is as follows:

$$\pi_0^* = \begin{cases} \frac{(a - bt)^2}{4b(1 + b\delta)} & \text{if } 0 < t < \frac{a}{b} \\ 0 & \text{otherwise} \end{cases}$$

Maximizing the Nash product of bargaining $B_0(v, f)$ with respect to v and f gives

$$\begin{cases} v^* = 0 \\ f^* = (1 - \alpha)(\Pi_{eop}^{Ind} - \pi_0^*) \end{cases}$$

Where f^* is the upstream profit.

The polluting firm profit in this case is $\pi_{eop/\theta}^* = \pi_0^* + \alpha(\Pi_{eop}^{Ind*} - \pi_0^*)$ and can be developed as follows:

$$\pi_{eop/\theta}^* = \begin{cases} \pi_0^* + \alpha \frac{t^2}{4}, & \text{if } 0 < t < \frac{a}{1 + b(1 + \delta)} \\ \text{(Partial abatement with } \pi_0^* > 0) \\ \pi_0^* + \alpha \left(\frac{a^2}{4b(1 + b(1 + \delta))} - \frac{(a - bt)^2}{4b(1 + b\delta)} \right), & \text{if } \frac{a}{1 + b(1 + \delta)} \leq t < \frac{a}{b} \\ \text{(Total abatement with } \pi_0^* > 0) \\ \alpha \frac{a^2}{4b(1 + b(1 + \delta))}, & \text{if } \frac{a}{b} \leq t \\ \text{(Total abatement with } \pi_0^* = 0) \end{cases}$$

We can easily see that the end-of-pipe solution dominates the no-abatement one since $\Pi_{eop}^{Ind} - \pi_0^* > 0$ in the three cases. So the polluter will use at least the end-of-pipe technology rather than paying taxes on all the pollution emitted.

¹The threshold $\frac{a}{1 + b(1 + \delta)}$ is obtained from $\frac{a}{1 + b(1 + \delta)} + v \frac{1 + b\delta}{1 + b(1 + \delta)}$ with $v = 0$

B.2.2 Clean technology as the monopoly's outside option

When the polluter decides to develop the clean technology, his outside option is $\pi_c^* = \frac{a^2}{4b(1+b\lambda)} - r$.

Maximizing the Nash product of bargaining $B_c(v, f)$ with respect to v and f gives $v^* = 0$ and

$$\begin{cases} \pi_{eop/c}^* = \pi_c^* + \alpha \bar{A} \\ \pi_{eop/c}^{up*} = f^* = (1 - \alpha) \bar{A} \end{cases}$$

With $\bar{A} = \Pi_{eop}^{Ind*} - \pi_c^* - r$ and can be developed as

$$\bar{A} = \begin{cases} \frac{1}{2(1+b\delta)} \left[\frac{a^2(\lambda - \delta)}{2(1+b\lambda)} - t(a - b\frac{t}{2}) + t^2(1+b\delta) \right] & \text{if } 0 < t < \frac{a}{1+b(1+\delta)} \\ \frac{a^2}{2(2+b(1+2\delta))(1+b\lambda)} + [\lambda - \delta - \frac{1}{2}] & \text{otherwise} \end{cases}$$

At the equilibrium, the profit of the polluting company buying end-of-pipe technology in a context of bargaining is composed of the profit of its outside option, and the part α of potential gains or losses induced by the adoption of the end-of-pipe technology \bar{A} . If \bar{A} is positive (negative), the polluting firm will adopt end of pipe (integrated) technology.

Note that when $t < \frac{a}{1+b(1+\delta)}$, \bar{A} is composed by three parts. The first is linked to the differential production costs between the two technologies. The more important the production costs λ compared to δ is, the more advantageous it is for the polluter to choose the end-of-pipe technology. The second part is linked to the taxes induced by the remaining pollution, which decrease the advantage of the end-of-pipe technology. However this disadvantage of remaining pollution is attenuated by the use of the end-of-pipe technology (the third part of \bar{A}). The derivatives of \bar{A} with respect to δ and t are negative while that to λ is positive. In other terms, the production costs of the technologies, the adoption costs of the end-of-pipe and the tax have important impacts on the polluter choice. These remarks, except those related to tax, are still valid when $t \geq \frac{a}{1+b(1+\delta)}$.

B.3 Different welfares

The different welfares are given by

$$\left\{ \begin{array}{l} W_c = \int_{p_c}^{a/b} D_c(p)dp + D_c(p_c)p_c - \lambda D_c(p_c)^2 - r, \\ W_{eop/\emptyset}(t) = \int_{p_{eop}}^{a/b} D_{eop}(p(t))dp + p_{eop}D_{eop}(p(t)) - \delta D_{eop}(p(t))^2 - \frac{\omega(t)^2}{2} - (D(p(t)) - \omega(t))^2 \\ W_{eop/\emptyset}^{TA} = \int_{p_{eop}}^{a/b} D_{eop}(p)dp + p_{eop}D_{eop} - \delta D_{eop}^2 - \frac{D_{eop}^2}{2} \end{array} \right.$$

Replacing by equilibrium outputs yields

$$\left\{ \begin{array}{l} W_c^* = \frac{a^2(3 + 2b\lambda)}{8b(1 + b\lambda)^2} - r, \\ W_{eop/\emptyset}^*(t^*) = \frac{a^2(3 + 2b(1 + \delta))}{2b(4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta)))} \\ W_{eop/\emptyset}^{*TA} = \frac{a^2(3 + b(1 + 2\delta))}{2b(2 + b(1 + 2\delta))^2} \end{array} \right.$$

And so

$$\left\{ \begin{array}{l} W_{eop/c}^*(t) = W_{eop/\emptyset}^* - r \\ W_{eop/c}^{*TA} = W_{eop/\emptyset}^{*TA} - r \end{array} \right.$$

Comparing $W_{eop/\emptyset}^*(t^*)$ and $W_{eop/c}^{*TA}$ shows that $W_{eop/\emptyset}^*(t^*) > W_{eop/c}^{*TA}$ since that $W_{eop/\emptyset}^*(t^*) - W_{eop/c}^{*TA} = \frac{a^2(3 + 2b(1 + \delta))^2}{8(1 + b(1 + \delta^2))(4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta)))} > 0$

B.4 Optimal tax

Under end-of-pipe, the welfare is given by

$$W_{eop}^*(t) = \int_{p_{eop}^*}^{a/b} D_{eop}(p(t))dp + p_{eop}^* D_{eop}(p^*(t)) - \delta D_{eop}(p(t))^2 - \frac{w(t)^2}{2} - (D(p(t)) - w(t))^2.$$

Maximizing $W_{eop}^*(t)$ with respect to tax yields:

$$\frac{\partial W_{eop}^*(t)}{\partial t} = -DD_p p_t + p_t D + p D_p p_t - 2\delta DD_p p_t - \omega \omega_t - 2E(D_p p_t - w_t).$$

Inserting FOC from polluter's profit maximization: $2\delta DD_p = D + p D_p - t D_p$ and $-v - \omega + t = 0$ yields:

$$\begin{aligned} -DD_p p_t + p_t D + p D_p p_t - D p_t - p D_p p_t + t D_p p_t - \omega_t(t - v) - 2E(D_p p_t - \omega_t) &= 0, \\ -DD_p[-DD_p + D + p D_p - D - p D_p] + t D_p p_t - \omega_t t + w_t v - 2E(D_p p_t - \omega_t) &= 0, \end{aligned}$$

yielding optimal tax:

$$t = 2E + \frac{-DD_p p_t}{D_p p_t - \omega_t} - \frac{\omega_t v}{D_p p_t - \omega_t}.$$

B.5 Simulations: case of $W_c^* < W_{eop/\emptyset}^*$

B.5.1 No Investment in R&D stage

$\max\{\pi_c^*; \pi_{eop/c}^*\} < \pi_{eop/\emptyset}^*$: In this case, the regulator fixes the optimal tax t^* and the monopolist will choose to use the end-of-pipe technology without over investing in R&D.

