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Abstract

Most empirical evidence indicates that the costs of environmental regulation represent a minor fraction of total production costs. This finding is at odds with the assumption of stringent environmental regulation of both propo-nents and opponents of the 'Porter Hypothesis'. A possible explanation may be provided by examining the nego-tiation of environmental regulation in a 'political market'. In this market, stakeholder attempt to ensure their pre-ferred level of stringency through influencing political decision makers. In most cases, the equilibrium stringency will require pollution abatement levels that can be met with best available technology (BAT) or predictable ad-vances over BAT. Accordingly, net benefits from environmental regulation as claimed by a 'strong version' of the 'Porter Hypothesis' are unlikely to emerge. On the other hand, competitiveness is equally unlikely to suffer. How-ever, compliance may impose disproportionate costs on technological laggards. The argument is illustrated with evidence from a study on the techno-economic consequences of Austrian VOC emission standards.

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I. Introduction

In 1991, in a brief essay in the 'Scientific American', Michael Porter advanced a provocative hypothesis which has ever since fuelled a heated debate among environmental economists (e.g. Ayres 1994; Jaffe *et al.* 1995; Palmer *et al.* 1995; Porter/van der Linde 1995 a, b; Jaffe/Palmer 1997; Xepapadeas/de Zeeuw 1999, Sinclair-Desgagné 1999). Building upon earlier work by Ashford *et al.* (1979, 1985), Porter (1991) advanced the hypothesis that properly structured environmental regulation might not only benefit the environment and thus society at large but also the regulated industries by stimulating innovation. This would give rise to a win-win situation in which the traditional trade-off between environmental quality and competitiveness could be overcome. Unsurprisingly, the possibility that environmental regulation might boost competitiveness through innovation has attracted great interest in parts of the policy-making community (cf. most notably Gore 1992).

Since Porter's argument is at odds with conventional wisdom in environmental economics, numerous subsequent studies have attempted to shed more light on the murky relationship between environmental regulation, subsequent behaviour of the regulated industries and its impact on competitiveness (e.g. Stewart 1993, Jaffe *et al.* 1995, Albrecht 1998, Newell *et al.* 1998). Empirical results are inconclusive. While there is some anecdotal that supports Porter's argument, more systematic econometric studies have failed to produce unequivocal results (cf. Jaffe *et al.* 1995, pp. 157-58). One striking result of these empirical investigations, however, is the fact that costs of compliance are typically very low compared to overall production costs (Stewart 1993, p. 2105, Jaffe *et al.* 1995, p. 158).

These findings may have important implications for the discussion on the 'Porter Hypothesis'. Both proponents and opponents assume that environmental regulation imposes a substantial constraint, i.e. assume environmental regulation to be stringent. In both cases, this should be reflected in substantial gross cost of compliance[1]. Empirical evidence, however, suggests this to be rather an exception than the rule. Why is this so and what does it imply for the techno-economic consequences of environmental regulation?

In this paper, a conceptual framework will be outlined to analyse how the stringency of actual environmental regulation is determined. The starting point will be the metaphor of a 'political market', in which the stringency of environmental regulation is the outcome of an interaction between suppliers and demanders of environmental regulation. This will permit to draw some tentative conclusions as to the technological and economic consequences of environmental regulation. The relevance of these will be illustrated with empirical evidence on the techno-economic consequences of three Austrian VOC (Volatile Organic Compounds) emission standards.

The remainder of this paper is organised as follows. In the next section, the 'Porter Hypothesis', some empirical evidence and its main assumption is discussed. This is followed by a description and qualitative analysis of the 'political market of environmental regulation'. Section four is devoted to the discussion of some key features of technological advance and the expected technological consequences of environmental regulation. In section five, the empirical evidence is presented. Finally, section six concludes the paper by discussing the implications of the findings for the 'Porter Hypothesis' and by making some suggestions for future research.

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1 Cost of compliance usually only measure expenditures due to regulation without considering possible benefits, such as more productive natural resources, which would have to be included in a proper estimate of the net cost of compliance.

II. The 'Porter Hypothesis' revisited

According to traditional economic theory, environmental regulation imposes private costs of compliance but may yield social benefits. At the level of the compliant firm, environmental regulation is modelled as a constraint in a static maximisation problem. Since adding a constraint to a maximisation problem cannot improve the outcome, it is argued that environmental regulation necessarily imposes private costs (cf. Palmer *et al.* 1995). When also considering the benefits that accrue to society through improved environmental quality, the overall effect, however, may be positive. For example, Repetto (1990) found that the total productivity of electric utilities had actually increased by an annual 0.68% for the period from 1970 to 1991, when also considering dollar values for environmental benefits derived from previous empirical studies, and not fallen by an annual 0.35% as indicated by measured productivity.

Porter, however, argues that the posited conflict between environmental and economic goals at the level of the individual firm results from a static view of environmental regulation. If one drops the *ceteris paribus* assumption on technology, products, processes and customers and acknowledges that a response to environmental regulation may change all these variables, the result may be dynamic competitive advantage. From a dynamic perspective, environmental regulation may actually 'trigger innovation that may partly or more than fully offset the costs [of compliance]' (Porter/van der Linde 1995b, p. 98).

Firms may benefit in two ways from environmental regulation. First, by being forced to try harder, firms may discover ways to reduce their production costs through increased 'resource efficiency' since pollution is frequently 'a form of economic waste' (Porter/van der Linde 1995a, p. 122). Second, environmental regulation may increase turnover and profits through creating markets for cleaner products and processes. This effect may be reinforced by a first-mover advantage if other countries subsequently introduce similar regulation.

The fact that environmental regulation may create markets for green technology and green products is uncontested (e.g. Jaffe *et al.* 1995). However, if 'green' firms benefit, 'dirty' firms should lose. Also, nobody denies that domestic firms may benefit from a first-mover advantage if domestic environmental regulation happens to precede the development in other countries (for empirical evidence see e.g. Bonifant 1994, Köppl/Pichl 1997, ELI 1999). But as a *first-mover* advantage can by definition only accrue to the first mover, the impact of this effect is naturally bounded.

Thus, the main sticking point in the debate is Porter's assertion that environmental regulation may *systematically* confer *private* benefits on the regulated industries by stimulating efforts to increase resource efficiency and to generate cleaner products and processes. Under standard economic assumptions, this may only be true if either firms systematically fail to exploit all profitable investment opportunities or if there is some sort of externality (cf. e.g. Palmer *et al.* 1995, Sinclair-Desgagné 1999, Xepapadeas/de Zeeuw 1999).

