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Climate Change Affectedness and Innovation in German Firms

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Abstract

Eco-innovations are crucial for the mitigation of climate change effects. It is therefore important to know if the existing climate change regulations and carbon pricing are appropriate and sufficient to trigger such innovations. Besides government measures, the demand for carbon neutral products or the impacts of climate change such as extreme weather conditions leading to higher costs for the affected firms may also promote eco-innovation activities. For the first time, the new wave of the Community Innovation Survey 2020 in Germany allows an analysis of the effects of climate change policy and costs, demand for climate friendly goods and extreme weather conditions on (eco-)innovation. The results of probit and treatment effect models show that innovative firms seem to be significantly more affected by climate change measures and consequences compared to other firms. All climate change indicators are positively correlated to eco-innovations. Interestingly, other innovation activities also profit from the extent to which a firm is affected by climate change albeit the marginal effects are lower compared to eco-innovations. Demand for climate neutral products is significantly important for all eco-product-innovations.

JEL-Classification: C25, C21, O31, Q54, Q55

Key words: Climate change, eco-innovation, Community Innovation Survey, probit regression, treatment effect models

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1. Introduction

Climate change increases the risk of extreme weather events including hurricanes, cyclones and typhoons, heavier rain, more frequent heat waves, and longer droughts. In 2019, Germany emitted 800 million tons of climate change relevant emissions (CO_2, methane and other gases). This is still far away from the goal of 437 million tons in 2030 and climate neutrality in 2045 (Umweltbundesamt 2022). The OECD (2022) states that "… many countries are taking action, but progress is insufficient to achieve the goals of the 2015 Paris Agreement and keep the global average temperature increase well-below 2°C above pre-industrial levels." Eco-innovations leading to less CO_2 emissions, e.g. via the reduction of energy use in production processes and products or an increased use of renewable energy sources, seem to be crucial for the solution of the climate change problem.

A key research question is whether government policies to mitigate climate change are adequate and sufficient to trigger such eco-innovation activities. Besides government regulation, extreme weather conditions caused by climate change will lead to higher (production and distribution) costs, which may increase the price of various inputs even for firms not directly affected by climate change. In addition, climate change may also create new demand for climate neutral products. These price signals and demand shifts might also be important for the realisation of eco-innovations. In the light of the "re-direction" literature (Acemoglu et al. 2012), there may be wider impacts of climate change on the entire innovation strategies of firms in order to shift from "dirty" to "clean" inputs. In this paper, we aim at investigating whether the way and extent to which firms are affected by climate change results in changes in the firms' innovation activities, both with respect to triggering eco-innovations and affecting other types of innovations.

A main element of the paper is to use a new measure on the affectedness of firms by climate change that has been developed for the European Commission's Community Innovation Survey (CIS) and was first implemented for the reporting year 2020 (CIS 2020). This measure offers a new opportunity for empirically analysing the effects of climate policy, demand for CO_2 advantageous products, climate change costs and extreme weather conditions on eco-innovation and other innovation activities of firms. As the measure is available for all firms, including non-innovative firms, this setting allows to identify the role of climate change on firms' (eco-)innovation activities.

The paper is organised as follows. Section 2 discusses the innovation effects of climate change affectedness from a theoretical background and gives a short overview of the already existing empirical literature. Section 3 presents the data basis and reports descriptive results. The econometric analyses in Section 4 uses probit and treatment effect models to assess the impact of climate change affectedness on firm behaviour. Section 5 concludes.

2. Innovation effects of climate change affectedness

Climate change affectedness

Climate change can affect business activities of firms in different ways. Following the literature (Winn et al. 2011, Berkhout et al. 2006, Linnenluecke et al. 2013), we consider four main dimensions of how changes in climate can affect firms:

1) Direct impacts from extreme weather conditions (e.g. damages from storms)

2) Costs of adjusting to climate change consequences (e.g. re-organising production and distribution to respond to hot weather)

3) Policy measures to mitigate climate change (e.g. emission taxes)

4) Customer demand for more climate-friendly products

The most immediate consequences may result from more extreme weather conditions caused by climate change, e. g. floods, droughts, storms or extreme cold (Winn et al. 2011). Extreme weather conditions can directly impact operations of firms by damaging facilities, restricting or stopping production, or complicating or impeding transportation. That such impacts materialise in adverse firm performance can be seen from the following quotation from a company report: "Partially offsetting the impact of higher prices was a decrease in sales volume of approximately 8% in the year ended December 31, 2018 as compared to the same period in 2017 as volumes were adversely impacted by persistently low water levels on the Rhine due to hot weather conditions. This led to constrained volumes and logistical restrictions within inland Europe which adversely impacted the operation rates of the Koln polymer and olefin assets." (Ineos Group Holdings 2018: 54). Climate change may also jeopardise entire production systems in certain sectors that rely on relatively narrowly confined temperature and seasonal conditions, including agriculture and tourism (Winn et al. 2011: 160).

In addition to these direct impacts, climate change may urge firms to adopt their business activities in various ways, from more resilient production and distribution methods that can cope with more extreme weather conditions to organisational changes (Berkhout et al. 2006) and the development of new business models (Linnenluecke et al. 2013). The disruptions to business activities caused by climate change are likely to result in increasing prices for products and services affected by these changes. These price changes will convert into higher input prices for other companies and may represent an indirect effect of climate change that affects a large number of sectors and businesses that do not experience climate change consequences directly. All in all, extreme weather conditions caused by climate change will lead to higher costs for the whole economy (German Environment Agency 2021).

Other consequences relate to government actions taken to mitigate climate change. These actions may range from regulations to reduce greenhouse gas emissions and the introduction of a greenhouse gas emission trading system (Haites 2018) and the introduction of new standards for climate-neutral activities (Dalhammar and Richter 2019) to increasing taxes on activities with negative climate impacts or imposing new reporting requirements on firms on how they respond to climate change challenges (Tang and Demeritt 2018). These policy measures, too, will lead to higher input and product prices in an economy.

Another indirect way of climate change impacts are changes in customer preferences that result from climate change (Berkhout et al. 2006). Such alterations in demand may range from low-carbon products (i.e. products that are produced and/or consumed with producing little or no greenhouse gas emissions) to requiring a comprehensive carbon-neutral approach from companies. These demand changes might lead to higher product prices but, on the other hand, they might also trigger product- and process-related environmental innovations.

The key research question of our paper is how these different dimensions of climate change affectedness are related to different types of innovation activities in firms. On the background of the extensive literature on the determinants of eco-innovation the before-mentioned dimensions of climate change affectedness will be highly relevant for eco-innovations, but it is also interesting to know more about the effects on other, non-environmentally related innovations.

