

Policy instruments and incentives for environmental R&D: a market-driven approach

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SUMMARY

Environmental policy instruments have an impact on the incentives to invest in environmental R&D and this link should deserve careful consideration when introducing new instruments. Some authors argue that environmental taxes and tradable permits have rather comparable impacts on environmental R&D but we think that only very specific conditions do lead to this kind of conclusions. If we broaden the perspective by integrating elements from the Industrial Organisation literature and depart from Pigouvian settings, a market-driven approach would link the incentive to invest in new technologies to the market potential offered by the policy instruments. If taxes turn out to be very expensive for the polluting or emitting industries, we can assume that these targeted firms would be more interested to invest in new - emission reducing - technologies than in cases where the chosen policy instrument will lead to a very limited cost. We therefore developed a dynamic model that enables to compare the incentives on environmental R&D resulting from taxes, emission trading, voluntary approaches and subsidizing environmental R&D. We do not claim to capture all relevant market interactions, but our findings confirm the intuition that environmental taxes have a clearly different impact on environmental R&D compared to emission trading.

Keywords : Research and Development, environmental policy, environmental taxes, emission trading, voluntary approaches, market interactions

JEL Classification : Q28, O31, H23

NON TECHNICAL SUMMARY

Economists argue that market incentives will create opportunities for entrepreneurs to develop new products and processes. It is clear that many environmental problems need new technologies to eliminate the detrimental externalities. Waiting for these new clean technologies to arrive would be unacceptable and too risky and therefore environmental policy designed many instruments that should lead to a market behaviour that enables it to internalize external effects. Environmental policy instruments all have an impact on the incentives to invest in environmental R&D and this link should deserve careful consideration when introducing new instruments. Some authors argue that environmental taxes and tradable permits have rather comparable impacts on environmental R&D but we think that only very specific conditions do lead to this kind of conclusions. If we broaden the perspective by integrating elements from the Industrial Organisation literature and depart for Pigouvian settings, a market-driven approach would link the incentive to invest in new technologies to the market potential offered by the policy instruments. If taxes turn out to be very expensive for the polluting or emitting industries, we can assume that these targeted firms would be more interested to invest in new - emission reducing - technologies than in cases where the chosen policy instrument will lead to a very limited cost. We therefore developed a dynamic model that enables to compare the incentives on environmental R&D resulting from taxes, emission trading, voluntary approaches and subsidizing environmental R&D. We do not claim to capture all relevant market interactions, but our findings confirm the intuition that environmental taxes have a clearly different impact on environmental R&D compared to emission trading.

The market - in terms of potentially avoidable costs - created by environmental taxes is always more important than the market resulting from a system of tradable permits that only captures emission reductions. This finding holds even when environmental taxes are low and permit prices much higher. Only when permits would be auctioned from the beginning of the programme, the impact on the incentive for environmental R&D would be comparable. We also found indications that other instruments like voluntary agreements and subsidies for technological R&D have a more interesting impact on the incentive for R&D compared to emission trading. In our model we could integrate and compare these four instruments since we included the cost of innovation and various parameters for uncertainty.

Our final conclusion is that environmental taxes, without important exceptions or escape clauses, offer the most clear incentives for the needed technological innovations.

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1. Introduction

For many environmental problems, technological innovations can offer fundamental solutions, especially when behavioural changes are limited by various inertia. Our industrial and technological infrastructure that did lead to significant externalities, can be transformed to limit detrimental environmental impacts. This transformation process is already happening very smoothly since environmental considerations started to influence all engineering and industrial designing phases. During the coming decades, our technological infrastructure will no longer be characterized by >brute-force= manipulation of scarce natural resources.

Efficiency could and should lead to sufficiency and sustainability (Huber, 1998). If this positive scenario works out, the most convinced >technology-believers= would even suggest that stringent and costly environmental policies could be postponed. For some areas like global warming policy, this possibility is considered because many scientific uncertainties could lead to the too early implementation of costly measures. We believe however that the strategy of waiting for superior technologies could turn out very disappointing. Like all other goods, technological products need an interesting market that stimulates the process of entrepreneurial and Schumpeterian dynamism. New technologies need to be commercialized and without clear and credible environmental policies or the threat to impose environmental measures in the near future, such markets for new technologies do not exist. Waiting has always a price in terms of lost opportunities and therefore we argue that an accelerated technological innovation and diffusion should be stimulated by the appropriate choice of environmental policy instruments. This consideration has already frequently been made during the 1970s and 1980s (Magat, 1979 ; Milliman and Prince, 1989) but recent environmental policy has not generally focused on the positive connection between environmental improvement and technological innovation. A possible explanation is that the early environmental movement often preoccupied itself with the adverse impacts of technology (OECD, 1997).

In the economic literature, many studies on the different effects of environmental policy instruments are based on the seminal paper by Weitzman (1974). He concluded that taxes should be preferred to quantity controls when expected marginal benefits were relatively flat. The relative curvature of the cost and damage functions is only part of the reason for preferring taxes. Weitzman also noted that when shocks to costs and benefits are correlated, this simple intuition breaks down (Pizer, 1997 ; Stavins, 1996).

Basic elements of Industrial Organization literature were integrated by authors like Biglaiser and Horowitz (1995) and Parry (1995, 1996). These authors work with Pigouvian taxes and permit price levels equalling marginal environmental damage under perfectly competitive conditions with homogeneous firms in terms of production and abatement costs. These market conditions are hard to find what makes the conclusions of the studies difficult to generalize.

Parry (1996) concludes that the incentives for environmental R&D are empirically similar under the Pigouvian tax and under the Pigouvian quantity of permits when innovations are minor and

there is a well-functioning permit market. In our work, we will depart from Pigouvian settings of taxes and quantities and illustrate that the different impact on the incentive for Research and Development (R&D) resulting from taxes or permits is very significant.

Furthermore, each sector or environmental problem has very specific characteristics that are not found in other industries or policies objectives. As a result, the >overall= effects of the environmental regulation on R&D tends to be ambiguous (Palmer, Oates and Portney, 1995).

In this paper, we have the ambition to work out in more detail the linkages between environmental instruments and the behaviour of the innovating sector. We introduce an investment decision that is made by firms that have the potential to invest in environmental R&D. We see innovation as an endogeneous and continuous process. By the latter, we mean that the decision to innovate - not to compare with the decision to imitate - can be made at any moment in our analysis and not only at the starting point of the simulation.

