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Impact of Carbon Pricing on Low-Carbon Innovation and Deep Decarbonisation: Controversies and Path Forward

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Abstract

There is an ongoing discussion about the effectiveness of carbon pricing, with a strong division between optimists and pessimists. A recent review study by Lilliestam, Patt and Bersalli (2021) of the impact of carbon pricing on low-carbon innovation and deep carbonization concludes that there is no evidence for such an impact. We evaluate this study and identify various shortcomings of it, which together cast strong doubts on its main conclusion. Instead, we conclude, based on the studies reviewed by the authors and additional, overlooked literature, that carbon pricing has had a small but positive and significant effect on low-carbon innovation. Our evaluation provides lessons for undertaking a systematic and objective review of research on this topic. Since the main goal of carbon pricing is changing choices by firms and consumers that affect carbon emissions, we also point the reader towards recent evidence for the broader effectiveness of carbon pricing.

Keywords Carbon tax · Emissions trading · Energy price · Induced innovation · Investment · Literature review

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1 Introduction

Attention to carbon pricing is on the rise. Many empirical studies examine its effectiveness, efficiency and equity performance compared to other instruments. A recent study by Lilliestam et al. (2021) reviews the empirical evidence for an impact of carbon pricing on technological change. While this type of assessment is timely and policy-relevant, it should be stressed that innovation impact is just one among multiple reasons to promote carbon pricing (Cramton et al. 2017).

In their abstract the authors state that "Critically, all articles examining the effects on zero-carbon investment found that existing carbon pricing scheme have had no effect at all. We conclude that the effectiveness of carbon pricing in stimulating innovation and zero-carbon investment remains a theoretical argument. So far, there is no empirical evidence of its effectiveness in promoting the technological change necessary for full decarbonization." We believe that a critical reader would judge these negative conclusions as being unwarranted, for several reasons—as discussed in the next section. We also provide suggestions for how to improve reviews of such a complicated issue.

2 Eight Considerations

2.1 Too High Expectations

Lilliestam, Patt and Bersalli (LPB hereafter) suggest that a climate policy is not good if it does not quickly and radically reduce emissions and stimulate innovation. By using the notion of "complete decarbonization", the authors create overly high expectations, resulting in an "appeal to extremes" fallacy. Their introductory discussion thus sets the stage for a biased judgement of carbon pricing. It ignores that "complete decarbonization" is an unfair short-term benchmark since climate policy can at best achieve gradual emissions reduction, indicated by policy jargon from distinct disciplines such as transition phases, intermediate (mid-century) targets, etc. Their stage-setting also overlooks that both low-carbon innovation processes and construction of renewable energy infrastructure will take considerable time (and fossil-fuel inputs). In addition, it is evident that a policy mix is needed, as has been acknowledged in economics, innovation studies, and climate policy assessment alike—albeit for distinct and not entirely congruent reasons (e.g., Jaffe et al. 2005; Tvinnereim and Mehling 2018, van den Bergh et al. 2021). Against this background, complete decarbonization is not a fair benchmark for evaluating a single policy instrument.

In addition, one cannot expect strong effects on innovation if carbon pricing is only implemented in some countries (currently covering just 22,3% of global emissions according to World Bank (https://carbonpricingdashboard.worldbank.org/). The reason is that low-carbon innovation responds to opportunities to sell associated products and technologies worldwide, and not just in the country where the innovation occurs (Dosi and Soete 1988; Niosi and Bellon 1994; Atkeson and Burstein 2010; Herrmann and Savin 2017). Hence, a few countries with (low) carbon prices are unlikely to generate a large innovation impact. Therefore, if one finds weak positive impacts, as documented in LPB, one should carefully interpret these rather than downplay them. Ironically, the authors note that "very low carbon prices should not be expected to have substantial effects." But inconsistent with this, their broader discussion suggests that carbon prices prevailing in the past have already been sufficiently high and that enough time has passed to observe considerable impacts on innovation activity. We elaborate these issues in the next two points.

2.2 Absolute Rather than Relative Effects

It was quite surprising to see that the review by LPB confuses small with insignificant effects. The reason is that it focuses on absolute rather than relative (or normalized) effects, that is, it does not control for the level of carbon prices. Evidently, with lower prices effects will be smaller. The authors only refer to maximum absolute carbon prices but not the generally much lower average carbon prices that result from incomplete coverage of emissions and reductions of carbon prices for certain (notably export) sectors.

Taking these factors into account, Finch and van den Bergh (2020) calculate very low average carbon prices in 31 countries with a carbon tax or market. Here the highest price of €38 per ton of CO_2 is found for Norway (while Sweden, often regarded to have the highest carbon price worldwide, is at a third position with €29) and the majority (21 out of 31) of countries have carbon prices below €10. For instance, according to LPB the ETS of New Zealand has no effect on technical change, but perhaps this is not odd given that its average carbon price of €9 falls in the latter category.