Porter and others cite a number of cases to back up their argument. Frequently quoted examples in the literature include the development of a substitute by DuPont in response to the phase out of ozone depleting CFCs (e.g. Albrecht 1998), 3M's Pollution Prevention Pays (3P) program (Smart 1992) or the 'energy contest' at the Louisiana Division of Dow Chemicals Co. in the US (Ayres 1994). Further evidence can be found for example on EPA's homepage under 'Pollution Prevention Success Stories' (http://www.epa.gov/ps/p2case.htm).

More systematic econometric tests of the issues addressed by the 'Porter Hypothesis' have either tried to find a relationship between environmental regulation and some measure of innovation or they have attempted to establish a link between environmental regulation and competitiveness. Examples of the first category find that compliance expenditures have a positive, albeit small effect on R&D expenditures by the regulated industry (Jaffe/Palmer 1997) and that regulatory compliance costs have a positive impact on patenting of environmental technologies (Lanjouw/Mody 1996). Examples of the second category yield inconclusive results. Two fairly recent, exhaustive reviews of this large literature (Stewart 1993, Jaffe *et al.* 1995) conclude that studies estimating the impact of environmental regulation on aggregate productivity, net-exports, overall trade flows, and plant-location decisions produced results that were either small, statistically insignificant or not robust to tests of model specification.

In other words, systematic empirical estimates could neither establish the negative relationship between environmental regulation and competitiveness that would be expected from standard economic reasoning, nor could they find the positive relationship claimed by Porter and others. Possible explanations for this somewhat surprising result include the following. First, existing data is severely limited in its ability to measure the relative stringency of regulation, which hampers comparative analyses. Second, international differences in regulatory stringency are usually not very pronounced. Third, the effectiveness of enforcement efforts is hard to measure. Finally, except for the most heavily regulated industries, the costs of complying with environmental regulation represent only a small fraction of total production costs (Stewart 1993, pp. 2105-06; Jaffe *et al.* 1995, pp. 158-59).

The last point may have far-reaching consequences for the debate. If reported costs of compliance are typically rather low, actual environmental regulation does not appear to impose a significant constraint. Yet both possible positive or adverse effects of environmental regulation on innovation and hence competitiveness critically hinge on the assumption that environmental regulation significantly constrains firm behaviour. Only if firms cannot comply at relatively low cost will the resulting costs of adjustment either hit their competitiveness, as standard economic theory would predict, or let them discover previously overlooked investment opportunities, as proponents of the 'Porter Hypothesis' assert.

Consequently, an enquiry into the process how the stringency of an environmental regulation is determined seems warranted. Under what circumstances will environmental regulation be stringent? How stringent can actual environmental regulation be? What does this imply for the techno-economic consequences of environmental regulation? The next two sections are devoted to a discussion of these issues.

III. The political negotiation of environmental regulation

The usual intellectual starting point for dealing with environmental regulation is welfare economics. Environmental pollution is an example of a negative externality that prevents the economic system from attaining the state of Pareto-optimality. So as to ensure a Pareto-optimal outcome, some sort of institutional solution – usually state intervention – must be found which curbs a polluting activity at a level where the marginal social benefits from that polluting activity equal its marginal social costs. Unfortunately, this textbook situation hardly ever occurs in real-world settings as both benefit and cost curves are subject to considerable uncertainty. This is such a trivial and well-known observation that usually not much is made of it.

One way to get around the problem is simply to assume the pollution abatement target to enter any economic problem as an exogenous constant (cf. seminally Baumol/Oates 1971). However, such a strategy leads to a rather odd separation between the behaviour of individuals in the market place, where institutional constraints are given, and their behaviour in the policy arena, where these institutional constraints are established and shaped (Majone 1976). Accordingly, so as to understand the regulatory process and its outcomes, it is necessary to deal with it explicitly.

Given incomplete knowledge about both costs and benefits of an environmental regulation, policy makers must involve other actors to obtain necessary information and to negotiate a feasible solution. A fruitful way to conceptualise this process is through the metaphor of a 'political market' which has frequently been used in the economic literature on 'public choice' and has also been employed in the context of policy instrument choice in recent years (cf. Hahn 1990, Boyer/Laffont 1999, Keohane *et al.* 1999). This market is composed of a number of self-interested participants who trade a commodity, namely their desired kind of environmental regulation, and pay for it by political support. Consequently, the subsequent analysis only applies to situations where politicians decide on environmental policy interventions.

Figure 1: The Political Market for Environmental Regulation

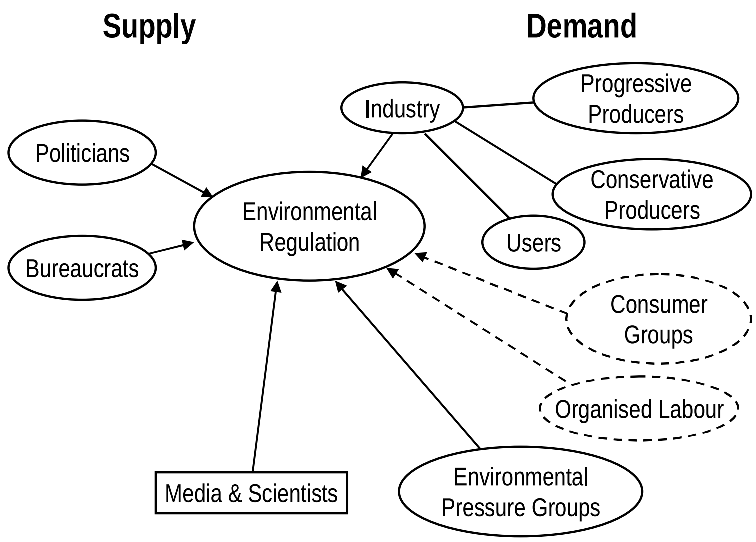

Figure 1 depicts potential stakeholders in this market in a schematic way. Solid lines indicate expected participation, while dotted lines stand for possible, but unlikely involvement. As indicated by the differently shaped frame, the media and scientists hold a special position in this framework for reasons explained below. On the supply side, there are politicians and bureaucrats. Bureaucrats devise and implement environmental regulations while politicians adopt them. The demand side consists of firms, environmentalists, and possibly organised labour and consumer groups, all of whom demand different kinds of environmental regulation. Before attention can be focused on the expected outcome of the interaction process, the characteristics and motivations of the different actors need to be examined in greater detail.

Supply of environmental regulation

Only elected politicians can adopt environmental regulation, for they alone have the power to legislate in democratic societies. Politicians derive utility from holding office, e.g. because it enables them to make policy, further the causes of their country or constituency, satisfy their ideological beliefs, enjoy the prestige and perquisites of office, etc., all of which they can only enjoy as long as they are (re)elected. To be elected, politicians need electoral support. However, electoral support does not come for free, which is why politicians also need funding to set up and maintain the necessary political machinery, finance election campaigns, and so on.