Table B.1: No Investment in R&D stage

	Parameters	Functions	Values	
Variables	a		400	
	b		10	
	δ		1	
	λ		5	
	r		10	
	α		0.5	
Optimal tax	t^*	$\frac{a(1 + 2b(1 + \delta))}{4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta))}$	12.93	
	\underline{t}	$\pi_{\emptyset}(\underline{t}) = \pi_c^*$		
	t'	given by $\pi_{eop/\emptyset}(t') = \pi_c^*$		
	\widehat{t}	given by $\pi_{eop/c}(\widehat{t}) = \pi_c^*$		
Monopolist profits	π_c^*	$\frac{a^2}{4b(1 + b\lambda)} - r$	68.43	
	$\pi_{eop/c}^*(t^*)$	$\pi_c^* + \alpha\left(\frac{(a - bt)^2}{4b(1 + b\delta)} + \frac{t^2}{4}\right)$	135.34	
	$\pi_{eop/\emptyset}^*(t^*)$		193.35	
	$\pi_{eop/c}^*(\underline{t})$			$\pi_{\emptyset}^*(\underline{t}) + \alpha\frac{t^2}{4}$
	$\pi_{eop/\emptyset}^{TA*}$			$\alpha\frac{a^2}{4b(1 + b(1 + \delta))}$
Welfare	W_c^*	$\frac{a^2(3 + 2b\lambda)}{8b(1 + b\lambda)^2} - r$	69.20	
	$W_{eop/\emptyset}^*(t^*)$		257.87	
	$W_{eop/\emptyset}(\underline{t})$			$\frac{a^2(3 + 2b(\delta - 1)) + 2abt(1 + 2b(1 + \delta)) - bt^2(4 + b(5 + 8\delta + b(1 + \delta)(1 + 2\delta)))}{8b(1 + b\delta)^2}$
	$W_{eop/\emptyset}(t')$			
	$W_{eop/c}(\widehat{t})$	$W_{eop/\emptyset}(\widehat{t}) - r$		
	$W_{eop/\emptyset}^{TA*}$	$\frac{a^2(3 + 2b(1 + \delta))}{8b(1 + b(1 + \delta))^2}$		

B.5.2 Investment in R&D

$$\max\{\pi_{eop/\emptyset}^*; \pi_{eop/c}^*\} < \pi_c^*$$

B.5.2.1 Investment: Laisser-faire case

In this case, the regulator can not obtain a higher welfare than W_c^* .

Table B.2: Investment: laissez-faire case

	Parameters	Functions	Values
Variables	a		500
	b		50
	δ		0.4
	λ		0.8
	r		5
	α		0.5
Optimal tax	t^*	$\frac{a(1+2b(1+\delta))}{4+b(5+8\delta+2b(1+\delta)(1+2\delta))}$	5.42
	\underline{t}	given by $\pi_{\emptyset}(t) = \pi_c^*$	
	t'	given by $\pi_{eop/\emptyset}(t') = \pi_c^*$	3.67
	\widehat{t}	given by $\pi_{eop/c}(\widehat{t}) = \pi_c^*$	3.13
Monopolist profits	π_c^*	$\frac{a^2}{4b(1+b\lambda)} - r$	25.49
	$\pi_{eop/c}^*(t^*)$	$\pi_c^* + \alpha \left(\frac{(a-bt)^2}{4b(1+b\delta)} + \frac{t^2}{4} \right)$	20.16
	$\pi_{eop/\emptyset}^*(t^*)$		16.17
	$\pi_{eop/c}^*(\underline{t})$	$\pi_{\emptyset}^*(t) + \alpha \frac{t^2}{4}$	
	$\pi_{eop/\emptyset}^{TA*}$	$\alpha \frac{a^2}{4b(1+b(1+\delta))}$	
Welfare	W_c^*	$\frac{a^2(3+2b\lambda)}{8b(1+b\lambda)^2} - r$	25.86
	$W_{eop/\emptyset}^*(t^*)$		27.47
	$W_{eop/\emptyset}(\underline{t})$	$\frac{a^2(3+2b(\delta-1)) + 2abt(1+2b(1+\delta)) - bt^2(4+b(5+8\delta+b(1+\delta)(1+2\delta)))}{8b(1+b\delta)^2}$	
	$W_{eop/\emptyset}(t')$		16.30
	$W_{eop/c}(\widehat{t})$	$W_{eop/\emptyset}(\widehat{t}) - r$	3.31
	$W_{eop/\emptyset}^{TA*}$	$\frac{a^2(3+2b(1+\delta))}{8b(1+b(1+\delta))^2}$	

B.5.2.2 Investment: lowering taxes and avoiding R&D investment

If $\pi_{eop/c}^* < \pi_{eop/\theta}^*(t^*) < \pi_c^*$, under some parameters values, the regulator can fix t' , a lower tax than t^* , to encourage the monopolist to use the end-of-pipe technology without investing in R&D.

Table B.3: Investment: lowering taxes and avoiding R&D investment

	Parameters	Functions	Values
Variables	a		200
	b		5
	δ		0.4
	λ		1
	r		30
	α		0.5
Optimal tax	t^*	$\frac{a(1 + 2b(1 + \delta))}{4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta))}$	17.54
	\underline{t}	given by $\pi_{\theta}(t) = \pi_c^*$	
	t'	given by $\pi_{eop/\theta}(t') = \pi_c^*$	14.16
	\widehat{t}	given by $\pi_{eop/c}(\widehat{t}) = \pi_c^*$	13.82
Monopolist profits	π_c^*	$\frac{a^2}{4b(1 + b\lambda)} - r$	303.33
	$\pi_{eop/c}^*(t^*)$	$\pi_c^* + \alpha \left(\frac{(a - bt)^2}{4b(1 + b\delta)} + \frac{t^2}{4} \right)$	280.20
	$\pi_{eop/\theta}^*(t^*)$		248.59
	$\pi_{eop/c}^*(\underline{t})$		$\pi_{\theta}^*(t) + \alpha \frac{t^2}{4}$
	$\pi_{eop/\theta}^{TA*}$		$\alpha \frac{a^2}{4b(1 + b(1 + \delta))}$
Welfare	W_c^*	$\frac{a^2(3 + 2b\lambda)}{8b(1 + b\lambda)^2} - r$	25.86
	$W_{eop/\theta}^*(t^*)$		397.66
	$W_{eop/\theta}(\underline{t})$		$\frac{a^2(3 + 2b(\delta - 1)) + 2abt(1 + 2b(1 + \delta)) - bt^2(4 + b(5 + 8\delta + b(1 + \delta)(1 + 2\delta)))}{8b(1 + b\delta)^2}$
	$W_{eop/\theta}(t')$		370.41
	$W_{eop/c}(\widehat{t})$	$W_{eop/\theta}(\widehat{t}) - r$	334.72
	$W_{eop/\theta}^{TA*}$	$\frac{a^2(3 + 2b(1 + \delta))}{8b(1 + b(1 + \delta))^2}$	

B.5.2.3 Investment: lowering taxes and incurring R&D investment

If $\pi_{eop/\emptyset}^* < \pi_{eop/c}^*(t^*) < \pi_c^*$, under some parameters values, the regulator can fix \widehat{t} to encourage the monopolist to use the end-of-pipe technology but can not deter the monopolist from investing in R&D.

