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Reviewing the Evidence on the Innovation Impact of the EU Emission Trading System

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Reviewing the evidence on the innovation impact of the EU Emission Trading System

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Abstract:

The Paris Climate Agreement calls for decarbonization of the economy in the second half of this century. This requires a radical redirection and acceleration of technological change towards low- and particularly zero-carbon solutions. Global carbon pricing is seen as a key enabler for such decarbonization, with the European Union's Emission Trading System (EU ETS) serving as an important pillar. In this paper, I therefore review the evidence on the innovation impact of the EU ETS. The review shows a very limited effect of the scheme on technological innovation, but there are clear signs of it having stimulated organizational innovation, with the impact being more pronounced for the electricity sector than for industry. The initially high expectations of the EU ETS regarding technological innovation largely dissipated once the scheme's lack of stringency became apparent and prices collapsed accordingly. Also, for many of the rather incremental innovations that have taken place, the EU ETS was shown to be only one contributing factor among others, with the broader policy mix and long-term targets playing a particularly pivotal role in stimulating innovation. In contrast, there is clear evidence that the EU ETS has been a key driver of various organizational innovations, including making climate change a top management issue. However, so far, these organizational innovations have only had limited effects on shifting corporate strategies towards low-carbon solutions because of low carbon prices, the relatively high share of free allocations in industry, and more pressing business concerns. Despite this, the scheme's positive impact on organizational innovations should not be underestimated, as these constitute a necessary precondition for future technological innovations. The findings suggest that the Commission's proposal for the fourth trading period of the EU ETS points in the right direction, but further efforts will be needed to significantly increase the scarcity of EU allowances and the share of auctioning in order to fully unleash the scheme's transformative power. If the identified shortcomings are not addressed, the EU ETS cannot play its foreseen role in guiding the decarbonization of the European economy, for which innovations in low-carbon solutions are a fundamental requirement.

JEL: O31, O38, Q54, Q55, Q58

Keywords: innovation, emission trading, EU ETS, climate policy, policy mix

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I. INTRODUCTION

At the international climate conference in Paris in December 2015 the political leaders of the world agreed to hold the global average temperature increase well below 2°C and to pursue efforts to limit the temperature increase to 1.5 °C.¹ Translated into global greenhouse gas emissions this implies that these should peak as soon as possible and thereafter be rapidly reduced so as to achieve the decarbonization of the economy in the second half of this century. This massive transformation calls for a radical redirection and acceleration of technological change towards low- and particularly zero-carbon solutions, which in turn necessitates policies inducing such changes. Global carbon pricing is seen as a key enabler for such a decarbonisation of the economy, and the European Union's Emission Trading System (EU ETS) as the world's largest and first multi-country greenhouse gas emission trading system may serve as pilot and starting point for implementing such carbon pricing. Therefore, in this chapter I review the empirical evidence on the innovation impact of the EU ETS, based on which I discuss the role such a cap-and-trade instrument can play in achieving a radical transformation towards a decarbonized economy.

Under the EU ETS, a certain absolute number of greenhouse gas emission allowances (EUAs) are allocated per year, where one EUA gives the right to emit one ton of CO₂e.² Operators can trade these EUAs at the market, and have to surrender the number of allowances equivalent to the amount of CO₂ emissions caused by their installations during the previous year. Ideally, such a cap-and-trade approach ensures that emissions are reduced where it is cheapest to do so, and that the market price for EUAs reflects the scarcity of allowances in the system. Eventually, the market mechanism ensures that all participants face the same marginal abatement costs so that overall reduction costs are minimized (*static efficiency*).

In addition, the EUA price also sets monetary incentives to adopt new technologies or implement new processes with lower emissions and to invest in research and development (R&D) in low-carbon technologies (*dynamic efficiency*). This direct innovation impact can be differentiated into the effect occurring at EU ETS firms and the one relevant for other actors conducting R&D on low-carbon technologies, such as technology providers, universities or research institutes. If the additional costs for CO₂ emissions are passed on and included in the product prices of EU ETS firms, emission trading may also induce indirect innovation effects on the demand side where those products are used as inputs. However, in this chapter I focus on the scheme's direct impact on innovation.

Focusing on the impact of the EU ETS on low-carbon innovation is particularly well justified in the context of long-term transformative change such as the envisioned decarbonization of the economy. Indeed, environmentally-friendly technological innova-

¹ See UNFCCC, Paris Agreement 2015.

² Carbon dioxide equivalent. For simplicity in the remainder of the chapter I will simply refer to CO₂.

tion has already early on been identified as "perhaps the single most important criterion on which to judge environmental policies" in the long haul.³ In addition, the EU Commission states as one of the major goals of the EU ETS the promotion of global innovation to act against climate change.⁴ It is therefore of utmost importance for policy evaluation studies to judge the EU ETS against this criteria.

Yet, judging the impact of the EU ETS on innovation is no straightforward exercise, as innovation is a complex and systemic phenomenon.⁵ Given the difficulties involved in measuring innovation as dynamic, interactive and uncertain process it may not come as a surprise that studies evaluating the innovation impact of a single instrument typically follow a rather linear understanding of the innovation process – often separating it in the three stages of invention, innovation and diffusion, or into innovation and diffusion.⁶ As is done in other context, studies on the innovation impact of the EU ETS utilize different input- and output-based indicators of the innovation process, such as expenditures for research and development (R&D), innovation activities, patents, or innovations. Both quantitative and qualitative as well as mixed method research designs are applied for studying the innovation impact of the EU ETS, including econometric analysis of patent data, regression analysis of company survey data, case study analysis based on interviews with company representatives, and expert interviews.

In this chapter, I follow the OECD Oslo Manual in defining innovation as “the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations”.⁷ Given the chapter’s focus on the EU ETS and climate change mitigation, I investigate findings on the impact of the EU ETS on low-carbon innovations which reduce greenhouse gas emissions. In the context of this chapter I further differentiate these into low-carbon technological and organizational innovation. The former covers both low-carbon product and process innovations, such as significant improvements in technical specifications, components and materials, or other functional characteristics, and in production and delivery methods. The latter refers to the implementation of new organizational methods, such as changes in business practices and in workplace organization which may facilitate the reduction of greenhouse gas emissions.

3 See A V. Kneese and CL Schultz, *Pollution, Prices and Public Policy* (Brookings Institute 1978).

4 See European Commission, ‘EU Action against Climate Change: EU Emissions Trading — an Open Scheme Promoting Global Innovation’ (2005).

5 See Jan Fagerberg, DC Mowery and RR Nelson, *The Oxford Handbook of Innovation* (Oxford University Press 2005).

6 See JA Schumpeter, *Capitalism, Socialism and Democracy* (Harper and Brothers 1942).

7 See p. 46 in OECD and Eurostat, ‘Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data’ (3rd edn, OECD and Eurostat 2005).

Before presenting the results of existing studies on the innovation impact of the EU ETS, in section II I will first provide an overview of the expected innovation impact of the EU ETS. In section III I will examine the empirical evidence of the impact of the EU ETS on technological innovation, and in doing so will differentiate between its three trading phases (2005-2007, 2008-12, 2013-2020). In section IV I will then present the findings on the scheme's impact on organizational innovation. In section V I conclude the chapter with some final observations on the innovation impact of the EU ETS as one instrument in the climate policy mix. I also offer some methodological recommendations for future studies and suggest implications for policy makers interested in the decarbonization of the economy.

II EXPECTED INNOVATION IMPACT

Economists have long argued for the superiority of market-based instruments, such as the EU ETS, in terms of cost efficiency and their continued provision of innovation incentives.⁸ In addition to these theoretical claims the empirical literature examining market-based environmental policies has delivered important insights into actual innovation incentives by studying the first applications of permit trading in the United States for pollutants such as SO₂, NO_x, and lead.⁹ Building on the theoretical environmental economics literature¹⁰ and empirical evidence from US trading schemes¹¹, the innovation impact of the EU ETS was expected to be rather low, at least in its first phase.¹² In addition, some early studies have estimated the potential innovation impact of the EU ETS by identifying design features that could be important in determining this effect.¹³

8 See William J Baumol and Wallace E Oates, *The Theory of Environmental Policy* (Cambridge University Press 1988); T Requate, 'Dynamic Incentives by Environmental Policy Instruments - a Survey' (2005) 54 *Ecological Economics* 175.

9 For an overview, see B Hansjürgens, *Emissions Trading for Climate Policy - U.S. and European Perspectives* (Cambridge University Press 2006).

10 See, for example, Carolyn Fischer, Ian WH Parry and William A Pizer, 'Instrument Choice for Environmental Protection When Technological Innovation Is Endogenous' (2003) 45 *Journal of Environmental Economics and Management* 523; CH Jung, K Krutilla and R Boyd, 'Incentives for Advanced Pollution Abatement Technology at the Industry Level: An Evaluation of Policy Alternatives' (1996) 30 *Journal of Environmental Economics and Management* 95; DA Malueg, 'Emission Credit Trading and the Incentive to Adopt New Pollution-Abatement Technology' (1989) 16 *Journal of Environmental Economics and Management* 52.

11 See, for example, S Kerr and RG Newell, 'Policy-Induced Technology Adoption: Evidence from the US Lead Phasedown' (2003) 51 *Journal of Industrial Economics* 317; David Popp, 'Pollution Control Innovations and the Clean Air Act of 1990.' (2003) 22 *Journal of Policy Analysis and Management* 641.

12 See Frank Gagelmann and Manuel Frondel, 'The Impact of Emission Trading on Innovation – Science Fiction or Reality?' (2005) 15 *European Environment* 203.

13 See F Gagelmann and B Hansjürgens, 'Climate Protection through Tradable Permits: The EU Proposal for a CO₂ Emissions Trading System in Europe' (2002) 12 *European Environment* 185.