In our approach, firms are not identical. Each of the polluting firms has different marginal abatement costs. To capture these differences in our model, we make use of probability density functions.

2. Presentation of the model

In our model, we work with two sectors ; the group of polluting firms and the group of firms investing in R&D to provide an abatement technology to the polluting sectors.

The group of the polluting firms causes the externality and is the target of the environmental policy. Government can use various instruments like taxes, tradable permits, technological standards, performance standards, product bans, environmental agreements and the disclosure of environmental information (e.g. compliance records). Each instrument has a different impact on the process of technological innovation and diffusion. A comparative approach would be preferred but is only possible for a limited selection of all available instruments. We therefore prefer to simulate the incentives for environmental R&D that are the result of specific instruments. Our findings could be an interesting complement to algebraic or game-theoretical approaches.

2.1 The polluting sector

We assume that abatement costs for the polluting firms differ. This is a realistic assumption in line with the findings of Hartman, Wheeler and Singh (1994) who used the U.S. Department of Commerce=s annual 20000-plant random survey of pollution abatement costs and expenditures (PACE). For 37 sectors, the average abatement costs in \$US (1993) per tonne were calculated for seven air pollutant categories : suspended particulate matter, sulphur dioxide, nitrogen oxides and carbon monoxide, hydrocarbons, lead, hazardous (toxic) emissions and other emissions.

They concluded that maximum/minimum ratios are frequently near ten, and occasionally near one hundred. Abatement costs for a selection of air pollutants and US industries are presented in Table I.

Table I - Average abatement costs by sector, 1979-1985 (\$1993/ton)

Industry	Particulates	Sulphur oxides	NO ₂ , CO	Hydro-carbons	Lead
Food	86	521	229	162	46612
Leather	132	377	8430	633	132
Industrial chemicals	46	75	304	213	1300
Chemical products	212	681	48	157	29
Metal products	343	1563	461	399	161
Electrical machinery	373	483	1559	215	365
Transport equipment	635	1266	468	1006	468
Motor vehicles	350	1523	1155	2441	21483

Source : Hartman, Wheeler and Singh, 1994, p.4

Another conclusion from the empirical analysis was that scale economies may apply to some abatement processes.

The polluting industry can develop its own abatement technologies or can buy technological solutions provided by the technological sector. Since end-of-pipe solutions were used for air pollution abatement, the data by Hartman e.a.(1994) are in most cases payments to technology providers. In our model, we assume that the polluting industry will always *buy* clean technologies. There will be no in-house development because these firms have no experience with environmental technology development and commercialization.

If abatement costs for air pollutants can vary from \$10 to \$ 46000 per tonne (Hartman e.a., 1994), it will be very complicated to determine ex-ante the optimal Pigouvian tax or permit price. We think it is useful to assume that abatement costs follow a normal distribution over the polluting firms.

2.2 The innovating sector

In our model, we consider the decision to innovate and the marketing of the resulting innovations as endogeneous. The innovating sector operates in a commercial environment and will base its decision to invest in environmental R&D on factors like the cost of the innovation, the chance

to achieve technological success, the discounted profits following from the commercialization, the rate of return of the project and the possibility of patent protection. In our threshold innovation model, we assume that firms want to invest in innovation if the cost of innovation (CI) does not exceed a critical value, determined by the discounted profits from innovation.

We calculate these discounted profits from innovation (DPI) for i years as :

$$DPI = \rho \sum [(p_i - c_i) * q_i] / (1+r)^i ,$$

with p_i = price for technology on the market ;
 c_i = cost of producing the technology ;
 q_i = quantity sold to polluting industries ;
 r = internal rate of return ;
 \tilde{n} = success probability (technical success and the possibility to commercialize the innovation) or uncertainty factor ($0 < \rho < 1$)

Investing in technological innovations is an activity with many business risks. We follow the approach indicated by Mansfield and identify three different success probabilities : (1) the probability that technological goals would be achieved ; (2) the probability that, conditional upon technical success, the resulting product or process would be commercialized ; and (3) given commercialization, the probability that the project yielded a return on investment at least as high as the opportunity cost of the firms capital (Scherer and Ross, 1990).

Scherer and Ross (1990) also present the empirical results of the investigations by Mansfield. For the firms in his analysis, the average probabilities were :

Technical success (ρ_1)	0.57
Commercialization, given technical success (ρ_2)	0.65
Financial success, given commercialization (ρ_3)	0.74
with $\rho = \rho_1 * \rho_2 * \rho_3 (=0.274)$	

It is clear that the choice of the used environmental policy instrument has a strong impact on the probability of realizing a financial success but not on the technical success probability. Suppose that in this example, the best environmental policy results in a financial success probability of 0.95 compared to a probability of only 0.55 for the worst policy option, the difference in total success probability would be 0.15 (0.35 - 0.20) what is much less than two times 0.20.

Some authors link total success probability to the number of firms that invest in environmental R&D. The higher the number of involved firms, the more limited is the probability of financial success. This is a reasonable assumption in the case when there is *only one* technology that can