More generally, LPB use €25 as a minimum threshold, but only 3 of the 31 countries studied by Finch and van den Bergh have an average price above this threshold. In addition, LPB report only the latest carbon prices, ignoring that until recently these prices were absent or much lower in many cases (witness the EU-ETS), which contributes to a potentially small effect on technological change.

This also raises the question whether stringent carbon pricing is more or less politically feasible than stringent other instruments (i.e., that are equally effective in emissions reduction). Whereas carbon pricing often gets more attention in public media as being resisted, implementation of other instruments (like technical standards) at stringent levels has so far not turned out to be politically feasible or sensitive to incompliance—witness "dieselgate". It is also worthwhile to note that the carbon price of EU-ETS, covering 31 developed countries, has been steadily rising from almost 25 € per ton CO_2 in November 2020 to more than 50 € in May 2021, and has stayed above the latter price since (i.e. until the moment of finishing this article, end of July 2021).[1] This severely undercuts the suggestive argument that high carbon prices—evidently needed for larger emission-reduction impacts through induced innovation and behavioural changes of households and firms—are not feasible. A critical factor underlying policy feasibility is international harmonization to avoid freeriding by national governments (Jordan and Lenschow 2010). Considering the example of successfully harmonized climate policies, carbon markets come out best as they have been already integrated among regions or countries in North America and Europe (van den Bergh et al. 2021). All these facts suggest we need to focus more, not less—as suggested by LPB—on carbon pricing.

2.3 Short Time Period for Induced Innovation

Whereas carbon prices have a very short history, innovation effects take a long time, given considerable lead times and uncertain outcomes of research, development, demonstration,

[1] https://ember-climate.org/data/carbon-price-viewer.

deployment, widespread diffusion, and feedbacks between these phases. To illustrate, Cantner et al. (2016) employed a time span of three decades (1980–2011) to identify the influence of the German policy mix on innovation activity in renewable energy. LPB's review focuses on studies that mostly (with the exception of studies for the Nordic countries) have a time span of 5–10 years only. This suggests it is too early to make definite statements about the lack of impact of carbon pricing on innovation or deep carbonization. Unfortunately, the authors do not give this subtle issue the attention it merits.

2.4 Incompleteness of the Review

One may also question the scope and completeness of the review. To begin with, it does not mention another review by Martin et al. (2016) of the impact of the EU Emissions Trading System (EU-ETS) on innovation, and neither various primary studies covered by it (e.g., Hoffmann 2007; Rogge and Hoffmann 2010). This older review paper concluded that "clean innovation has experienced a steep increase since 2005, and there is robust evidence that the EU-ETS caused a small part of this increase in phase II." In addition, another overview study by Tietenberg (2013) and various studies cited therein (e.g., Bellas and Lange 2011; Sterner and Turnheim 2009; Johansson 2000) are neither mentioned. This is unfortunate, as all these studies conclude positively about there being empirical support for carbon pricing inducing emission-reducing innovation.

LPB further overlooked an important study using an impressive firm-level panel dataset to analyse innovation in the automotive industry across 80 countries over several decades (Aghion et al. 2016). It found that firms tend to innovate more in clean (and less in dirty) technologies when they face higher tax-inclusive fuel prices. This study provides arguably more comprehensive and solid evidence than some other studies covered by the LPB review, which tend to rely more on qualitative and arguably less reliable methods, such as case studies or interviews with a selected set of firms or industry representatives.

2.5 Downplaying Positive Findings

The study by LPB further downplays effects documented in several reviewed studies, stating that no clear effect was found. However, Table 4 of their article indicates that of the 19 studies they review, 4 had positive effects (even though weak), one had no effect, and 14 are summarized as N/A (not available). It is not clear then why these 14 studies were included in the review. They confuse a clear view on the main finding, namely that among the reviewed studies which actually measured the role of carbon pricing on innovation, the positive result, even though weak, is dominant: namely 4 out of 5 studies, i.e. 80% of relevant studies. The authors somehow recognize this as, contrary to the overall negative claims they make in the abstract and general conclusions, their final section also contains the moderating statement "in actual, existing carbon pricing schemes, technological change effects have been very modest." Nevertheless, even this comes down to downplaying as it does not recognize points 2 and 3 above.

