Work in Progress Summary: The Effects of Natural Disasters on Green Innovation

In the 21st century, climate change is one of the largest challenges of humankind. Its effects are global, far-reaching, and potentially catastrophic. A common notion in society is that the development of greener technologies is essential for sustaining growth in living standards while simultaneously decreasing the carbon footprint. Likewise, the economic literature emphasizes the role of green innovation in combating climate change. For instance, Acemoglu et al. (2012) develop a directed technical change model where without the switch to green technologies a complete environmental catastrophe is unavoidable.

In this article, we study how the already visible effects of climate change, in particular more frequent natural disasters, affect innovation activity. More precisely, we ask, how exposure to natural disasters affects green innovation, as measured by green patents. We contribute to an existing knowledge gap on how natural disasters affect innovation of mitigation technologies . More generally, we contribute to the scientific discourse about the effects of natural disasters on local beliefs and economic outcomes. To do so, we estimate difference-in-difference models using random variation in natural disaster exposure. Second, we propose in a theoretical model and provide empirical evidence that inventors respond to natural disasters by updating beliefs on future consumer demand for green goods.

We proceed with our empirical analysis as follows: Using patent data from 1994-2014 and the location of inventors from De Rassenfosse et al. (2019), we identify inventors of green technologies and geo-match them to the location of natural disasters. Our sample includes France, Germany, the United Kingdom, Belgium, Italy, the Netherlands, Switzerland, and Poland (referred to as our European sample in the following). We use data from the Emergency Events Database (Guha-Sapir et al. 2022) complemented with geolocations from the Geocoded Disasters dataset (Rosvold and Buhaug 2021). We exploit a patent classification that identifies a patent as green if its technical content is for mitigation or adaptation against climate change. For our event study design, we aggregate all patents and natural disasters by region. These regions corresponds to e.g. the arrondissement level in France, or to Kreise in Germany. In our event study designs we look at innovation activity following the 10 years after each natural disaster. Additionally, we control for technology trends for every region-year pair and include region and country-year fixed effects.

We find that in areas exposed to a natural disaster green patenting increases by about 20%, compared to the sample average. This corresponds to 0.23 additional green patents in the exposed region. For comparison, there are on average 1.12 new green patents per region per year, when taking the average across all 2285 European regions in our sample. Innovation activity picks up slowly in the first year following disaster exposure. This is in line with the time lag associated with innovation activity . Two years after the disaster we already observe an increase of about 10% in green patents. This then increases to 15-25% after 3 years. The effect is persistent on that level and lasts for roughly 9 years, before slowly diminishing 10 years after disaster exposure. We find no effect on non-green patents. Innovation responses are particularly strong for mitigation technologies. Mitigation technologies are those that reduce greenhouse gas (GHG) emissions of electricity generation, goods production, transportation, etc. Perhaps surprisingly, effects for mitigation technologies are stronger than for adaptation technologies e.g. technologies for protection against harsher weather or flood protection. Our results also hold when only considering high value patents as measured by patent citations (Trajtenberg 1990).

We then investigate potential mechanisms driving our results. For instance, local governmental responses such as changes in policy, research subsidies, or local infrastructure projects might influence innovation choices. Innovation could also be affected through belief updating of either the inventor herself, consumers, investors or any other stakeholder. Our observed difference in responses of green and non-green innovation is striking. In particular since much of our observed increase in innovation comes from mitigation technologies. We believe this is indicative of the fact that affected inventors draw a connection to climate change. The literature has shown that the personal experience of natural disasters affects beliefs about climate change itself (Brulle et al. 2012 Akerlof et al. 2013, Taylor et al. 2014, Osberghaus and Fugger 2022, Hoffmann et al. 2022) and its associated risks. Moreover, affected individuals are more likely to support climate policy (Owen et al. 2012, , Egan and Mullin 2012, Hazlett and Mildenberger 2020, McAllister and Oslan 2021, Bechtel and Mannino 2023, Dechezleprêtre et al. 2022).