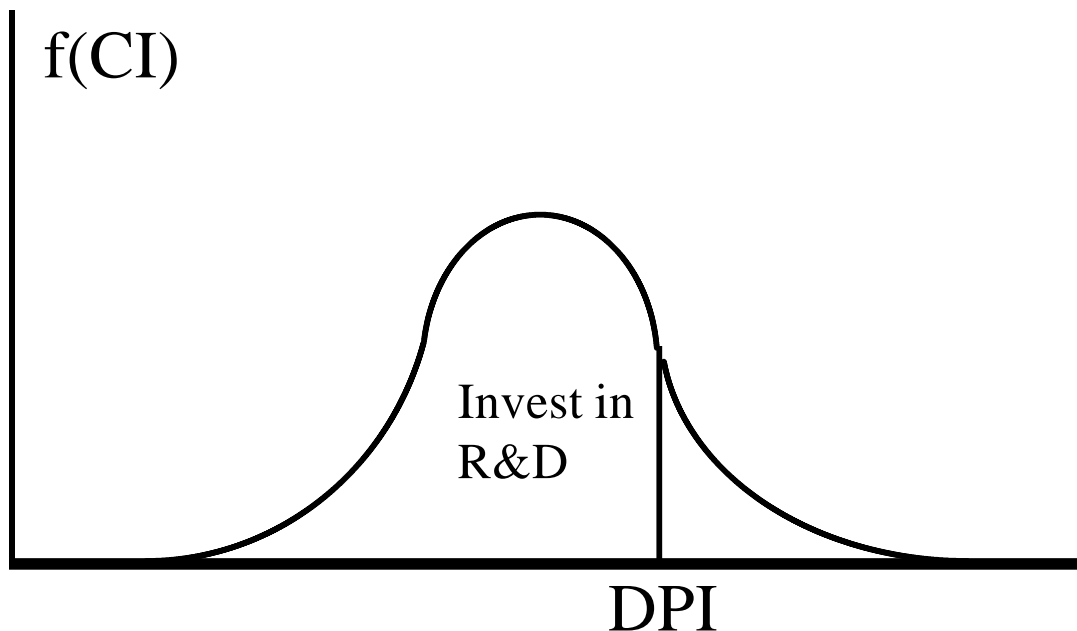
be innovated and developed. In reality, many technologies offer positive environmental outcomes and we have a competition among new technologies on the market. For many pollution abatement possibilities, there is also a competition between new clean technologies and new cleaner inputs. Car emissions can be reduced by diverse types of new engines (electric vehicles, fuel cell vehicles, hybrid vehicles, engines using compressed air,...), the increased use of weight-saving materials and the introduction of cleaner and alternative fuels (low-sulphur fuels, biofuels, ethanol, methanol,...).

When analysing the findings of Hartman e.a.(1994), we think that the differences in sectoral abatement costs are partly explained by different technological needs for each sector and for each pollutant to abate.

We also should be aware of cluster economies or external economies of scale resulting from collective or simultaneous R&D efforts. Spill-over effects can generate additional market dynamics that contribute to the long term profitability of the environmental R&D sector.

The cost of the innovation (CI) differs for each firm, especially if we assume that many technologies will be developed. From the business literature, many examples of very cheap and very expensive R&D projects can be found. Scherer and Ross (1990) conclude that it is useful to think about R&D project costs in terms of a frequency distribution. In reality, this distribution could turn out to be highly skewed but we will start working with a normal distribution like in Figure I.

Figure I - Distribution of innovating costs for the environmental technology industry



In our threshold approach, only when the discounted profits from the innovation exceed the costs of innovation, firms are prepared to invest in environmental R&D. The proportion of firms that

will invest in R&D given a certain DPI can be found on the left side of DPI. It is clear that when DPI increases, more firms will be prepared to invest in environmental R&D.

In our later simulation, we assume that each firm uses the same r for calculating DPI, that market demand for the environmental technology is linear ($p_i = a - bq_i$) and that producing the technology gains positive economies of scale ($c_i = d - eq_i$).

The calculation and evaluation of DPI is not restricted to the beginning of our simulation. We consider it as a continuous process. Firms that have the potential to innovate are already familiar with the technological needs of their future products. If they decide not to invest in environmental R&D because the potential market is not attractive enough, they can wait and re-evaluate the market during the coming years when new events like changed priorities in strategic management of the polluting firms, unexpected price developments, scientific findings or government policies have a significant impact. So it is possible that they decide to invest in environmental R&D some years later and develop then a new technology.

2.3 Adoption of the new technology

After its development, we assume that the diffusion of the new technology will follow a pattern of a threshold model. Like in Kemp (1997), we first attribute to the polluting industry a willingness to pay (W) for the environmentally desirable innovation. In their investment decision, these firms include the emission reduction achieved by the technology or the reduction of used environmental inputs and the price level of the emission or environmental input.

Some firms can also include other elements like management priorities, the reduced risk for environmental liabilities and/or penalties, positive impacts on the firms' image, etc. As a result, we assume that this willingness to pay will be distributed normally.

If the willingness to pay exceeds the market price of the environmental technology p_i , the firms will be prepared to buy and install the new technology.

2.4 The market potential for environmental technologies

Firms will invest in environmental R&D if DPI exceeds CI. Polluting firms will buy the environmental technology if W exceeds p_i . The value of DPI depends mainly on the expected market reaction (p_i , q_i). The quantity of environmental technologies sold, q_i , depends on the effective need to reduce emissions. We therefore need to focus on the different impact each environmental instrument has on the needed reductions of emissions by the polluting industries. If the reduction target is ambitious, this will stimulate or even force these industries to install the technologies presented by the innovating sector.

An instrument with only price implications, like environmental taxes, offers less certainty on the effective reduction of emissions than quantity instruments like tradable emission rights. In the case of environmental taxes, the innovating sector needs information on the expected tax level

and the price elasticity for the demand of the taxed good. Additional problems are related to built-in tax exceptions or rebates for industries that are very intensive in the use of the taxed input. This is a very relevant element in many energy tax systems based on carbon content (see the European proposal for a CO₂ tax).

In the case of quantity instruments, there are clear emission reduction or emission stabilization targets when the instrument is introduced. This reduction target can increase over time. The environmental effectiveness and price implications of quantity instruments depend to a significant extent to the initial (and annual) allocation of the permits. Are these emission rights distributed for free (grandfathered) or are they auctioned?

A similar clear reduction target is included in most voluntary agreements proposed by industry. Potential innovators can estimate their potential market for new technologies starting from these reduction targets that industry wants to achieve as a result of internal process changes and the installation of bought environmental technologies.

