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Explaining Green Innovation

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Abstract

While consumption and degradation of natural resources and the environment continue to grow worldwide, worries about declining competitiveness of European industry vis-à-vis US and Asian competitors persist. Against this background, the question of *what drives environmental innovation in industry and what role regulation plays in this regard* has become ever more relevant. Ten years ago Porter and van der Linde popularized the win-win proposition, stating that environmental regulation could induce innovation by making industry aware of and willing to exploit otherwise missed opportunities. This, they claimed, would result in environmental benefits *and* increased competitiveness. The Porter hypothesis has spurred a substantial amount of research on the influence of environmental regulation on innovation, but the results have so far remained inconclusive. We discuss the key problems in extant research and outline a comprehensive analytical framework for studying the effects of environmental regulation on innovation alongside firm-internal conditions and external market forces. This framework also takes into account varying opportunities for direct customer benefits across areas of environmental innovation. Very few political scientists have, thus far, ventured into this research area. Those who have have focused on the sectoral, national or systemic (international) level. To complement this research we propose to improve the micro-foundations of our understanding of environmental innovation by applying the framework outlined in this paper at the firm and innovation field level within and across firms, industries, and countries.

1. Introduction

"Financial performance and environmental performance can go hand in hand. Eco-efficiency is the key to sustainability, in both economic and ecological terms. The key to eco-efficiency is innovation and productivity improvement."

Alex Krauer, Chairman and CEO, Ciba-Geigy, Switzerland, *cited in Milmo (1995:22)*

Krauer's statement is one of countless examples of the "Porter spirit", which has emerged in the last 10-15 years in advanced industrialized countries. It reflects the belief that so called win-win opportunities could benefit industry and the environment alike. The best known heralds of such win-win opportunities are Porter and van der Linde who argued that "...properly designed environmental standards can trigger innovation that may partially or more than offset the costs of complying with them" (Porter and van der Linde, 1995b:98). Environmental regulation could, they claimed, induce innovation by making industry aware of and willing to exploit otherwise missed opportunities.

The "Porter hypothesis" has spurred substantial amounts of research on the influence of environmental regulation on innovation. While adherents of the Porter hypothesis have sought to demonstrate the empirical relevance of the win-win claim, neoclassical economists have argued that such win-win opportunities are exceptions. They have pointed to significant compliance costs of industry, competitive disadvantages of domestic firms in international markets, and opportunity costs of forced environmental activities (e.g., Jaffe et al., 1995; Palmer et al., 1995). Recent research has sought to bridge the boundaries between "traditional" economists and "revisionists" by combining assumptions from neoclassical and evolutionary economics, and by testing propositions in large-N quantitative studies (e.g., Johnstone et al., 2005)¹). But thus far the results have remained inconclusive.

The question of *what drives environmental innovation in industry and what role environmental regulation can or should play in this regard* has become ever more policy-relevant in recent years. On the one hand, worldwide consumption and degradation of natural resources and the environment has continued to grow and environmental innovations are considered an important option for mitigation or avoidance of environmental degradation. On the other hand, worries about declining competitiveness of European industry vis-à-vis American and Asian competitors persist and policy makers are seeking to reduce the regulatory burden on industry. We address this debate by developing *an empirically useful analytical framework* for studying the drivers (regulatory and other) of environmental innovation.

We argue that identifying key determinants of "green" innovation requires analysis of the effects of environmental regulation alongside market and firm-internal conditions. Presently, research on innovation, including "green" innovation, is scattered across different academic disciplines; each piece of research tends to focus on a narrow range of determinants and particular levels of analysis. Industrial organization specialists concentrate on market structure, while strategic management specialists focus primarily on firm-internal variables. Those studying the impact of environmental regulation on green innovation (most often economists, but also some political scientists) tend to sideline non-regulatory influences. We use previous work by authors such as Hemmelskamp (1999), Kemp (1997), and Klemmer, Lehr et al. (1999) as a starting point. Our contribution focuses on identifying gaps, deficiencies, and unresolved issues in extant studies and developing a framework for further research.

We locate the principal weaknesses in existing research primarily in problematic definitions / operationalizations of the dependent variable (i.e., innovation), level of analysis problems (i.e., sector / industry, firm, facility, regulated activity), and poorly understood causal effects of explanatory variables on each other and on innovation. We argue that changing the focus from the sector / industry level to the firm and innovation field level – the levels at which environmental

¹ This publication reports preliminary results from an OECD study that covers more than 4000 facilities in seven OECD countries.

innovations in fact take place - can improve our understanding of causal mechanisms. Those few political scientists who have thus far worked on issues of environmental innovation have concentrated on cross-sector and cross-country comparisons (e.g., Jaenicke et al., 2000; Jacob et al., 2005). This research has offered very useful insights into macro-level trends in this field but needs to be combined with stronger insights into the underlying micro-level processes, notably, innovation-related decisions and behavior at the firm level. To this end, our paper builds primarily on the economic and business studies literature.

The paper is organized as follows. After clarifying some definitional issues, we review the existing literature and develop an analytical framework for further research. We end by discussing how this framework could be applied in empirical research.