Table B.4: Investment: lowering taxes and incurring R&D investment

	Parameters	Functions	Values
Variables	a		1000
	b		30
	δ		0.3
	λ		1
	r		10
	α		0.5
Optimal tax	t^*	$\frac{a(1 + 2b(1 + \delta))}{4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta))}$	19.90
	\underline{t}	given by $\pi_0(t) = \pi_c^*$	
	t'	given by $\pi_{eop/\emptyset}(t') = \pi_c^*$	15.93
	\widehat{t}	given by $\pi_{eop/c}(\widehat{t}) = \pi_c^*$	17.22
Monopolist profits	π_c^*	$\frac{a^2}{4b(1 + b\lambda)} - r$	258.82
	$\pi_{eop/c}^*(t^*)$	$\pi_c^* + \alpha \left(\frac{(a - bt)^2}{4b(1 + b\delta)} + \frac{t^2}{4} \right)$	241.58
	$\pi_{eop/\emptyset}^*(t^*)$		184.85
	$\pi_{eop/c}^*(\underline{t})$	$\pi_0^*(t) + \alpha \frac{t^2}{4}$	
	$\pi_{eop/\emptyset}^{TA*}$	$\alpha \frac{a^2}{4b(1 + b(1 + \delta))}$	
Welfare	W_c^*	$\frac{a^2(3 + 2b\lambda)}{8b(1 + b\lambda)^2} - r$	263.15
	$W_{eop/\emptyset}^*(t^*)$		340.05
	$W_{eop/\emptyset}(\underline{t})$	$\frac{a^2(3 + 2b(\delta - 1)) + 2abt(1 + 2b(1 + \delta)) - bt^2(4 + b(5 + 8\delta + b(1 + \delta)(1 + 2\delta)))}{8b(1 + b\delta)^2}$	
	$W_{eop/\emptyset}(t')$		261.97
	$W_{eop/c}(\widehat{t})$	$W_{eop/\emptyset}(\widehat{t}) - r$	294.50
	$W_{eop/\emptyset}^{TA*}$	$\frac{a^2(3 + 2b(1 + \delta))}{8b(1 + b(1 + \delta))^2}$	

B.5.3 Over-investment in R&D to boost bargaining power

$$\max\{\pi_c^*; \pi_{eop/0}^*\} < \pi_{eop/c}^*$$

B.5.3.1 Over-investment: Laisser-faire case

In the following simulation, the regulator fixes t^* and incurs a decline in the welfare by the mountain of R&D.

Table B.5: Over-investment: laissez-faire case

	Parameters	Functions	Values
Variables	a		280
	b		7
	δ		0.05
	λ		1.65
	r		3
	α		0.2
Optimal tax	t^*	$\frac{a(1 + 2b(1 + \delta))}{4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta))}$	28.36
	\underline{t}	given by $\pi_0(t) = \pi_c^*$	26.99
	t'	given by $\pi_{eop/0}(t') = \pi_c^*$	
	\widehat{t}	given by $\pi_{eop/c}(\widehat{t}) = \pi_c^*$	
Monopolist profits	π_c^*	$\frac{a^2}{4b(1 + b\lambda)} - r$	220.11
	$\pi_{eop/c}^*(t^*)$	$\pi_c^* + \alpha \left(\frac{(a - bt)^2}{4b(1 + b\delta)} + \frac{t^2}{4} \right)$	250.82
	$\pi_{eop/0}^*(t^*)$		215.76
	$\pi_{eop/c}^*(\underline{t})$	$\pi_0^*(t) + \alpha \frac{t^2}{4}$	255.79
	$\pi_{eop/0}^{TA*}$	$\alpha \frac{a^2}{4b(1 + b(1 + \delta))}$	
Welfare	W_c^*	$\frac{a^2(3 + 2b\lambda)}{8b(1 + b\lambda)^2} - r$	229
	$W_{eop/0}^*(t^*)$		639.53
	$W_{eop/0}(\underline{t})$	$a^2(3 + 2b(\delta - 1)) + 2abt(1 + 2b(1 + \delta)) - bt^2(4 + b(5 + 8\delta + b(1 + \delta)(1 + 2\delta)))$	619.53
	$W_{eop/0}(t')$	$8b(1 + b\delta)^2$	
	$W_{eop/c}(\widehat{t})$	$W_{eop/0}(\widehat{t}) - r$	
	$W_{eop/0}^{TA*}$	$\frac{a^2(3 + 2b(1 + \delta))}{8b(1 + b(1 + \delta))^2}$	

B.5.3.2 Over-investment: Lowering taxes

In the next example, the regulator will fix \underline{t} to avoid the deadweight loss in r and hence, increase the welfare from $W_{eop/c}^*(t^*)$ to $W_{eop/\theta}(\underline{t})$ but can't reach the best welfare available $W_{eop/\theta}^*(t^*)$.

Table B.6: Over investment: lowering taxes

	Parameters	Functions	Values
Variables	a		280
	b		7
	δ		0.2
	λ		1.65
	r		3
	α		0.2
Optimal tax	t^*	$\frac{a(1 + 2b(1 + \delta))}{4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta))}$	23.20
	\underline{t}	given by $\pi_0(t) = \pi_c^*$	22.65
	t'	given by $\pi_{eop/\theta}(t') = \pi_c^*$	
	\widehat{t}	given by $\pi_{eop/c}(\widehat{t}) = \pi_c^*$	
Monopolist profits	π_c^*	$\frac{a^2}{4b(1 + b\lambda)} - r$	220.11
	$\pi_{eop/c}^*(t^*)$	$\pi_c^* + \alpha \left(\frac{(a - bt)^2}{4b(1 + b\delta)} + \frac{t^2}{4} \right)$	243.56
	$\pi_{eop/\theta}^*(t^*)$		232.74
	$\pi_{eop/c}^*(\underline{t})$	$\pi_0^*(t) + \alpha \frac{t^2}{4}$	245.02
	$\pi_{eop/\theta}^{TA*}$	$\alpha \frac{a^2}{4b(1 + b(1 + \delta))}$	
Welfare	W_c^*	$\frac{a^2(3 + 2b\lambda)}{8b(1 + b\lambda)^2} - r$	229
	$W_{eop/\theta}^*(t^*)$		516.11
	$W_{eop/\theta}(\underline{t})$	$a^2(3 + 2b(\delta - 1)) + 2abt(1 + 2b(1 + \delta)) - bt^2(4 + b(5 + 8\delta + b(1 + \delta)(1 + 2\delta)))$	514.73
	$W_{eop/\theta}(t')$	$8b(1 + b\delta)^2$	
	$W_{eop/c}(\widehat{t})$	$W_{eop/\theta}(\widehat{t}) - r$	
	$W_{eop/\theta}^{TA*}$	$\frac{a^2(3 + 2b(1 + \delta))}{8b(1 + b(1 + \delta))^2}$	

B.6 Simulations: case of $W_{eop/\emptyset}^* < W_c^*$

B.6.1 Investment in stage 2

The monopolist uses the clean technology since $\max\{\pi_{eop/\emptyset}^*; \pi_{eop/c}^*\} < \pi_c^*$.

Table B.7: Investment in R&D

	Parameters	Functions	Values
Variables	a		350
	b		1
	δ		3
	λ		1
	r		7500
	α		0.3
Optimal tax	t^*	$\frac{a(1 + 2b(1 + \delta))}{4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta))}$	35.39
	\underline{t}	given by $\pi_\emptyset(t) = \pi_c^*$	
	t'	given by $\pi_{eop/\emptyset}(t') = \pi_c^*$	
	\widehat{t}	given by $\pi_{eop/c}(\widehat{t}) = \pi_c^*$	
Monopolist profits	π_c^*	$\frac{a^2}{4b(1 + b\lambda)} - r$	7812.5
	$\pi_{eop/c}^*(t^*)$	$\pi_c^* + \alpha\left(\frac{(a - bt)^2}{4b(1 + b\delta)} + \frac{t^2}{4}\right)$	5168.53
	$\pi_{eop/\emptyset}^*(t^*)$		6280.04
	$\pi_{eop/c}^*(\underline{t})$	$\pi_\emptyset^*(t) + \alpha\frac{t^2}{4}$	
	$\pi_{eop/\emptyset}^{TA*}$	$\alpha\frac{a^2}{4b(1 + b(1 + \delta))}$	
Welfare	W_c^*	$\frac{a^2(3 + 2b\lambda)}{8b(1 + b\lambda)^2} - r$	11640.66
	$W_{eop/\emptyset}^*(t^*)$		7570.22
	$W_{eop/\emptyset}(t)$	$\frac{a^2(3 + 2b(\delta - 1)) + 2abt(1 + 2b(1 + \delta)) - bt^2(4 + b(5 + 8\delta + b(1 + \delta)(1 + 2\delta)))}{8b(1 + b\delta)^2}$	
	$W_{eop/\emptyset}(t')$		
	$W_{eop/c}(\widehat{t})$	$W_{eop/\emptyset}(\widehat{t}) - r$	
	$W_{eop/\emptyset}^{TA*}$	$\frac{a^2(3 + 2b(1 + \delta))}{8b(1 + b(1 + \delta))^2}$	

B.6.2 No-Investment: highering tax

When $\pi_{eop/\emptyset}^{TA*} < \pi_c^* < \pi_{eop/\emptyset}^*$, the regulator can increase the tax so as to make the use of the end-of-pipe technology unprofitable.