When total emissions of a target group - like the most important utilities in a region - need to be reduced by x percent, total sales of environmental technology ($\exists q$) over the period of analysis depend on the ratio (total emission reduction / reduction by new technology (R_E)) ;

$$\exists q = v(x(1+g)FE_F)/R_E,$$

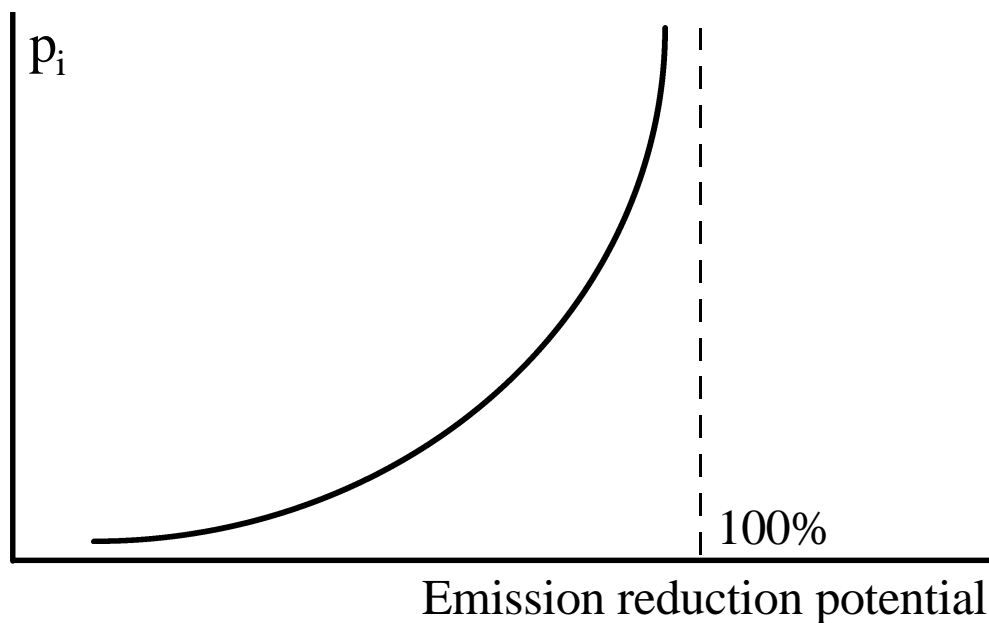
- with
- F : number of facilities that need to reduce emissions ;
 - E_F : emissions per facility ;
 - x : emission reduction target (%) ;
 - g : projected growth of industrial activity ;
 - R_E : emission reduction (%) by the new technology ;
 - v : vintage effect with $0 < v < 1$.

Economic growth ($g > 0$) can lead to increased emissions in the business-as-usual scenario. High growth of sectoral output could be positive for the potential sales of emission reduction technologies, especially when auctioned quantity instruments are used and when the proportion of emissions to output is relatively stable over time. In the case of price instruments, growth of industrial activity can be anticipated by setting higher levels of the environmental taxes. It is mostly assumed that as a result of the environmental taxes, the growth of industrial emissions will be limited. This is however never certain and could be a partial explanation for the limited environmental success of some environmental tax programmes.

The vintage effect indicates what fraction of the needed reduction will lead to the installation of environmental technologies. Some firms will not invest in environmental R&D or technologies because these new investments cannot be easily integrated into their long term investment cycle. Investment planning follows here a vintage model. Other firms do not invest because they are not interested in, or aware of, the environmental instrument. Finally, they also could just prefer to buy emission rights on the market or pay the environmental taxes..

The market for the environmental technologies is also influenced by the emission reduction potential of the developed technologies. If the new technologies are very efficient - like in the extreme case where they reduce plant emissions by 100% - the market will be readily saturated with a low sales volume for the innovating firms. But when the technologies can only reduce plant emissions by 10%, it will take much longer to achieve a significant reduction of emissions. The price of the environmental technology (p_i) is also depending on the emission reduction potential. This is illustrated in Figure II where the price increases exponentially with the emission reduction potential (R_E). This pattern could develop when shadow prices of emissions increase strongly over time (e.g. as a result of stricter emission reduction targets).

Figure II - Emission reduction potential and price of the technology



Very performant technologies will have a higher price that will compensate for the lower sales volume. Presenting a radical technology to the market has the limitation of a smaller market in terms of quantities sold and the higher business risk, but this is compensated by the reduced risk for imitation or outperformance by better technologies. It is obvious that incremental technological improvements are more vulnerable for outperformance by competing technologies.

3. Taxes versus permits

In a first step, we will use a part of our model to shed some light on the different market incentives for technological innovation that result from using environmental taxes compared to quantity instruments like tradable permits. We focus on the market potential created by the chosen instrument. If the policy instrument turns out to be very expensive for the polluters, the incentives to capture this flourishing market for technological innovations are great. If the cost

of the instrument is neglectable, the market potential for innovators is limited and the investment in environmental R&D very risky.

Before we compare two instruments, it is necessary to define the relevant characteristics of the instruments. We will focus on the differences resulting from grandfathering (and not of auctioning) of tradable permits and environmental tax regimes that include (temporary) exceptions for some heavy polluting or emitting industries.

For industry, both environmental instruments will lead to a cost : paying taxes or buying permits. In the case of taxes, emissions constitute the taxable base while in the case of grandfathered permits, *only* the reduction of emissions will lead to costs to pay. This is a fundamental difference and those who argue that industry will behave more or less similar towards both instruments should consider this. But again, the latter conclusion is only relevant when permits are (each year) grandfathered based on past emission trends. When the permits are auctioned and need to be bought from the initial instalment of the policy instrument, we can compare the emission base for the environmental taxes with the spend budget for emission permits.

We worked out a basic simulation exercise to indicate the potential differences between taxes and grandfathered emission rights. We want to stress that the difference depends on the period of analysis. In a stable regulatory framework, taxes not only need to be paid this year but also during the coming years. Permits need to be bought over the complete period (*i* years) and the foreseen reductions of emissions will strongly influence the demand for permits on the market. We defined total tax and permit cost (*i* years) as :

$$\text{Tax Cost} = t \ni (1+g_i) (1- z_i)FE_F$$

$$\text{Permit Cost} = p_p \ni (1+g_i) x_i FE_F$$

with t = environmental tax ;

g_i = evolution in industrial growth over time ;

z_i = evolution of exemptions from environmental taxes ;

x_i = evolution of emission reduction over time (as % of initial emissions) ;

p_p = permit price.

We assumed that the exemptions permitted in the tax policy will be reduced over time and that emission reduction objectives in permit trading programmes will increase over time. The absolute cap on emissions is held constant.

In our simulation for a period of 10 years, we started with 1000 firms ($F=1000$), each releasing 1000 tonnes of a substance (e.g. CO_2 ; $E_F=1000$). We kept these numbers constant and then calculated tax costs and permit cost for 10 moments over a period of 10 years. Each calculation for year *i* represents total costs if the time horizon of the instrument would be limited to the first *i* years. For instance, we conclude from Table II that after 5 years during which taxes have been paid and permits have been bought each year, the total cost of the tax programme would be \$ 145

million while the cost of the permit programme would be only \$ 15 million for the emitting industry. The tax programme would be 9.59 times more expensive. So it is no surprise that in this basic case, industry would be in favour of permit trading (after a free grandfathering) compared to paying environmental taxes.