2. Literature Review and Analytical Framework

We begin by clarifying some definitional issues before reviewing the existing literature. *Regulation* can be defined broadly “to include the full range of legal instruments by which governing institutions, at all levels of government, impose obligations or constraints on private sector behavior. Constitutions, parliamentary laws, subordinate legislation, decrees, orders, norms, licenses, plans, codes and even some forms of administrative guidance can all be considered as regulation” (OECD, 1997a:9). Environmental regulation includes environment-related regulation that considers and impacts the environment (Kemp, 1998:14).

Environmental innovations encompass all innovations that have a beneficial effect on the environment regardless of whether this effect was the main objective of the innovation². They include process, product, and organizational innovations (OECD, 1997b). We will focus primarily on explanations of product and process innovations.

- *Organizational innovations* do not reduce environmental impacts directly, but facilitate the implementation of technical (process and product) environmental innovations in companies (Murphy and Gouldson, 2000).
- *Process innovations* are defined as improvements in the production process resulting in reduced environmental impacts, e.g., closed loops for solvents, material recycling, or filters.
- The principal environmental impact of many products stems from their use (e.g., fuel consumption and CO₂ emissions of cars) and disposal (e.g., heavy metals in batteries) rather than their production. Accordingly, *product innovations* aim at reducing environmental impacts during a product’s entire life cycle (from cradle to grave).

Environmental innovations are different from other innovations; besides producing the spillover effect typical of most R&D efforts they also produce positive externalities in and of themselves, i.e., they reduce external environmental costs of production or products. Rennings (1998:8) has called this characteristic a “double externality effect”.

The literature on the determinants of innovation is vast. Yet, most of this literature focuses on particular determinants of innovation, and only small parts of this literature focus on environmental innovation. Contemporary research on the relationship between environmental innovation and regulation is based on the assumption that technology push and market pull factors, firm internal conditions, and regulatory conditions drive the extent and form of environmental innovations. Kemp, Smith et al. (2000), for example, propose to focus on the incentives to innovate, meaning competitive pressure and market demand, the ability of firms to process and integrate knowledge, and the managerial capability to handle the innovation process within and across companies. This approach combines perspectives from evolutionary economics and environmental economics, as explained in Rennings (2000). It is used in recent “multi-dimensional” studies that take into account regulatory, market, and firm-internal conditions.

The following literature review, from which we derive a set of hypotheses, is structured along the following lines: (1) research concentrating on the impact of regulation on green innovation, (2)

2 The terms *eco-innovation* and *green innovation* are used synonymously for *environmental innovation*.

studies on market factors and how they influence green innovation, and (3) research focusing on impacts of firm-internal factors on green innovation.

2.1 Regulation

Environmental regulation is viewed in neoclassical economics as a means to force firms to internalize external costs they would otherwise impose on society. Environmental regulation is (or rather should be), therefore, implemented in cases of market failure. Though, in principle, its necessity under conditions of market failure is uncontested in environmental economics (Rennings, 1998:8), the policies to be chosen (instrument type) in particular cases and the stringency of regulation are very much subject to debate.

Traditionally, the neoclassical economic view has been that (strict) regulation has negative effects on productivity and competitiveness, as it leads to higher expenses by businesses and imposes constraints on industry behavior. Regulation can also increase uncertainty associated with future investments, so that they are postponed. Given that investment budgets are limited, enforced R&D for cleaner technology can have the effect of reduced R&D expenditure in other, more profitable areas, such as a firm's core business (Gray and Shadbegian, 1995).

In the 1990s, Porter and van der Linde popularized the claim that properly structured environmental regulation may not only benefit the environment – and hence society as a whole – but also the regulated industries by making firms realize otherwise neglected investment opportunities (1995a; Porter and van der Linde, 1995b)³. Specifically, Porter et al. argued that (strict) environmental regulation and associated compliance costs could force industry to innovate and thus increase resource efficiency and enhance productivity. They suggested that environmental regulation could also increase turnovers and profits by creating markets for environmentally improved products and technologies, and that compliance costs may be offset by the gains from these innovations, so-called innovation offsets.

Neoclassical economists have heavily criticized the “win-win” hypothesis. They have argued that regulation might motivate firms to develop eco-innovations, but that these efforts would produce opportunity costs offset only in exceptional cases (see e.g., Jaffe et al., 1995; Palmer et al., 1995). Some authors have refined Porter's argument and have offered more nuanced theoretical explanations for the existence of previously overlooked win-win opportunities that could be stimulated by regulation (see e.g., Roediger-Schluga, 2004). Applying principal-agent theory, bounded rationality, and spillover effects, Gabel and Sinclair-Desgagné (1998), Bonato and Schmutzler (2000), Schmutzler (2001) and Mohr (2002) derive possible but rare conditions under which regulation can induce innovations that fully offset compliance costs.