Designing an environmental regulation is a time-consuming task (for example, in Austria the minimum period is about one year) that requires a lot of detailed information. Lacking both, politicians delegate this task to specialised bureaucrats. A bureau is essentially a non-profit organisation, financed by a periodic appropriation or grant, in exchange for which it produces some expected output (Niskanen 1994, p. 271). Consequently, bureaucrats in charge of environmental protection will try to protect the environment and design environmental regulations, not only on politicians' request but also on their own initiative. For two sets of reasons, bureaucrats are expected to favour significant pollution abatement[2]. First, stringent regulations may allow them to enhance their status, influence, etc. Second, bureaucrats are highly risk-avers, as the only serious threat to a bureau is a crisis or a scandal, and will therefore actively try to draw up rules to 'cover their flanks' in all contingencies (cf. Wilson 1980).

Lacking knowledge, time, and resources, politicians are unable to fully monitor bureaucrats, which provides the latter with some discretion to pursue their private goals, especially through their ability to selectively pass on information and define the agenda and scope of a regulatory project. Thus, although politicians may reject a draft regulation, any amendments will be based on the drafts they receive from bureaucrats.

Demand for environmental regulation

Of course, actors do not demand regulation as such, they demand certain effects of regulation (Needham 1983, p. 19). Therefore, each demander will attempt to shape environmental regulation in a way that matches his or her preferences. In other words, some agents will demand a lot of pollution abatement, and other agents will demand less or even none. Demand may originate from two sources, firms and individuals. Individuals may be categorised as 'environmentalists', 'consumers', or 'workers', to the extent that they are affected by the environmental regulation's impact on environmental quality and human health, the prices of goods and services, and demand for labour, respectively. Clearly, individuals may fall in more than one category or switch roles depending on the situation and context.

Single agents will rarely command sufficient political support to become a stakeholder in the political arena. For this reason, and since building political support is costly, firms and individuals will generally have to team up and form interest groups to influence the policy process. However, since environmental regulation is usually a public good[3], any individual or firm will only receive a small share of the rewards for a direct lobbying effort which introduces a potential free-riding problem that limits the size of interest groups (cf. Olson 1965). Unless membership is compulsory, any interest group must offer its members sufficient benefits to make membership worthwhile. Involvement in the policy design process is then determined by comparing expected marginal benefits to expected marginal costs of lobbying.

Firms can be expected to have less difficulties in organising than individuals as expected benefits from lobbying are more narrowly distributed which increases the incentive to spend resources on attaining them. Furthermore, membership is usually smaller, making individual contributions more significant. Also, firms tend to have more resources which may render even substantial contributions negligible. Conversely, citizen groups are much harder to organise, since benefits are widely spread, individual

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[2] Assuming a single type of bureaucratic behaviour is a gross simplification. More accurately, the behaviour described in this paragraph only applies to bureaucrats who spend their whole career in the bureau. If they pursue careers outside bureau either in politics or in industry, they will try not to displease these groups which may modify their behaviour (cf. Wilson 1980, p. 374).

[3] Regulation need not necessarily be non-exclusive. Loopholes, narrow clauses or special exemptions may provide sufficient incentive for some individuals to lobby on their own (cf. Keohane *et al.* 1999, p. 331).

contributions are much smaller and the necessary number of members to attain critical mass tends to be much bigger. Lacking a compelling moral mission that may help environmental pressure groups to overcome the associated free-riding problem, consumer groups and organised labour will therefore find it difficult to take up a role in the policy process.

These arguments suggest that among citizen groups, only environmental pressure groups should be expected to be significant demanders of environmental regulation. Industry organisations, on the other hand, will certainly be involved in the negotiation process, both for the above reasons and because firms hold more accurate information on the true costs of pollution abatement which renders their participation indispensable. As a result, industry organisations are very likely to be over-represented in the negotiation process relative to other demanders of environmental regulations (cf. Keohane *et al.* 1998, pp. 331-33).

What kind of environmental regulation will these two groups of actors demand? Since environmental advocacy groups are commonly funded through membership fees and contributions, they will demand highly visible and hence substantial pollution reduction. Similarly, firms will also try to benefit from environmental regulation or at least avoid any negative impact on their competitiveness. Thus, unless there is an overriding positive effect, firms will strive to avoid costly pollution abatement that would force them to change their standard operating procedures by pointing to substantial compliance costs. But what could be such an overriding positive effect, or more generally, how can firms benefit from environmental regulation? Here are a few examples.

First, environmental regulation favours producers of 'green' products, technologies or services over producers of 'dirty' products, technologies or services. In this respect, environmental regulation almost inevitably produces winners or losers. Therefore, firms from the former group may favour regulation that increases demand for their 'green' products, technologies, or services. Thus, these firms may favour strict environmental regulation to increase the market for their output. Second, not all firms operate at or nearby the production possibility frontier. Assuming that 'progressive firms' which operate in the vicinity of this frontier have greater skills and competencies than 'conservative firms' which lag behind, the former group may expect to benefit relative to the latter from an external shock. Third, incumbent firms may take advantage of environmental regulation to raise barriers to entry. Fourth, environmental regulation may work as a non-tariff trade barrier. In this case, domestic firms may try to influence domestic environmental regulation in a way that it favours them over their foreign rivals.

Thus, in any of the four cases, some firms may attempt to use environmental regulation to create new markets or to restrain competition in existing markets. In the latter three cases, this may even imply that they are willing to accept costly policy interventions as long as their rivals are hurt even more. Thus, industry is essentially in a cartel situation where some firms may have an incentive to defect and disclose information to policy makers that compliance is less costly than claimed by industry's 'official' line. Whether defection will indeed occur then depends on the remaining firms' ability to sanction potential defectors. Actual sanctioning mechanisms will have to be established on a case by case basis, but one generalisable mechanism found to be relevant in the author's work on Austrian environmental regulation was pressure exerted by customers of potential defectors who were vehemently opposed to using inferior products that would have been a consequence of very strict environmental regulation.

Scientists and the media stand apart from all other actors in this framework, in that both are crucial in building up pressure for public intervention, but *a priori* hold no stake in the negotiation process. Scientific findings trigger public perception of an environmental problem, if the media pick up the issue and a societal communication processes commences (cf. Luhmann 1989). However, while environmental risks make excellent headlines to maximise circulation or audience in order to attract advertising money[4], the actual details of a policy intervention are usually far too specific to appeal to the general public. Hence, media attention is expected to wane once an impression can be created that 'something is done about the issue'.