The calculations in Table II are based on a tax of \$ 50, a permit price of \$ 50, a percentage of tax exceptions of 50% in the first year that will be reduced to 0% after 10 years and an emission reduction target for the permit programme that starts at 3.5% for the first year and increases to 15% in the last year. The growth rate of industrial activity starts at 1.5% and increases to 3.5%. After the first year, the difference is the greatest because after this year the cumulative permit cost increases faster than the cumulative tax cost. However, the absolute difference between the two policies per annum increases during the first years (26.16 - 1.77 = 24.39 difference for year 1 / cost for permits in year 2 : 4.19 - 1.77 = 2.42 - cost for taxes in year 2 : 53.62 - 26.16 = 27.46 / difference for year 2 : 27.46 - 2.42 = 25.04) . As a result, the cumulative values in Table II will converge over time

Table II - Tax cost versus permit cost, \$ mln (period of 10 years)

Year	permit cost	tax cost	ratio (tax/permit)
1	1.77	26.16	14.71
2	4.19	53.62	12.79
3	7.37	82.64	11.20
4	10.95	113.05	10.32
5	15.17	145.58	9.59
6	20.19	180.01	8.92
7	25.74	215.63	8.38
8	31.70	254.02	8.01
9	38.08	305.86	8.03
10	45.27	357.90	7.90

Our calculations for Table II are of course parameter-specific. A different situation will develop if exceptions for the environmental taxes change or when the permit price differs from the tax price. We therefore present in Table III the outcomes of the simulations for seven other scenarios.

For each scenario, the values of the parameters and evolution patterns for the variables are given below. Changes compared to the preceding scenario are presented in *italic*.

Scenario 1 : t=50	$p_p=100$	$z_i : 50\% \rightarrow 0\%$	$x_i : 3.5\% \rightarrow 15\%$
Scenario 2 : t=50	$p_p=100$	$z_i : 30\% \rightarrow 0\%$	$x_i : 3.5\% \rightarrow 15\%$
Scenario 3 : t=50	$p_p=100$	$z_i : 30\% \rightarrow 0\%$	$x_i : 5\% \rightarrow 40\%$
Scenario 4 : t=50	$p_p=100$	$z_i : 30\% \rightarrow 0\%$	$x_i : 1\% \rightarrow 8\%$
Scenario 5 : t=50	$p_p=100$	$z_i : 10\% \rightarrow 0\%$	$x_i : 1\% \rightarrow 8\%$
Scenario 6 : t=50	$p_p=75$	$z_i : 33\% \rightarrow 0\%$	$x_i : 1\% \rightarrow 15\%$
Scenario 7 : t=50	$p_p=100$	$z_i : 0\% \rightarrow 0\%$	$x_i : 5\% \rightarrow 20\%$

Table III - Ratios of (tax cost / permit cost) for 7 scenarios

Scenario	1	2	3	4	5	6	7
Year 1	7.36	9.93	7.32	23.17	29.83	45.00	9.05
2	6.39	8.48	6.22	21.54	28.00	33.57	8.14
3	5.60	7.33	4.72	17.70	23.12	22.98	7.29
4	5.16	6.69	3.89	14.39	18.71	17.95	6.64
5	4.80	6.16	3.39	12.02	15.45	14.03	6.31
6	4.46	5.68	3.04	10.43	13.27	12.18	5.98
7	4.19	5.33	2.76	9.56	11.96	10.47	5.70
8	4.01	5.11	2.51	9.08	11.07	9.21	5.37
9	4.02	4.94	2.29	8.70	10.34	8.25	5.02
10	3.95	4.73	2.11	8.34	9.72	7.54	4.72

In each of the seven cases, permit prices are much higher than taxes and still the total cost of taxes is much higher than the cost of the permit programme for the polluters. It is also no surprise that each scenario leads to a different outcome. Tax programmes without exemptions are clearly much more expensive for industry compared to buying permits for the share of emissions that needs to be reduced. If we had taken the combination of a high energy tax with a cheap tradable permit, the difference would be even more pronounced. In the case of carbon dioxide emissions, the probability that we end up with very cheap permits is relatively high if Russia will be able to sell its excess permits - resulting from the economic recession - to the energy-intensive developed countries.

As a result, the different costs for industry resulting from both instruments clearly creates a bigger market for environmental technologies in the case of environmental taxes. Only when the permit price and the emission reduction objective are high (like in scenario 3), the total costs are somehow comparable.

In this basic simulation, we did not include many other important aspects like the performance of the technological innovation (in terms of reduced emissions), the price of the technology, scale economies in the production of new environmental technologies, etc.

We will integrate these elements in the next sections.

4. The general model

For a period of 15 years, we analyse the incentive to invest in environmental R&D by making use of the assumptions used to define DPI and total sales of the new environmental technology (Σq). For the first model runs in the base-line situation without an environmental policy instrument implemented, there is only a reduction target for emissions that the innovating sectors assumes to become the effective target in later policy frameworks. So there are no environmental policy instruments used at this moment and we focus on the proportion of potential innovators that will each year effectively invest in environmental R&D as it was presented in Figure I. We will work out a graphical presentation for the total period of analysis. Therefore we need to introduce CI, the cost of the technological innovation. We assume that CI consists of a fixed cost, set at \$ 1 million in our model, and a variable part since each product sold on the market will result in some feedback from clients that demand for adaptations of the technology to their specific demands.

We then define a new variable, $R\&D\ Incentive = (DPI - CI)/CI$, to qualify the difference between DPI and CI over time like used in Figure I.

We present our findings making use of the following settings : $p=20000 - 0.03q$; $c=15000 - 0.03q$; $R_E = 0.2 + 2q/1000000$; an industrial growth rate starting at 1.5% and increasing by 10% ($0.10 * 1.5\%$) each year; $\rho_1=0.33$; $\rho_2=0.33$; $v = 0.75$.