Effects on eco-innovation and other innovations

There is a vast empirical literature on the determinants of eco-innovation including the role of regulation on the background of the Porter hypothesis (see e.g. Brunnermeier and Cohen 2003, Horbach 2008, Johnstone et al. 2010, Demirel and Kesidou 2011, Horbach et al. 2012, Del Rio et al. 2016, Lanoie et al. 2011, Horbach 2019 for an overview). It is beyond the scope of this paper to give an overview of this literature. The main common "stylized facts" of these papers can be summarised as follows: Regulation measures, the demand for environmentally benign products and the motivation to save (resource) costs are the most important factors for eco-innovation. In the light of the Porter hypothesis (Porter and van der Linde 1995), environmental regulation-induced eco-innovation may even lead to a win-win situation so that pollution is reduced and profits are increased (Rexhäuser and Rammer 2014). Eco-innovations thus show clear specificities compared with other innovations that are confirmed by many empirical analyses. As discussed above, climate change affectedness includes these main determinants and it remains an empirical question if and to what extent the specific climate change regulations and price signals and the demand for climate neutral products are relevant for eco-innovation activities. Following the literature on the determinants of eco-innovation we thus formulate Hypothesis 1:

H1: The more a firm is affected by climate change, the more likely it will engage in innovations for mitigating adverse impacts on the environment ('eco-innovations').

Eco-innovations cover a broad range of different innovations activities from directly related CO_2 mitigation measures or energy savings to waste and recycling or noise reduction. Thus, probably not all eco-innovation activities are affected by climate change measures in the same way leading to Hypothesis 2:

H2: Climate change affectedness is related to different types of eco-innovations in different ways.

Acemoglu et al. (2012) postulate a redirection of innovation from polluting technologies to low-carbon ones in response to environmental regulation measures (see also Dechezleprêtre et al. 2016). Acemoglu et al. (2012) show that if "dirty" and "clean" inputs are substitutable, even a temporary taxation of the dirty inputs would be sufficient to redirect the production process to a more sustainable path.

Climate change may not only trigger innovations that directly reduce adverse impacts on the environment but may also change other innovation activities in firms. On the one hand, a re-direction towards eco-innovation may crowd-out other innovations. On the other hand, achieving more climate-friendly ways of production, e.g. through energy saving measures, may require a re-design of the entire production processes, including innovations not directly related to reducing adverse environmental impacts. Similar effects might be observed regarding products. As an example, electric cars need additional noise systems to warn pedestrians. These systems are introduced for security reasons, they even increase environmental noise damages. All in all, climate change affectedness can have positive or negative effects on other innovations so that the answer to this question also remains an empirical one. We thus formulate Hypothesis 3:

H3: The more a firm is affected by climate change, the more likely it will adjust other ('non-eco') innovation activities in order to cope with the new situation caused by climate change.

Existing empirical analyses on innovation impacts of climate change

The literature on the specific effects of climate change related factors as determinants of (eco)-innovation is quite scarce (Linnenluecke et al. 2013). In a recent paper, von Schickfus (2021: VI) shows that there may be "… a nonzero relationship between the importance of climate issues in firms, and firms' green innovation activities". The author uses green patenting as eco-innovation indicator and exposure to a climate-related shock to measure climate change affectedness. Penna and Geels (2015) analyse the impact of climate change on the U.S. car industry from 1979 to 2012. The authors analyse "… the dynamics of the climate change problem in terms of socio-political mobilization by social movements, scientists, wider publics and policymakers." (Penna and Geels 2015: 1029). They find that the reorientation of the U.S. car industry towards low-carbon technologies was quite slow apparently due to only weak external pressures during the considered time-period.

Aghion et al. (2020) analyse the role of the demand side for green technology choices. The authors find out "… that "greener" consumer values push innovation in the clean direction, by reducing the rate of growth of dirty innovations. Competition has a strong significant positive effect on clean innovation, but it actually increases all types of innovation." Aghion et al. (2020: 21). Their econometric analysis also shows that higher energy costs are associated with a higher growth rate of clean patents compared to dirty ones.

Lilliestam et al. (2021) review 19 peer-reviewed empirical papers on the effects of carbon pricing on innovation and zero-carbon investment. They restrict their overview on relatively ambitious carbon pricing systems because very low carbon prices might not have substantial effects, considering the ETS in the EU and New Zealand, and the carbon tax systems in British Columbia, France, Switzerland, and four Nordic countries. The 19 papers cover a wide range of methods from qualitative approaches to quantitative analyses based on firm- and country-level data. The authors conclude that "some articles find short-term operational effects, especially fuel switching in existing assets, but no article finds mentionable effects on technological change." (Lilliestam et al. 2021: 1). Following their analysis, the effectiveness of carbon pricing in stimulating innovation remains a mere theoretical argument. One reason for the weak effects of carbon pricing might be that many of the analysed papers used data of the early phases of the ETS when the prices of the certificates were quite low. Quirion (2021) supports this view showing that the problem of over-allocation of permits occurred in nearly all emission trading systems. From a theoretical background, especially in the early transition phase from carbon-intensive technologies to green ones, high price incentives are necessary to overcome lock-in effects in using carbon-intensive technologies, already existing networks and learning curve effects (Lilliestam et al. 2021). Calel and Dechezleprêtre (2016) investigate the impact of the European Union Emissions Trading System (EU ETS) on innovation activities based on a patent analysis. The authors find "… that the EU ETS has increased low-carbon innovation among regulated firms by as much as 10%, while not crowding out patenting for other technologies. We also find evidence that the EU ETS has not affected patenting beyond the set of regulated companies. These results imply that the EU ETS accounts for nearly a 1% increase in European low-carbon patenting compared to a counterfactual scenario." (Calel and Dechezleprêtre 2016: 173). Martin et al. (2016) provide a review of quantitative analyses and case studies on the impact of the EU ETS on the regulated firms. They conclude that there is robust evidence that the EU ETS caused partly an increase of eco-innovation activities in the second trade period of the ETS.

Joseph (2016) also detects a clear relationship between stringency of climate policy measures and innovation activities measured by the number of patents in Europe. His results show that an excess of the supply of certificates in the market e.g. caused by an economic crisis is correlated to a decrease in the number of patents. Dechezleprêtre et al. (2020) also use international patent data for their analysis of innovation activities in technologies for climate change adaptation. The authors find a nearly doubling of the share of climate change mitigation technologies in total innovation from 1995 to 2015 but a stagnating development of climate change adaptation inventions. Borghesi et al. (2015) analyse sector-specific responses to climate and energy policy based on a qualitative analysis. They find out that "Policies appear to be relevant in some sectors, namely energy, coke and refinery, and paper, but energy costs considerations dominate over the potential effects of CO_2 targeted policies." (Borghesi et al. 2015: 377).

3. Data and descriptive results

A new measure of climate change affectedness

This paper uses a newly developed measure of climate change affectedness of firms that was introduced in the European Commission's Community Innovation Survey (CIS) 2020 survey for the first time.[1] For developing such a measure, a number of criteria had to be met in order to fit into the methodology of the CIS. First, the measure should be relevant to all types of firms from all sectors of the economy. Secondly, it should be simple in order to allow all types of respondents to provide a reliable answer, taking into consideration that the respondents of the CIS are typically owners or general managers in case of small or medium-sized firms, or innovation managers in larger firms. While the measure should cover the most important likely impacts on climate change on firms, it should be short and concise and apply design features common to CIS questions. Finally, the measure should be exogenous to a firm's activities related to climate change actions.