Of course, if either group of actors chooses to pursue its private agenda as 'environmentalist', 'consumer', or 'worker', it may become important demanders of environmental regulation. Given that knowledge about environmental problems is usually incomplete, scientific expert advice is required at all stages of the environmental regulation process. This provides scientists with substantial scope for shaping the stakeholders' perception of the issue. Similarly, the media command substantial power over public opinion and may try to influence the negotiation process through this mechanism. Although these are fascinating and to the author's knowledge entirely unexplored issues in the economics literature, an analysis would go beyond the scope of this paper.

Matching supply with demand

Designing and adopting an environmental regulation is a costly process. Given limited resources, politicians will only devote their scarce attention and time to an environmental problem if there is sufficient political demand for a policy intervention. In this context, it is useful to distinguish two categories of environmental hazards. Hazards of the former category are so dangerous that the only appropriate response is an immediate ban, irrespective of any adjustment costs that this might impose. Hazards of the latter category are characterised by a rather imprecise knowledge about the risks that they might pose at some future date. However, examples from the former category are more appropriately referred to as health or safety hazards for they pose a direct and immediate threat to human health, and typically occur e.g. in the pharmaceutical industry. The only 'environmental' example the author can think of is the emission of TCDD (dioxin) that may result from overheating in the production of trichloro phenol. Typical 'environmental hazards', such as the emission of NO_x, CO_2, VOCs, or CFCs, rather fall in the second category. For such hazards, the desired amount of pollution abatement is determined in a political negotiation process in which politicians match supply and demand for different amounts of pollution abatement.

In this process, politicians need to consider the interests of voters. Some voters may be primarily concerned with environmental quality, while other voters may not bother at all and only care about their material well-being. The majority of voters, however, is assumed to care about both. For the kind of environmental hazards defined above, these voters will demand and support pollution abatement provided that it does not significantly reduce their material wealth. However, politicians do not need support from all voters. In democratic societies, holding office only requires a certain, institutionally defined majority of votes[5]. Moreover, most voters tend to be myopic and rather poorly informed, which allows politicians to pursue private goals, i.e. their own ideological preferences and the goals of special interests to the extent that these are able to wield political support, e.g. through influencing and mobilising the electorate, financial contributions, and lobbying. The relative importance of either of these mechanisms depends on the institutional framework. For example, while campaign contributions are crucial in the US, they only play a minor role in many European countries where political parties are publicly funded.

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4 Even publicly funded media that do not rely on advertising money for funding must care about circulation or audience to justify public support.

5 In fact, in political systems with majority voting, politicians or political parties may not even require majority support. They only need to have sufficient support to hold the balance of power which ensures that no coalition can be formed without them.

In choosing an equilibrium quantity of pollution abatement, politicians thus maximise a composite utility function which comprises the utility of the relevant constituencies and interest groups and their own. Formally, the utility *P* of a policy *x* is given by $P(x) = \mu^1 v^1(x) + \mu^2 v^2(x) + ... + \mu^N v^N(x)$, where $v^i(x)$ stands for the utility function of component *i (i=1,…,N)* of P and μ^i denotes its 'political influence weight' (cf. van Winden 1999, pp. 10-14). The solution to this problem thus depends on a) the size of each $v^i(x)$, and b) the size of each μ^i. Realistically, at least some of the $v^i(x)$ will interdepend. For example, while firms will generally try to oppose costly pollution abatement, pressure from environmentalists may affect this stance.

To make the decision problem even more complicated, politicians only know about their own utility while they cannot fully assess the other players' utility in this framework. They do know that marginal political benefits of an intervention increase with the visibility and danger of an environmental problem while marginal costs increase with the number of jobs that might be lost in the future. However, they do not know about the exact size of either effect and must therefore base their decision on the information they receive from interest groups, mostly via bureaucrats (which may bias the outcome towards higher stringency).

In particular, politicians need to consult with industry (representatives) on the consequences of a pollution reduction on profits and employment. Thus, politicians need to assess by how much pollution can be reduced without forcing firms to discontinue domestic operation (i.e. either relocate to a country with lower environmental standards or go out of business), both because industry commands considerable power in the political arena (because of its superior ability to organise, industry's political influence weight μ is bigger than all other μ^i), and because typical environmental hazards are too uncertain to warrant any sizeable job losses.

The ultimately prescribed amount of pollution reduction crucially depends on the information policymakers receive from firms about the costs of pollution abatement. This can only be estimated on the basis of existing technology or predictable improvements of existing technology, since no information exists about technology that is not yet available. Unless pollution abatement is exceptionally inexpensive, the most likely outcome under these circumstances is environmental regulation that will require some pollution abatement to satisfy environmentalists and prove to the electorate that 'something was done about the problem' but that can *certainly* be attained by the large majority of affected firms without significant harmful economic consequences, including no sizeable negative impact on competitiveness. Other outcomes are possible, but less likely, as they would require special configurations, such as exceptionally high public pressure (which was ruled out above for typical environmental problems), an exceptionally radical anti-business stance among politicians and/or bureaucrats, or policymakers completely captured by firms that expect to benefit from a stricter environmental regulation.

IV. Environmental regulation and technological advance

What do these observations imply for the expected technological consequences of environmental regulation? To answer this question, it is necessary to establish some stylised features of technological advance. Although technologies are incredibly diverse and different technologies are governed by totally different physical and/or chemical principles, decades of research on the economics of innovation of technological change have revealed a few important regularities.

First, although technologies are surprisingly malleable and do respond to external changes such as relative factor prices (cf. Newell *et al.* 1999), they are nowhere as malleable to fit standard micro-economic models. Thus, if environmental considerations dictate certain performance characteristics of a technology, there is a very good chance that these will be met at some point in the future. However, when this will be and how these requirements will be achieved is uncertain.

Second, technological advance can be pictured as an evolutionary process punctuated by periods of discontinuous change (cf. Anderson/Tushman 1990). Extended periods of stable, incremental advance are interrupted by rare and unpredictable discontinuities, which introduce massive uncertainty. These technological breakthroughs trigger a period of technological experimentation or ferment, in which competing designs vie for dominance, both because the potentials of the technology are ill-understood and because the ultimate, optimal shape to meet eventual demand is not yet clear. As more and more experience is acquired, the competing design configurations tend to converge to a 'dominant design' (Abernathy/Utterback 1978). The emergence of a 'dominant design' ends the period of ferment and ushers in a period of incremental improvements within the dominant architecture. This period is characterised by fairly stable patterns of change along so-called 'technological trajectories' (Dosi 1982, p. 152), i.e. the economic and technological trade-offs defined by the design configuration and the way how scientists and engineers view the technology and its potentials for development. Consequently, incremental change within the dominant architecture is much easier to predict than discontinuous change.