This theoretical controversy has motivated empirical research on a considerable scale on the relationship between regulation and green innovation. So far the empirical results have remained inconclusive. While qualitative case studies (e.g., Bonifant et al., 1995; Porter and van der Linde, 1995b; 1995a; Shrivastava, 1995) are based on rather anecdotal evidence, more systematic econometric studies have failed to produce unequivocal results (e.g., Jaffe et al., 1995). Quantitative studies in particular often use (overly) simple indicators, e.g. measuring innovation by the number of patents and R&D investment (including also non-environmental R&D). Jaffe and Palmer (1997) for instance obtain different results for the aforementioned two innovation indicators. Brunnermeier and Cohen (2003) find that increases in pollution abatement expenditure influence green innovation (measured by the number of successful environmental patent applications granted to industry), but only marginally. Using a theoretical model, Bonato and Schmutzler (2000) derive strategic (spillover effects) and organizational (principal agent problem) factors explaining why environmental regulation could stimulate cost-reducing innovations that would not have been undertaken without regulation.

Another important area of research focuses on the influence of instrument choice, notably market-based incentives versus command-and-control instruments, on technological innovation⁴. Since

³ Ashford et al. (1985) and Ashford and Heaton (1983) had made this point already in the early- to mid-1980s.

⁴ See Jaffe et al. (2004, 2002, 1997, 1995). See Jaffe et al. (2002, 2004) for a detailed review of studies on the effects of instrument choice on technological innovation.

market-based incentives provide more flexibility for economic actors, they are generally viewed as more efficient than command-and-control instruments. However, it remains unclear how and to what extent instrument choice actually affects innovation (Jaffe et al., 2004). In his comparison of instruments, Kemp (1997:317) finds that “there is no single best policy instrument to stimulate clean technology, all instruments have a role to play, depending on the context in which they are to be used”. Based on case studies, Klemmer, Lehr et al. (1999) reach the same conclusion. A recent study by Frondel, Horbach et al. (2004) shows that policy stringency is more important than policy instrument choice.⁵

Jaenicke, Blazejczak et al. (2000) observe that a combination of different policy instruments works better and propose to take into account policy style, arguing that “[a] policy style is innovation friendly if it is based on dialogue and consensus, is calculable, reliable and has continuity, is decisive, proactive and ambitious, is open and flexible...” (Jaenicke et al., 2000: 135). How these variables could be made operational for purposes of large-N research remains open (Jacob et al., 2005).

Recent research has moved the unit of analysis from the industry level to the individual firm and facility level. It also distinguishes between process and product innovations. These studies survey firms’ environmental behavior and the role played by several determinants of green innovation. They have produced plausible evidence for some firm-internal determinants of green innovation. However, effects of regulation have been observed only for environmental *process* innovation (Cleff and Rennings, 1999; Johnstone et al., 2005), but remain unclear for environmental *product* innovation. For example: a study by Hemmelskamp (1999) suggests a negative influence of regulation on environmental product innovation, whereas Rehfeld, Rennings et al. (2006) as well as Johnstone, Scapecchi et al. (2005) find positive effects and Cleff and Rennings (1999) find a positive effect solely for market-based regulation.

In other words, responding to the question of whether (strict) environmental regulation fosters or impedes environmental innovation appears to require a differentiation between process and product innovation. Most studies have failed to do so.

We submit that further research should pay particular attention to two aspects of (environmental) regulation that may have an influence on environmental innovation: *stringency* and (reliable) *predictability*. Regulation, measured in those terms, may have two types of effects on environmental innovation. On the one hand, it can push environmental innovations that have no sufficient market pull or technology push effects or were simply overlooked by a firm. By setting standards regulations can force companies to adapt products or production processes. On the other hand, regulation can promote environmental (product) innovations by establishing market incentives that promise an increase in turnovers and profits (market pull effects).

The *stringency* of regulation can be measured in terms of how much change in a given firm regulation induces. Whether stringency has a weak or strong effect on innovation at the firm level depends in part on how well the firm can adapt to external pressure. The ability to adapt may vary with firm size and market structure, how research driven the firm is, etc. For example, firms may choose to abstain from research on and development of environmentally friendly products if costs are very high and potential markets do not look promising.

→ H1: We hypothesize that the *stringency* of regulation influences environmental innovation. The direction and extent of this influence depends on market and firm-internal factors. Regulation is more likely to have a positive impact on process innovations than on product innovations.

Innovation processes usually involve substantial risks and uncertainties; the strategies concerned require a long planning horizon. Therefore, *predictability* – the degree to which future regulation and its properties can be foreseen – has a positive influence on innovation because it reduces risks and uncertainty. Predictability not only means that new regulations are announced early. Early signals of future regulation will only induce prospective action if regulators are considered to be reliable; reliability goes hand in hand with credibility (Jaenicke, 1997). This means that in assessing predictability we have to take into account at least the two dimensions: early announcements” by a “reliable” actor.

⁵ For a discussion of why it is so difficult to determine the influence of single policy instruments see Jaenicke (1997).

→ H2: We hypothesize that predictability of regulation supports environmental innovation.