This attention to the scheme's design features rests on the increasing recognition that rather than the instrument type what seems to be more influential for innovation are its design features,¹⁴ such as its stringency,¹⁵ predictability¹⁶ or flexibility¹⁷. These design features have been analyzed in detail, e.g. for the pilot phase of the EU ETS from 2005-2007 and for its second trading phase 2008-2012.¹⁸ Based on Schleich and Betz (2005) Table 1: provides a summary of those design features which may be most relevant for the innovation impact of the EU ETS: (1) the cap or emission budget, (2) the rules of banking from one period to the next, (3) the allocation method for existing installations, (4) the treatment of new entrants, including transfer rules from existing to new installations, (5) allocation rules for the closure of installations, and (6) information provided about future allocations.¹⁹

Based on an analysis of its design features for its pilot phase a limited innovation impact of the EU ETS is anticipated. This can be traced back to the scheme's lenient cap, generous links to the project-based Kyoto Mechanisms Clean Development Mechanism (CDM) and Joint Implementation (JI) which further reduce EUA prices, the prohibition of banking allowances into the second trading period and the negligible role of auctioning as an allocation mechanism. In addition, the free allocation to new entrants based on differentiated benchmarks, the termination of free allocations to closing plants as well as uncertainty about future rules are all said to weaken the scheme's expected innovation impact. However, incentives for low-carbon innovation generated by the EU ETS have improved between phase 1 and phase 2, for example through tighter emission caps and the gradual introduction of auctioning. Some of the remaining shortcomings in the

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- 14 *See* René Kemp and Serena Pontoglio, 'The Innovation Effects of Environmental Policy Instruments — A Typical Case of the Blind Men and the Elephant?' (2011) 72 *Ecological Economics* 28; Karoline S Rogge and Kristin Reichardt, 'Towards a More Comprehensive Policy Mix Conceptualization for Environmental Technological Change' (2013) S 3/2013.
- 15 *See* Nicholas A Ashford, Christine Ayers and RF Stone, 'Using Regulation to Change the Market for Innovation' (1985) 9 *Harvard Environmental Law Review* 419; Manuel Frondel, J Horbach and K Rennings, 'What Triggers Environmental Management and Innovation? Empirical Evidence for Germany' (2008) 66 *Ecological Economics* 153; Manuel Frondel, Jens Horbach and Klaus Rennings, 'End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions Across OECD Countries' (2007) 16 *Business Strategy and the Environment* 571.
- 16 *See* Jens Hamprecht, 'Regulatory Uncertainty: A Reason to Postpone Investments? Not Necessarily Volker H. Hoffmann, Thomas Trautmann and.'
- 17 *See* Ivan Hascic, Nick Johnstone and Margarita Kalamova, 'Environmental Policy Flexibility, Search and Innovation' (2009) 59 *Finance a úvěr - Szech Journal of Economics and Finance* 426.
- 18 *See* R Betz, K Rogge and J Schleich, 'EU Emissions Trading: An Early Analysis of National Allocation Plans for 2008-1012' (2006) 6 *Climate Policy* 361; Regina Betz, Wolfgang Eichhammer and Joachim; Schleich, 'Designing National Allocation Plans for EU-Emissions Trading - A First Analysis of the Outcomes' (2004) 15 *Energy & Environment* 375.
- 19 *See* Joachim Schleich and Regina Betz, 'Incentives for Energy Efficiency and Innovation in the European Emission Trading System' (2005).

scheme's design have been addressed within its third phase.²⁰ Despite these improvements several studies point out the general insufficiency of an emission trading system like the EU ETS for promoting the development of breakthrough technologies, but see its strength in achieving short-term cost minimization, e.g. by getting commercially available technologies off the shelf.²¹

Table 1: EU ETS design elements relevant for the innovation effect of the EU ETS²²

No.	Element	Innovation effect
1	Cap	The lower the total quantity of allowances allocated to installations, the higher the price, the higher the innovation incentive
2	Banking	Banking from one period to the next accelerates innovation
3	Allocation method for existing installations	Auctioning tends to have stronger innovation effects than grandfathering
4	New entrant rules, including transfer rules	Highest innovation incentive if new entrants have to buy allowances on the market; when benchmarking is used the innovation incentive is greatest for undifferentiated product-specific benchmarks because they do not limit the innovation incentive to specific sub-groups, such as certain fuels or technologies
5	Closure rules	Termination of allowances issuance within the period of plant closures results in too long operation times for old plants and postponements of new investments
6	Information about future rules	Clarity reduces investment uncertainty which is beneficial for innovation

In conclusion, the literature-based, ex-ante examinations of the potential impact of the EU ETS on innovation expect modest incentives at best, which, however, should increase in the second and third trading period, given some improvements in instrument design. However,

²⁰ See Joachim Schleich, Karoline Rogge and Regina Betz, 'Incentives for Energy Efficiency in the EU Emissions Trading Scheme' 37. For an example of the largely distortive replacement incentives generated by the allocation rules of the EU ETS for the power sector in 2008-12 see Karoline S Rogge and Christian Linden, 'Cross-Country Comparison of the Incentives of the EU Emission Trading Scheme for Replacing Existing Power Plants in 2008-12' (2010) 21 *Energy & Environment* 757.

²¹ See Björn A Sandén and Christian Azar, 'Near-Term Technology Policies for Long-Term Climate Targets — Economy Wide versus Technology Specific Approaches' (2005) 33 *Energy Policy* 1557; Christian Egenhofer and others, 'The EU Emissions Trading Scheme: Taking Stock and Looking Ahead' (2006); Cedric Philibert, 'Technology Innovation, Development and Diffusion' (2003); David Montgomery, 'Creating Technologies to Reduce Greenhouse Gas Intensity: Public Options & Opportunities' (2005).

²² Summarized from p. 1497ff. in *ibid.*

the improvements in the stringency of the emissions cap have been largely compensated by the unforeseen emissions reductions associated with the financial and economic crisis, resulting in continuously low EUA prices. Therefore, taking into consideration this additional crisis-driven lack of scarcity in EUA an even smaller innovation impact of the EU ETS is to be expected. In the following sections I review the empirical evidence on the scheme's actual innovation impact, starting by examining the impact of the EU ETS on technological innovation (section III) and then taking a closer look at its impact on organizational innovation (section IV).

II. IMPACT ON TECHNOLOGICAL INNOVATION

In this section I review the empirical evidence of the impact of the EU ETS on technological innovation. In doing so, I exclude its impact on investment in new plants or modernization of existing plants even though some of these adoption decisions may represent low carbon solutions new to the firm, which, however, most studies do not clarify. Given these blurry boundaries between innovation and diffusion, in this section I only include studies with an explicit focus on innovation. These studies use patents, R&D expenditures or introduced low-carbon product or process innovations as proxies for innovation.

a. Evidence for phase 1 (2005-07)

Early studies on the impact of the EU ETS on technological innovation draw a moderately positive picture of the scheme's incentives for low-carbon research and development (R&D). One of the earliest insight results from a survey conducted by McKinsey and Ecofys in June-September 2005 across EU Member States and across all sectors regulated by the EU ETS.²³ Based on the responses of 147 firms the study finds that more than half of the respondents (53%) claim that the EU ETS has a strong or at least medium impact on company decisions to develop innovative low-carbon technologies. In contrast, less than one fifth of respondents (16%) stated that all R&D decisions are made independently of the EU ETS and thus see no innovation impact of the EU ETS at all. The study shows striking differences across sectors, which range from all companies saying that the EU ETS has no impact at all on the development of innovative technologies (aluminum industry) to over two thirds of firms claiming a strong innovation impact (steel industry). According to this study, a positive impact of the EU ETS on technological innovation should be expected, with the strongest impact for steel (84%), refineries (60%), other ETS sectors (59%) and power generation (55%), and the weakest in chemicals (41%), pulp and paper (33%) and aluminum (0%).

This fairly positive finding of the innovation impact of the EU ETS during the pilot phase is confirmed by a large-scale cross-sectoral study specifically evaluating the innovation impact of the EU ETS in its first trading phase conducted by Borghesi et al. (2015) for the

²³ See McKinsey and Ecofys, 'Review of EU Emissions Trading Scheme: Survey Highlights' (2005).

manufacturing industry in Italy.²⁴ This study links firm-specific data on eco-innovation – aiming at energy and CO₂ reduction – of the Italian Community Innovation Survey (CIS) from 2008²⁵ with sector-specific data regarding the sector's coverage by the EU ETS – using an ETS dummy for paper and paper products, coke and refinery, ceramics and cement and metallurgy.²⁶ In addition, each of these sector's EU ETS stringency – in terms of the sector's ratio of emissions to allocated EU allowances (EUA) – is considered. On the one hand, the regression results – using the ETS dummy – show that in phase 1 ETS sectors were more likely to innovate than non-ETS sectors (n=6,483). On the other hand, for the ETS sectors (n=1,613) the study finds a statistically significant albeit negative link between ETS stringency and eco-innovation, indicating an increased likelihood to innovate in sectors with lower EU ETS stringency. One of the reasons the study provides for this surprising finding is that innovative firms may have reacted early in anticipation of the introduction of the ETS which would confirm the innovation impact of expected environmental regulation. Another reason suggested are sector specific weaknesses in adopting eco-innovations which seem to be particularly pronounced for cement and ceramic firms, and thus for sectors with high ETS stringency indicators. However, the evidence may also be due to the use of sector specific instead of firm specific data on EU ETS stringency. Therefore, the study provides mixed evidence on the innovation impact of the EU ETS. However, when only considering whether a sector is covered by the EU ETS or not, then the analysis provides clear support of a positive effect of the first phase of the EU ETS on the adoption of energy and CO₂ saving eco-innovations. Yet, the underlying data does not allow for a differentiation of technological and organization innovation.