Third, technological discontinuities introduce order-of-magnitude improvements in terms of cost, performance and/or quality over existing technology. These are the radical innovations so vividly described by Schumpeter as the innovations that 'strike not at the margins of the profits and the outputs of existing firms, but at their foundations and very lives' (Schumpeter 1942, p. 84). In contrast, although there is disagreement in the literature on this point (cf. Anderson/Tushman 1990, p. 618), cumulative technological performance improvement is much smaller during periods of continuous, incremental change.

Fourth, technological innovation requires appropriate knowledge. Innovations are commonly defined as new or novel combinations of existing knowledge. However, firms are heterogeneous both in terms of their knowledge base and their ability to generate innovations. Thus, while most firms can be expected to master modest improvements, more radical improvements may exceed the abilities of some or most firms.

Fifth, developing a new technology takes time. Although development can be speeded up by increasing R&D spending (cf. Mansfield *et al.* 1981), development will never be instantaneous. For example, the average period between the first consideration of a process-integrated pollution abatement measure and its implementation is 8-10 years in the German chemical industry (Faber *et al.* 1994, p. 60). Similarly, long-term performance tests for new corrosion protection coatings may take up to 15 years.

Above, it was argued that policymakers need to be certain that compliance with an environmental regulation does not impose major economic costs on the majority of the affected firms. The only way how policymakers can be reasonably certain about this is if compliance is technically feasible with existing technology or with predictable improvements of this technology (note only the popularity of best available technology (BAT) clauses). In terms of the language used above, this means that compliance must be feasible with existing design configurations or with foreseeable improvements within the design architecture of these configurations. The latter may require vigorous R&D efforts but improvements will have to be attainable with near certainty.

More radical change is too uncertain to serve as a basis for environmental regulation. First, nobody knows how long it will take to develop such technology. Second, nobody knows what this technology will look like and what it will imply for the structure of the industry. Tushman and Anderson (1986) draw a useful distinction between 'competence-enhancing' and 'competence-destroying' discontinuous technological advance, where the former allows incumbents to strengthen their position while the latter triggers a wave of new entrants. Given that environmental regulation is negotiated with incumbent firms, there is every reason to expect that these will try to avoid the latter situation. Third, such radical advance may go beyond the technical capabilities of some or most firms, who will therefore attempt to oppose it. In both cases, firms can point to potential job losses and expect to be heard by politicians.

Under these circumstances, the expected technological consequence of environmental regulation is at most *incremental improvements* of BAT. If 'green' technological breakthroughs occur, they are expected to do so *independently* of environmental regulation. However, once they have emerged, they may then serve as a basis for new regulation, which may have been the prime motivation for firms to develop them in the first place.

At the level of the industry, this will mean little or no technological advance on what is already technologically feasible. However, this does not mean that no change may occur. At the level of the industry, compliance may for example require the substitution of a dominant design configuration with a different design that has already been available but was not widely used. If this design comes to dominate the market, it will certainly be improved in the diffusion process, as technologies never cease to evolve as long as they are in use. The same applies if compliance only requires changes within the design configuration of the dominant design[6]. 'Natural trajectories' such as changes in the scale of production, improvement of process yields, improvement in inputs materials, improvements in product characteristics and design for market segments (Cohen 1995, p. 220) govern the evolution of every technology.

At the level of the individual firm, however, there may be a need of substantial change. All firms will have mastered the dominant design, but this need not be the case for an alternative design required for compliance. Therefore, unless environmental regulation is extremely lax, technological laggards can be expected to suffer. However, the aggregate political weight of these 'victims' must be comparatively low, otherwise they could effectively veto the environmental regulation by playing the 'job-loss card'. In the next section, some empirical evidence on the arguments in the two preceding sections shall be presented.

V. Some empirical evidence on Austrian VOC emission standards

Background information and data sources

VOCs (Volatile Organic Compounds) are highly reactive organic chemical compounds that play a major role in ground-level ozone formation. In the presence of sunlight, VOCs react with NO_x emitted e.g. by road traffic or combustion processes to form ground-level ozone. As a so-called secondary air pollutant, ground-level ozone formation cannot be directly tackled but can only be combated by reducing the emission of its main precursor substances.

In the mid- and late 1980s, ground level ozone had become a major environmental concern in Austria. This concern eventually led to the implementation of a series of three legislative measures to reduce the

6 This also covers the most frequent compliance strategy by means of end-of-pipe equipment.

use and emission of VOCs in paints, coatings, printing inks, and adhesives as well as their application in industrial production processes. The regulatory measures in question were the Solvent Ordinance, issued in 1991, on which work started in mid-1990, the amended Solvent Ordinance 1995, and the Paint Shop Ordinance, both issued in 1995.

These regulations outlawed the industrial use and sale of systems containing CFCs and benzene as of July 1, 1992, and restricted the maximum content of aromatics and organic solvents in paints, coatings, printing inks and adhesives to 5 and 10 (15) mass-percent, respectively, as of Jan 1, 1996 (safe for a number of exemptions). However, if required by foreign customers, exports were exempt from the restrictions on organic solvents. Furthermore, all users of the products in question who emitted more than a very low threshold of VOCs (2000 kg/a) were required to either switch to low-solvent or solvent-free systems or to install appropriate end-of-pipe equipment that would ensure similar abatement levels. For new installations, these requirement applied as of Jan 1, 1996. Depending on their size, existing installation had to meet slightly less restrictive emission limits as of Jan 1, 1998 and Jan 1, 2000, respectively.

Although Austria was rather a late-comer to restrict the use of VOCs (the first VOC regulations date back to the 60s in the US and the 70s in Germany), the Austrian standards were and still are by far the strictest in the world in terms of emission limits and maximum organic solvent content. Furthermore, one of the stated aims of this legislative initiative was to speed up the development and use of cleaner substitutes to solvent-based systems. For these two reasons, the standards are an excellent example to study some of the issues raised above.

By regulating both the production and the use of solvent-borne systems, the standards affect a large number of industries. Apart from the chemical industry, where the products in question are produced, the standards also apply to every industry that uses coatings, printing inks, or adhesives above a relatively small scale. In the manufacturing sector, this amounts to approximately 2,900[7] firms out of a total of 24,500[7].

In the following, some of the conjectures put forward above shall be confronted with empirical evidence drawn from official statistical sources and a survey on the techno-economic consequences of Austrian VOC emission standards on Austrian manufacturers of the products in question. The survey consisted of a series of 28 standardised interviews with R&D managers or board members of all Austrian producers of coatings, printing inks and adhesives except one. Mere trading outlets of foreign companies were not included in the investigation. Although precise figures cannot be determined, the sample covers more than 90% of revenues and employment in these industries.