The question developed for the CIS 2020 distinguishes four broad areas of likely climate change impacts on firms (government policies, customer demand, input cost, extreme weather conditions) and asks respondents to rate the degree of importance of each type of impact as a factor for the firm's business operations on a Likert scale, employing the standard 4-point scale that is used in the CIS (see Figure 1). This final question was the result of cognitive testing efforts in different countries, covering firms from various sectors and size classes.[2] The draft version used for cognitive testing included a large number of items, alternative wordings for items, and an alternative response scale. Cognitive testing also resulted in a deliberately broad phrasing of the question ("importance of factors for your business") in order to include all possible forms of how climate change may affect activities of firms.

[1] The measure was developed by a task force of the Statistical Office of the European Commission (Eurostat). The task force included representatives from statistical agencies and other data collection organisations as well as academics from economics and environmental studies, including one of the co-authors of this paper, while the other co-author served as external expert.
[2] See Eurostat document Eurostat/G4/STI/CIS/2019/Document 11C.

Figure 1 Question on climate change in the CIS 2020

During 2018 to 2020, how important were the following factors related to climate change for your business?				
	Degree of importance			
	High	Medium	Low	Not relevant
Government policies or measures related to climate change	o	o	o	o
Increasing customer demand for products that help mitigate or adapt to climate change (e.g. low-carbon products)	o	o	o	o
Increasing costs or input prices resulting from climate change (e.g. higher insurance fees, higher prices for water, adaptation of processes or facilities)	o	o	o	o
Impacts of extreme weather conditions (e.g. damages, disturbances)	o	o	o	o

Source: Eurostat, CIS 2020 (Eurostat/G4/STI/WG/2019/Document 4).

The final version met the quality requirements set out by Eurostat in terms of comprehensibility, reproducibility and validity. The harmonised data collection for CIS 2020 proposed to position the climate change question upfront (in a first part of the questionnaire) and separate it from a question on environmental innovation. This design should avoid a mutual influence of the two questions and ensure that the climate change question purely focuses on climate change as an external factor for the firm. The question on climate change in the CIS 2020 was a non-mandatory question, i.e., it was up to national statistical authorities to include the question in the national versions of the CIS 2020.

Descriptive results for Germany

In this paper, we use data from the German part of the CIS 2020. The sample of the German CIS 2020 contains 8,462 observations. The results of the climate change question show that 7.3 percent of all firms from the target population of the survey (firms with 5 or more employees from goods production industries and business-oriented services[3]) reported that extreme weather conditions were an important factor for their business, and further 18.7 percent reported medium importance (Table 1).[4] For increasing costs or input prices resulting from climate change, a significantly larger share reported high (18.1 percent) or medium (27.8 percent) importance, showing that adverse impacts of climate change are not confined to a smaller group of firms with weather-dependent business operations, but that there seem to be substantial spillovers to other firms via higher costs. Government policies or measures related to climate change is another factor that is more important (high for 11.9 percent, medium for 22.4 percent) than

[3] Nace rev. 2 classes B to E, 46, H, J, K, 69 to 74, 78 to 82.
[4] Note that all figures reported in this section are weighted results.

extreme weather conditions. Increasing customer demand for products that help mitigate or adapt to climate change was reported by 7.4 percent of firms as highly important and by further 21.4 percent as medium important.

Taking all four types of climate change affectedness together, 28.2 percent of all firms in Germany reported a high importance for at least one of the four factors. Another 32.6 percent did not report any highly important, but at least one medium important factor, showing that a majority of firms in Germany are affected by climate change already.

Table 1 Firms in Germany affected by climate change (2020)

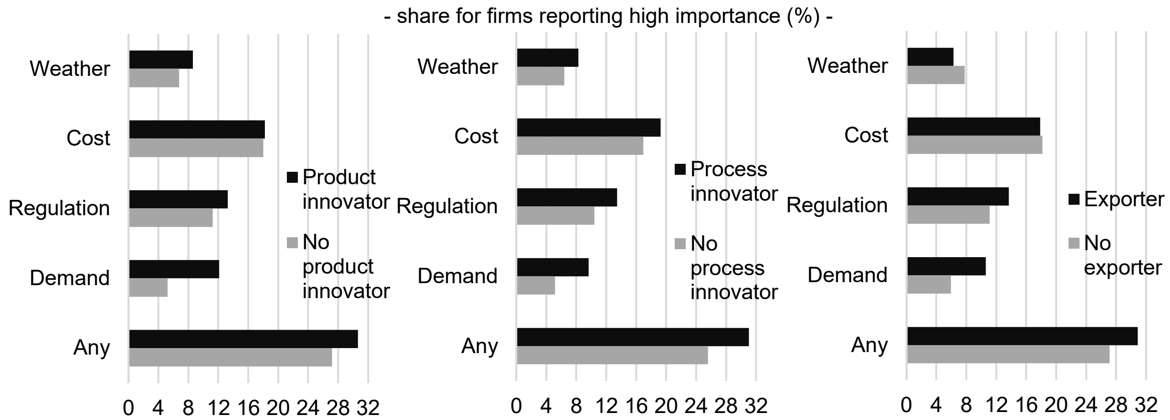
Share in all	Weather		Cost		Regulation		Demand		Any[a)]	
firms (%)	high	medium	high	medium	high	medium	high	medium	high	medium
Total	7.3	18.7	18.1	27.8	11.9	22.4	7.4	21.4	28.2	32.6
Size (employees)										
5 to 9	8.2	17.8	16.6	24.8	10.1	18.0	5.5	18.2	25.1	28.3
10 to 19	5.3	18.7	17.4	25.2	10.5	22.0	7.2	18.6	27.5	32.0
20 to 49	8.0	19.6	21.3	32.1	14.6	25.9	8.0	25.5	31.2	37.2
50 to 99	7.4	20.4	17.1	33.5	13.3	30.3	7.5	26.7	29.8	38.3
100 to 249	7.8	20.5	22.4	34.1	15.9	25.2	12.6	31.6	36.5	38.3
250 to 499	6.6	17.6	16.1	34.7	16.7	32.5	15.9	28.8	32.7	41.1
500 to 999	12.6	14.6	17.7	31.9	20.2	33.3	20.3	31.0	39.1	36.6
1,000+	10.9	18.5	17.1	37.7	24.2	32.1	27.0	27.3	46.2	34.7
Industry (Nace)										
10 to 12	13.2	18.4	30.7	26.3	10.9	18.8	4.8	19.7	39.3	26.5
13 to 15	4.1	14.8	20.4	32.7	4.2	22.1	8.6	25.9	23.5	39.7
16 to 17	10.3	30.9	24.8	43.6	7.7	46.1	14.2	45.6	37.0	42.4
20 to 21	6.0	20.0	22.5	32.2	16.2	29.5	14.6	18.4	37.1	37.2
22	2.3	16.1	21.4	35.2	10.4	38.9	12.5	24.7	33.1	38.5
23	7.9	25.8	32.2	26.5	17.5	37.0	9.8	26.7	41.5	35.3
24 to 25	2.3	15.7	23.1	38.3	12.7	25.4	7.2	18.1	30.2	43.3
26 to 27	1.9	13.4	12.0	31.1	12.6	22.6	7.9	22.5	25.0	35.2
28	10.4	12.8	22.2	27.9	18.3	26.8	14.7	24.0	37.0	31.3
29 to 30	1.5	11.0	21.0	36.7	8.3	39.1	18.8	19.9	34.2	35.2
31 to 33	1.7	13.3	13.8	30.6	7.6	22.8	7.0	17.8	23.7	36.2
5 to 9, 19, 35	12.0	26.4	34.3	32.6	42.9	21.3	23.3	32.9	55.9	27.1
36 to 39	12.2	24.7	16.1	39.0	18.5	29.4	9.1	14.0	31.0	37.3
46	7.7	25.5	15.6	34.5	12.9	24.8	6.8	22.4	29.4	40.8
49 to 53	15.7	27.9	39.8	30.7	25.9	27.2	8.4	31.1	50.8	31.0
18, 58 to 60	3.9	10.0	16.1	29.5	5.3	24.3	9.7	25.3	24.0	34.9
61 to 63	1.8	8.6	3.9	14.8	4.8	8.8	6.8	7.7	10.2	20.0
64 to 66	13.7	16.7	7.7	22.3	7.7	11.6	6.3	17.8	23.6	30.5
71 to 72	6.5	14.2	11.9	24.5	17.4	24.5	12.1	19.5	27.3	32.8
69 to 70, 73	0.4	4.8	3.0	11.2	1.9	8.9	1.1	10.9	5.5	19.7
74, 78 to 82	9.6	27.4	14.6	28.9	6.0	23.7	5.2	26.2	24.4	34.9