Table B.8: No-Investment: highering tax case

	Parameters	Functions	Values
Variables	a		400
	b		1
	δ		9
	λ		4.5
	r		3800
	α		0.5
Optimal tax	t^*	$\frac{a(1 + 2b(1 + \delta))}{4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta))}$	18.22
	\underline{t}	given by $\pi_{\emptyset}(t) = \pi_c^*$	
	t'	given by $\pi_{eop/\emptyset}(t') = \pi_c^*$	
	\widehat{t}	given by $\pi_{eop/c}(\widehat{t}) = \pi_c^*$	
Monopolist profits	π_c^*	$\frac{a^2}{4b(1 + b\lambda)} - r$	3472.73
	$\pi_{eop/c}^*(t^*)$	$\pi_c^* + \alpha \left(\frac{(a - bt)^2}{4b(1 + b\delta)} + \frac{t^2}{4} \right)$	1699.8
	$\pi_{eop/\emptyset}^*(t^*)$		3685.38
	$\pi_{eop/c}^*(t)$		$\pi_{\emptyset}^*(t) + \alpha \frac{t^2}{4}$
	$\pi_{eop/\emptyset}^{TA*}$	$\alpha \frac{a^2}{4b(1 + b(1 + \delta))}$	1818.18
	$\pi_{eop/c}^{TA*}$	$\frac{a^2(1 + b(1 - \alpha)(1 + \delta) + \alpha b\delta)}{4b(1 + b(1 + \delta))(1 + b\lambda)} - r$	1654.55
Welfare	W_c^*	$\frac{a^2(3 + 2b\lambda)}{8b(1 + b\lambda)^2} - r$	4133.88
	$W_{eop/\emptyset}^*(t^*)$		3991.32
	$W_{eop/\emptyset}(t)$		
	$W_{eop/\emptyset}(t')$		
	$W_{eop/c}(\widehat{t})$	$W_{eop/\emptyset}(\widehat{t}) - r$	
	$W_{eop/\emptyset}^{TA*}$	$\frac{a^2(3 + 2b(1 + \delta))}{8b(1 + b(1 + \delta))^2}$	3801.65

B.6.3 No-Investment: Laisser-faire case

The case where $\pi_c^* < \pi_{eop/\theta}^{TA*}$, the monopolist will always use the end-of-pipe technology whatever the amount of the tax is.

Table B.9: No-Investment: Laisser-faire case

	Parameters	Functions	Values
Variables	a		840
	b		25
	δ		2
	λ		0.1
	r		2000
	α		0.5
Optimal tax	t^*	$\frac{a(1 + 2b(1 + \delta))}{4 + b(5 + 8\delta + 2b(1 + \delta)(1 + 2\delta))}$	6.58
	\underline{t}	given by $\pi_\theta(\underline{t}) = \pi_c^*$	
	t'	given by $\pi_{eop/\theta}(t') = \pi_c^*$	
	\widehat{t}	given by $\pi_{eop/c}(\widehat{t}) = \pi_c^*$	
Monopolist profits	π_c^*	$\frac{a^2}{4b(1 + b\lambda)} - r$	16
	$\pi_{eop/c}^*(t^*)$	$\pi_c^* + \alpha \left(\frac{(a - bt^*)^2}{4b(1 + b\delta)} + \frac{t^2}{4} \right)$	-941.85
	$\pi_{eop/\theta}^*(t^*)$		94.89
	$\pi_{eop/c}^*(\underline{t})$	$\pi_\theta^*(\underline{t}) + \alpha \frac{t^2}{4}$	
	$\pi_{eop/\theta}^{TA*}$	$\alpha \frac{a^2}{4b(1 + b(1 + \delta))}$	46.42
	$\pi_{eop/c}^{TA*}$	$\frac{a^2(1 + b(1 - \alpha)(1 + \delta) + \alpha b\delta)}{4b(1 + b(1 + \delta))(1 + b\lambda)} - r$	-945.58
Welfare	W_c^*	$\frac{a^2(3 + 2b\lambda)}{8b(1 + b\lambda)^2} - r$	304
	$W_{eop/\theta}^*(t^*)$		111.99
	$W_{eop/\theta}(\underline{t})$	$\frac{a^2(3 + 2b(\delta - 1)) + 2abt(1 + 2b(1 + \delta)) - bt^2(4 + b(5 + 8\delta + b(1 + \delta)(1 + 2\delta)))}{8b(1 + b\delta)^2}$	
	$W_{eop/\theta}(t')$		
	$W_{eop/c}(\widehat{t})$	$W_{eop/\theta}(\widehat{t}) - r$	
	$W_{eop/\theta}^{TA*}$	$\frac{a^2(3 + 2b(1 + \delta))}{8b(1 + b(1 + \delta))^2}$	93.45

Appendix C

Appendix Chapter 3

C.1 Summary: focus and main results from the literature review

Table C.1: Overview of empirical studies on the impact of environmental regulations on eco-innovations

References	Level of analysis	Policy drivers and indicators	Dataset	Methodology	Main Results
Weak version of the Porter Hypothesis: Impact of Environmental regulations on innovation					
Arimura et al (2004)	Firms level	ER proxies: environmental conservation investment/ standards/ taxes/ R&D subsidies. <u>Environmental innovation proxies:</u> i) environmental R&D expenditures ii) Exhaust gas regulation	Japanese manufacturing facilities from Survey of Research and Development and Survey of Capital Investment.	Probit model with random effects / Random effect Tobit model	i) The ER stringency has a significantly positive impact on the probability to conduct an environmental R&D program; ii) Effect of flexible regulations was larger than direct regulations; iii) performance-based standards increase environmental R&D expenditure more than technology-based standards; iv) Input or emission taxes effects are not clear in the Japanese context.
Nelson et al (1993)		Two Environmental regulation (ER) proxies: i) air pollution cost ii) total pollution control costs per KW capacity	44 U.S. electric utilities over the 1969-1983 period	Panel data analysis: Three-stage least squares and linear fixed effects	i) ERs significantly increases age of capital; ii) Age of capital has no statistically-significant impact on emissions; iii) Air pollution regulation impacts emission levels.
Brunnermeier and Cohen (2003)	Industry Level	ER proxy: pollution and abatement control expenditures (PACE) and inspections <u>Innovation proxy:</u> environmentally-related patents	146 US manufacturing sector Data from 1983 to 1992	Panel data analysis: linear fixed effects / Poisson-Negative binomial model (fixed and random effects)	i) A small positive relationship of PACE on eco-patents ii) No impact of increased inspections and enforcements
Jaffe and Palmer (1997)		ER proxy: pollution abatement costs <u>Innovation proxies:</u> i) R&D expenditures; ii) patent applications	US manufacturing sector Data from 1973 to 1991	Panel data analysis: linear fixed effect model	i) Positive relation with R&D expenditures ii) No statistically significant effect on patent applications
De Vries and Withagen (2005)	Country level	ER proxy: i) international agreements (dummy variable), ii) Index of Environmental Sensitivity Performance (IESP) for acidification iii) Environmental stringency as a latent variable <u>Innovation proxy:</u> patents aiming at reducing SO ₂	14 OECD countries 1970-2000	Instrumental variable approach: fixed effects estimation	i) The two direct measures have no significant impact on innovation; ii) The third estimation reveals a positive impact of the regulation stringency on innovation.