2.2 Market Factors

Research in innovation economics has long centered on whether technological development (technology push) or demand factors (market pull) are more important drivers of technological innovation. Empirical research has shown both to be relevant (Pavitt, 1984). Technology push seems to be more important at the beginning of the product cycle, market opportunities seem to be more important at later stages (Mowery and Rosenberg, 1979; Freeman, 1994; Jaenicke et al., 2000). A peculiarity of environmental innovation, however, may be that market pull and technology push are comparatively weak, calling for a “regulatory push/pull effect” (Rennings, 1998:9).

Market pull includes aspects such as competitiveness (mostly considered by the industrial organization literature) and customer demand (be it the end consumer or corporate customers; mainly studied by strategic management research). Technology push includes aspects such as energy or materials efficiency and product quality.

The industrial organization literature focuses on market structure as a key determinant of innovation. Many of these studies are, in one way or another, derived from Schumpeter’s hypothesis (Schumpeter, 1942), postulating a positive influence of market concentration and firm size on innovation. Schumpeter argued that market concentration reduces market uncertainty and motivates firms to invest in R&D. Other authors argue the opposite, claiming that concentration leads to inertia and hinders innovation due to missing competitive pressure (Levin et al., 1985). Schumpeter (1939) states, furthermore, that the possibility of large firms to act in a monopolistic way increases their willingness to take risks.

Many authors have tested Schumpeter’s hypothesis, predominantly in regard to forms of innovation other than environmental. According to Acs and Audretsch (1987), large firms are more innovative in concentrated, capital-intensive markets; smaller firms have an advantage in markets that are more competitive. Their smaller size enables them to react faster to change, because of less bureaucracy, higher commitment of management, more exposure to competition, higher R&D efficiency, and niche strategies (Geschka, 1990; Rothwell and Dodgson, 1994). Levin, Cohen et al. (1985) emphasize the importance of appropriate technological opportunities and reject the influence of market concentration on innovation. Baylis et al. (1998b) and Clayton et al. (1999) argue that environmental activities go along with a higher amount of financial and human resources, which is why larger firms have better opportunities and abilities to reduce environmental impacts. Several empirical studies show that, by and large, firm size has a positive influence on environmental innovation (e.g., Cleff and Rennings, 1999; Rehfeld et al., 2006).

The strategic management and green marketing literature focuses on various market factors, but pays particular attention to market demand for green products (Meffert and Kirchgeorg, 1998; Belz, 2001). In this literature environmental product innovations are seen as a differentiation tool for firms that helps maintain/increase market share. In the 1980s and early 1990s, green consumerism, i.e., consumers’ consideration of environmental aspects in purchasing situations and their willingness to pay premiums for green products, was widely believed to emerge and gain momentum (Peattie, 2001). For example: Straughan and Roberts (1999) identify high income, high education level, liberal political orientation and, most importantly, perceived consumer effectiveness (PCE)⁶ as positive determinants of environmental attitudes and behavior (see also (Roberts, 1996; Roberts and Bacon, 1997). Yet, other studies show that consumers’ claims to prioritize green attributes have mostly not matched their actual purchasing behavior (Wong et al., 1996; Kuckartz, 1998; Prakash, 2002).

Meffert and Kirchgeorg (1998) emphasize that (public) environmental benefits need to be combined with private consumer benefits for products to be successful in the market. Examples of such customer benefits include cost savings through energy efficient appliances, improved product quality and durability, beneficial health effects, and prestige enhancement (ibid). Products that have no customer benefits additional to their environmental benefits are not likely to be favored by the

⁶ Consumers’ attitudes and responses to environmental issues are a function of their beliefs that they can positively influence the outcome of environmental problems. See Straughan and Roberts (1999).

mass-market (Villiger et al., 2000). Provision of understandable and credible information on products' environmental attributes is noted as a further success factor for green products (Wong et al., 1996; Meffert and Kirchgeorg, 1998; Reinhardt, 1998). Such efforts can be facilitated by eco-labelling schemes (Hemmelskamp and Brockmann, 1997; Prakash, 2002).

Only few studies have looked at differences between demand for environmental product and process innovations, and between corporate customers and end consumers, in respect to purchasing behavior and, therefore, influence on strategic decisions. Cleff and Rennings (1999) find that, empirically, market considerations are more important for product, and environmental regulation more important for process innovations. While a firm's visibility from a public perspective decreases with its distance from the end consumer, supply chain pressure – large firms demanding environmentally friendly behavior from their suppliers – can be an important driver (Gunningham et al., 1999). But the importance of such supply chain pressure has not been systematically analyzed and rests on anecdotal evidence, for instance from the automobile industry.

In summary, the industrial organization literature provides ambiguous evidence on the influence of market concentration on environmental innovation. The green marketing literature predicts market success primarily for environmentally improved *products* that have bundled customer benefits and / or provide credible information on their environmental quality. However, empirical studies focusing on these determinants of innovation are sparse. We submit that further research should focus particularly on *competitiveness* and *customer demand* as potential determinants of environmental innovation.