a) "high" if at least one "high importance" for weather, cost, regulation or demand; "medium" if no "high importance" for weather, cost, regulation and demand, but at least one "medium importance" for weather, cost, regulation or demand. Source: German CIS 2020, weighted results.

A breakdown by size class reveals that the share of affected firms tends to increase by size, particularly with respect to demand and regulation, but not in terms of higher cost. The size effect partly reflects the observation that larger organisations tend to operate more facilities at more diverse places and offer a large portfolio of products, which all increases the probability that at least some part of their activities is affected by climate change. A breakdown by industry shows that most industries show a share of more than 20 percent of firms reporting high importance of climate change for their business. The largest shares are found for energy supply and mining (Nace 5 to 9, 19, 35) with 55.9 percent and transportation and storage (Nace 49 to 53) with 50.8 percent. Very low shares of firms rating climate change factors as highly important are found in legal, accounting, consulting and advertising services (Nace 69 to 70, 73) with 5.5 percent and telecommunications, computer programming and information technology services (Nace 61 to 63) with 10.2 percent.

The importance of climate change varies by innovator status of the firm. Firms with product innovations more often report to be affected by climate change, which is particularly true for increasing customer demand for more climate-friendly products. This result indicates that firms that are faced by such a demand seem to respond by innovations. The same seems to hold for process innovators. This group shows a higher share of firms that are affected by higher input costs resulting from climate change - which may reflect that process innovation is related to tackle such higher costs through more efficient processes.

Figure 2 Firms in Germany affected by climate change, by innovator and exporter status (2020)



Source: German CIS 2020, weighted results.

For firms selling products on markets abroad (exporters), we also find a higher share of affected firms compared to non-innovators. This result holds for both demand-side impacts and government regulations related to climate change. This finding may be linked to the global dimension of climate change, which challenges internationally active firms to a greater extent.

4. Econometric analysis

Estimation strategy

The aim of our analysis is to investigate the role of climate change affectedness (*cca*) for innovation (*inn*) by considering different types *m* of how firms *i* are affected by climate change, and different types *k* of innovations, while taking into account other factors driving firms' decision to innovate ($\boldsymbol{x}$):

$$inn_{k,i} = f\,(cca_{m,i},\ \boldsymbol{x}_i) \qquad (1)$$

Model (1) is implemented in two ways, (a) through probit regression analysis and (b) by propensity score matching. While the former model includes all firms in order to establish the role of *cca* for innovation, the latter model compares each firm that are affected by climate change with a firm that shows the same features in terms of the vector $\boldsymbol{x}$ (i.e. no statistically significant difference) but which is not affected by climate change. Propensity score matching methods are in general more precise in estimating treatment effects compared to the results of regressions (see e.g. Martens et al. 2008) but this is only the case when a sufficient number of observations is available so that non-treated “twins” for the treated firms can be identified.

We distinguish four dimensions *m* of *cca* as described in the previous section: direct impacts from extreme weather conditions, higher cost, climate change related regulation, and demand for more climate-friendly products. The output variables of our model measure whether a firm *i* has introduced a certain type of innovation *k*, distinguishing various forms of eco-innovation (Horbach et al. 2012) and 'traditional' (non-eco) product and process innovation, following the definitions of innovation and eco-innovation laid down in international manuals (OECD and Eurostat 2018 for innovation, Kemp et al. 2019 for eco-innovation). Both *cca* and *inn* are measured for the same reference period.

All dependent variables are binary so that probit models are applied. For example, for each innovation activity, a firm decides whether to realise a specific innovation activity ($Y = 1$) or not ($Y = 0$). Following the theoretical considerations, different factors such as our indicators for climate change affectedness and additional control variables, summarised by a vector $\boldsymbol{x}$, may influence this decision. Therefore, an estimation of the probability $Prob\ (Y = 1 \mid \boldsymbol{x}) = F\ (\boldsymbol{x}, \boldsymbol{\beta})$ is needed. The $\boldsymbol{\beta}$ parameters reflect the impact of changes in $\boldsymbol{x}$ on this probability (Greene 2008: 772). Average marginal effects for all covariates are calculated, allowing comparisons of the different innovation fields. For the propensity score estimations, we consider *cca* as treatment variable for the outcome variable *inn*. The propensity score matching estimator calculates the conditional probability that an observation receives a specific treatment given certain covariates $\boldsymbol{x}$. The unknown potential output without treatment is estimated using an average of the outcomes of similar subjects (Heckman et al. 1997, List et al. 2003).

Description of variables

The variables *climateweather, climatecost*, *climateregulation* and *climatedemand* indicate the climate change affectedness of firms, based on the four items shown in Figure 1 and discussed in Section 3. A firm is considered to be affected by one of the four types of climate change impact if it reported a high degree of importance of the respective impact on the firm's business activities.

We use a series of dummy variables to capture the innovation behaviour of firms. *Ecoinno* equals one if a firm realised at least one eco-product or eco-process innovation during 2018 to 2020, distinguishing four types of eco-product and nine types of eco-process innovation (based on a standard question in the CIS which has been widely used to analyse environmental innovation activities in firms, see Ghisetti et al. 2015, Horbach et al. 2012, Horbach 2016, Marzucchi and Montresor 2017). Eco-product innovations comprise *energypd* (reduced energy use or CO_2 'footprint' during product use), *emissionpd* (reduced other emissions during product use), *recyclingpd* (facilitated recycling of product after use) and *lifetimepd* (extended product life through longer-lasting, more durable products). Eco-process innovations comprise *energypc* (reduced energy use by unit of output), *matwaterpc* (reduced material and water use by unit of output), *CO2pc* (reduced CO_2 emissions of business operations), *airpc* (reduced other air emissions of business operations), *watersoilpc* (reduced water or soil pollution of business operations), *noisepc* (reduced noise pollution of business operations), *renewablepc* (substitution of fossil energy sources by renewables), *dangsubstpc* (substitution of dangerous substances), *recyclingpc* (recycling of waste, water or materials). Firms are considered eco-innovators only in case they reported that the respective type of eco-innovation made a significant contribution to protecting the environment.