To formalize our findings and outline the potential mechanism through belief updating, we propose a theoretical model and test its implications empirically. Our model adapts and extends work proposed in Aghion et al. (2023). Consumers have preferences over the consumption value of a good and its carbon footprint.

Put differently, consumers care about a good e.g. "transportation to destination A" and the emissions of their chosen mode of transportation. We extend their model by introducing local inventors and uncertainty about future payoffs from innovation. In our model local inventors have expectations about how much consumers care about their own carbon footprint and thus the value of green goods in the future. These expectations are affected by information shocks through Bayesian updating, e.g. by local natural disaster exposure. An inventor's expectations about the value of future green goods determine her decision to innovate. This is exacerbated by competition. An inventor in a competitive industry is more inclined to innovate, as green innovation differentiates her product from her competitors. We can thus derive the hypothesis that inventors in competitive industries react more strongly to natural disaster exposure.

To test this hypothesis, we show empirically that inventors in competitive industries respond significantly more to natural disaster exposure than those in non-competitive industries. Our findings suggest that inventor's beliefs about the economic environment are strongly affected by their personal experience of climate change.

We rule out government research funding as an alternative mechanism. By matching data on research grants to our sample regions, we show that there is neither a significant uptick in the number of research grants nor in the amount granted to affected areas post natural disaster.

Our work contributes to two strands of the literature in environmental and innovation economics:

First, we contribute to the literature that studies the effects of climate change on innovation, which predominantly focuses on technologies that adapt to the direct damages of climate change. Miao and Popp (2014) show in a cross-country study that floods, droughts, and earthquakes induce more innovation in technologies that directly deal with the adverse effects of these disasters.In a similar vein, Moscona (2021) and Moscona and Sastry (2023) show that droughts and extreme temperature events lead to an increase in agricultural technologies resistant to these changing conditions. In their model green innovation mainly reduces incurred environmental damage for the producer.

Here, our contribution is twofold. To our knowledge, we are the first to show that natural disasters have an effect on mitigation technologies. We thus expand the scope of analysis onto patents for technologies that not only adapt to the adverse effects of climate change but also combat its root cause: green house gas emissions. Mitigation technologies are a significantly larger part of overall green technologies than adaptation technologies. Furthermore, our proposed mechanism highlights a different avenue of how changes in expected consumer demand can affect green innovation. This mechanism is not only relevant in the context of natural disasters, but can apply to other types of information shocks as well.

Second, we contribute to the more general literature that discusses the economic and behavioral impact of natural disasters. The first strand of the literature shows that disasters carry information and thus impact economic outcomes such as migration or labor market sorting. For instance, Boustan et al. (2020) find that out-migration is larger when the disaster carries additional information on subsequent disaster risk, e.g. an unexpected flood that informs on future flood risks. There is also the idea that disasters, through their destruction, force a more efficient outcome, e.g. Hornbeck and Keniston (2017) on faster urban growth, or Deryugina et al. (2018) on more efficient labor market sorting through post-disaster relocation. An additional part of the literature is the already mentioned work on how natural disasters affect environmental beliefs and environmental policy support.

Additionally, our findings speak to the literature on how memory and personal experience shape expectations about economic outcomes (Kuchler and Zafar 2019; Laudenbach et al. 2023; Bordalo et al. 2022; Malmendier and Nagel 2011). In particular we investigate how the personal experience of natural disasters yields changes in inventor expectations. We propose that inventors extrapolate these experiences onto expectations about wider economic conditions, namely green good demand. Thereby, personal experience is instrumental in the high stakes decision of pursuing green innovation.

Lastly, our model highlights an important inefficiency, which gives rise to policy implications. The local character of how information shocks, such as natural disasters, are internalized by the inventor leads to a suboptimal level of aggregate innovation output. We show that a policy maker can improve on the status-quo by equalizing information across locations. Namely, propagating the information to unaffected regions. Depending on the cost of such information campaigns, this is perhaps a more cost effective method of incentivizing green innovation than providing subsidies to inventors.

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