In *competitive markets* firms' principal differentiation tools are price and quality– innovations are important either to enhance efficiency (reduce costs) or to improve a product's quality. Radical innovations often imply high R&D efforts, long development time, and high risks. Large firms in concentrated markets are more likely to have the capacity for such efforts.

→ H3: We hypothesize that the more competitive a market is the more environmental innovations will occur, particularly in large firms.

Customer demand can be a strong driver of firm behavior. The most promising environmental innovations, from the perspective of firms, are those that offer a *triple* benefit: for the environment, the customer, and the producer alike. Such innovations are more likely to be *product* innovations, because in this case the *potential benefits for the customer* are clearer and easier to market.⁷ Products of this kind should offer *direct* customer benefits in addition to diffuse environmental improvement. Such direct benefits include for instance better quality, longevity, better repair, upgrade, and disposal possibilities, as well as reduced consumption costs (e.g., energy efficiency) or health impacts (depending on the industry analyzed).

Not every environmental improvement in a product holds the same potential for direct customer benefits. For instance, higher energy efficiency of products yields a clearer customer benefit than a reduction of materials – notably, if combined with higher energy prices (due to market developments or energy taxes). Also, immediate economic benefits such as higher product longevity or energy efficiency can be more attractive to customers than more hidden, long-term benefits such as a reduction in toxic substances. We denote the aspects of products that can be improved as *innovations fields*.

→ H4: We hypothesize that firms are more likely to engage in environmental innovation the higher and more obvious the *potential customer benefits* in an environmental innovation field are.

2.3 Firm-Internal Factors

The strategic management literature provides insights into firm-internal conditions and firm strategies. Theoretically, the consideration of firm-internal factors is often based on evolutionary theory and most notably the resource-based view of the firm (Nelson and Winter, 1982; Wernerfelt, 1984; Barney, 1991). The resource-based view of the firm holds that firm-internal characteristics, such as strategy, structure, and core capabilities, are important determinants of innovation

⁷ There are, of course, also non-monetary, say ideational or ideological benefits for certain customers from buying a “green” product without material benefits. But such products tend to occupy very small niche markets.

(Fagerberg et al., 2005) and important to competitive advantage. Resources are classified into tangible (e.g., financial reserves), intangible (e.g., reputation), and personnel-based (e.g., culture, training) resources. The consideration and benefits of intangible properties are particularly emphasized. Organizational capabilities to “assemble, integrate, and manage” these bundles of capabilities / resources play an important role (Russo and Fouts, 1997: 537). Collis and Montgomery note that “[r]esources cannot be evaluated in isolation, because their value is determined in the interplay with market forces” (Collis and Montgomery, 1995: 120).

Building on the resource-based view, Hart (1995) links competitive advantage to a firm’s relationship with the natural environment. The strategic implications focus on pollution prevention, product stewardship, and sustainable development. Pollution prevention can provide win-win opportunities through process innovations (resource-efficiency). Product stewardship can foster competitive advantage through product differentiation and prevention of potential regulation⁸. Russo and Fouts (1997) elaborate on this concept and postulate a positive link between firms’ environmental and economic performance based on reputation benefits from environmental performance. Sharma and Vredenburg (1998) find empirical evidence that companies develop green organizational capabilities after having adopted a proactive environmental strategy.

As regards innovation, an important asset is the general commitment to innovation. Besides showing a high commitment, R&D units are considered tools for solving organizational problems. R&D expenditure is a common proxy for and closely related to a firm’s innovation activity (Sánchez, 1997). Rehfeld, Rennings et al. (2006) find that R&D activities tend to have a positive influence on environmental product innovation. But they find no effect for process innovation.

Building on the Porter hypothesis, a considerable body of literature classifies and analyzes corporate environmental strategies and their potential for gaining competitive advantage.⁹ Most typologies differentiate between two dimensions (Meffert and Kirchgeorg, 1998): first, the timing of corporate activities in relation to regulations or public concerns; such timing is often viewed in terms of proactiveness or reactivity. Second, the scope of corporate environmental activities – usually defined as firm-internal (processes) or market-oriented (products) or both. Cleff and Rennings (1999) find significant effects on environmental *product* innovation only for the strategic goal of maintaining or increasing market share. In contrast, Rehfeld, Rennings et al. (2006) find significant effects for the goal of complying with existing / anticipated legal requirements. As regards environmental *process* innovation, Cleff and Rennings (1999), but not Rehfeld, Rennings et al. (2006), observe that legal compliance as an innovation goal has a significant effect on environmental innovation.