The analysis conducted by Anderson et al. (2010) for all EU ETS sectors in Ireland provides further evidence of a positive albeit very moderate impact of the EU ETS on technological innovation.²⁷ This result is derived from a mail survey conducted with Irish EU ETS firms during the first trading phase (n=27, representing a response rate of 40%), and was supplemented with follow-up interviews with seven of the participating firms. Based on descriptive statistics and qualitative data analysis the study concludes that the introduction of a CO₂ price has increased firms' appetite for low-carbon innovation, but that the EUA price is too low, the EU ETS is too uncertain and that energy prices tend to be more im-

24 I.e., energy sectors are explicitly excluded from the analysis. *See* Simone Borghesi, Giulio Cainelli and Massimiliano Mazzanti, 'Linking Emission Trading to Environmental Innovation: Evidence from the Italian Manufacturing Industry' (2015) 44 *Research Policy* 669.

25 The eco-innovation dummy becomes 1 if a company has introduced a product, process, organizational or marketing innovation with an environmental benefit in the period 2006-2008 – the study differentiates between reduced energy use per unit of output (ECOEN) and reduced CO₂ 'footprint' (total CO₂ production) by an enterprise (ECOCO). In total, the study finds 17.6% ECOEN innovators and 14.1% ECOCO innovators (n=6,483).

26 That is, a firm must not necessarily be participating in the EU ETS, e.g. if its production is below the ETS thresholds, but it is classified as EU ETS sector if it belongs to a sector that is covered by the EU ETS. Also, note that manufacture of chemicals and chemical products is not included as EU ETS sector, nor is manufacture of machinery and equipment, thereby omitting potential effects at firms supplying production equipment for EU ETS firms.

27 *See* Barry J Anderson, Frank Convery and Corrado Di Maria, 'Technological Change and the EU ETS: The Case of Ireland. Working Paper n.43' [2010] *SSRN Electronic Journal* 1.

portant than the EU ETS.²⁸ As a matter of fact, the large majority of firms reported that the EUA price had no effect on their decision relating to machinery and equipment (74%), process change (70%) and fuel switching (78%), but that these were mainly encouraged by rising energy prices. The study concludes that in the pilot phase of the EU ETS mainly low-cost and low-risk abatement opportunities were employed, such as process changes and fuel switching. However, the study also highlights that Irish firms tend to be technology takers buying new technologies from external suppliers (92%) rather than developing them internally (8%), and thus their innovation responses may not be representative for EU ETS firms in other EU member states.

In addition to these cross-country and/or cross-sectoral studies Pontoglio (2010) provides early evidence regarding the innovation impact of the EU ETS in the Italian pulp and paper industry.²⁹ Her unit of analysis is not EU ETS firms but EU ETS plant operators of which thirty eight (of 163) participated in a survey conducted in May-June 2006. The study finds a wait-and-see strategy of operators: they addressed the typical shortage in allowances by making use of borrowing (and banking) provisions of the EU ETS. That is, most pulp and paper producers followed a conservative and cautious approach to decision making, with so far only thirteen percent of them having invested in technological innovation aimed at reducing CO₂ emissions. However, one third of respondents (35%) indicated that they were developing CO₂ and energy saving innovation projects to be implemented in subsequent years. Based on these findings and additional interviews with industry experts Pontoglio concludes that the EU ETS in its pilot phase did not or at best did only modestly encourage technological innovation.

Finally, two studies of German power generators provide in depth insights in the innovation impact of the first phase of the EU ETS, and thereby further supplement the aforementioned cross-country, cross-sectoral quantitative studies. The study by Hoffmann (2007) is based on five company case studies for which 20 interviews with senior managers of German electricity providers were conducted in March-July 2006.³⁰ It finds that in its first trading phase the EU ETS only had limited effects on R&D efforts, mainly by accelerating selected R&D activities within the fossil fuel regime. Most predominantly, the EU ETS was found to provide additional incentives for ongoing R&D projects aiming at an increase of the energy efficiency of fossil-fuel power plants. It was also shown to increase companies' interest in carbon capture and storage technologies (CCS), despite their detrimental effect on energy efficiency and the associated high regulatory and technological uncertainties. The study of Cames (2010) supports and sheds further lights on these findings of the limited innovation impact of the EU ETS in the German electricity sector by drawing on qualitative panel

28 For example, the study finds that 74% of respondents have undertaken process changes leading to a reduction of energy use and emissions, but despite being short firms claimed to be more driven by energy than EUA prices. In addition, only a small share of R&D spending is related to CO₂, and the little that is done focuses on process innovations.

29 See Serena Pontoglio, 'An Early Assessment of the Influence on Eco-Innovation of the EU Emissions Trading Scheme - Evidence from the Italian Paper Industry' in A Mazzanti, M.; Montini (ed), *Environmental Efficiency, Innovation and Economic Performance* (Routledge 2010).

30 See Volker H Hoffmann, 'EU ETS and Investment Decisions' (2007) 25 *European Management Journal* 464.

analysis among twenty German power generators.³¹ In this before-after research design interviews took place in 2004 – and thus before the start of the EU ETS – and were then repeated in 2007, i.e. 2.5 years after the scheme’s introduction. The study finds that, before the inception of the EU ETS, there were mainly organizational innovations, while hard innovations involving larger investments were postponed. But even by 2007, the EU ETS had not generated enough incentives to trigger substantial investments in R&D activities, with the exception of clean coal and particularly CCS. Cames also notes an increased interest in renewable energy technologies, as the EU ETS has enforced the perception that renewable energy will play an important role in the future electricity system.

Overall, these studies suggest a positive but moderate impact of the EU ETS on the development of low-carbon technologies which occurred across multiple sectors and different countries. Most studies also point out that the effect would have been stronger with a higher CO₂ price and lower regulatory uncertainty about the future of the EU ETS.

b. Evidence for phase 2 (2008-12)

The evidence on the impact of the EU ETS on low-carbon technological innovation in its second trading phase (2008-12) is less positive, as revealed by two cross-sectoral, cross-country studies and a few more focused sectoral studies. Calel and Dechezleprêtre (2013) provide a comprehensive analysis based on low-carbon patents (up to 2010) of 743 EU ETS firms and 1’019 non-EU ETS firm in 18 EU Member States.³² While the study finds an increase of the overall share of low-carbon patents since the introduction of the EU ETS in 2005, their more sophisticated econometric estimations – based on the combination of matching methods with difference-in-differences – suggest that the EU ETS had “virtually no impact at all on low-carbon technological change“ (p. 18). This finding is partly alleviated by Martin et al. (2011) who find mixed results regarding the innovation impact of the EU ETS.³³ Their regression analysis is based on phone interviews conducted in August-October 2009 with 800 manufacturing firms across 6 EU Member States – among them 446 ETS firms. It finds that the EU ETS in its second phase had a positive impact on the development of cleaner products, but not on cleaner production processes – using a dummy variable for measuring if a firm is part of the EU ETS or not. However, when looking at the perceived stringency of the EU ETS – measured by the amount of allowances companies receive for free in the EU ETS – the study finds the opposite result, namely that higher stringency of the firm-specific cap is associated with more clean process innovations but

31 See Martin Cames, ‘Emissions Trading and Innovation in the German Electricity Industry’ (TU Berlin 2010).

32 See Raphael Calel and Antoine Dechezleprêtre, ‘Environmental Policy and Directed Technological Change: Evidence from the European Carbon Market’ (2012).

33 See Ralf; Martin, Mirabelle; Muûls and Ulrich Wagner, ‘Carbon Markets, Carbon Prices and Innovation: Evidence from Interviews with Managers’, *Paper presented at the EAERE conference 29 June–2 July 2011* (2011).

irrelevant for product innovations. Hence, while the EU ETS may not have a measurable impact on patenting behavior of EU ETS firms, it seems to have partly influenced clean product and process innovations. However, in a comparable study based on 190 manufacturing firms in the UK – 33 of them subject to the EU ETS – interviewed in January-March 2009, Martin et al. (2012) do not find support of a positive impact of the EU ETS on low carbon product or process innovation, but only on general R&D.³⁴

The lack of evidence of a positive innovation impact of the EU ETS in its second trading phase is partly corroborated but also slightly modified in sector-specific analyses. Most of these sector-specific analyses have been performed for the electricity sector. Based on company data gathered in an online survey of electricity generators and technology providers in six EU Member States conducted in November-December 2009, i.e. just before the Copenhagen climate summit, Schmidt et al. (2012) find that the EU ETS in its first two trading phases neither had a positive impact on R&D in renewable nor in fossil fuel electricity generation technologies (n=130).³⁵ A preceding qualitative study by Rogge et al. (2011) based on in-depth interviews conducted with nineteen companies in the electricity sector from June 2008 until June 2009 had already alluded to this limited innovation impact of the EU ETS.³⁶ However, this study also shows that the innovation impact of the EU ETS varies tremendously across technologies and firms, with the largest impact occurring among the most carbon-intensive technologies and among incumbents with large-scale coal power generation technologies in their portfolios. More precisely, the study finds that the largest impact of the EU ETS on corporate R&D occurs for CCS and improvements of the energy efficiency of coal technologies. This effect appeared particularly pronounced for power generators for whom the EU ETS apparently signaled the beginning of fundamental change in their business environment to which they decided to respond, among others, with an increased engagement in CCS R&D projects with German and international technology providers and chemical industry players. The reason for this not showing up in the findings of other studies, such as in the regression results by Schmidt et al., may simply be that only a handful of large companies are involved in such R&D activities on CCS. In addition, as Rogge et al. point out, it is not only the EU ETS which has driven the increase in R&D on CCS but that other factors have played a role, as well, including the prospects of stringent long-term climate policy, debates about the introduction of performance standards for thermal power plants, public research funds, and a lack of public acceptance for coal.