For measuring innovation activities other than eco-innovation, we use the variables *pcnoneco* and *pdnoneco*. *Pcnoneco* equals one if a firm reported a process innovation but did not report any eco-innovation (neither product nor process). Note that the definition of process innovation is based on the fourth edition of the Oslo Manual (OECD and Eurostat 2018) and includes business process innovation related to new or improved organisational methods or new or improved marketing methods. Similarly, *pdnoneco* denotes product innovators without an eco-innovation. In the model estimations on *pcnoneco* and *pdnoneco*, firms with eco-innovations are excluded from the sample so that the reference group are firms with neither eco-innovation nor process innovation (in case of *pcnoneco*) or nor product innovation (in case of *pdnoneco*). Finally, we use the variable *allinno* to denote firms with either eco-innovation or any non-eco-innovation.

Control variables include *size_ln* for the number of employees of the firm, and *age_ln* for the age of the firm in years (both variables in logarithms). *Academic* captures the share of the employees with a university degree. The dummy variable *R&D* describes the fact if the firm realised research activities or not. Furthermore, the dummy variables *export* (existence of export activities of the firm), *subsidies* from public institutions, *cooperation* with other firms or institutions are included. The variable *compintensity* combines different competition relevant situations such as a high threat to market positions because of new entrants, if product or services are rapidly obsolete or if price changes induce a loss of customers. Furthermore, sector dummies are always included but not reported.

For a detailed description of all variables and descriptive statistics see Table A1 in the Appendix.

Climate change affectedness and type of innovation

In a first step, we analyse the climate change affectedness of eco-innovators (*ecoinno*) and all innovators (*allinno*). The results (Table 2) show that all indicators for climate change affectedness are positively correlated to both eco-innovation and all types of innovation supporting H1 and H3. This result corresponds to the descriptive finding that innovators show a higher climate change affectedness (see Figure 2). For all climate change indicators, the marginal effects are always higher for eco-innovations compared to other innovations. The results of the treatment effect models perfectly confirm these findings. For *climateweather* and *climatecost*, average treatment effects based on matching suggest a stronger role for innovation as compared to the marginal effects of probit estimations. Concerning the control variables, the size of the firm (*size_ln*), *R&D* activities, general *subsidies*, *cooperation* activities and competition intensity (*compintensity*) are positively correlated whereas the age (*age_ln*) of the firm is negatively correlated with innovation.

Table 2 Climate change affectedness of (eco-) innovators compared to non-innovators: results of probit estimations and propensity score matching

Correlates	Allinno	Ecoinno	Allinno	Ecoinno	Allinno	Ecoinno	Allinno	Ecoinno
Climateweather	0.056**	0.081**						
	(0.020)	(0.022)						
Climatecost			0.072**	0.130**				
			(0.013)	(0.015)				
Climateregulation					0.082**	0.179**		
					(0.016)	(0.018)		
Climatedemand							0.123**	0.243**
							(0.017)	(0.021)
Size_ln	0.042**	0.025**	0.042**	0.025**	0.042**	0.022**	0.040**	0.020**
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Academic	0.066**	-0.092**	0.071**	-0.076**	0.061**	-0.098**	0.058**	-0.105**
	(0.022)	(0.025)	(0.022)	(0.025)	(0.022)	(0.025)	(0.022)	(0.025)
R&D	0.195**	0.142**	0.194**	0.138**	0.192**	0.134**	0.192**	0.135**
	(0.013)	(0.016)	(0.013)	(0.016)	(0.013)	(0.016)	(0.013)	(0.015)
Subsidies	0.049**	0.048**	0.048**	0.048**	0.047**	0.043**	0.050**	0.049**
	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Export	0.040**	0.014	0.043**	0.019	0.041**	0.018	0.040**	0.014
	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Age_ln	-0.031**	-0.015*	-0.030**	-0.014*	-0.031**	-0.016*	-0.030**	-0.012+
	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Cooperation	0.120**	0.074**	0.121**	0.074**	0.119**	0.070**	0.117**	0.066**
	(0.013)	(0.014)	(0.013)	(0.014)	(0.013)	(0.014)	(0.013)	(0.014)
Compintensity	0.012**	0.007**	0.011**	0.005**	0.012**	0.005**	0.012**	0.006**
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
	climateweather		climatecost		climateregulation		climatedemand	
Average treatment	0.106**	0.136**	0.098**	0.136**	0.088**	0.161**	0.121**	0.254**
effect	(0.027)	(0.035)	(0.018)	(0.023)	(0.025)	(0.036)	(0.025)	(0.028)
Observations	6,483	6,483	6,481	6,481	6,483	6,483	6,481	6,481

Average marginal effects are reported for the probit models, treatment effects models (propensity score matching, average treatment effects are calculated). Sector dummies are included but not reported. Standard errors in parentheses: ** $p<0.01$, * $p<0.05$, + $p<0.1$.

In the next step, eco-innovators have been excluded from the sample to find out which type of other (non-eco) innovations are triggered by climate change. The results (Table 3) show that climate regulation measures (*climateregulation*) do not significantly affect other innovations. The same result holds for climate change related weather conditions (*climateweather*, e.g. storms, inundations, drought). Interestingly, demand for climate-neutral products (*climatedemand*) triggers other product innovations showing that climate neutrality is also relevant for many products that are not specifically reducing negative environmental impacts. The cost of climate change (*climatecost*) triggers other process innovations. This result indicates that firms need to adapt many parts of their production process in order to cope with new challenges resulting from climate change, supporting H3.

Table 3 Climate change affectedness on non-eco-innovations - differences between process and product innovations (results of probit models)