Table C.1 –

References	Level of analysis	Policy drivers and indicators	Dataset	Methodology	Main Results
Johnstone et al (2012)		ER proxy: Perceived policy stringency extracted from a survey. Innovation proxy: i) environmental patents; ii) General innovative capacity (Non-environmental patents/ GDP / R&D / Intellectual property rights index/ Net international trade)	Environmental patent data of 77 countries over the period 2001-2007	Panel data analysis: A subsequent two-stage model / Negative binomial model	- Higher environmental stringency positively affects environmental innovation
Lanjouw and Mody (1996)		ER proxy: - pollution abatement costs. Innovation proxy: share of environmental patents/total number of patents	Country data 1971-1988	Descriptive statistics (time series correlation)	i) Positive impact of the PACE in Germany, Japan and US; ii) In developing countries there is an increase of innovation imports for regulatory compliance accompanied by an increase of local innovations for adapting generic technologies to local conditions.
Narrow and Strong versions of the Porter Hypothesis: Impact of environmental regulations on Productivity					
Doran and Ryan (2012)	Firm level	ER proxies: i) Existing regulation, ii) Expected regulation, iii) Voluntary agreements, iv) Government Grants Productivity proxy : Turnover per worker	2,181 Irish firms Data from Irish Community Innovation Survey 2006-2008	Probit and OLS estimations	i) Regulations impact positively the eco-innovation; ii) Eco-innovation is found to be more important than non-eco-innovation in determining firm performance.
Gray and Shadbegian (2003)		ER proxies: Pollution and abatement control expenditures, ii) Input prices Firms business performance: i) Production function (labor, capital and materials inputs), ii) Growth rate	116 US paper mills, 1979-1990	Ordinary Least Squares(OLS) / Generalized Method of Moments model (GMM)	i) Significant reduction in productivity associated with abatement efforts particularly in integrated paper mills; ii) Older plants appear to have lower productivity but are less sensitive to abatement costs; iii) Renovated plants are less sensitive to abatement costs.
Costantini and Mazzanti (2012)	Industry level	ER proxies: i) Energy and environmental tax revenues, ii) Private compulsory and voluntary actions: PACE, Environmental Management System (EMS); Performance proxy: (green) export flows	Exporting countries : All EU15 members where Belgium and Luxembourg are merged / 145 importing countries / Time period: 1996-2007	Dynamic panel gravity models	Test “narrow” and “strong” version: Strict environmental regulation may stimulate green innovation and increase competitiveness in exports of environmental technologies.

Table C.1 –

References	Level of analysis	Policy drivers and indicators	Dataset	Methodology	Main Results
Franco and Marin (2015)		ER proxy: Environmental taxes Innovation proxy: Patents Performance proxy: Productivity	Panel data for 13 manufacturing sectors for 7 European countries, 2001-2007		The strongest effects on the “weak” and “strong” version of PH come from the downstream sectors The strongest impact on productivity come from the direct effect The indirect effect, i.e. the effect of the innovations on productivity is not significant
Lanoie et al (2008)		ER proxy: i) Changes in the ratio of the value of investment in pollution control equipment to the total cost, ii) OSH (regulation on safety in the workplace index) Productivity: Total factor productivity (TFP) growth	17 Quebec manufacturing industries 1985-1994	Generalized least-squares (GLS) procedure	i) Contemporaneous effect of environmental regulation on productivity is negative, but positive impact is detected when using lagged variables of environmental regulation; ii) ERs have a significant positive impact on productivity growth rate, especially in the sectors highly exposed to outside competition.
Lanoie et al (2011)		ER proxies : stringency/standards/taxes (dummy variables) Innovation proxy: Environmental R&D (dummy variable); Environmental performance index; Commercial performance (dummy variable)	Survey of over 4000 manufacturing facilities in 7 OECD countries from the OECD survey on environmental practices.	Descriptive statistics	i) Test the three versions of PH; ii) Strong positive impact of ER on R&D (“weak version”); iii) Greater incentive of flexible regulations than prescriptive ones on innovations using the impact on environmental results (“narrow version”); iv) No impact of ER on commercial performance (“strong version”).
Rubashkina et al (2015)		ER proxy: PACE Innovation proxy: Patents, Competitiveness proxy: Total factor productivity (TFP)	Panel data on the manufacturing sectors of 17 European countries, 1997-2009	Two-Stage Least Squares regression (2SLS) / Instrumental variable-GMM (IV-GMM)	Test the “weak” version of PH is verified but not the “strong” one
Albrizio et al (2014)	Cross-Country	ER proxy: Environmental Policy Stringency (EPS) index, Productivity proxy: Estimated multi-factor productivity function for each country	19 OECD countries over the 1990-2010 period	Panel data analysis: linear fixed effect	At the macro level, a negative effect on productivity growth is found one year ahead of the policy change. This negative “announcement effect” is offset within three years after the implementation.

Table C.1 –

References	Level of analysis	Policy drivers and indicators	Dataset	Methodology	Main Results
De Santis and Jonas-Lasinio (2015)		ER proxies: i) EPS index, ii) CO ₂ emissions as a difference with respect to the 2020 target iii) Environmental taxes iv) The introduction of the European Emission Trading System v) The ratification of the Kyoto agreement. Innovation proxies: i) ICT, ii) R&D. Productivity proxy: Labour productivity	11 European economies in 1995-2008	A difference in difference approach	i) the “narrow” version of PH is verified; ii) Market based environmental stringency measures stimulate innovations and productivity better than non-market based.
Morales et al (2016)		ER proxy: EPS index Innovation proxy: i) R&D, ii) Patents applications. Production proxy: Total factor productivity	14 OECD countries over the period 1990-2011	Panel models: LS model estimation with country-sector and time fixed effects and Newey-West correction / Panel-quantile regression with time fixed effects	i) Positive impact of ER stringency on innovation and productivity (“weak” and “strong” versions of the PH); ii) Quantile regressions show that ER has greater impact on the lower quantile of R&D and the highest quantiles of Patents and TFP distribution

Table C.2: Articles testing the trichotomy of Rennings

References	Dataset	Supply push and firms specific factors determinants	Demand pull determinants	Regulatory push-pull determinants	Methodology	Mains Resultats
Cleff and Rennings (1999)	Mannheim Innovation Panel (1996), and a subsequent telephone survey of environmental innovators	i) Cost saving; ii) Size; iii) geographical origin	i) Market share, ii) Customer demand/Image	i) Existing (expected) regulation; ii) Soft regulations (e.g. labels, eco-audits).	Multinomial logit models	i) Regulation : + (process innovations); ii) soft regulation: + (pioneers); iii) Hard regulations: + (diffusion); iv) strategic market goals : + (product technologies)
Cuerva et al (2014)	Spain, Agri-foods SMEs (2010)	i) R&D; ii) Human Capital; iii) Quality management; iv) Financial constraints	i) CSR; ii) Label, geographic indication, iii) Anticipated demand iv) Product differentiation	Subsidies	A bivariate probit regression	i)Product differentiation:+; ii) Quality management: +; iii) Subsidies : 0
Demirel Kesidou (2011)	UK firms DEFRA Government Survey of Environmental Protection Expenditure by Industry, 2005 and 2006	firm specific factors (cost savings/EMS /ISO14001/ employees/ turnover / productivity...)		policy tools (environmental regulation compliance / environmental taxes)	Tobit model	+Determinants' effects differ according to the type of innovation
Doran and Ryan (2012)	2,181 Irish firms, Data from Irish Community Innovation Survey 2006-2008	i) Intramural /extramural R&D; ii) Firm Specific Factors (Employment, capital, Irish owned firms); iii) Sectors	i) consumer expectations; ii) Firms collaboration in the development of new innovations (with suppliers, customers, consultants, competitors,universities and public research institutes) ¹	i) Existing Regulation, ii) Expected regulation Regulation, iii) voluntary agreements, iv) Government Grants	Probit estimation	i) Regulation : +; ii) Customer perception : +; iii) Collaboration with suppliers and consultants:+; iv) Other collaborations: 0; v) Intramural R&D: +; vi) Extramural R&D: 0; vii) Size : +; viii) Irish owned firms:0; ix) Sectors: 0
Frondel et al (2008)	OECD countries (Canada, France, Germany, Hungary, Japan, Norway and USA)	i) R&D investment, ii) interest groups andOrganizations (internal forces, Industrial associations and labour unions...), iii) Management tools, iv) Facility Characteristics (size, turnover, environmental impacts, green employment, v) Industry dummies	i) Incidents, ii) Corporate Image, iii) Cost Savings, iv) interest groups andOrganizations (Green organisations, Customers, buyers and Suppliers, banks...)	Policy Stringency (dummy): i) Regulatory Measures ((input bans, standards), ii) Market Instruments, iii) Information (for consumers and buyers), iv) Voluntary Measures, v) Subsidies	Multinomial logit models / a binary probit model	i) Regulation: + (end-of-pipe technologies); ii) Cost savings, management system : + (clean technologies)
Green et al (1994)	UK: a 1993 questionnaire survey of innovating activities (R&D and development of new eco-products and processes) of firms in response to environmental pressure	Inputs: i) cost savings, ii) availability of new technologies, iii) Change in supplied components	i) Retailer / wholesaler pressure, ii) Prospect of expanding market share, iii) Rival eco-products / processes appearing, iv) Rival eco-products/processes feared, v) expected customer demand	i) Existing UK/EC regulations; ii) anticipated UK/EC regulations	Case studies	i) Studied drivers: +; ii) Other drivers have to be added (from sociology of technology and evolutionary theory)