34 However, the significance of this relationship vanishes when more covariates are included, which, however, could be due to the small sample size, *see* Ralf Martin and others, ‘Anatomy of a Paradox: Management Practices, Organizational Structure and Energy Efficiency’ (2012) 63 *Journal of Environmental Economics and Management* 208.

35 *See* Tobias S Schmidt and others, ‘The Effects of Climate Policy on the Rate and Direction of Innovation’ (2012) 2 *Environmental Innovation and Societal Transitions* 23.

36 The sample included 7 electricity generators, 10 technology providers, and 2 project developers, *see* Karoline S Rogge, Malte Schneider and Volker H Hoffmann, ‘The Innovation Impact of the EU Emission Trading System — Findings of Company Case Studies in the German Power Sector’ (2011) 70 *Ecological Economics* 513.

Comparable qualitative results for the pulp and paper sectors in Germany, Italy, Sweden and Norway suggest that the EU ETS in its second trading phase has not impacted technological innovation in the paper industry. Based on case study interviews and a survey of German pulp and paper producers (n=19) as well as technology providers (n=17) conducted between June 2008 and September 2009 Rogge et al. (2011) conclude that the EU ETS has hardly impacted corporate innovation activities.³⁷ Instead, market factors and here particularly the price and demand for paper have been singled out as key for innovation activities in the German pulp and paper industry. In addition, and in contrast to the electricity sector, the regulatory pull effect of the EU ETS has barely trickled down from companies regulated by the EU ETS to those providing the equipment for producing paper and pulp. Gasbarro et al. (2013) arrive at a similar conclusion on the absence of an innovation impact of the EU ETS for the Italian pulp and paper industry.³⁸ Based on interviews with six Italian companies conducted from December 2010 until March 2011 the study finds that pulp and paper producers have not undertaken any additional investment in technological innovation in response to the EU ETS. Reasons for this include, among others, low and volatile carbon prices, the EU ETS just being one of many investment factors, and long-time horizons of investments – with most recent ones having been planned prior to the introduction of the EU ETS. Finally, Gulbrandsen and Stenquist (2013) show that the EU ETS has also not triggered a search for innovative low-carbon solutions in the pulp and paper industry in Sweden and Norway.³⁹ This insight is based on interviews with one pulp and paper producer in Sweden and one in Norway and three complementary interviews conducted from June 2010 until October 2011. Taken together, this evidence allows for the conclusion that the impact of the EU ETS on technological innovation which was limited in the electricity sector is even weaker, or non-existent for the pulp and paper industry.

Empirical evidence for the link between the EU ETS and innovation for other industry sectors is limited, but the few studies that do exist confirm the existence of sectoral differences in companies' responses to environmental regulation in general, including the EU ETS.⁴⁰ One of the few studies of the innovation impact of the EU ETS in industry

³⁷ See Karoline S. Rogge and others, 'The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry' (2011) 11 *International Journal Technology, Policy and Management* 250.

³⁸ See Federica Gasbarro, Francesco Rizzi and Marco Frey, 'The Mutual Influence of Environmental Management Systems and the EU ETS: Findings for the Italian Pulp and Paper Industry' (2013) 31 *European Management Journal* 16.

³⁹ See Lars H Gulbrandsen and Christian Stenqvist, 'The Limited Effect of EU Emissions Trading on Corporate Climate Strategies: Comparison of a Swedish and a Norwegian Pulp and Paper Company' (2013) 56 *Energy Policy* 516.

⁴⁰ See Simone Borghesi and others, 'Carbon Abatement, Sector Heterogeneity and Policy Responses: Evidence on Induced Eco Innovations in the EU' (2015) 54 *Environmental Science & Policy* 377. Based on 29 interviews conducted with industry associations in eight EU Member States in June – July 2013 this study provides some evidence on the limited but varying role of the EU ETS as one of several other policy instruments on the following sectors: ceramics and cement, paper, energy, coke and refinery.

(other than in the paper industry) was conducted for the German cement industry by Schleich et al. (2010), using evidence from interviews conducted with company representatives of four cement manufacturers and four technology providers between October 2008 and July 2009.⁴¹ This study finds that the EU ETS has led to a somewhat stronger focus of R&D activities on energy, given the add-on effect of costs for allowances to energy costs. The EU ETS is also one of several factors supporting some engagement of cement producers in R&D activities on CCS. It also seems to reflect positively on ongoing research on green cement, but in general product innovations tend to be incremental and largely driven by customer demands which are not yet paying much attention to CO₂. The study also notes that the innovation impact of the EU ETS on technology providers is negligible since demand for new cement plants is largely located outside of Europe where climate policies play a much smaller role.

Overall, it can therefore be concluded that despite the improvements in the EU ETS design it did not generate any significant impact on technological innovation in its second trading phase; the only exception to this is an increased interest in R&D on carbon capture and storage technologies, particularly in the electricity sector.

c. Outlook for phase 3 (2013-20)

While there is yet no empirical study which has investigated the actual innovation impact of the EU ETS in its third trading phase, several of the studies conducted during the second trading phase also provide indications on the expected innovation impact of the EU ETS up to 2020. All of these studies suggest that the impact of the EU ETS on technological innovation is going to increase in its third phase.

In their cross-sector, cross-country study Martin et al. (2011) find no significant link between the EU ETS and technological innovation – neither for clean product nor clean process innovation – when only using a dummy variable for the EU ETS which captures whether a company expects to be subject to the EU ETS in its third trading phase or not.⁴² Similarly, firms' expectations of the CO₂ price by 2020⁴³ are not significantly related with higher levels of low-carbon innovation, i.e. higher price expectations do not seem to be associated with more clean product nor clean process innovation. In contrast, the study finds that firms expecting their future allowance allocation to be more stringent pursue more clean product innovation, and in some models also more clean process innovation. This suggests that not the price of CO₂ but rather the actual costs – rather than opportunity costs – associated with CO₂ emissions stimulate low-carbon innovation. That is, free allocation seems to disincentivize low-carbon innovation, while paying for – at least a part of – CO₂ emissions leads to more low-carbon innovation, with particularly strong evidence for clean product innovation.

41 See Joachim Schleich and others, 'Wirkungen Neuer Klimapolitischer Instrumente Auf Innovationstätigkeiten Und Marktchancen Baden-Württembergischer Unternehmen' (2010).

42 See Martin, Muûls and Wagner.

43 The median price expected for 2020 by companies was €30€, the mean €40.

For their cross-country study of the electricity sector Schmidt et al. (2012) find that firms' perceptions of the EU ETS negatively affect their R&D investments for non-emitting power generation technologies, in particular for renewable energies.⁴⁴ That is, those companies which perceive the EU ETS in its third trading phase as more negative increase their R&D in non-emitting technologies, i.e. in renewable energies. In contrast, no significant link is found for overall R&D or R&D in emitting technologies, as was already the case for the first two phases of the EU ETS. Since all power generators are required to purchase all of their allowances this implies that particularly power generators with higher emitting technologies in their portfolio are incentivized to spend more on R&D in clean technologies, suggesting a redirection of innovation activities in this sector towards low-carbon solutions.

Finally, for industry sectors, two studies on the German pulp and paper sector and the cement sector indicate that despite its so far negligible impact on technological innovation firms expect the relevance of the EU ETS for R&D to increase by 2020.⁴⁵

However, these expectations were largely resting on the assumption of rising stringency and allowance prices of the EU ETS. Yet, EUA prices have remained low, and have remained low after the landmark agreement at COP 21 in Paris. This suggests that companies do not yet believe that the global climate agreement reached in Paris will be translated into strengthening the stringency and thus the allowance prices of the EU ETS. Should these expectations turn out to be true, then future studies on the impact of the EU ETS on technological innovation in its third trading phase are unlikely to lead to results which differ significantly from the very limited effect found for its second trading phase.

III. IMPACT ON ORGANISATIONAL INNOVATION

Studying the impact of the EU ETS on organizational innovation has been somewhat neglected in the literature when compared to technological innovation, both in terms of scope of analysis and methodological rigor. First, there is no study which dedicatedly addresses the impact of the EU ETS on organizational innovation. Rather, studies either treat it as a side aspect alongside technological innovation,⁴⁶ address only selected aspects of organizational innovation – often in a non-systematic manner – or address organizational change (or elements thereof) rather than organizational innovation.⁴⁷ Second, many studies stop short

⁴⁴ See Schmidt and others.

⁴⁵ See Rogge and others, 'The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry'; Schleich and others.

⁴⁶ As a matter of fact, the evidence presented here on the impact of the EU ETS on organizational innovation largely draws on some of the studies already reviewed within the section on technological innovation, but is complemented with a few specialized studies focusing on organizational aspects only.

⁴⁷ According to the Oslo manual the difference between organizational change and organizational innovation is that the latter "has not been used before in the firm and is the result of strategic decisions taken by management", see p. 51 in OECD and Eurostat.

at identifying organizational innovation but do not investigate the role the EU ETS played for the observed changes. As a consequence, insights on the causal link between the EU ETS and observed organizational innovation remain limited. Finally, evidence is largely based on qualitative case studies based on interviews and often limited to one particular sector and country. The few quantitative studies including some selected aspects of organizational innovation only use descriptive statistics in analyzing their data, making their contribution to the evidence base rather small, at least in comparison to some of the rigorous case study analyses. Yet, despite these limitations the combination of insights of the identified studies reveals a relatively clear picture regarding a positive impact of the EU ETS on organizational innovation which in most instances has already occurred in the first trading phase.