Correlates	Pcnoneco	Pdnoneco	Pcnoneco	Pdnoneco	Pcnoneco	Pdnoneco	Pcnoneco	Pdnoneco
Climateweather	-0.000	0.046						
	(0.025)	(0.036)						
Climatecost			0.044**	0.017				
			(0.015)	(0.025)				
Climateregulation					0.019	0.042		
					(0.019)	(0.029)		
Climatedemand							-0.030	0.112**
							(0.026)	(0.033)
Size_ln	0.027**	-0.001	0.028**	-0.001	0.027**	-0.001	0.027**	-0.003
	(0.005)	(0.007)	(0.005)	(0.007)	(0.005)	(0.007)	(0.005)	(0.007)
Academic	0.001	0.023	0.002	0.024	0.000	0.021	0.002	0.018
	(0.024)	(0.036)	(0.024)	(0.036)	(0.024)	(0.036)	(0.024)	(0.036)
R&D	0.004	0.180**	0.003	0.180**	0.003	0.178**	0.004	0.179**
	(0.015)	(0.023)	(0.015)	(0.023)	(0.015)	(0.023)	(0.015)	(0.023)
Subsidies	-0.002	0.045*	-0.002	0.045*	-0.002	0.045*	-0.003	0.047*
	(0.014)	(0.022)	(0.014)	(0.022)	(0.014)	(0.022)	(0.014)	(0.021)
Export	-0.013	-0.005	-0.011	-0.004	-0.013	-0.004	-0.013	-0.006
	(0.015)	(0.023)	(0.015)	(0.023)	(0.015)	(0.023)	(0.015)	(0.023)
Age_ln	-0.005	-0.021+	-0.005	-0.021+	-0.005	-0.021+	-0.005	-0.020+
	(0.008)	(0.011)	(0.008)	(0.011)	(0.008)	(0.011)	(0.008)	(0.011)
Cooperation	0.030*	0.071**	0.032*	0.071**	0.030*	0.071**	0.030*	0.069**
	(0.013)	(0.021)	(0.013)	(0.021)	(0.013)	(0.021)	(0.013)	(0.021)
Compintensity	0.002	0.006*	0.001	0.006*	0.002	0.005*	0.002	0.005*
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
	climateweather[1]		climatecost[1]		climateregulation[1]		climatedemand	
Average treatment effect	0.101*	0.077*	0.021	-0.003	0.035*	0.055	-0.022	0.154**
	(0.0511)	(0.035)	(0.018)	(0.037)	(0.016)	(0.044)	(0.033)	(0.046)
No. observations	2,831	2,831	2,830	2,830	2,831	2,831	2,832	2,832

Average marginal effects are reported for the probit models, treatment effects models (propensity score matching, average treatment effects are calculated). Sector dummies are included but not reported. Standard errors in parentheses: ** p<0.01, * p<0.05, + p<0.1. [1]In these cases, the average treatment effects models are less reliable compared with the probit models because of very few observations in the non-treated groups preventing the identification of fitting "twins".

Climate Change affectedness and type of eco-innovation

In the following, we aim at finding out which aspects of climate change are relevant for different types of eco-innovation, testing our Hypothesis 2 that climate change exerts different effects on different types of eco-innovation. For this purpose, we restrict the sample to eco-innovators only. This implies that the general impact of climate change affectedness on eco-innovation will not be visible anymore. The marginal effects instead show whether climate change affectedness has a stronger or weaker impact on a certain type of eco-innovation as compared to eco-innovations in general.[5]

The econometric results for eco-product innovations (Table 4) show that demand for climate neutral products (*climatedemand*) leads to stronger innovation activities for all four types of

[5] Results for the entire sample of firms (including firms without eco-innovations) are reported in Table A2 and Table A3 in the Appendix.

eco-product-innovations, i.e. eco-innovation activities are shifted towards eco-product innovation. The highest marginal effect (18.8%) and ATE (15.2%) can be observed for innovations that reduce energy consumption or CO_2 footprint of the product, and the second highest for product innovations that reduce other types of emissions. Climate regulation measures trigger eco-product innovations related to lower energy consumption and other emissions whereas higher costs from climate change (*climatecost*) do not lead to certain types of eco-product innovations. Climate related weather changes (*climateweather*) are pushing eco-innovations towards new products with lower other emissions, though the effect is only weakly significant in statistical terms.

Table 4 Climate change affectedness and eco-innovations - relative impacts on eco-product innovations: results of probit estimations and propensity score matching (eco-innovators only)

Correlates	Energypd	Emissionpd	Recyclingpd	Lifetimepd
Climateweather	0.047	0.070+	0.036	0.026
	(0.040)	(0.038)	(0.034)	(0.036)
Climatecost	-0.013	0.019	0.002	-0.015
	(0.027)	(0.025)	(0.023)	(0.024)
Climateregulation	0.139**	0.134**	0.006	0.004
	(0.029)	(0.028)	(0.024)	(0.026)
Climatedemand	0.188**	0.112**	0.094**	0.075**
	(0.031)	(0.029)	(0.027)	(0.028)
Average treatment effect				
Climateweather	0.034	0.116*	0.062	0.066
	(0.043)	(0.048)	(0.043)	(0.064)
Climatecost	0.027	0.077+	0.050	0.059*
	(0.045)	(0.044)	(0.039)	(0.027)
Climateregulation	0.161**	0.170**	0.029	0.055
	(0.038)	(0.032)	(0.033)	(0.038)
Climatedemand	0.152**	0.112**	0.101**	0.054
	(0.034)	(0.033)	(0.035)	(0.037)
No. of observations	1,747	1,747	1,747	1,747

Average marginal effects are reported for the probit models, treatment effects models (propensity score matching, average treatment effects are calculated). Additional control variables such as size or sector dummies are included but not reported. Standard errors in parentheses: ** p<0.01, * p<0.05, + p<0.1.

The estimation results for eco-process innovations (Table 5) show that climate regulation and demand for climate-neutral products are shifting eco-innovations towards processes that reduce CO_2 emissions (*CO2pc*) or substitute fossil by renewable energy sources (*renewablepc*). There is no additional effect of these two climate change variables on energy efficiency, however. The results of the probit models are confirmed by those of the treatment effect models and suggest that adopting to climate change primarily leads to eco-innovations that substitute dirty by clean technology but put less emphasis on increasing the productivity of the use of natural resources.

Climate-related weather changes (*climateweather*) are highly relevant for eco-process innovations that reduce other air emission and water or soil pollution, as well as for increasing the efficiency of material and water use. Firms that experience higher costs due to climate change (*climatecost*) do not focus on specific types of eco-process innovations, except for reducing water or soil pollution. All in all, our results confirm our Hypothesis 2.

Table 5 Climate change affectedness and eco-innovations - relative impacts on eco-process innovations: results of probit estimations and propensity score models (eco-innovators only)

Correlates	Energypc	Matwaterpc	CO2pc	Airpc	Watersoilpc	Noisepc	Renewablepc	Dangsubstpc	Recyclingpc
Climateweather	-0.007	0.085*	0.054	0.063*	0.099**	0.038	0.020	-0.006	0.026
	(0.038)	(0.035)	(0.036)	(0.031)	(0.032)	(0.030)	(0.035)	(0.026)	(0.036)
Climatecost	0.019	0.038+	0.010	-0.016	0.034+	-0.010	0.034	-0.030+	0.042+
	(0.027)	(0.022)	(0.025)	(0.019)	(0.019)	(0.019)	(0.025)	(0.017)	(0.025)
Climateregulation	0.004	0.018	0.079**	0.016	0.019	-0.018	0.060*	-0.048**	-0.045+
	(0.028)	(0.024)	(0.027)	(0.021)	(0.019)	(0.019)	(0.026)	(0.016)	(0.025)
Climatedemand	0.040	0.034	0.091**	0.032	-0.009	-0.018	0.104**	0.016	0.010
	(0.030)	(0.025)	(0.029)	(0.023)	(0.019)	(0.020)	(0.029)	(0.021)	(0.027)
Average treatment effect									
Climateweather	-0.019	0.116**	0.022	0.067*	0.115**	0.058	0.042	0.058	-0.050
	(0.041)	(0.030)	(0.039)	(0.032)	(0.040)	(0.062)	(0.046)	(0.060)	(0.035)
Climatecost	-0.023	0.021	0.003	-0.033	0.062*	0.002	0.019	-0.027	0.023
	(0.032)	(0.024)	(0.030)	(0.023)	(0.026)	(0.039)	(0.028)	(0.023)	(0.027)
Climateregulation	0.019	0.012	0.113**	0.038	-0.001	-0.019	0.051+	-0.077**	-0.074*
	(0.033)	(0.029)	(0.029)	(0.031)	(0.020)	(0.021)	(0.032)	(0.016)	(0.031)
Climatedemand	0.052	0.028	0.107**	0.077*	-0.006	0.000	0.104**	0.010	-0.040
	(0.037)	(0.035)	(0.036)	(0.031)	(0.024)	(0.027)	(0.036)	(0.028)	(0.031)
No. observations	1,747	1,747	1,747	1,747	1,747	1,747	1,747	1,747	1,747