Some authors concentrate on organizational capabilities, particularly environmental management systems (EMS), and their influence on green innovation. The assumption is that (certified) EMS such as ISO 14’001 or its European version EMAS facilitate the introduction of environmental innovations directly by mandating companies to establish environmental goals and management structures as well as programs to achieve them (Coglianese and Nash, 2001; Johnstone, 2001); and indirectly by inducing organizational learning and providing critical environmental information (Melnyk et al., 2003). Thereby the “capacity to innovate” is enhanced (Bradford et al., 2000:10). Empirically, a positive impact of EMS on green innovation activity is observed in a recent OECD study (Johnstone et al., 2005). Melnyk, Sroufe et al. (2003) examine the impacts of certified / non-certified EMS. They find that certified EMS are associated with stronger overall environmental performance of a firms. Dyllick and Hamschmidt (2000) observe that the influence of ISO 14’001 appears to be gradually shifting from process to product innovation. When voluntary self-regulations are employed as surrogate environmental regulations, a major concern is of course that they might be employed as fig leaves because there are no impartial control mechanisms. In a quantitative analysis of data from the US EPA’s Toxic Release Inventory (TRI), King and Lenox (2000) find that particularly the larger, dirtier, and more visible firms participated in the voluntary Responsible Care program of the chemical industry. But as the authors note, it could also be that participating firms report their emissions more reliably, and therefore just appear to be dirtier.

⁸ There are some indications that the *low hanging fruits* of direct cost savings through environmental innovations have mostly been found and realized already. See Hoffman (2000).

⁹ Examples include Rugman and Verbeke (1998) and Hoffman (2000).

In summary, several studies have examined the influence of firm internal factors on environmental innovation. EMS certification appears to have a positive effect on environmental innovation, but for environmental strategy / innovation goals the results are inconclusive. Further research should focus particularly on the effects of *green capabilities*, *R&D intensity*, and *firm size*.

Green capabilities comprise a firm's attitude towards and knowledge of environmental issues relevant to its business, and procedures for acting and reacting on these issues. These capabilities as well as related structures and activities facilitate the identification of potential environmental innovations. Moreover, when forced by regulation, the acquired knowledge and procedures facilitate the development and implementation of environmental innovations to meet those requirements. *Green corporate strategies* affect whether the search for environmental opportunities is part of the main scope and a leverage instrument for competitive advantage. The implementation and advancement of an *environmental management system* generates knowledge on the firm's environmental impacts as well as procedures to mitigate them.

→ H5: We hypothesize that with growing maturity of a firm's green capabilities more environmental innovations will take place.

General *innovativeness* increases the probability that firms will also be environmentally innovative. As shown in previous studies, the R&D activity of a firm may indicate its commitment to and experience with environmental innovation. Although R&D does not automatically lead to innovations, R&D is still the most widely used strategy aiming at innovation - its importance for a firm mirrors the importance of innovation in a firm's competitive setting.

→ H6: Firms with a stronger commitment to innovation in general (R&D intensity) are more likely to engage in environmental innovation.

Larger firms tend to have more resources for R&D and environmental activities. They are also able to exploit economies of scale more easily and thus to acquire innovation benefits.

→ H7: We expect firm size to have a positive influence on green innovation.

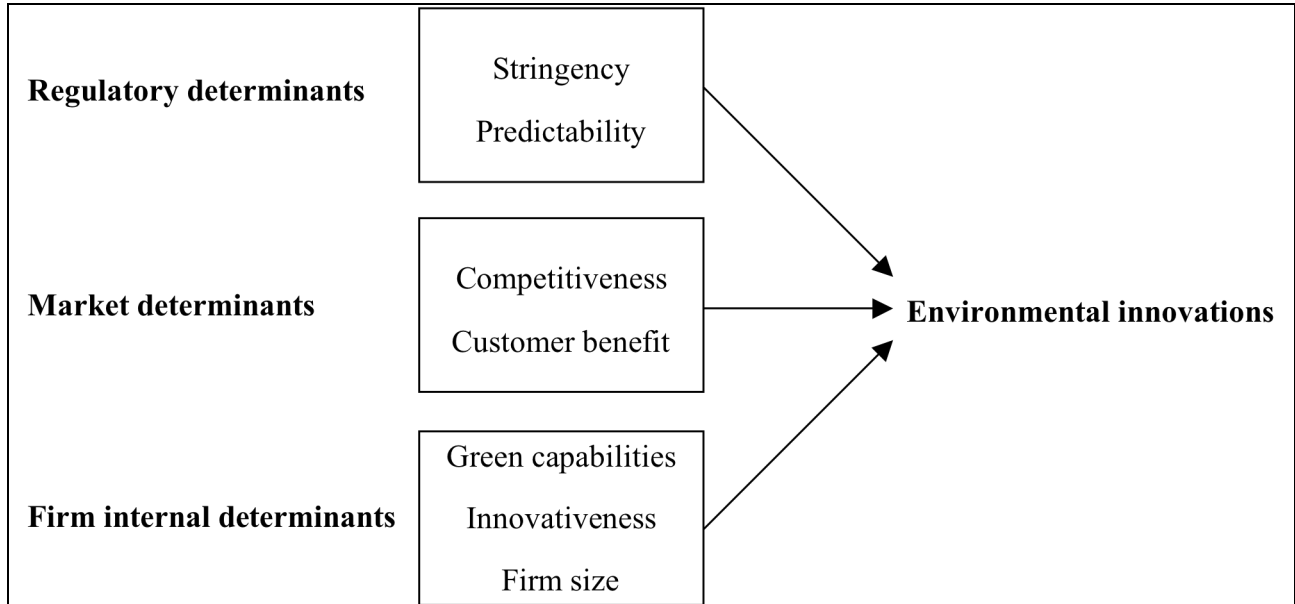


Figure 1. Framework for studying the determinants of environmental innovations

3. Empirical Application

Recent research focusing on the three types of determinants (regulation, market and firm-internal conditions) *simultaneously* has advanced our understanding of when and how these factors influence innovation activity and how they might interact. Yet, many if not most of the empirical results on the impacts of individual factors – most notably regulation – as well as on their

interacting effects have remained inconclusive or controversial. This section discusses how the analytical framework sketched above could be applied in empirical research.