In reviewing the evidence on the impact of the EU ETS on organizational innovation, I will structure this section according to the relevant aspects provided by the Oslo Manual's definition of organizational innovation as "the implementation of a new organizational method in the firm's business practices, workplace organisation or external relations".⁴⁸ Organizational innovations in *business practices* comprise "new methods for organising routines and procedures for the conduct of work". This component of organizational innovation is by far the most widely studied in the context of the EU ETS. It is, of course, often connected to innovations in *workplace organization* which capture "new methods for distributing responsibilities and decision making among employees for the division of work within and between firm activities (and organisational units), as well as new concepts for the structuring of activities, such as the integration of different business activities". Here, many studies allude to the role of top management in dealing with the EU ETS, but also address other structural changes. Finally, organizational innovation also includes innovations in *external relations*, i.e. "new ways of organizing relations with other firms or public institutions". While several studies find such new collaborations, integration with suppliers, outsourcing or subcontracting in the context of the EU ETS, they typically do not address this explicitly as an organizational innovation. Also, the empirical evidence suggests that EU ETS triggered innovations in business practices go along with changes in workplace organization and/or external relations. However, for analytical purposes these different aspects of organizational innovations will be discussed in turn rather than in an integrated manner.

a. Innovations in business practices

Organizational innovation in business practices covers new routines and procedures associated with the introduction of the EU ETS. Some studies refer to this as procedural change⁴⁹ and others suggest differentiating between those practices concerning physical CO₂ management and those addressing financial CO₂ management.⁵⁰ Innovations in *physical CO₂*

48 See p. 51f. in *ibid*. Note that the reviewed studies typically do not apply this standard definition of organizational innovation which complicates a systematic analysis of the findings.

49 See Rogge, Schneider and Hoffmann; Rogge and others, 'The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry'; Schleich and others.

50 See Gasbarro, Rizzi and Frey.

management cover, among others, the introduction of carbon emission monitoring, verification and reporting as well as the set up of other compliance procedures for the novel market-based instrument EU ETS. Cross-sectoral anecdotal evidence collected during the first phase of the EU ETS by Kenber et al. (2009) from nine companies located in different countries indicates that firms have significantly expanded and improved their CO₂ monitoring and cost-assessment capabilities, including the introduction of precise monitoring of CO₂ emissions and the implementation of a carbon accounts for investment decisions.⁵¹ Similarly, for Ireland an early cross-sectoral survey conducted by Anderson et al. (2010) finds that the EU ETS has led to the adoption of verifiable emissions accounting and a greater awareness of CO₂ emissions reduction possibilities in companies subject to the EU ETS.⁵² In line with these findings Sandoff and Schaad (2009) report how Swedish companies subject to the EU ETS had implemented the novel instrument in their organization.⁵³ For 2006, they find that of the multiple organizational innovations involved the measurement and verification of emissions is the most time consuming of the compliance-related activities.⁵⁴ On a more strategic level Anderson et al. (2010) report that for almost half of the Irish EU ETS firms (46%) the scheme has influenced how investments in capital and infrastructure are analyzed.⁵⁵

The most detailed account on the dynamics and scope of organizational innovation in response to the EU ETS is provided by Cames (2010) for the German electricity sector.⁵⁶ He finds that a few months prior to the introduction of the EU ETS the large majority of the interviewed twenty two power generators had already introduced CO₂ emission scenarios and about half of them had established continuous monitoring of CO₂ emissions as well as implemented a tool for comparing EU allowances and CO₂ emissions. In contrast, only few power generators had started to work with avoidance cost curves and only a minority had introduced risk management procedures. However, towards the end of the pilot phase of the EU ETS more companies had implemented

51 This is based on interviews with nine large companies based in different countries and belonging to different sectors directly or indirectly covered by the EU ETS conducted during the pilot phase of the EU ETS, *see* Mark Kenber, Oliver Haugen and Madeleine Cobb, ‘The Effects of EU Climate Legislation on Business Competitiveness : A Survey and Analysis’, vol 09 (2009).

52 *See* Anderson, Convery and Di Maria.

53 These insights are based on a web-based company survey conducted among the 221 EU ETS firms in Sweden in April – July 2006 (response rate of 52%), *see* Anders Sandoff and Gabriela Schaad, ‘Does EU ETS Lead to Emission Reductions through Trade? The Case of the Swedish Emissions Trading Sector Participants’ (2009) 37 *Energy Policy* 3967.

54 Sandhoff and Schaad (2009) found a gap between companies’ perception on the administrative efforts required due to the introduction of the EU ETS by companies and themselves. They themselves judged the labor time employed to be fairly moderate and did not see the EU ETS as raising questions regarding the administrative efficiency of the EU ETS. A similar complaint about the time and effort needed to comply with the EU ETS was reported for both the German paper and cement industry, *see* Schleich and others.

55 *See* Anderson, Convery and Di Maria.

56 Note that Cames uses the term “soft” institutional innovations, *see* Cames.

organizational innovations. For example, by 2007 all power generators had introduced a tool comparing EUA with emissions, almost all were working with emission scenarios and the majority of companies had adapted their risk hedging strategies. A comparable study conducted in 2008/09 by Rogge et al. (2011) confirms the strong impact the EU ETS had on the business procedures of German power generators and finds that overall the EU ETS has led to a change in companies' CO₂ cultures.⁵⁷ The findings also suggest that organizational innovations were first introduced regarding operational aspects and continuously moved towards more strategic aspects, such as the integration of CO₂ into all investment appraisals.

The impact of the EU ETS on organizational innovation has also been investigated for the pulp and paper industry – by means of company interviews conducted in four different countries during the second trading phase of the EU ETS.⁵⁸ For Italy, Gasbarro et al. (2013) showed how the physical management of CO₂ has been integrated for all but one of the studied six Italian paper producers into existing environmental management systems. However, none of the analyzed paper producers introduced specific procedures for a systemic management of emission reduction opportunities, but instead has treated this within existing procedures for managing investments. Similarly, Gulbrandsen and Stenqvist (2013) find an increase of resources being put into site-level administration and reporting of greenhouse gas emissions data since the introduction of the EU ETS for the studied Norwegian and Swedish paper producers.⁵⁹ The descriptive survey results by Rogge et al. (2011) for the German paper industry allow some further insights on the implementation of organizational innovation between 2005 and 2009.⁶⁰ By 2009, almost seventy percent of paper producers had started to integrate CO₂ and climate policy as a factor when constructing future scenarios. Surprisingly, however, the new cost factor CO₂ had only been taken into account as new factor in operative business areas by 42% of paper producers. This share decreases further (to 37%) when considering the integration of CO₂ as standard factor in investment analysis and product development processes, and goes down to 21% of companies for the integration of CO₂ as standard factor when planning R&D.⁶¹ The latter is supported by Gasbarro et al. (2013) who find that only one of the surveyed six Italian paper producers systematically engaged in ETS-oriented investment planning for their R&D department. The limited strategic importance of the EU ETS is also underlined by the EU ETS seen as one among many factors influencing firm strategies, and certainly not one having more importance than others. In addition, the influence of allowance prices on investment choices still seemed to be unclear to Italian

57 See Rogge, Schneider and Hoffmann.

58 See Gasbarro, Rizzi and Frey for Italy; Gulbrandsen and Stenqvist for Sweden and Norway; Rogge and others, 'The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry' for Germany.

59 See Gulbrandsen and Stenqvist.

60 See Rogge and others, 'The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry.'

61 In contrast, the two paper producers from Sweden and Norway interviewed by Gulbrandsen and Stenqvist (2013) had integrated CO₂ prices in investment appraisals, see Gulbrandsen and Stenqvist.

paper producers. This situation somewhat improves for German cement producers subject to the EU ETS for whom Schleich et al. (2010) find that the costs for emitting CO₂ are now seen as important factor in investment appraisals.⁶²

While the large majority of EU ETS firms seem to have introduced new business practices regarding physical CO₂ management, the picture is less favorable for *financial CO₂ management*. Innovations in financial CO₂ management cover, among others, the implementation of a carbon trading strategy, of establishing routines for EUA trading and introducing practices for CO₂ market monitoring.⁶³ As suggested by cross-sectoral, cross-country survey data from 2009 by Martin et al. (2011) more than half of the surveyed 446 EU ETS participants did not engage in trading EUAs.⁶⁴ Furthermore, thirty percent of EU ETS firms did not consider allowances as a financial asset and rather focused on compliance with the EU ETS, although this share differs significantly across sector (but not countries). This insight on the reluctance towards an active trading strategy confirms findings of an earlier study by Sandoff and Schaad (2009) who surveyed the Swedish EU ETS participants in 2006 and found that almost eighty percent of companies only traded once a year. The study suggests that trading was mainly conducted to minimize risks and for compliance purposes, rather than as a market opportunity.⁶⁵ This finding was further supported by almost half of respondents (46%) claiming to reduce a potential EUA shortage within the second trading phase of the EU ETS through internal measures, such as improving and developing new production processes (18% and 56%, respectively) and developing new products (18%). They also note that back then JI/CDM was of marginal importance. Overall, it can thus be argued that financial CO₂ management has become more widespread over the first two phases of the EU ETS, but a significant share of companies has remained reluctant.