¹These determinants can be considered as supply-pull one (Pereira and Vence, 2012)

Table C.2 –

References	Dataset	Supply push and firms specific factors determinants	Demand pull determinants	Regulatory push-pull determinants	Methodology	Main Results
Hammar and Lofgren (2010)	Four major sectors in Sweden between 2000 and 2003	i) Internal learning by doing and knowledge (R&D investments), ii) Firms' size (revenues, energy price)			Random effects logit model	Determinants' effects differ according to the type of innovation (end of pipe / clean technology)
Horbach (2008)	German Industry (2001-2004) German firms	i) R&D activity, ii) employees' qualifications, iii) cooperation, iv) sector/region/size/age	i) Expected customer demand ii) Expected employment level	i) Subsidies, ii) Compliance with (future) environmental regulation	Multinomial logit model	i) R&D: +, ii) Size: 0 and +, iii) Sectors: - for some / 0 for others, iv) Demand: +, v) Compliance with regulation: +, vi) Subsidies: +
Horbach et al (2013)	4th CIS 2002-2004 for France and Germany, Industry	i) Cost reduction, ii) Production flexibility	i) Increasing market share, ii) Increasing product quality	i) Perception of regulations or standards' severity, ii) Subsidies, iii) Abatement costs	A bivariate probit regression	i) Regulation: +, ii) Cost reduction: +, iii) Production flexibility: +, iv) Market pull determinants: + in Germany, 0 in France
Kammerer (2009)	German electronics and electrical appliances industry	i) R&D employees, ii) Green capabilities	Customers benefits/satisfaction	Compliance with environmental regulation	Logit regression	i) Demand pull: +, ii) Regulation: +, iii) R&D: 0
Mazzanti and Zoboli (2005)	Italian firms in the manufacturing sector	i) Environmental R&D, ii) Environmental investment, iii) Environmental costs, iv) Structural characteristics (share of revenue in international markets, the share of final market production, sector of activity, membership to national or international industrial groups), v) Past firms' performances (value added per Employee, gross profit/turnover)...		i) Compliance with (future) environmental regulation, ii) environmental voluntary auditing schemes (EMS or ISO)	OLS / Probit / Tobit / two-stage regressions	i) Supply push: +, ii) Regulation: +
Rave et al (2011)	German firms in late 2007 and 2009	i) Size, ii) Age, iii) cost saving, iv) Network activities	i) Social pressure or image, ii) Demand from and image vis-à-vis customers, iii) Maintenance or enlargement of current/new markets	i) Subsidies, ii) predictable and strict environmental policy	Probit / Random-effects probit / Negative binomial / Ordered probit	i) cost saving: +, ii) Regulation: +, iii) creation of new markets: +; (Determinants' effects differ according to the type of innovation)
Rehfeld et al (2007)	German case studies	i) R&D activities, ii) Specific company characteristics (ISO9001, Size, age)	i) Customers benefits/satisfaction, ii) Exportation	i) Compliance with (future) environmental regulation, ii) Soft regulation (EMS, waste disposal, life cycle assessment activities environmental labelling)	Binary and multinomial logit models	+

Table C.2 –

References	Dataset	Supply push and firms specific factors determinants	Demand pull determinants	Reugulatory push-pull determinants	Methodology	Mains Resultats
Triguero et al (2013)	27 EU countries, all sector SMEs (2011)	i) Technological and organizational improvements, ii) Collaboration with research institutes and universities, iii) Access to information from external technological services, iv) Input price, v) Energy price	i) Consolidation or increase in market share, ii) Anticipating demand of green product	i) Existant regulation, ii) Anticipation of future regulation, iii) Subsidies	a Trivariate probit model	i) Demand-pull determinants: + on product eco-innovations, ii) The Technology-push determinants: + on process eco-innovations, iii) Regulatory determinants: + on organizational eco-innovations
Ziegler (2005)	Germany, manufacturing industry (2003-2005)	i) R&D, ii) Number of employees	Competitive advantage related to: i) Environment, ii) Price, iii) Quality, iv) Consumers	Binary variable: localization in Western Germany	Multinomial logit and probit models	i) R&D : +, ii) Number of establishments : 0, iii) Market pull: little effect

Table C.3: Some empirical articles on the drivers of innovation at a country level

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Bayar (2015)	Eurozone countries during the period 1999-2012	Dependent variable: Patents; Independent variables: i) R&D expenditures, ii) Economic growth: Real GDP per capita growth (annual %), iii) Financial development: domestic credit to private sector, iv) Inflation: Consumer price index, v) foreign direct investment inflows, vi) Gross domestic savings, vii) High technology exports	Poisson regression, negative binomial regression	Economic growth, financial development, savings, R&D expenditures and high technology exports had positive impact on technological progress.
Coe et al (2009)	24 countries over 1971-2004	Dependent variable: Total factor productivity (real value added in business sector, capital stock, labour input); Independent variables: i) R&D: business sector R&D expenditure, R&D capital stocks in the business sector, foreign R&D capital, ii) Human capital : average years of schooling, iii) Openness : ratio of total imports of goods and services to GDP, iv) institutional variables : legal origin and patent protection	Panel cointegration estimation techniques	Institutional differences are important determinants of total factor productivity and that they impact the degree of R&D spillovers

Table C.3 –

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Eyraud et al (2011)	35 advanced and emerging countries with annual data over 2000-2010	Dependent variable: Renewable investment; Independent variables: R&D, GDP (GDP/capita), population, inflation, International gasoline price, Crude oil price, Domestic gasoline price, wage, unit labour cost, profit, Cost of starting a business, Interest rates, tax on business, fossil fuel use, green parties, domestic credit, bank capital, energy dependency, carbon emissions, policy support for renewable electricity generation (Feed-In-Tariffs , Renewable Portfolio Standards), Biofuel mandates, Carbon pricing schemes, Spending on tertiary Education, Enrolment in tertiary education, coal price	Fixed-effect estimation	i) Economic growth, low interest rates, high fuel prices, introduction of carbon pricing schemes, "feed-in-tariffs": +; ii) biofuel support:0