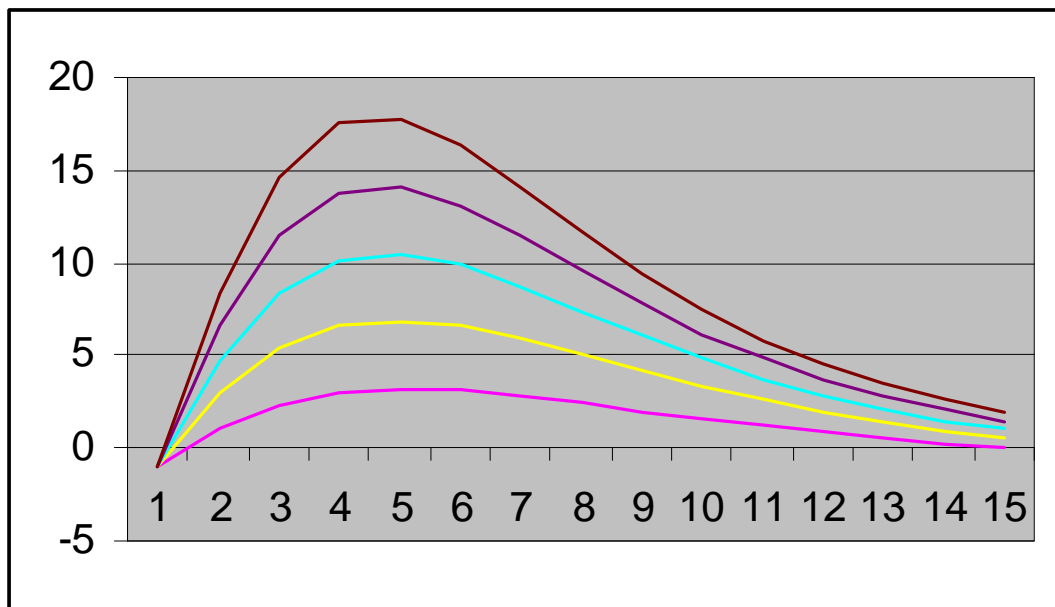
The reduction of the emissions is linked to the technological performance of the new technology - in terms of emission reduction - what results in a sales estimate for the new technology. The manufacturers then set initial prices and production costs that should both decline over time. Only when the profits from future sales outweigh the costs of the technological innovation by a certain factor or baseline, manufacturers will start investing.

In Figure III, a sensitivity analysis was made for the variable R&D Incentive when the initial reduction target - used by the innovating industries in their investment decision - ranges from 5% to 25% with an increase by 10% each year. We notice that the value for R&D Incentive exceeds 1 in most cases. Industry is however aware of the many uncertainties surrounding the environmental policy process and could therefore work with very short pay-back periods for environmental investments or could require that R&D Incentives exceeds factor 5 before starting

the new investment programme. Only when environmental policy instruments are implemented by a transparent and stable regulation with detailed information for all involved parties, a baseline set at 1 would sufficiently capture all uncertainties.

If the baseline was set at 5, and the reduction target starts at 5% of total emissions, there will be no incentive to invest. The market created by the low reduction target is too small. For entrepreneurs that are less risk averse, a lower baseline could be used. We also notice that the incentive to invest increases over time. If industrial activity grows and the reduction target also increases over time, the market for the new technology becomes more attractive. The price for the technology will decline over time for various reasons - new entrants, outperforming new technologies - what reduces the market attractiveness.

Figure III - R&D Incentive for 5 reduction targets



It is clear that the higher the reduction target for emissions, the more attractive the market for the new technologies becomes. Similar findings can be found when we include a sensitivity analysis for the parameter ρ_2 in our model. The initial and fixed value for ρ_2 was set at 0.33 but when we include values from 0.2 to 0.6, the incentives for R&D change develop a same pattern as in Figure III. The reduction of the uncertainty leads to a increased market for the environmental technologies.

4.1 Environmental taxes on emissions

If government decides to install taxes on emissions, polluting firms can opt for paying the taxes

or they can invest in new emission reducing technology. Their choice will depend on the relative cost of both alternatives that are calculated in our model. As a result, the level of the environmental tax and the price of the new technology are two crucial variables.

We first compare the total cost of the tax option with the total cost of the technology option.

We calculate the preference for technology as :

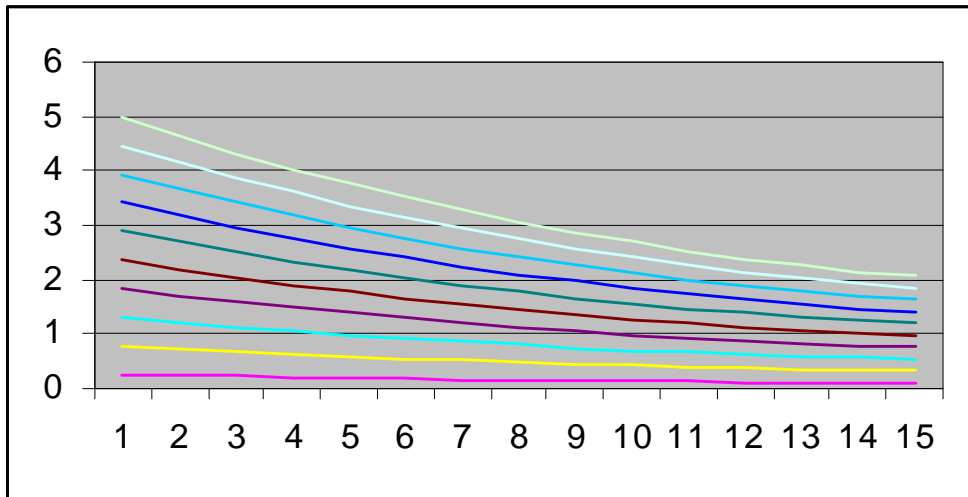
$$\text{PrefT} = (\text{cost tax option}) / (\text{cost technology option})$$

For simplicity, we assume that every firms or industry needs to pay the tax : there are no exceptions or preferential regimes. We did run the model for 10 levels of the environmental tax : ranging from \$ 25 per tonne emissions to \$ 500 per tonne. The taxes are set to achieve a clear environmental target in terms of a percentage reduction of emissions.

The results are presented in Figure IV. It is clear that in the cases with low tax levels, the cost of paying taxes is lower than the cost of investing in new environmental technologies as specified in our model ($\text{PrefT} < 1$). When environmental taxes exceed \$ 150, paying taxes turns out to be more expensive than investing in new technologies at the given market prices. In our situation of an effective environmental policy with an increasing emission reduction target and a slowly increasing environmental performance of the technologies, opting for investing in technology becomes also more expensive over time. Only when technological progress would develop very fast, all the lines in Figure IV would have positive slopes.