3.1 Dependent Variable

Most empirical studies on environmental innovation use questionable indicators for the dependent variable. Environmental innovation is usually measured in a binary fashion (yes/no), often at the facility level, or in terms of patents or R&D expenditure. R&D expenditure does not necessarily lead to innovation, many patents do not lead to innovations, and some innovations are not patented. Also, many industry sectors cannot and/or do not patent their innovations at all.

We submit that environmental innovation should be measured in more comprehensive ways. We suggest defining the outcome to be explained in terms of the *extent* and *type* of environmental innovation as well as *environmental performance improvement* for individual innovations.

Extent of innovation: The number of environmental innovations within each field of innovation provides a much better understanding of firms' innovation activities than the simple yes/no measurement of innovation.

Type of innovation (product or process innovation): As discussed above, this distinction is necessary to disentangle the effects of potential determinants.

Environmental performance improvement: It is important to measure the environmental relevance of innovations because the ultimate question is in fact to what extent green innovations really benefit the natural environment.

3.2 Explanatory Variables

Most empirical studies to date have not systematically considered how explanatory variables may impact differently on different types of environmental innovations (notably, product and process innovations) and how they interact. Most importantly, we submit that the relevance of regulation as a trigger of environmental innovation is likely to depend on how important market demand is. It will be crucial to understand under what conditions governments establish regulation to compensate for weak market pull, and with what effect on environmental innovation and environmental performance.

Analyses of market pull factors mostly focus on market structure and fail to consider differences between innovation types and *direct customer* benefits of environmental innovations (in addition to environmental improvements). As noted above, product innovations in particular can deliver additional customer benefits (e.g., reduced maintenance costs). These benefits can constitute the firm's motivation to implement those innovations in the first place. Producer benefits, in particular cost savings through process innovations, have been considered in some studies. But these benefits / cost savings have been observed only at the firm level, even though, depending on the environmental innovation field, different kinds of process innovations may have different potentials for cost savings (e.g., increased process efficiency versus reduction of toxic emissions).

3.3 Level of Analysis

In designing empirical studies for the hypotheses outlined above we need to ascertain sufficient variation on key explanatory variables and the dependent variable (environmental innovation). In principle, such tests are possible at various levels of analysis.

Sector / industry level. At this level of analysis, the effects of changes in regulation on sector-wide environmental innovation activity can be studied over time (i.e., with panel-data). Regulation is usually designed for and applied to entire industries. It is not tailor-made for individual firms. Yet, generating comparable macro-level environmental and innovation data on industries or sectors without surveying individual firms is difficult. One option is to measure *environmental innovation* in terms of the relative improvement in environmental outcomes (e.g., emissions, concentrations of pollutants, energy and water and raw materials consumption, extent of recycling, number of organic products, EMS certification, etc.) along with economic developments of the sector and its regulation over time. Unfortunately, reliable environmental and innovation data is usually not

available for many sectors and certainly not for long periods of time. Moreover, drawing inferences in respect to firm-level decision-making and behavior from sectoral or industry-level data is vulnerable to ecological fallacies.

Firm level. Collecting data on decision-making and behavior at the firm level – the level where environmental innovation in fact occurs – allows for more direct testing of the hypotheses outlined above. It also allows for the study of such phenomena at the level of individual environmental innovations within firms. Sufficient variation on regulatory variables, arguably the most problematic aspect in focusing on the firm level, can be obtained by running comparisons of firms across industries, sectors, countries, or time. Longitudinal studies are very difficult, however, because environmental and innovation data is usually available only for a few (recent) years. Comparisons across industries, sectors, or countries require control of a plethora of other explanatory variables – controlling systematically for such influences requires sample sizes that usually exceed the resources of academic researchers. However, sufficient variation in regulatory variables can be obtained even when comparing firms within a single sector and country: the solution here is not to focus on sectoral regulation per se (which tends to vary only over time), but to concentrate on individual firms' (perceived, or actually experienced) exposure to regulation (e.g., measured in terms of compliance costs).

Innovation fields. Yet another option is to focus on certain innovation fields, i.e. the various aspects of a product or process that can be improved. Regulations are usually targeted at such particular aspects or environmental media (e.g., water or air pollution). Examples include energy use, concentration of pollutants, and prohibition or limitation of certain toxic substances in products. Data for such research will have to be generated at the firm level. Additionally, this approach provides variation on the regulatory variable even within firms, that is, the influence of different regulatory conditions can be compared with constant values for the other explanatory variables. Cross-sector and cross-country comparisons are also possible within individual innovation fields.