This hesitance towards trading is confirmed by Gasbarro et al. (2013) for the Italian pulp and paper industry.⁶⁶ In general, their findings suggest a higher orientation of EU ETS firms with compliance rather than trading, and confirm a very limited interest in JI/CDM. Not surprisingly, then, the study points to companies pursuing internal emission reductions as main strategy. In contrast, for the electricity sector Comes (2010) shows that German power generators had already integrated CO₂ trading into their existing trading floors from the very beginning of the EU ETS and started to actively engage with JI/CDM toward the end of the pilot phase.⁶⁷ The findings for the German cement industry by Schleich et al. (2010) suggest that cement producers could be positioned in the middle of this spectrum of trading strategies, with particularly the larger ones having implemented CDM projects – typically with subsidiaries located in developing countries.⁶⁸ In addition, almost all compa-

62 See Schleich and others.

63 See Gasbarro, Rizzi and Frey.

64 See Martin, Muûls and Wagner.

65 See Sandoff and Schaad.

66 See Gasbarro, Rizzi and Frey.

67 See Comes.

68 See Schleich and others.

nies with CDM projects planned to use the project-based CDM credits for EU ETS compliance purposes up to the limit of 22% valid in the second trading phase. However, actual trading varies largely across cement producers, with some companies banking any access EUAs for the third trading phase, others having created a new business unit on CO₂ trading and those with internationally active companies having delegated any trading activities to their headquarters which tend to cooperate with banks. These sectoral differences point to a discrepancy regarding financial CO₂ management between sectors in general, and the electricity and industry sectors in more particular, thereby corroborating the need for cross-sectoral studies.⁶⁹

b. Innovations in workplace organization

Many of the aforementioned innovations in business practices were associated with innovations in workplace organizations. However, there is limited systematic evidence regarding the impact of the EU ETS on this aspect of organizational innovations. Still, the existing evidence allows for one general and two sector-specific observations regarding novelties in the distribution of responsibilities and decision making among employees as well as new concepts for the structuring of activities in response to the introduction of the EU ETS. The first cross-sectoral finding concerns the engagement of top management with climate policy, in general, and with the new cost factor CO₂, in particular. For example, already Kenber et al. (2009) note that the EU ETS has led to a shift in management awareness towards climate change which as a new topic has arrived in the boardroom.⁷⁰ Similarly, in their cross-sectoral study Sandoff and Schaad (2009) find that the EU ETS has quickly become a top management issue in Swedish companies.⁷¹ In particular, the study notes that trading decisions are taken by top management in almost two thirds of EU ETS firms (64%) and even actual trading was conducted by management in more than forty percent of companies (41%). Yet, only a third of the companies (37%) have introduced a CO₂ reduction target, suggesting limited managerial attention to climate change, despite it being a top management issue.

The second group of observations concern innovations in workplace organization in the electricity sector. In his study of the German electricity sector Cames (2010) shows that already prior to the start of the pilot phase of the EU ETS most of the interviewed twenty two power generators had already established a task force coordinating the implementation of the novel policy instrument into corporate practices.⁷² Interestingly, three years later these task forces were meeting less often as the new task arising from the introduction of the EU ETS had been integrated into daily business routines. According to Rogge et al. (2011) this decentral integration of the EU ETS even goes as far as some power generators stating not to have a specific person responsible for climate policy, as everyone plays a

⁶⁹ See Borghesi and others.

⁷⁰ See Kenber, Haugen and Cobb.

⁷¹ See Sandoff and Schaad.

⁷² See Cames.

part.⁷³ In addition, Cames' second round of interviews showed that by 2007 the large utilities had set up new departments for sourcing project-based CO₂ certificates from the Clean Development Mechanism and Joint Implementation projects (CDM/JI). This finding on the establishment of new organizational units for CDM/JI sourcing is also confirmed by Rogge et al. (2011) who find that this organizational innovation is directly and predominantly driven by the EU ETS.⁷⁴ In contrast, the EU ETS only indirectly contributes to the establishment of new business units for renewables in German utilities seen towards the end of the pilot phase of the EU ETS. Rather, this innovation in workplace organization leading to the build-up of new competencies is driven by vision changes of companies regarding internal 2020 renewables and greenhouse gas emission targets, which in turn have been shown to result from the impact the implementation the EU ETS and the existence of policy support for renewables in the form of feed-in tariffs had for companies' perceptions on the much increased credibility of the EU's 2020 targets.⁷⁵ Despite this only indirect link of the EU ETS with several workplace organizations it can be clearly stated that in the electricity sector the EU ETS has led to the attention of top management to climate change issues.

The third group of observations concerns changes in the workplace design within the paper industry. For the Italian paper industry Gasbarro et al. (2013) report the introduction of new functions, the hiring of partly dedicated ETS staff, and the coordination of EU ETS activities.⁷⁶ More precisely, two of the six paper producers employed new ETS-dedicated staff, although in different functions. Interestingly, it was these firms who also stood out in terms of a more active engagement with trading, particularly in one company which introduced a specific function for EUA trading. Similarly to findings from earlier cross-sectoral studies the authors further find that in the majority of companies the executive management was actively involved in EUA trading decisions, although the extent of involvement varies greatly among companies. These insights are confirmed and complemented by a study by Rogge et al. (2011) for the German pulp and paper industry which finds that the large majority of companies (84%) had appointed a responsible party or coordinator for the topics of CO₂ and climate policy and had become more involved with these topics at management level.⁷⁷ However, only less than a third of companies (31%) had set up new strategic departments in the field of climate protection. That is, the attention of top management to the EU ETS has led to ample vision changes, which however, do not yet fully translate into operational changes. A reason for this may be the difference between real costs vs opportunity costs, the low stringency of the EU ETS, but also operational slack and transaction costs.

⁷³ See Rogge, Schneider and Hoffmann.

⁷⁴ *See* *ibid.*

⁷⁵ These long-term targets of the EU encompass a 20% reduction of CO₂ emissions, an increase in the share of renewable energies to 20%, and a 20% improvement of energy efficiency to be reached by 2020.

⁷⁶ See Gasbarro, Rizzi and Frey.

⁷⁷ *See* Rogge and others, 'The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry.'

c. Innovation in external relations

Organizational innovation is also given if a company implements new ways of organizing relations with other firms or public institutions in response to the EU ETS. Cross-sectoral evidence for this is largely limited to the study by Sandoff and Schaad (2009) conducted for Swedish EU ETs firms.⁷⁸ It finds that over half of paper producers uses brokers for CO₂ tradings (60%) while only a third (36%) of the large companies use a CO₂ exchange. Of course, all EU ETS firms were required to establish a link with the national administrative body responsible for the implementation of the EU ETS, but this is not explicitly studied.

For the electricity sector Cames (2010) finds that by 2007 some large German power generators had started cooperating with smaller utilities by offering them market access.⁷⁹ In addition, when taking into consideration the impact of the EU ETS on the sectoral innovation system for power generation technologies Rogge and Hoffman (2010) identify new linkages of power generators with technology providers active in the chemical industry.⁸⁰ These new external relations are a direct result of the EU ETS which led power generators to jointly conduct R&D on CCS, thereby effectively broadening the boundaries of the innovation system.

Finally, for the paper industry Gasbarro et al. (2013) find that rather than extending its environmental management system regarding EU ETS related activities one Italian paper producer worked with a consulting service for regulatory updating, for annual emission communication, for relationships with the Authority, and for the calibration of instruments. Three other companies outsourced the calibration of instruments, and one decided to conduct its carbon market monitoring and allowance trading through a 100% controlled energy service subsidiary.⁸¹ In a similar spirit of changes in external relations Rogge et al. (2011) find that in the German pulp and paper industry one fifth of companies (21%) had intensified climate relevant R&D partnerships after the introduction of the EU ETS.⁸²

d. Outlook

In conclusion, the EU ETS seems to have triggered – or at least contributed to – various organizational innovations, with the evidence base being largest for innovations in busi-

78 *See* Sandoff and Schaad.

79 *See* Cames.

80 *See* Karoline S Rogge and Volker H Hoffmann, ‘The Impact of the EU ETS on the Sectoral Innovation System for Power Generation Technologies’ (2010) 38 *Energy Policy* 7639.

81 *See* Gasbarro, Rizzi and Frey.

82 *See* Rogge and others, ‘The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry.’

ness practices. While keeping in mind the limits of the largely qualitative evidence base two key patterns for this impact of the EU ETS on organizational innovation emerge. First, the companies in the electricity sector seem to have been faster and more thorough in implementing the full range of organizational innovations. Key reasons for this may include the EU ETS affecting core production processes and the fertile ground prepared through the process of liberalization of the electricity sector.⁸³ Second, the implementation of organizational innovations was found to be much more pronounced for EU ETS firms than for their counterparts supplying them with production equipment. Again, this varies across sectors, with the EU ETS having led to some organizational innovations in other parts of the value chain in the electricity sector – particularly for large diversified power generation suppliers. In contrast, such a trickle through effect has remained largely irrelevant for suppliers of production equipment in the cement industry.⁸⁴ Similarly, in the pulp and paper industry organizational innovations seem to be much less pronounced among technology providers when compared to paper producers.⁸⁵

Overall, these findings on organizational innovations driven by the EU ETS are in line with general insights by Borghesi et al. (2015) on the impact of environmental policy on innovation which has shown that organizational innovations have been important in most sectors.⁸⁶ They can be seen as operating as a leading force in technological innovation, and thus as an important precondition for wider and deeper technological changes should the design of the EU ETS and the policy mix into which it is embedded be improved.

IV. CONCLUSION

In this chapter I have reviewed the evidence on the innovation impact of the EU ETS and have found a very limited effect on technological innovation but clear signs of the scheme having stimulated organizational innovation.

Regarding the very moderate impact on technological innovation I found initially high expectations regarding its innovation impact which, however, have dissipated after the scheme's lack of stringency became apparent and prices have collapsed accordingly. The innovation impact varied across sectors and technologies, with the strongest effects occurring for the electricity sector and carbon capture and storage technologies. However, with hindsight the spike of innovation in CCS needs to be seen as a temporary phenomenon, which has been reduced significantly in recent years, among others due to

83 *See* Rogge and Hoffmann; Borghesi and others.

84 *See* Rogge, Schneider and Hoffmann; Schleich and others.

85 *See* Rogge and others, 'The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry', p. 266.

86 *See* Borghesi and others.

low carbon prices in Europe and other factors, such as a lack of public acceptance for storing CO₂ in Germany, and changed political priorities leading to the cancellation of a demonstration program in the UK. So far, the impact of the EU ETS on technological innovation is likely to remain low, despite attempts of strengthening the scheme's design in its third trading phase (2012-2020).