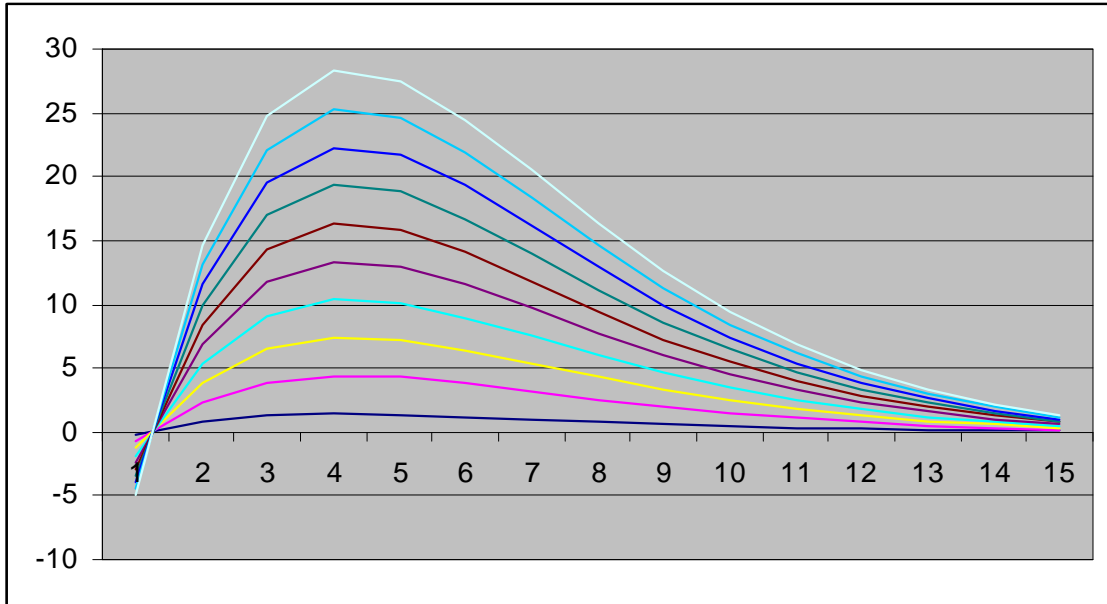
Over time, the emission reduction potential of the new technology increases but the demand for new technologies will increase since the reduction target and industrial activity also increase over time. This growing demand for the emission reduction technologies leads to the declining ratio of PrefT, even when the price of the technology decreases. Setting a reduction target that changes over time requires a dynamic approach and for this objectives a fixed tax is a rather arbitrary policy tool.

Figure IV - Preference for technology in the case of environmental taxes



If we include these findings in the a priori investment decisions of the firms that can invest in environmental R&D, the impact on our variable R&D Incentive might be significant. In Figure V, we present our findings for tax levels from \$ 25 to \$ 500 per tonne emissions reduced. The emission reduction target is not changed.

Figure V - R&D Incentive for 10 environmental tax levels (\$25 -> \$500)



Compared to Figure III, it is clear that high environmental taxes have the same incentive effect as the highest reduction targets for emissions. Without the environmental taxes, the maximum value for R&D Incentive would be 7.32 if the same reduction target as in Figure V would be

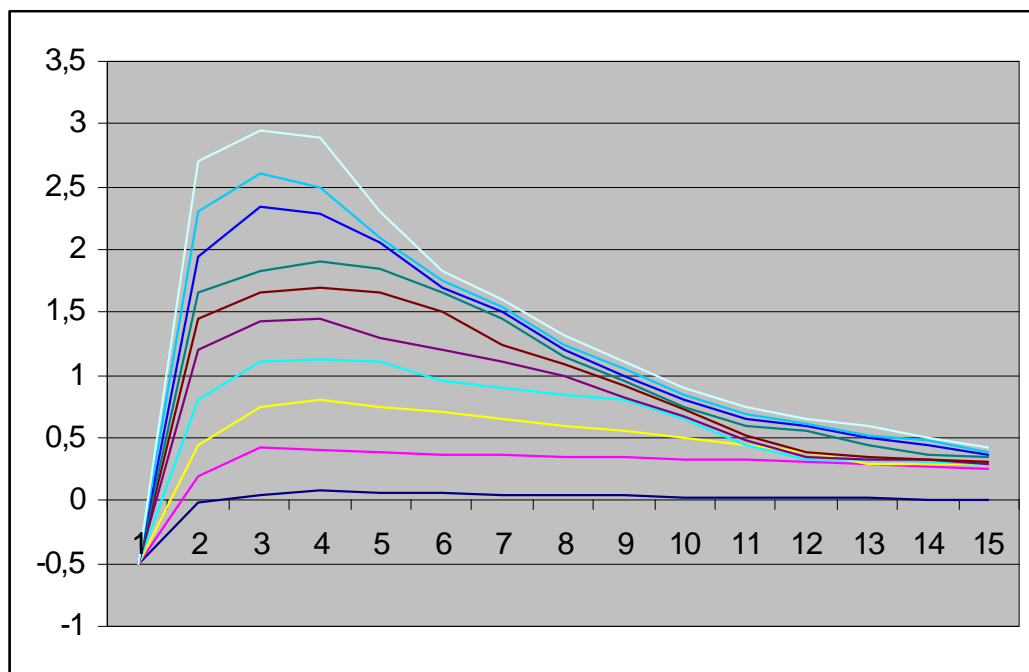
used. High environmental taxes without exceptions provide clearly an attractive market even for very risk averse investors.

4.2 Tradable emission permits

We repeat the same analysis when no taxes are used but tradable permits are introduced to reduce total emissions by a certain percentage. Polluting firms can reduce emissions by installing new technologies or they can buy permits if their emissions exceed a certain threshold. The preference for technologies is calculated as the cost of buying the needed permits divided by the cost of installing new environmental technologies. As could be expected - see section 3 -, it is more expensive to introduce new technologies when permit prices are not extremely high. The highest value for PrefT was 0.5 in the first year. For the other years, the value declines to 0.23.