The data is limited in two important respects. First, the survey only covers a comparatively small subset of affected firms[8], and is hence only representative of a very particular industry, not of all firms affected by the VOC emission standards. Second, after Austria's accession to the European Union in 1995, the

7 These numbers are derived from an *ex-ante* study based on data from 1988 by the Federal Environmental Agency (UBA 1993) which attempted to estimate the potential emission reduction from a Paint Shop ordinance. Given the poor quality of the available data, the figures should be interpreted as an upper limit subject to a considerable margin of error.

8 The original plan of the study had been to survey both producers and users of the products in question. Unfortunately, the latter part fell victim to public budget cuts that became necessary to qualify for the Euro.

classification of official data was completely overhauled which renders any comparison of data before and after that data virtually impossible[9].

The economic impact of Austrian VOC emission standards

Available data does not permit a sophisticated analysis of the economic impact of Austrian VOC emission standards. It does, however, allow to identify some very rough trends. In particular, any markedly positive or negative impact of the standards in question should show up as a clear structural break in the data.

Since 1995, data on environmental compliance costs by industry has become available, since 1997 it is published annually[10]. Table 1 reports the figures for the main industries affect by the VOC emission standards. Manufacturing and the chemical industry are listed at the bottom of the table to give a feeling for proportions. The second column displays data on environmental expenditures as a fraction of total expenditures, the third column shows environmental expenditures and investment as a share of total expenditures and investment and the fourth column reports the results for environmental investment as a fraction of total investment.

Table 1: Environmental Expenditures

	Environmental Expenditures/ Total Expenditures			Environmental Expenditures and Investment/ Total Expenditures and Investment			Environmental Investment/ Total Investment		
Industry	1995	1997	1998	1995	1997	1998	1995	1997	1998
Coatings and Printing Ink <243*>	0.39	0.40	0.40	0.63	0.65	0.69	5.08	7.35	6.48
Leather and Leather Products <19>	0.11	0.32	0.24	0.19	0.79	0.36	3.30	12.57	3.68
Wood and Wood Products (excluding furniture) <20>	0.17	0.13	0.13	0.32	0.16	0.26	2.28	0.61	2.16
Publishing, Printing and Reproduction of Recorded Media <22>	0.16	0.04	0.03	0.15	0.06	0.06	0.05	0.37	0.49
Fabricated Metal Products, Machinery and Equipment <28, 29>	0.07	0.08	0.08	0.14	0.16	0.13	1.47	1.65	1.11
Transport Equipment <34, 35>	0.10	0.09	0.09	0.23	0.31	0.29	2.93	3.93	4.56
Furniture; Manufacturing n.e.c. <36>	0.12	0.09	0.12	0.29	0.17	0.19	3.38	1.83	1.57
Construction <45>	0.07	0.06	0.06	0.08	0.07	0.07	0.37	0.25	0.21
Manufacturing <D>	0.45	0.40	0.51	0.66	0.56	0.66	4.53	3.17	3.14
Chemicals and Chemical Products <24>	0.94	1.42	1.31	1.19	1.62	1.57	5.51	4.25	5.33

Source: Statistic Austria, own calculations. * NACE categories

Two features stand out: First, compliance expenditures are generally rather low, which matches international findings. In particular, compliance expenditures are lower than in the overall manufacturing sector and considerably lower than in the total chemical industry, which throughout the world is known as one of the most heavily regulated industries. Second, precious little appears to have changed. Expect for the leather and leather products industry which reports a substantial hike both for compliance expenditures and environmental investment, compliance expenditures are flat or even declining with respect to 1995. There is greater fluctuation in the column on environmental investments, yet the trend is patchy across

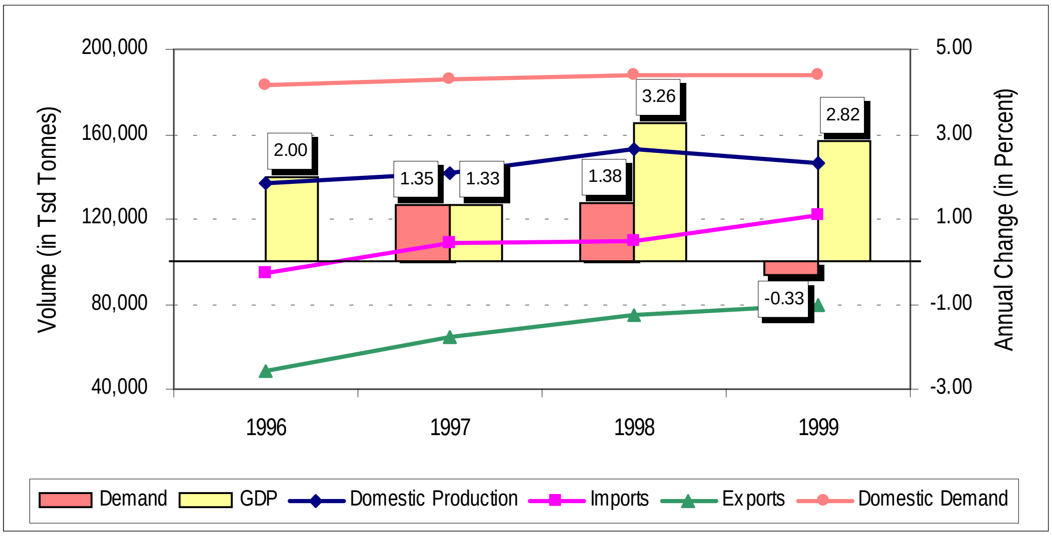
[9] Foreign trade: Before 1995, all data was recorded at the border. Since 1995 this only applies to third-country trade, while intra-EU trade is measured by a selective survey, which introduced significant adjustment problems.
Production: Before 1995, all data was organised by economic activity. Since 1995, production data follows the PRODCOM classification, which is based on technological criteria. Production volumes are only reported at the 10-digit level, many of which cannot be disclosed because of privacy requirements (less than 3 firms per category). Therefore, aggregate figures are only available for production values.

[10] Statistic Austria experienced major difficulties in the changeover after Austria's accession to the EU. Questionnaires on environmental compliance costs were sent out so late in 1995 that the next round could only be conducted in 1997.

industries. While the share of environmental investment is growing in the transport equipment industry, it is declining in furniture or the metal and machinery industries. However, any rises in environmental investment can be attributed to compliance with VOC emission standards, as these were the only significant new environmental regulations introduced at that time. VOC emission standards therefore seem to have stimulated some environmental investment. Except for the leather industry, however, the impact appears to have been modest.