In contrast, there is clear evidence that the EU ETS has been a key driver in various organizational innovations, such as incorporating CO₂ into business practices, making climate change a top management issue or building external relations to address the challenge of climate change, may that be with consultants, CO₂ exchanges or new R&D partners. While many of these organizational innovations may still be in place – the exception perhaps being the shut-down of new business units primarily established in large companies for sourcing JI/CDM credits – these organizational innovations have so far had only limited effects on shifting corporate strategies towards low-carbon solutions. Reasons for this include low carbon prices, the relatively high share of free allocations in industry sectors, and more pressing business concerns.

The findings of this review point to three main patterns of the innovation impact of the EU ETS. First, the impact of the EU ETS on innovation seems to be more pronounced for the electricity sector than for industry sectors. This could both be observed for technological innovation and for organizational innovation. While there may be good reasons for these sectoral differences, such as the importance of CO₂ as cost factor in the production process or a higher share of auctioning in the electricity sector, it points to the need of focusing future efforts in stimulating low-carbon innovation towards industry sectors. Of course, there remains quite some diversity within industry sectors themselves, as the examples of the pulp and paper industry compared to the cement industry have shown. Second, the innovation impact of the EU ETS was found to be much stronger for those firms regulated by the EU ETS than suppliers of these firms' production equipment. This suggest that the trickle through effect of the EU ETS to other parts of the value chain remains limited, particularly in industry sectors but also for suppliers of power generation technologies based on fossil-fuels which have largely remained locked-in. Given the relevant sectoral patterns of innovation found in the EU ETS sectors this limited trickle through effect is likely to be a major limitation for triggering innovation in the related innovation systems. This calls for a wider innovation system perspective in future research and policy.⁸⁷ Finally, for many of the observed technological innovations – typically incremental – the EU ETS was shown to be a contributing factor among others – including the broader policy mix but also the wider business environment. In some instances it even has only played an indirect role for certain innovations. This complexity of the causal link between the EU ETS and innovation has both methodological and policy implications.

⁸⁷ See Keith Pavitt, 'Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory' (1984) 13 *Research Policy* 343; Rogge and Hoffmann.

However, before moving on to these implications it needs to be noted that the evidence reviewed here did not include the impact of the EU ETS on diffusion. Clearly, several studies have investigated the impact of the EU ETS on investment decisions, such as for modernizations, fuel switching and new plants. The evidence suggests that the EU ETS has mainly contributed to incremental process innovations (including fuel switching), typically strengthening the effect of energy prices. For example, in Ireland over two thirds of EU ETS companies (74%) implemented process or behavioral changes, half of them (48%) employed new machinery or equipment and a good third (41%) switched fuels, thereby contributing to reductions in CO₂ emissions.⁸⁸ Another example concerns the electricity sector where the impact of the EU ETS on investment seems to have been most pronounced for retrofitting of existing plants. Regarding the investment in new plants the EU ETS with its free allocation for new entrants was shown to have initially led to more investments in polluting plants, while not influencing adoption decisions on non-polluting plants.⁸⁹ In this context it was shown that incentives considerably depend on the specific design of the EU ETS, such as the overall cap, share of auctioning, allocation rules for incumbents and new entrants, or closure provisions and transfer rules.⁹⁰

This limitation notwithstanding, this review finds a so far very limited impact of the EU ETS on technological innovation, but a fairly strong impact on organizational innovation. Two main policy implications regarding an innovation-proof design of the EU ETS – and other emission trading schemes – arise from these findings: (1) increase of the carbon price and (2) increase of the share of auctioning. First, this review finds that a higher carbon price provides higher incentives for innovation. For this to happen the scarcity of EUA needs to be increased. Two possible key mechanisms to achieve this are the further reduction of the current and future cap of the EU ETS and the permanent retirement of excess allowances from earlier trading phases. In addition, the introduction of a minimum price should be reconsidered so that the currently very weak carbon price would be strengthened. Second, since free allocation was shown to be detrimental for innovation the share of auctioning should eventually be increased. This implies reconsidering industry exemptions based on competitiveness. A promising way forward in this regard could be the development of a gradual phase-out strategy for free allocation - coordinated with other emission trading systems, such as the soon to be implemented Chinese ETS, in order to address carbon leakage concerns while at the same time strengthening innovation incentives. Resulting auctioning revenues could be earmarked to further stimulate radical innovations in low-carbon solutions in industry sectors. Clearly, these policy implications for the redesign of the EU ETS raise difficult questions regarding both political and legal feasibility, and thus tackling them remains a major challenge – but arguably a smaller one than introducing an EU wide carbon tax. Without addressing the identified shortcomings the EU ETS cannot play its foreseen

88 See Anderson, Convery and Di Maria.

89 See Hoffmann; Cames; Rogge, Schneider and Hoffmann; Schmidt and others.

90 For a detailed empirical examination of the innovation incentives arising from different design features of the EU ETS for the German electricity sector, see Cames.

role in guiding the decarbonization of the European economy for which innovations in low-carbon solutions are a fundamental requirement.

Despite the limited impact of the EU ETS on technological innovation different indicators for low-carbon innovation, such as patents or innovation expenditures, indicate a positive innovation trend. This increasing pattern of low-carbon innovation is in contrast to Taylor's (2012) observation of declining inventive activity after the introduction of permit trading schemes for sulfur dioxide and nitrogen oxide control in the US.⁹¹ But if it is not the EU ETS which is driving this positive development, the question remains what else is behind it. One important part of the answer to this question is provided by those studies which did not only consider the EU ETS as political driver of low-carbon innovation but also included elements of the wider policy mix⁹² in their analysis.⁹³ For example, the empirical evidence gathered for the electricity sector suggests that long-term emission reduction targets, such as the EU's 2020 targets, have been an important determinant of corporate innovation activities in non-polluting technologies, i.e. in renewable energies. In addition, the existence of technology-specific instruments promoting the diffusion of low-carbon solutions, such as feed-in tariffs for renewable energies, have been found as another important element of the policy mix and as such complement the EU ETS.⁹⁴ The relative importance of long-term targets and concrete policy instruments differs among innovation dimensions, with long-term targets being particularly important for R&D activities of technology providers.⁹⁵

This review also allows for deriving a number of methodological challenges in evaluating the innovation impact of the EU ETS which should be tackled by future research. First, evaluating the innovation impact of the EU ETS calls for dedicated data collection, for example in the form of specialized company surveys or rigorous case studies. Alternatively, the utilization of existing data, such as patent data or data originating from the Community Innovation Survey, requires the creation of meaningful proxies capturing the EU ETS and its design features. Second, given the different strengths but also limitations of the employed methodological approaches it seems most promising to combine different methods into a multi-method research design combining qualitative and quantitative methods. Third, studies attempting to establish the innovation impact of the EU ETS should pay closer attention to the different sectoral patterns of innovation and thus extend the boundaries of their investigation accordingly. Typically, this will

91 See Margaret R Taylor, 'Innovation under Cap-and-Trade Programs' (2012) 109 PNAS 4804.

92 See Karoline S Rogge and Kristin Reichardt, 'Going Beyond Instrument Interactions : Towards a More Comprehensive Policy Mix Conceptualization for Environmental Technological Change', vol 12 (2015) SWPS 2015-12.

93 See Borghesi, Cainelli and Mazzanti; Borghesi and others; Hoffmann; Schmidt and others; Rogge, Schneider and Hoffmann; Rogge and others, 'The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry.'

94 In particular, see the findings of the cross-country study conducted by Schmidt and others.

95 See Karoline S Rogge, Tobias S Schmidt and Malte Schneider, 'Relative Importance of Different Climate Policy Elements for Corporate Climate Innovation Activities', vol 49 (2011).

imply assuming an innovation system perspective in which not only EU ETS firms will be found to perform innovative activities but also other key actors in the system. Finally, as the EU ETS is embedded in a broader policy mix studies should pay greater attention to the role played by long-term targets and other policy instruments as well as their interaction. However, such a thorough analysis of the innovation impact of the EU ETS in its third phase – ideally covering multiple sectors and countries – would be best postponed until the major shortcomings of the scheme have been addressed. In the meantime, these methodological recommendations may be also valuable for setting up evaluation programs of the innovation impact of the many national and regional CO₂ trading schemes and carbon taxes implemented around the world.⁹⁶

Finally, I want to emphasize that while the impact of the EU ETS on technological innovation has remained limited, its positive impact on organizational innovation should not be underestimated. The reason for this is that organizational innovations – as by now widely acknowledged in the innovation studies literature – provide a necessary precondition for future technological innovations.⁹⁷ In this regard it is promising to see that companies aware of climate change – an awareness for which the EU ETS has been the main driver – introduce more low-carbon innovations than companies without such an awareness.⁹⁸ In addition, Martin et al. (2012) show that managers aware of climate change tend to introduce firm-internal targets, e.g. regarding the reduction of greenhouse gas emissions – something to which the EU ETS has been shown to contribute to, alongside other elements of the policy mix. These internal targets, in turn, have been shown to positively impact low-carbon innovation. As several of the studies reviewed in this chapter have shown it is indeed the EU ETS which has made managers more aware of climate change. However, the scheme currently does not provide sufficient incentives for turning corporate aspirations into lucrative business opportunities, something that needs to be urgently corrected if policy makers are taking the Paris Agreement seriously.

Indeed, it is the momentum of COP21 in December 2015 and the global agreement reached there to hold the global average temperature increase well below 2°C which provides European and national climate policy makers with the mandate to think creatively how to find the political majorities to significantly increase the stringency of the EU ETS beyond what has been proposed by the European Commission for the fourth trading phase. As the studies surveyed in this review have shown this implies first and foremost increasing the scarcity of EUAs, thereby contributing to higher yet predictable carbon prices. The permanent retiring of EUAs parked in the market stability reserve, the further strengthening of the reduction factor, and the establishment of an intelligent mechanism which guarantees a minimum EUA price are three possible avenues for increasing the so far limited innovation incentives generated by the EU ETS. Making the

⁹⁶ See World Bank and Ecofys, ‘State and Trends of Carbon Pricing’ (2015).