Table C.3 –

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Furman et al (2002)	17 OECD countries over 1973-1995	Dependent variable: patents / patents per million population; Independent variables: i) <u>Quality of the common innovation infrastructure</u> : GDP per capita, stocks of patents, population, employed scientists and engineers, R&D expenditures, openness, protection for intellectual property, share GDP spent on higher education, antitrust policies; ii) <u>Cluster-specific innovation environment</u> : R&D funded by private industry (%), Ellison-Glaeser concentration Index; iii) <u>Quality of linkages</u> : R&D performed by universities (%), Strength of Venture capital markets	OLS Fixed effects models	The paper introduces and testes the novel framework based on the concept of national innovative capacity which investigates the overall sources of innovation systems at the country level.
Guloglu et al (2012)	G7 countries 1991-2009	Dependent variable: Patents; Independent variables: royalty payments, Gross Domestic Expenditures on R&D, Foreign Direct Investment, high-technology exports, openness to trade, rate of interest	Poisson regression, Negative binomial regression techniques	i) rate of interest: -; ii) investments in the R&D sector, high-technology exports, net FDI inflows: +; iii) openness to trade ratio : 0

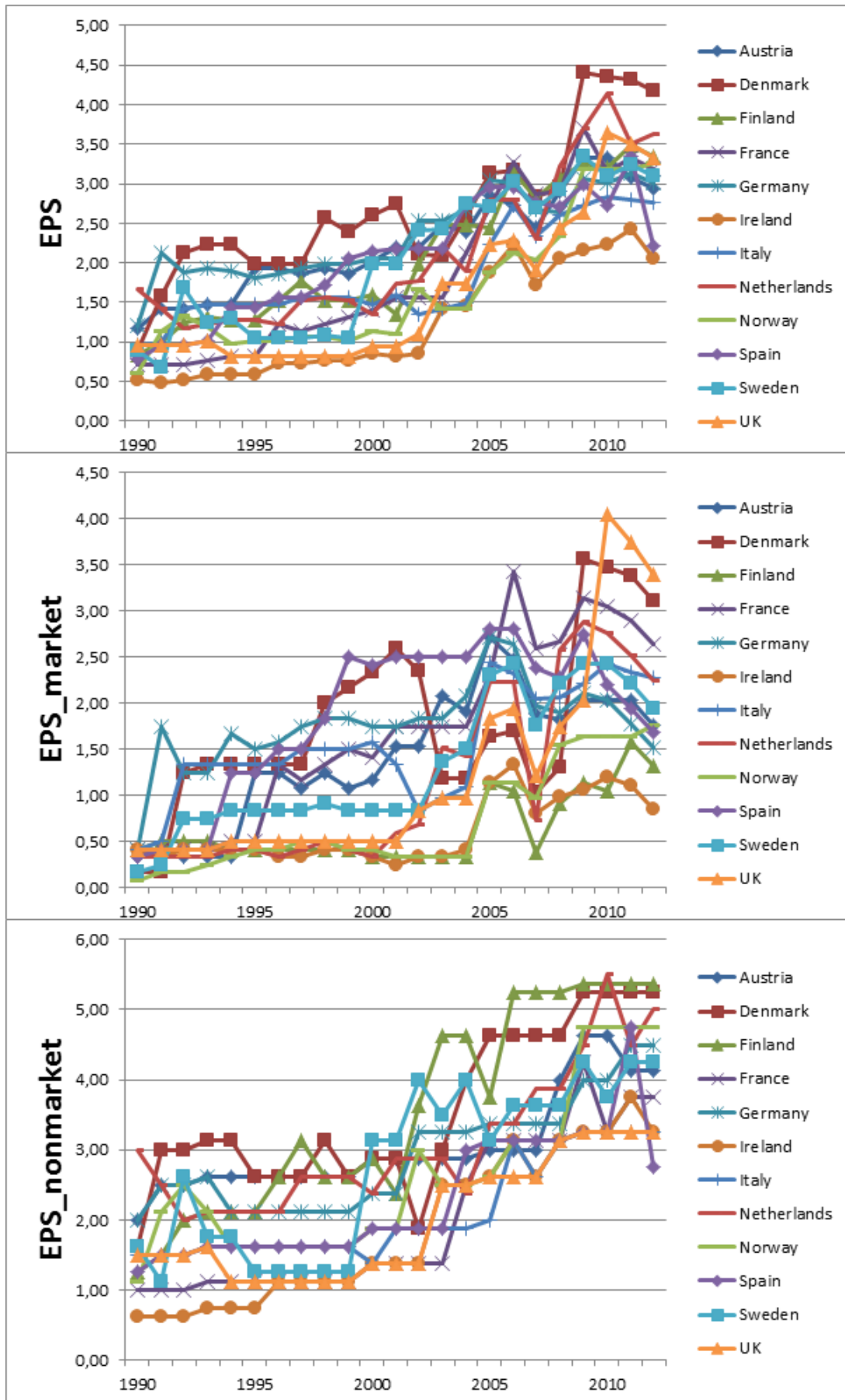
Table C.3 –

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Huňady and Orviská (2014)	26 European countries 1999-2011	Dependent variable: i) <u>Innovation</u> : summary innovation index/ index of innovation growth; ii) <u>Economic growth</u> : annual GDP change; <u>Independent variables</u> : R&D expenditure, GDP per capita, FDI, openness of trade, effective average corporate tax rate, unemployment, public debt, average of statutory corporate tax rates in neighboring countries, corruption	Correlation analysis and Fixed effect model	i) Positive correlation between innovation and GDP per capita, ii) R&D impact positively innovation, iii) All the variables have the expected impact on GDP growth.
Khan and Roy (2011)	5 OECD countries and the BRICS 1997-2010	Dependent variable: Patents, <u>Independent variables</u> : R&D expenditures, trade openness, enrolment in tertiary education, internet access, ethnic diversity Index, per capita power consumption, fiscal variables (Maximum Corporate Income Tax Rate, Maximum Personal Income Tax Rate)	Random and fixed effect regressions	Focusing more on BRICS: i) R&D's impact is lower for BRICS than OECD, ii) Education , openness: +, iii) Internet access, ethnic diversity Index : 0
Krammer (2009)	16 Eastern European transition countries 1991-2007	Dependent variable: Patents <u>Independent variables</u> : Patent stocks, R&D expenditures/number of researchers, Foreign direct investment, Trade intensity, Intellectual property rights index, Cost of doing business, Industrial distortion index, Education expenditure, Population	FGLS / OLS with Newey-West standard errors / Poisson regression / Negative binomial maximum likelihood / two-step negative binomial quasi-generalized maximum likelihood estimator	i) Patent stocks and R&D :+; ii) Policy measures: +, iii) Transitional downturn and industrial restructuring: -; iv) Globalization : +

Table C.3 –

References	Level of analysis	Policy drivers and indicators	Methodology	Main Results
Ulku (2004)	20 OECD and 10 Non-OECD countries for the period 1981–1997	Dependent variable: Innovation: patents applications; Independent variables: GDP, investment, secondary school enrolments, employment, openness, expropriation risk index, import/trade in manufacturing	Fixed Effects / GMM / OLS regressions	i) R&D stock on innovation: + on OECD countries 0 Non-OECD countries; ii) Innovation and GDP per capita : +
Varsakelis (2006)	29 developed and developing countries for 1995-2000	Dependent variable: Innovation: patents; Independent variables: i) Education system: scores in mathematics and natural sciences, numbers of students enrolled in higher education with science orientation ii) Research activity: R&D expenditure intensity; iii) Institutional variables: political rights, civil liberties, corruption perception index, press freedom	Random effect panel estimation	The quality of education and governmental institution impact the innovation activity