Figure 2 displays further evidence on the economic impact of Austrian VOC emission standards. Two sets of effects must be distinguished. First, the standards may reduce demand for coatings, printing inks, and adhesives, as the cheapest way to reduce emissions and maintain the technological advantages of conventional systems is to increase application efficiency to reduce emissions and thereby stay below the compliance threshold[11]. Second, if the standards impose a constraint on affected firms, this should show up in the trade data. Recall that the standards apply equally to domestic and foreign firms in Austria. Moreover, exports are largely exempt from the limits imposed by the VOC standards (this exemption was only introduced after vehement lobbying by industry representatives). Thus, if the standards work as a non-tariff trade barrier, e.g. because foreign firms are unwilling to develop special products for a comparatively small market, Austrian firms should be able to win market share. On the other hand, if compliance diverts resources or if domestic firms are unable to reap economies of scale because they have to manufacture different products for the domestic market and foreign ones, exports should suffer.

Figure 2: Demand, Production, and Trade



Source: Statistic Austria, own calculations.

Data on the evolution of imports, exports, domestic production, and domestic demand (i.e. domestic production plus imports minus exports) of paints, coatings, printing inks, and adhesives in Austria (cf. Figure 2) measured by volume[12] provides some clues on both effects. Generally, demand for the prod-

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11 Conventional spraying, the simplest and most versatile application technique, has an application efficiency of < 30%.

12 As explained in footnote 9, production volumes are not directly available. However, for approximately half of the total production value, volumes are also available via PRODCOM 10-digit categories. These were used to compute weighted unit values for each year. Dividing the reported total production value by these unit values allowed to approximate actual total production volumes. Although the resulting figures are only an imperfect substitute for the true data, they are plausible in light of the interview evidence and are therefore reported.

ucts in question tends to grow roughly in line with GDP. While this was true for 1997, in 1998 and 1999 domestic demand failed to keep up with GDP growth. Thus, the VOC emission standards seem to have led to a modest slowdown in domestic demand for the regulated products, which was also reported by the surveyed producers.

There is no evidence that the standards helped Austrian firms to gain market share in Austria, as the share of imports in total domestic demand increased from about 52% in 1996 to around 65% in 1999. Assuming no re-exports, this would actually point to a loss of market share of domestic firms. On the other hand, the balance of trade in the products in question improved over the same period as exports grew substantially quicker than imports. Although all the results are blurred by the impact of Austria's accession to the EU which lowered barriers to trade, interestingly both with the EU and also with third countries (cf. Breuss 2000, p. 173), the results for this particular industry are slightly better than for the overall economy (cf. Breuss 2000, p. 175). This is particularly remarkable for 1996 (+16 vs. +12%), the year when firms should have struggled most with compliance. Similar evidence comes from the surveyed firms directly, who were asked whether VOC emission standards had had any lasting impact on their competitiveness in Austria, the EU (and EFTA), and other countries[13]. Table 2 displays the results to this question. The large majority of firms reported to have neither suffered nor benefited from the regulation in all three areas. Some firms, however, reported that their competitiveness deteriorated (10-15%) and a roughly equal number of firms declared to have gained.

Table 2: Reported Impact of VOC Emission Standards on Competitiveness

	Austria	EU/EFTA	Other Countries
unaffected	75.0%	66.7%	79.0%
deteriorated	14.3%	11.1%	10.5%
improved	10.7%	22.2%	10.5%

Source: Survey results.

To summarise, these results match the findings of other empirical studies that actual environmental regulation appears to have little economic impact, which is also the expected result if one believes that environmental regulations are politically negotiated in the way described above. Some firms may benefit and others may suffer, but the large majority will remain virtually unaffected. Is there also empirical support for the expected technological consequences of such environmental regulation?

Austrian VOC emission standards and technological change

Conventional measures of innovation and technological change include R&D expenditures and patent counts (cf. Jaffe/Palmer 1997, Lanjouw/Mody 1996). As shown in Table 3, R&D intensity (R&D expenditures as a fraction of revenues) in the surveyed industries did increase slightly (and statistically insignificantly) from 4.03% in 1990 to 5.07% in 1998. This is no unexpected result as compliance may require technological adaptations which may show up in higher R&D spending. However, so as to test the conclusions put forward above, data on the quality and the targets of this R&D is required. For this purpose, neither R&D spending nor patents are appropriate.

Table 3: R&D Intensity in the Austrian Coatings, Printing Ink, and Adhesive Industry

	Mean	Std. Dev.	Minimum	Maximum
1990	4.03	3.12	1	15
1998	5.07	3.32	2	15

13 The category 'other countries' mainly comprises reform countries from Central- and Eastern Europe. Trade with the U.S. and Asia is negligible.

Source: Survey results.

To find out about whether compliance could be attained with existing technology, firms were asked in the survey when they had started work on alternative, low-solvent or solvent-free technologies. Table 4a shows the results to this question. Responses fall more or less evenly into four categories. Roughly 30% of the firms had started with R&D in alternative technologies before 1970. About a quarter of the firms had done so before 1980. Another 22% of the firms started in the 1980s. Finally, the remaining 22% only started after 1990, of which a full half only did so in 1995. These figures indicate that more than three quarters of the interviewed firms had some experience in alternative technologies prior to 1990, i.e. before the negotiation of the first Solvent Ordinance commenced.

Table 4a: R&D in Low-Solvent Technologies

until 1970	29.6%
until 1980	25.9%
until 1990	22.2%
after 1990	22.2%
of which in 1995	11.1%

Source: Survey results.

Table 4b provides a finer breakdown of these results by displaying similar information on the different cleaner technological compliance options presently available. The most widely used option are water-borne systems which are manufactured by almost 93% of the interviewed firms. The second-most popular technology are high-solid systems which are produced by almost 52% of the firms in the sample. Radiation-curing systems are manufactured by 37% of the firms, while powder coatings are a fairly marginal technology that are manufactured by only around 7% of the firms. Development in all four technologies started long before the introduction of Austrian VOC emission standards. In water-borne systems, R&D had started as early as 1940. High-solid systems were first developed in Austria in 1955. Work on radcure systems started in 1970 and first R&D in powder-coatings occurred in 1974.

Table 4b: R&D in Low-Solvent Technologies

Quartiles	Water-Borne Systems	Powder Coatings	High Solid Systems	Radiation Curing Systems
25%	1970	1974	1978.75	1980.25
50%	1979	1977	1984	1986.5
75%	1989	1980	1991	1990.25
Minimum	1940	1974	1955	1970
Maximum	1995	1980	1994	1991
Share	92.6%	7.4%	51.9%	37.0%

Source: Survey results.