Average marginal effects are reported for the probit models, treatment effects models (propensity score matching, average treatment effects are calculated). Additional control variables such as size or sector dummies are included but not reported. Standard errors in parentheses: ** p<0.01, * p<0.05, + p<0.1.

5. Summary and conclusions

The paper aimed at shedding light on the way climate change is linked to innovation in firms. We distinguished four dimensions of how climate change may affect firms in their innovation decisions: 1) Direct impacts from extreme weather conditions (e.g. damages from storms) might lead to adaptation measures such as the re-design of buildings and production processes or more climate-resilient products. 2) Furthermore, firms are subject to policy measures to mitigate climate change, such as emission taxes, direct regulations or tradable permits. These measures may incentivise firms to change their production processes and product characteristics in order to comply with the new regulation. 3) Both the effects of extreme weather events as well as climate policy measures can increase firms´ costs, e.g. through higher prices for material, energy or transport. This increase of costs might trigger innovations such as energy saving measures or a shift to more renewable energy, but also innovations to re-design the entire production process. 4) The product demand side should also be considered. A shift of consumer preferences towards products and production methods that are more climate-friendly may lead to a re-design and improvement of existing products or the introduction of new products that meet these requirements of customers.

The most recent Community Innovation Survey of the European Commission (for the reference year 2020) included a question on the extent to which firms are affected by these four types of climate change impacts, allowing an analysis of the link of climate change and innovation. Results from the German part of the CIS 2020 show that 28.2 percent of all firms in Germany reported a high importance for at least one of the four factors.

The results of our econometric estimations reveal that all indicators for climate change affectedness are positively correlated with both eco-innovation and non-eco innovation. For all climate change indicators, the marginal effects are always higher for eco-innovations compared to other innovations. Among non-eco innovations, we find two impacts of climate change. First, demand for climate-neutral products triggers other product innovations, indicating that climate neutrality is also relevant for new products that are not designed to lower negative environmental impacts. Second, increasing costs resulting from climate change trigger non-eco process innovations. Firms need to adapt their whole production processes requiring further innovation activities because of higher energy and climate costs.

Our results offer new insights on how climate change affects innovation. In contrast to the literature survey of Lilliestam et al. (2021), who conclude that there were no considerable effects on technological change, we find strong effects that are not limited to eco-innovations but provide general incentives for more innovation activities. Our result is in line with the finding of von Schickfus (2021) who finds a significant positive relationship between the importance of climate issues in firms and the firms’ green innovation activities, as well as of Joseph (2016), who demonstrates that an increase in the supply of tradable permits lower the number of CO_2 related patents.

Our paper also shows that climate change affectedness exerts heterogeneous effects on eco-innovation. Increasing demand for climate neutral products is particularly triggering eco-product innovations, which is of course not surprising at all. The highest marginal effect can be observed for innovations that lower energy consumption of products. In addition, regulations to mitigate climate change are another important driver for shifting eco-innovation activities towards eco-product innovation. With respect to eco-process innovation, climate policy and the demand for climate-neutral products are significantly and positively correlated to eco-process innovations that reduce CO_2 emissions or substitute fossil by renewable energy sources.

From a political perspective, the results confirm the positive effects of CO_2 regulations not only for eco-innovations, but also for other innovation activities. The role of demand is crucial for eco-product innovations. Strengthening the environmental awareness and an environmentally friendly consumer behaviour appear to be very important for the mitigation of climate change effects.

This paper made a first attempt to investigate how the affectedness of firms by climate change is linked to the firms' innovation activities. Our analysis relied on a new firm-level measure on climate change affectedness which captures four dimensions of how climate change is altering business activities. A main advantage of this measure is to provide a metrics that can be applied to all types of firms from all types of sectors. However, the measure rests on an assessment by the managers of firms, which can be subject to idiosyncratic views. Future research could aim at complementing this assessment-based measure by more objective measures. Another avenue for future research would be to quantify the innovation activities resulting from a firm's climate change affectedness and to relate this quantitative (eco-)innovation impact to other factors that stimulate innovation.

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Table A1: Definition of variables and descriptive statistics

Variables	Description	Mean	Std. Dev.
Innovations (aggregated variables, time period 2018-2020)			
Allinno	1: Innovator, 0: Otherwise	.693	.461
Ecoinno	1: Eco-innovator, 0: Otherwise	.244	.430
Pcnoneco	1: Non-eco process innovations, 0: Otherwise (eco-innovators excluded from the sample)	.523	.499
Pdnoneco	1: Non-eco product innovations, 0: Otherwise (eco-innovators excluded from the sample)	.355	.479
Eco-process innovations (time period 2018-2020)			
Energypc	1: Reduced energy use by unit of output with significant environmental benefit, 0: Otherwise	.098	.297
Matwaterpc	1: Reduced material and water use by unit of output with significant environmental benefit, 0: Otherwise	.053	.224
CO2pc	1: Reduced CO_2 emissions with significant environmental benefit, 0: Otherwise	.074	.262
Airpc	1: Reduced other air emissions with significant environmental benefit, 0: Otherwise	.042	.201
Watersoilpc	1: Reduced water or soil pollution with significant environmental benefit, 0: Otherwise	.031	.174
Noisepc	1: Reduced noise pollution with significant environmental benefit, 0: Otherwise	.035	.185
Renewablepc	1: Substitution of fossil energy sources by renewables with significant environmental benefit, 0: Otherwise	.065	.246
Dangsubstpc	1: Substitution of dangerous substances with significant environmental benefit, 0: Otherwise	.034	.180
Recyclingpc	1: Recycling of waste, water or materials with significant environmental benefit, 0: Otherwise	.072	.259
Eco-product innovations (time period 2018-2020)			
Energypd	1: Reduced energy use or CO_2 'footprint' with significant environmental benefit, 0: Otherwise	.108	.311
Emissionpd	1: Reduced emissions (air, water soil, noise) with significant environmental benefit, 0: Otherwise	.068	.252
Recyclingpd	1: Facilitated recycling of product after use with significant environmental benefit, 0: Otherwise	.060	.238
Lifetimepd	1: Extended product life through longer-lasting, more durable products with significant environmental benefit, 0: Otherwise	.070	.255
Climate change affectedness (time period 2018-2020)			
Climateweather	1: High importance of the impacts of extreme weather conditions, 0: Otherwise	.072	.258
Climatecost	1: High importance of climate change induced costs, 0: Otherwise	.183	.387
Climateregulation	1: High importance of climate regulation measures, 0: Otherwise	.136	.343
Climatedemand	1: High importance of demand for climate friendly products, 0: Otherwise	.102	.303
Control variables			
Size_ln	Number of employees in 2018 (logarithmic)	3.322	1.606
Academic	Share of employees with a university degree in 2020	.253	.296
R&D	R&D activities 2018-2020 (1: Yes, 0: No)	.352	.478
Subsidies	Receipt of subsidies from public institutions 2018-2020 (1: Yes, 0: No)	.229	.420
Export	Export activities (1: Yes, 0: No)	.383	.486
Age_ln	Age of the firm in years (logarithmic)	3.183	.808
Cooperation	Cooperation with other firms or institutions 2018-2020 (1: Yes, 0: No)	.286	.452
Compintensity	Competition intensity	10.34	4.521
Ecopolicy	Importance of existing or future regulations (1: High, 0: Otherwise)	0.222	0.416
Ecosubsidies	Importance of public subsidies for eco-innovations (1: High, 0: Otherwise)	0.054	0.226
Demand	Importance of demand, reputation and self-commitment (1: High, 0: Otherwise)	0.150	0.357
Energycost	Importance of rising energy cost (1: High, 0: Otherwise)	0.180	0.385
Ecoprocurement	Importance of public procurement (1: High, 0: Otherwise)	0.039	0.194