C.2 Evolution of the environmental policy stringency



C.3 R&D expenditures

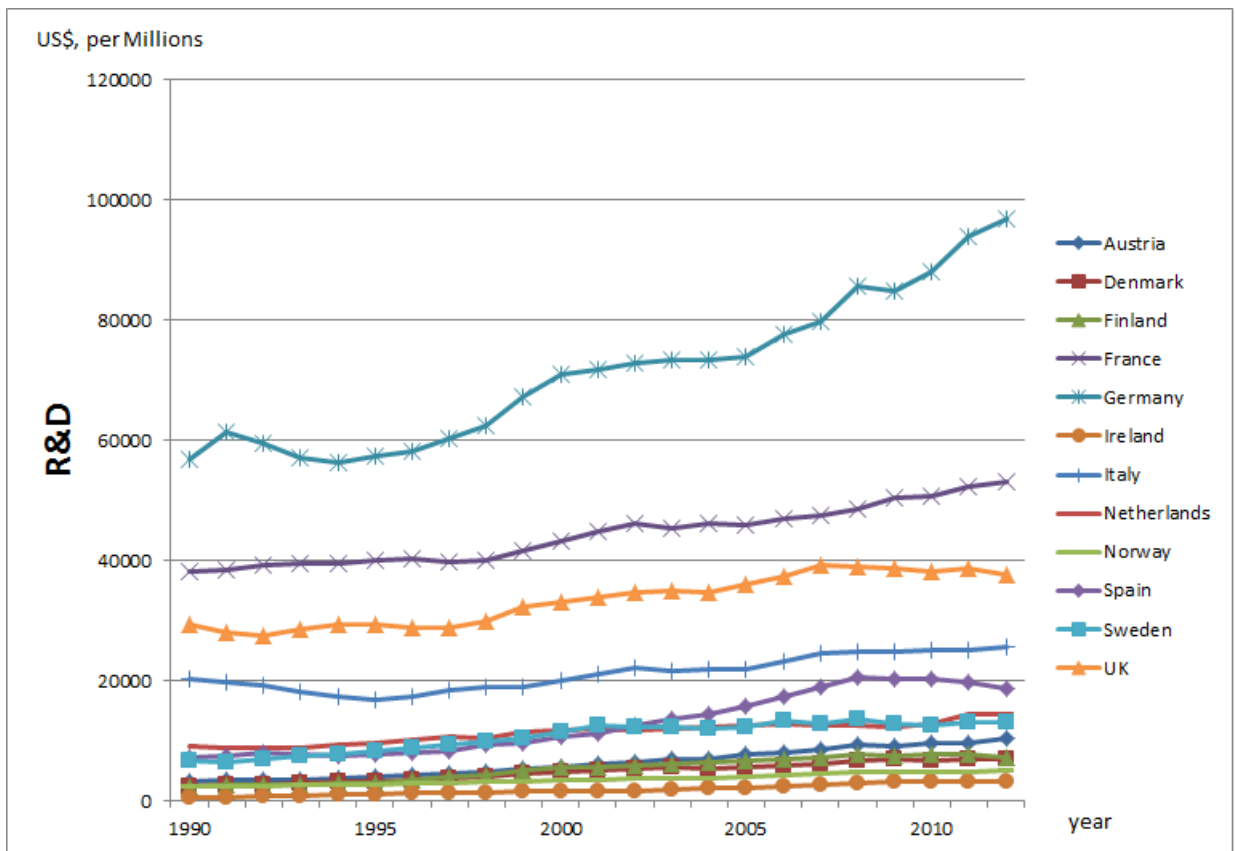


Figure C.1: R&D expenditures

C.4 Evolution of Government expenditures on education (as% of GDP)

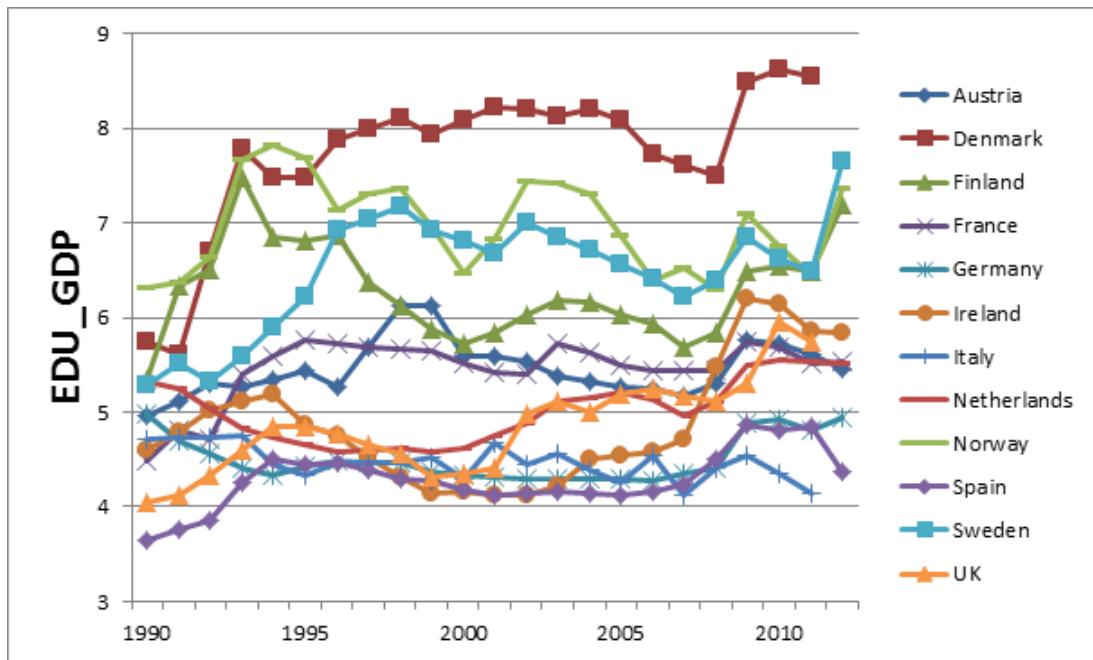


Figure C.2: Government expenditures on education (as% of GDP)

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Abstract: Essays on Environmental Innovation: The Role of Vertical Relations and Public Policies

Innovation in the 21st century has no longer as the mere objectives the survival of companies in the market and the stimulation of growth at the country level. From now on, there is an urgent need to preserve the environment to ensure the development of present and future generations. Therefore, several empirical studies and theoretical accounts place the matter at the heart of innovation and economic fields of research. The first objective of this thesis is to examine how, at a microeconomic level, the emergence and diffusion of environmental innovations is impacted by strategic inter-firm relationships within supply-chains. In order to achieve this goal, the first chapter shows that a monopoly maintains a low-quality product on the market with the sole intention of increasing his bargaining power against a supplier offering a drastic innovation - a costless high-quality product. The second chapter explains how bargaining powers between vertically related firms can influence the adoption choice of environmental technology leading to a sub-optimal level of depollution or welfare. To deal with this situation, the regulator must adapt its regulatory policy, in this case a tax, to modify the choice of the polluting firm. However, its intervention may prove insufficient under certain conditions. The second objective of the dissertation is developed in the third chapter which identifies theoretically and empirically the macroeconomic determinants of environmental innovations in order to help the regulator to better target its interventions.

Résumé : Essais sur l'innovation environnementale : le rôle des relations verticales et des politiques publiques

L'innovation du 21^{ème} siècle n'a plus comme *simple* objectif la survie des entreprises sur le marché et la relance de la croissance des pays. Désormais, elle doit, *en plus*, préserver l'environnement pour assurer le développement des générations actuelles et futures. Cette nouvelle tâche la place au centre des recherches d'innombrables travaux mobilisant les champs de l'économie de l'innovation et de l'économie environnementale. L'ambition de cette thèse est, dans un premier temps, d'examiner comment -à un niveau micro-économique-, l'émergence et la diffusion des innovations environnementales sont impactées par les relations stratégiques inter-firmes au sein des chaînes de valeur. Pour ce faire le premier chapitre montre qu'un monopole est prêt à maintenir sur un marché un produit de moins bonne qualité pour augmenter son pouvoir de négociation face à un fournisseur offrant une innovation drastique –un produit de meilleur qualité sans coûts additionnels-. Le second chapitre explique comment les pouvoirs de négociation entre les firmes verticalement liées peuvent influencer le choix de l'adoption de la technologie environnementale engendrant un niveau de dépollution ou de bien-être sous-optimal. Pour faire face à une telle situation, le régulateur doit adapter sa politique de régulation –une taxe en l'occurrence- pour modifier le choix de la firme polluante. Or son intervention peut se révéler insuffisante sous certaines conditions. Dans un deuxième temps, le troisième chapitre cette thèse identifie, théoriquement et empiriquement les déterminants macro-économiques des innovations environnementales afin d'aider le régulateur à mieux cibler ses interventions.