Furthermore, Table 4b displays the quartiles when 25, 50, and 75% of the firms in the sample had started to conduct R&D in the respective technologies. In all four cases, 75% of the interviewed producers of coatings, printing inks and adhesives had done so before or at the time when the first Austrian Solvent Ordinance was devised. Finally, all firms started developing cleaner alternatives to solvent-borne systems before the main restrictions imposed by the Solvent Ordinance entered into force.

The results show that all four compliance options had been known for a considerable period of time to a large majority of the affected firms. Moreover, the results show that no new technological compliance option was developed in response to the strictest VOC regulation in the world. Finally, the results show that even relative latecomers started their R&D in cleaner substitute technologies before the regulations entered into force.

However, the fact that firms conduct R&D does not convey any information on the quality or intensity of that R&D effort. Developing new technologies is very time consuming and firms tend to work on many technologies that do not necessarily have to show up in the output produced and sold (cf. Patel/Pavitt 1997). Therefore, firms were also asked how big a technological step was required to develop products that complied with the VOC emission standards. Table 5 shows how firms responded to this question.

Table 5: Technological Adaptations in Response to VOC Regulations

	Water-Borne Systems	Powder Coatings	High Solid Systems	Radiation Curing Systems
a small step	17%	-	-	-
a series of small steps	50%	-	61%	33%
a large, radical step	33%	-	31%	67%

Source: Survey results.

* The percentages express the share of answers by firms that manufacture the respective technologies.

Powder coatings did not have to be adapted for compliance, as they are non-liquid systems that do not contain any solvents. The remaining systems needed some adaptation. For the majority of firms, this involved incremental improvements ('a small step' or 'a series of small steps') over what had already been the state of the art in the respective firm. With water-borne systems, 67% of the firms could comply with incremental changes, while 33% had to make radical alterations. Similarly, 61% of the firms could comply with high-solid systems by making a series of small changes. Radcure systems stand out in that a majority of 67% had to make radical changes and only 33% of the firms could comply with incremental developments. This may be explained by the fact that radcure systems are the most recent technological option in this field and are therefore less-well explored than their rival technologies.

The numbers support the conjecture that the majority of firms will be able to comply with small adaptations. It also shows that some firms apparently had to struggle much harder. It should be noted that the results in Table 5 probably overstate the true adaptation triggered by the environmental regulations. A proper estimate of this would have to establish 'normal' technological advance in all the compliance options and then try to determine the 'supra-normal' component triggered exclusively by the need to comply with the environmental regulations. Unfortunately, this cannot be done in a survey.

VI. Conclusions and directions for further research

There is a very small literature on the technological consequences of actual environmental regulation (cf. Kemp 2000). According to these studies, the most common responses to environmental regulation are incremental innovations in process and products and the diffusion of existing technology. The present paper represents an attempt to make sense of these observations and relate them to the on-going discussion on the 'Porter Hypothesis' in environmental economics.

It is commonly assumed that actual environmental regulation imposes a substantial constraint on economic behaviour. Empirical data on the actual costs of compliance, however, appears to suggest the opposite. So as to make sense of this puzzling result, a conceptual argument was put forward according to which the stringency of actual environmental regulation is determined by the interplay of a number of self-interested stakeholders in a 'political market'. Because environmental hazards tend to be uncertain, resulting equilibrium stringency will induce some behavioural changes subject to the constraint that these do not overburden industry (cf. Verbruggen 1994). As a consequence, environmental regulation is not expected to have a sizeable negative impact on competitiveness.

With respect to technology, this implies that compliance must be technologically feasible. Technological feasibility is only guaranteed if compliance can be achieved with already existing technology or technology that is within reach of a possibly vigorous R&D effort. In other words, environmental regulation is expected to stimulate the diffusion of existing technology or at most incremental changes over BAT, *at the level of the regulated industry*. At the level of the individual firm, however, the need for change may be substantial if compliance requires the substitution of a dominant design with a new variant and the firm has no prior experience in that alternative.

How does this relate to the 'Porter Hypothesis'? This paper neither validates nor refutes the 'Porter Hypothesis'. Rather it argues that regardless of whether there is massive scope for improvement and firms only need to be alerted to this or whether there is not[14], actual environmental regulation will not force firms to look for it. Since actual environmental regulation is determined on the basis of already existing technologies or predictable improvements thereof, compliance does not require the development of entirely new technologies, which are too uncertain to serve as a basis for technically and legally feasible environmental regulation. Accordingly, whenever minor improvements within the design configuration of an existing technology permit increases in resource-efficiency (chemical processes offer plenty of examples, cf. Faber *et al.* 1994), economic and environmental goals may by co-optimised. However, since only radical innovations ensure unequivocal superiority along all dimensions, 'win-win' situations cannot be counted on as a general rule.

Empirical evidence on the impact of Austrian VOC emission standards supports these conjectures. Although these standards are the strictest of their kind in world, compliance does not seem to have been very costly and significant major impact on the affected firms in the Austrian chemical industry could be identified. A plausible explanation for this is that compliance technologies had been available for some time and a large majority of firms already had some experience with them when the regulations started to be devised. Most firms could comply with incremental improvements of these technologies. Some firms, however, had to make radical improvements.

This paper shows that the process how environmental regulation comes about is a non-trivial issue and may considerably affect the outcome of the process. In particular, both pollution abatement targets and technology do not enter the process as external constants but as endogenous variables. However, the paper is only a very preliminary step in this direction and can be extended and refined in various ways. An obvious way to refine the main conclusions of this paper is to formally model the political market delineated above. The 'composite utility function' sketched out in this paper might serve as a fruitful basis and existing models in the public choice literature might be adapted to this end. However, it is probably advisable to start with a far less complicated interaction process than the one described above.

Another route is to provide further evidence on the nature of R&D efforts in response to environmental regulation. In this paper, only producers of cleaner products could be studied. One might argue that the development of cleaner products represents one-off transition costs while the real costs are borne by the users of these products who cannot switch to superior alternatives. Therefore, studies on these users or on environmental regulation affecting process technology may yield different results. Also, empirical patterns may be highly technology-specific. For this reason, studies of other technologies and industries at a similarly disaggregated level might produce interesting insights.

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14 Given the present state of knowledge in economics on actual firm behaviour, this is mainly a matter of faith. While standard assumptions in neo-classical economics rule out such a possibility, it is not very far-fetched from an evolutionary perspective assuming routine-based behaviour (cf. Sinclair-Desgagné 1999 for a lucid treatment of this and related issues).

Finally, it would be very instructive to empirically explore the political negotiation process that precedes environmental regulations. This should allow to validate the main claim in this paper that the stringency of environmental regulation is based on available technological options. To this end, case-study research on the emergence of environmental regulation might be a highly fruitful route to provide further evidence on the interaction processes between suppliers and demanders of environmental regulation.

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