⁹⁷ See OECD and Eurostat.

⁹⁸ See Martin and others.

EU ETS more stringent as outlined above would not only unleash its transformative power by generating greater incentives to invest in low-carbon innovation, but it would also send out a strong political signal that Europe takes the agreement struck in Paris seriously and implements it accordingly. It is exactly this line of thinking in terms of consistent and credible policy mixes made up of ambitious long-term targets which are implemented by a combination of well designed demand pull, technology push and systemic instruments which is needed for successfully governing the decarbonization of the economy.⁹⁹

⁹⁹ See Karoline S Rogge and others, 'Green Change: Renewable Energies, Policy Mix and Innovation' (2015).

REFERENCES

- Anderson BJ, Convery F and Di Maria C, 'Technological Change and the EU ETS: The Case of Ireland. Working Paper n.43' [2010] SSRN Electronic Journal 1
- Ashford NA, Ayers C and Stone RF, 'Using Regulation to Change the Market for Innovation' (1985) 9 *Harvard Environmental Law Review* 419
- Baumol WJ and Oates WE, *The Theory of Environmental Policy* (Cambridge University Press 1988)
- Betz R, Eichhammer W and Schleich J, 'Designing National Allocation Plans for EU-Emissions Trading - A First Analysis of the Outcomes' (2004) 15 *Energy & Environment* 375
- Betz R, Rogge K and Schleich J, 'EU Emissions Trading: An Early Analysis of National Allocation Plans for 2008-2012' (2006) 6 *Climate Policy* 361
- Borghesi S and others, 'Carbon Abatement, Sector Heterogeneity and Policy Responses: Evidence on Induced Eco Innovations in the EU' (2015) 54 *Environmental Science & Policy* 377
- Borghesi S, Cainelli G and Mazzanti M, 'Linking Emission Trading to Environmental Innovation: Evidence from the Italian Manufacturing Industry' (2015) 44 *Research Policy* 669
- Calel R and Dechezleprêtre A, 'Environmental Policy and Directed Technological Change: Evidence from the European Carbon Market' (2012)
- Cames M, 'Emissions Trading and Innovation in the German Electricity Industry' (TU Berlin 2010)
- Egenhofer C and others, 'The EU Emissions Trading Scheme: Taking Stock and Looking Ahead' (2006)
- European Commission, 'EU Action against Climate Change: EU Emissions Trading — an Open Scheme Promoting Global Innovation' (2005)
- Fagerberg J, Mowery DC and Nelson RR, *The Oxford Handbook of Innovation* (Oxford University Press 2005)
- Fischer C, Parry IWH and Pizer WA, 'Instrument Choice for Environmental Protection When Technological Innovation Is Endogenous' (2003) 45 *Journal of Environmental Economics and Management* 523
- Frondel M, Horbach J and Rennings K, 'End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions Across OECD Countries' (2007) 16 *Business Strategy and the Environment* 571
- Frondel M, Horbach J and Rennings K, 'What Triggers Environmental Management and Innovation? Empirical Evidence for Germany' (2008) 66 *Ecological Economics* 153
- Gagelmann F and Frondel M, 'The Impact of Emission Trading on Innovation – Science Fiction or Reality?' (2005) 15 *European Environment* 203
- Gagelmann F and Hansjürgens B, 'Climate Protection through Tradable Permits: The EU Proposal for a CO2 Emissions Trading System in Europe' (2002) 12 *European Environment*

185

Gasbarro F, Rizzi F and Frey M, 'The Mutual Influence of Environmental Management Systems and the EU ETS: Findings for the Italian Pulp and Paper Industry' (2013) 31 *European Management Journal* 16

Gulbrandsen LH and Stenqvist C, 'The Limited Effect of EU Emissions Trading on Corporate Climate Strategies: Comparison of a Swedish and a Norwegian Pulp and Paper Company' (2013) 56 *Energy Policy* 516

Hamprecht J, 'Regulatory Uncertainty : A Reason to Postpone Investments ? Not Necessarily Volker H . Hoffmann , Thomas Trautmann and'

Hansjürgens B, *Emissions Trading for Climate Policy - U.S. and European Perspectives* (Cambridge University Press 2006)

Hascic I, Johnstone N and Kalamova M, 'Environmental Policy Flexibility, Search and Innovation' (2009) 59 *Finance a úvěr - Szech Journal of Economics and Finance* 426

Hoffmann VH, 'EU ETS and Investment Decisions' (2007) 25 *European Management Journal* 464

Jung CH, Krutilla K and Boyd R, 'Incentives for Advanced Pollution Abatement Technology at the Industry Level: An Evaluation of Policy Alternatives' (1996) 30 *Journal of Environmental Economics and Management* 95

Kemp R and Pontoglio S, 'The Innovation Effects of Environmental Policy Instruments — A Typical Case of the Blind Men and the Elephant ?' (2011) 72 *Ecological Economics* 28

Kenber M, Haugen O and Cobb M, 'The Effects of EU Climate Legislation on Business Competitiveness : A Survey and Analysis', vol 09 (2009)

Kerr S and Newell RG, 'Policy-Induced Technology Adoption: Evidence from the US Lead Phasedown' (2003) 51 *Journal of Industrial Economics* 317

Kneese A V. and Schultz CL, *Pollution, Prices and Public Policy* (Brookings Institute 1978)

Malueg DA, 'Emission Credit Trading and the Incentive to Adopt New Pollution-Abatement Technology' (1989) 16 *Journal of Environmental Economics and Management* 52

Martin R and others, 'Anatomy of a Paradox: Management Practices, Organizational Structure and Energy Efficiency' (2012) 63 *Journal of Environmental Economics and Management* 208

Martin R, Muûls M and Wagner U, 'Carbon Markets, Carbon Prices and Innovation: Evidence from Interviews with Managers', *Paper presented at the EAERE conference 29 June–2 July 2011* (2011)

McKinsey and Ecofys, 'Review of EU Emissions Trading Scheme: Survey Highlights' (2005)

Montgomery D, 'Creating Technologies to Reduce Greenhouse Gas Intensity: Public Options & Opportunities' (2005)

OECD and Eurostat, 'Oslo Manual: Guidelines for Collecting and Interpreting Innovation Data' (3rd edn, OECD and Eurostat 2005)

Pavitt K, 'Sectoral Patterns of Technical Change : Towards a Taxonomy and a Theory' (1984)

13 Research Policy 343

Philibert C, 'Technology Innovation, Development and Diffusion' (2003)

Pontoglio S, 'An Early Assessment of the Influence on Eco-Innovation of the EU Emissions Trading Scheme - Evidence from the Italian Paper Industry' in A Mazzanti, M.; Montini (ed), *Environmental Efficiency, Innovation and Economic Performance* (Routledge 2010)

Popp D, 'Pollution Control Innovations and the Clean Air Act of 1990.' (2003) 22 Journal of Policy Analysis and Management 641

Requate T, 'Dynamic Incentives by Environmental Policy Instruments - a Survey' (2005) 54 Ecological Economics 175

Rogge KS and others, 'Green Change : Renewable Energies , Policy Mix and Innovation' (2015)

Rogge KS and Hoffmann VH, 'The Impact of the EU ETS on the Sectoral Innovation System for Power Generation Technologies' (2010) 38 Energy Policy 7639

Rogge KS and Linden C, 'Cross-Country Comparison of the Incentives of the EU Emission Trading Scheme for Replacing Existing Power Plants in 2008-12' (2010) 21 Energy & Environment 757

Rogge KS and Reichardt K, 'Towards a More Comprehensive Policy Mix Conceptualization for Environmental Technological Change' (2013) S 3/2013

——, 'Going Beyond Instrument Interactions : Towards a More Comprehensive Policy Mix Conceptualization for Environmental Technological Change', vol 12 (2015) SWPS 2015-12

Rogge KS, Schmidt TS and Schneider M, 'Relative Importance of Different Climate Policy Elements for Corporate Climate Innovation Activities', vol 49 (2011)

Rogge KS, Schneider M and Hoffmann VH, 'The Innovation Impact of the EU Emission Trading System — Findings of Company Case Studies in the German Power Sector' (2011) 70 Ecological Economics 513

Rogge KS. and others, 'The Role of the Regulatory Framework for Innovation Activities: The EU ETS and the German Paper Industry' (2011) 11 International Journal Technology, Policy and Management 250

Sandén BA and Azar C, 'Near-Term Technology Policies for Long-Term Climate Targets — Economy Wide versus Technology Specific Approaches' (2005) 33 Energy Policy 1557

Sandoff A and Schaad G, 'Does EU ETS Lead to Emission Reductions through Trade? The Case of the Swedish Emissions Trading Sector Participants' (2009) 37 Energy Policy 3967

Schleich J and others, 'Wirkungen Neuer Klimapolitischer Instrumente Auf Innovationstätigkeiten Und Marktchancen Baden-Württembergischer Unternehmen' (2010)

Schleich J and Betz R, 'Incentives for Energy Efficiency and Innovation in the European Emission Trading System' (2005)

Schleich J, Rogge K and Betz R, 'Incentives for Energy Efficiency in the EU Emissions Trading Scheme' 37

Schmidt TS and others, 'The Effects of Climate Policy on the Rate and Direction of Innovation' (2012) 2 *Environmental Innovation and Societal Transitions* 23

Schumpeter JA, *Capitalism, Socialism and Democracy* (Harper and Brothers 1942)

Taylor MR, 'Innovation under Cap-and-Trade Programs' (2012) 109 *PNAS* 4804

World Bank and Ecofys, 'State and Trends of Carbon Pricing' (2015)

UNFCCC, Paris Agreement 2015

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