Sector dummies			
Sec1	Food products and beverages, tobacco	.039	.193
Sec2	Textiles, clothing, leather products	.024	.154
Sec3	Wood and paper products, printing	.024	.152
Sec4	Chemical and pharmaceutical industry	.025	.157
Sec5	Rubber and plastic products	.025	.155
Sec6	Glass, ceramics and concrete products	.021	.144
Sec7	Basic metals and fabricated metals	.068	.251
Sec8	Electrical machinery, electronics, instruments	.045	.208
Sec9	Machinery	.060	.237
Sec10	Motor vehicles, other transport equipment	.021	.143
Sec11	Medial products, furniture and other products	.063	.244
Sec12	Energy and water supply, mining, mineral industry	.028	.166
Sec13	Recycling, waste and waste water removal	.047	.211
Sec14	Wholesale trade	.042	.200
Sec15	Transport and logistics	.078	.268
Sec16	Media services	.040	.196
Sec17	Computer programming, data processing, telecommunication	.031	.174
Sec18	Financial services	.053	.224
Sec19	Technical and R&D services	.081	.273
Sec20	Business consulting and advertising	.064	.245
Sec21	Other business services	.121	.326

Table A2 Climate change affectedness and eco-innovations - relative impacts on eco-product innovations: results of probit estimations and propensity score matching (all firms)

Correlates	Energypd	Emissionpd	Recyclingpd	Lifetimepd
Climateweather	0.065**	0.066**	0.044**	0.045**
	(0.018)	(0.016)	(0.014)	(0.016)
Climatecost	0.062**	0.057**	0.041**	0.043**
	(0.012)	(0.010)	(0.009)	(0.010)
Climateregulation	0.142**	0.120**	0.049**	0.055**
	(0.015)	(0.014)	(0.011)	(0.012)
Climatedemand	0.203**	0.142**	0.108**	0.103**
	(0.018)	(0.016)	(0.015)	(0.015)
Average treatment effect				
Climateweather	0.123**	0.138**	0.100**	0.110**
	(0.035)	(0.023)	(0.029)	(0.025)
Climatecost	0.062**	0.059**	0.046**	0.063**
	(0.020)	(0.019)	(0.017)	(0.013)
Climateregulation	0.151**	0.124**	0.057**	0.044**
	(0.017)	(0.018)	(0.015)	(0.016)
Climatedemand	0.199**	0.138**	0.101**	0.112**
	(0.025)	(0.024)	(0.019)	(0.020)
No. observations	6,400	6,400	6,395	6,382

Average marginal effects are reported for the probit models, treatment effects models (propensity score matching, average treatment effects are calculated). Additional control variables such as size or sector dummies are included but not reported. Standard errors in parentheses: ** p<0.01, * p<0.05, + p<0.1.

Table A3 Climate change affectedness and eco-process innovations: results of probit estimations and propensity score models (all firms)

Correlates	Ener-gypc	Matwa-terpc	CO2pc	Airpc	Water-soilpc	Noisepc	Renew-ablepc	Dangsub stpc	Recy-clingpc
Climate-	0.035*	0.056**	0.055**	0.045**	0.057**	0.034**	0.036*	0.016	0.036*
weather	(0.016)	(0.015)	(0.016)	(0.014)	(0.014)	(0.013)	(0.014)	(0.011)	(0.015)
Climatecost	0.066**	0.052**	0.053**	0.029**	0.040**	0.024**	0.050**	0.016*	0.056**
	(0.011)	(0.009)	(0.010)	(0.008)	(0.008)	(0.007)	(0.010)	(0.007)	(0.010)
Climateregu-	0.077**	0.050**	0.093**	0.050**	0.042**	0.026**	0.072**	0.012	0.034**
lation	(0.013)	(0.011)	(0.013)	(0.010)	(0.009)	(0.009)	(0.012)	(0.007)	(0.011)
Climatede-	0.111**	0.069**	0.118**	0.065**	0.043**	0.033**	0.118**	0.043**	0.074**
mand	(0.016)	(0.013)	(0.015)	(0.012)	(0.011)	(0.010)	(0.015)	(0.011)	(0.014)
Average treatment effect									
Climate-	0.080*	0.141**	0.074**	0.090**	0.133**	0.075**	0.086**	0.017	0.043
weather	(0.034)	(0.030)	(0.025)	(0.026)	(0.023)	(0.025)	(0.034)	(0.016)	(0.030)
Climatecost	0.063**	0.057**	0.047**	0.032**	0.057**	0.026**	0.057**	0.030**	0.047**
	(0.014)	(0.013)	(0.012)	(0.010)	(0.012)	(0.010)	0.023	(0.010)	(0.012)
Climateregu-	0.083**	0.050**	0.127**	0.053**	0.041**	0.022*	0.069**	0.003	0.009
lation	(0.021)	(0.017)	(0.029)	(0.017)	(0.016)	(0.010)	(0.015)	(0.008)	(0.011)
Climatede-	0.134**	0.078**	0.148**	0.076**	0.038**	0.033**	0.131**	0.058**	0.101**
mand	(0.024	(0.017	(0.025)	(0.019)	(0.014)	0.015)	(0.024)	(0.016)	0.021
No. observa-tions	6,347	6,342	6,336	6,340	6,342	6,343	6,342	6,341	6,327

Average marginal effects are reported for the probit models, treatment effects models (propensity score matching, average treatment effects are calculated). Additional control variables such as size or sector dummies are included but not reported. Standard errors in parentheses: ** p<0.01, * p<0.05, + p<0.1.

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