The two crucial variables for our model with this instrument are permit price and the reduction target for total emissions. In Figure VI, we present the model output for 10 permit price levels - from \$25 to \$500 per tonne emissions - and a reduction target that starts at 10%. The highest calculated value for R&D Incentive is 2.91 what provides a low incentive to innovate. If we set the reduction target at 20%, the resulting model output is similar to Figure VI. The highest value is in this case 5.38, still much below the incentive provided by environmental taxes..

Figure VI - R&D incentive for 10 emission permit prices



We arrive at the conclusion that using tradable permits offers less incentives to the innovating

industry compared to introducing environmental taxes.

4.3 Voluntary agreements to reduce emissions

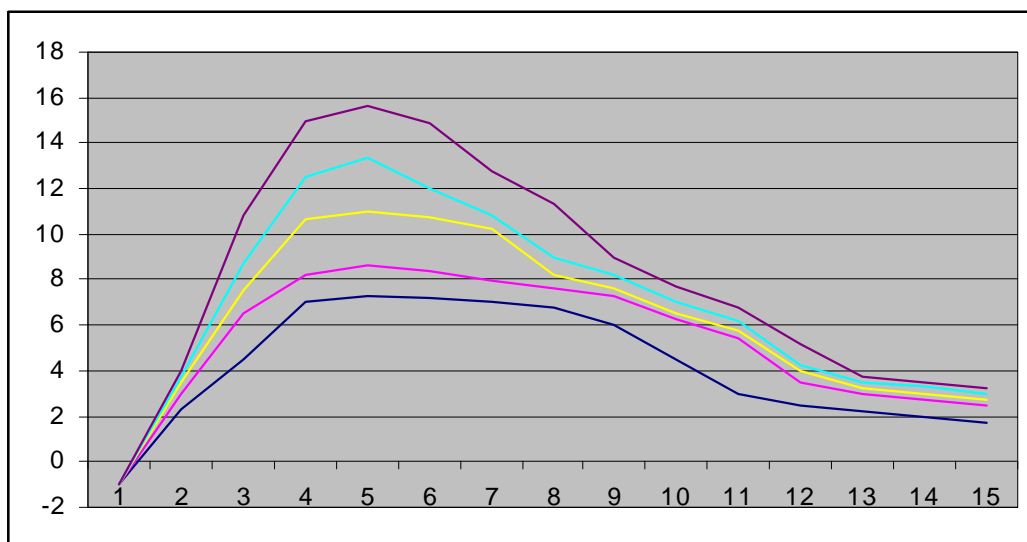
Another approach would be to negotiate a voluntary agreement with industry to reduce emissions. This instrument offers the advantage to industry that environmental investments can be optimally integrated into their long-term investment decision. For the innovating sector, this agreement does not create immediately a market for new technologies, especially when the time frame to accomplish the agreed reduction target is relatively long. Agreements offer however another type of certainty to the innovating sector since industry needs to reduce emissions. This compensates for the uncertainty on the existence of the future market for emission reduction technology.

We included an approximation of the effect of voluntary agreements in our model by assuming that the reduction of uncertainty - a higher value for ρ_2 , the probability for a successful commercialization - captures the impact on the incentive for environmental R&D.

ρ_2 varied from 0.33 to 0.66. Another possibility to integrate the effect of voluntary agreements was by setting a higher price because industry surely needs to invest in cleaner technologies and this dependency on future innovations could influence price developments on the markets for these new technologies. This is however uncertain because it could also be possible that the polluting industry selects certain partners that will benefit more from the emission reduction programmes than external firms. In this latter case, the finding in Figure VII are not valid for all firms in the industry.

From the results, it is clear that voluntary agreements create an incentive to innovating firms that outweighs our model simulations in the case of emission trading.

Figure VII - R&D Incentive and voluntary agreements



4.4 Subsidies for technological R&D

Government could also opt for subsidizing R&D of environmental technologies. In principle, this policy would provide a very strong incentive for the firms that will receive these subsidies. If new entrants to the R&D market have no access to this funding, the subsidy could create a barrier. We wanted to introduce the subsidy option in our model and therefore assumed that every firm will receive the subsidy - or at least projects to receive this funding for the investment decision - and that each firm receive the same amount. As a result, the subsidy reduces CI (the cost of the environmental R&D). Since the incentive to invest depends on the difference between DPI and CI, it is obvious that subsidies are important for the investment decision of innovating firms.

We introduced five levels of the subsidy; from no subsidies to a subsidy of \$500000, each step increasing by \$100000.

We found that the value for R&D Incentive increased to 14.01 in the case of the highest subsidy. When the subsidy was \$400000, R&D Incentive amounted to 11.08 and with a subsidy of \$100000 the calculated value was 8.5. Compared to our findings in the case of emission trading, subsidizing environmental R&D has a more interesting impact on the incentive to invest in new technologies.

5. Conclusions

Environmental policy instruments have an impact on the incentives to invest in environmental R&D and this link should deserve careful consideration when introducing new instruments. Some authors argue that environmental taxes and tradable permits have rather comparable impacts on environmental R&D but we think that only very specific conditions do lead to this kind of conclusions. If we broaden the perspective by integrating elements from the Industrial Organisation literature and depart for Pigouvian settings, a market-driven approach would link the incentive to invest in new technologies to the market potential offered by the policy instruments. If taxes turn out to be very expensive for the polluting or emitting industries, we can assume that these targeted firms would be more interested to invest in new - emission reducing - technologies than in cases where the chosen policy instrument will lead to a very limited cost. We therefore developed a model that enables to compare the incentives on environmental R&D resulting from taxes, emission trading, voluntary approaches and subsidizing environmental R&D. We do not claim to capture all relevant market interactions, but our findings confirm the intuition that environmental taxes have a clearly different impact on environmental R&D compared to emission trading. The market - in terms of potentially avoidable costs - created by environmental taxes is always more important than the market resulting from a system of tradable permits that only captures emission reductions. This finding holds even when environmental taxes are low and permit prices much higher. Only when permits would be auctioned from the

beginning of the programme, the impact on the incentive for environmental R&D would be comparable. We also found indications that other instruments like voluntary agreements and subsidies for technological R&D have a more interesting impact on the incentive for R&D compared to emission trading. In our model we could integrate and compare these four instruments since we included the cost of innovation and various parameters for uncertainty. Our final conclusion is that environmental taxes, without important exceptions or escape clauses, offer the most clear incentives for the needed technological innovations.

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