Only very few political scientists have thus far ventured into research on environmental innovation. They have focused on cross-sector and cross-country comparisons (e.g., Jaenicke et al., 2000; Jacob et al., 2005). Recent quantitative studies by management experts and economists have surveyed innovations at the facility level (cf. Johnstone et al., 2005), whereas the development of product innovations usually happens at the firm level. Furthermore, the simple empirical definitions of environmental innovation at the facility level cannot provide direct insights into the causal linkages between regulation and innovation – notably, the design of these studies can usually not exclude the possibility that green innovation (if reported as yes/no) is in another field than those targeted by existing environmental regulation. That is, firms may report environmental innovations and state that they experience strict regulation, but the two phenomena may be causally unrelated.

We propose to account for variation in the relevance of particular determinants not only at the firm level, but also at a *deeper level within the firm*. Regulatory frameworks and non-environmental benefits vary at the level of environmental innovation fields within firms (e.g., energy-efficient products, resource-efficient production processes). Strengthening the micro-foundations of our understanding of environmental innovation by applying the analytical framework sketched above to the firm and innovation field level within and across firms, industries, and countries is important for complementing research on environmental innovation at the sector / industry and country level.

3.4 Sample Size

The research framework outlined in this paper can easily be applied in large-N, medium-N, and small-N (qualitative case study) research at the firm- and innovation field-level. In view of the advantages and shortcomings of each of the three approaches discussed below we submit that a combination of all three approaches will be most fruitful.

The main advantage of large-N surveys, based on questionnaires administered via mail or telephone – with pure or stratified random samples of several hundred to several thousand firms – lies in the ability to use sophisticated statistical procedures for drawing broadly generalizable inferences. The main disadvantage, as evident from surveys in this field carried out to date, stems from response rates that are usually lower than 30% (sometimes no more than 10%). Since it is virtually impossible to control for selection bias with such low response rates the results are quite vulnerable

because the coefficients may be strongly biased. Moreover, large-N surveys are usually based on closed-end questions that do not generate very detailed data on the characteristics of environmental innovations, how they emerged in firms, and what their drivers were. That is, they usually do not allow for more than (albeit rigorous) testing of rather simple and static hypotheses.

Medium-N surveys – usually with sample sizes of less than one hundred firms – can obtain much higher response rates. Moreover, they are usually carried out person-to-person. This allows for open questions and collection of much more detailed data, particularly on the dynamics of environmental innovation and their drivers. The downside is the smaller number of observations and, therefore, the need to rely on simpler statistical tools (usually descriptive statistics, contingency tables, simple OLS, logit or probit regression with few explanatory variables). Surprisingly in view of its potential for contributing important insights into environmental innovation processes, research based on medium-N surveys is, thus far, very rare, probably because it is very time-consuming and less attractive to academics intent on demonstrating their statistical skills.

Comparative small-N qualitative case studies, preferably based on most similar or most different case designs (Mitchell and Bernauer, 2004), are still rare in research on the determinants of environmental innovation. The business studies literature contains many case studies, but comparison across cases (firms) is usually not very systematic. The form of reasoning and empirical analysis in those studies often consists of arguing by example or deriving “lessons learned”, rather than testing hypotheses. Carefully designed qualitative, comparative case studies can provide important insights into the processes that lead from firm-external stimuli (such as regulation or market forces) to environmental innovation. However, future research will have to engage in much more hypotheses-oriented case studies based on careful case selection as an instrument for controlling (or holding constant) variables that are of lesser theoretical interest.

4. Conclusion

What started with a simple claim has, ten years after Porter and van der Linde made the win-win proposition popular among business leaders, turned into a lively field of academic research. Economists and business studies scholars have carried out most of this research. Political scientists have only recently started to engage in this endeavor, focusing mainly on the effects of environmental regulation on innovation at the sector or national level.

Besides theoretical controversies – particularly among advocates of neoclassical, evolutionary, and ecological economics – empirical research on the effects of environmental regulation on innovation has thus far produced inconclusive and contested results. At this state of theoretical and empirical knowledge, we are unable to say whether these inconclusive findings are due to incomplete or wrong model specifications, deficient empirical definitions of key concepts, or problematic data for key variables, or whether the win-win proposition as such is fundamentally flawed (in the sense that win-win outcomes are very rare, as neoclassical economists claim).

In this paper we have argued that the jury is still out, and that systematic empirical testing requires simultaneous analysis of the effects of regulation on environmental innovation alongside firm-internal and market conditions. We have also proposed that focusing on firms and innovation fields within and across firms, industries, and jurisdictions can provide important insights into the combined effects of regulation and producer and/or consumer benefits of particular environmental innovations. Such research will take us beyond the overly simplistic focus on whether or not environmental regulation promotes or hinders environmentally beneficial innovation. It forces us to look in more sophisticated ways at the conditions under which particular kinds of regulation are more or less conducive to particular kinds of environmental innovation.

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