In addition, it should be noted that some interpretations and summaries by the authors deviate from the original primary papers: for example, Calel and Dechezleprêtre (2016) find that the EU-ETS increased low-carbon innovation among regulated firms by as much as 10%, while not crowding out patenting for other technologies; however, these findings are summarized in the table as "2% increase" based on the debatable argument that "the regulated firms account for only a small portion of all low-carbon patents, only 2% of the post-2005 surge in low-carbon patenting can be attributed to the EU-ETS."

Our discussion in points 4 and 5 illustrates that there is considerable and undeniable empirical evidence for a significant impact of carbon pricing on low-carbon innovation.

2.6 Older Evidence for Induced Innovation through Energy Prices

The review by LPB ignores older evidence showing a significant impact of energy prices on the speed and direction of energy innovation. For instance, a much cited and award-winning[2] study by Popp (2002) uses US patent data from 1970 to 1994 to estimate the effect of energy prices on energy-efficient innovations, finding a strong positive effect. While this omission may perhaps be justified, it would be good to acknowledge that this type of evidence is directly relevant for assessing carbon pricing, as the latter's innovation effects will inevitably run through energy prices.

The literature on energy innovation and prices can be considered as complementary to that on carbon pricing because it addressed a longer history of prices and innovations, in turn allowing for more comprehensive statistical analysis of their relationship. Both classic studies by Newell et al. (1999) and Popp et al. (2010) find that innovation increased significantly following periods with higher energy prices. In a more specific context, Noailly and Smeets (2015) find, using patent data on both fossil-fuel and renewable-energy technologies for 5000 European firms from 1978–2006, that higher fossil fuel prices encourage renewable energy innovation. For more evidence see the review by Popp (2019).

2.7 Evidence for General Effectiveness of Carbon Pricing

The article by LPB also questions the effectiveness of carbon pricing in general to reduce emissions beyond innovation impacts, through behavioural change by consumers and firms, possibly in combination with adoption of low-carbon technologies or substitution of energy inputs. However, several studies using relevant data and state-of-the-art statistical methods provide strong evidence to the contrary. For example, Sen and Vollebergh (2018) estimate the long-run effect of a carbon tax on energy consumption for OECD countries, finding that 1€ increase in energy taxes reduces fossil-fuel based carbon emissions by 0.73% in the long run.

A second study by Best et al. (2020) analyses data for 142 countries over a period of two decades, 43 of which by the end of the study period had a carbon price in place at the national or sub-national level. They find that average annual growth of CO_2 emissions is about 2% lower in countries with a carbon price, and that 1€ per ton of CO_2 reduces annual emissions growth by 0.3%. As these results are for low carbon prices, they reflect a high relative effectiveness.

A third study by Bayer and Aklin (2020) focuses on the EU-ETS, finding that between 2008 and 2016 it avoided 1.2 billion tons of CO_2 emissions, equivalent to 3.8% of total EU-wide emissions. Moreover, emission reductions in sectors covered by EU-ETS were higher, namely between 20 and 25% against the counterfactual.

[2] Namely the "2017 Publication of Enduring Quality Award" from the Association of Environmental and Resource Economists.

Finally, the review of studies of EU-ETS by Martin et al. (2016) concludes that "First, concerning the issue of carbon emissions, the available evidence suggests that the EU-ETS has had a robust negative impact on them. Sector-level studies find that emissions across all regulated sectors—energy and industry—declined by around 3 percent in phase I and during the first 2 years of phase II, relative to estimated business-as-usual emissions. Based on firm-level data for France and Germany, there is robust evidence of a reduction in emissions by industrial firms during phase II (in the range of 10 percent to 26 percent)". All these results are not surprising in view of the solid theoretical arguments and formal-model support for the effectiveness of carbon pricing, for both emissions trading and carbon taxation (e.g., Baumol and Oates 1975; Tietenberg 1985; Hahn and Hester 1989; Newell and Stavins 2003; Aldy et al. 2010; van den Bergh 2011; Cramton et al. 2017; Baranzini et al. 2017).

2.8 Impact on Deep Carbonization is Easily Underestimated

The abundant evidence in the previous point further casts doubt on LPB's conclusion that carbon pricing is not essential for achieving deep carbonisation. Indeed, not only does carbon pricing positively affect innovation, but more importantly it alters decisions of all consumers, producers and investors towards low-carbon options. Because of its economy- and society-wide scope, this could well create a social multiplier effect (Konc et al. 2021) or even contribute to surpassing thresholds of social tipping points (Otto et al. 2020). If implemented well, i.e. covering all carbon-containing energy sources, then it will regulate all indirect carbon emissions due to lifecycle effects, and hence limit any rebound effects (van den Bergh 2011; Font Vivanco et al. 2016; Freire-González 2020)—unlike other instruments, such as technical or performance standards that tend to be sector-, product- or technology-specific. Carbon pricing will stimulate both technology innovation and adoption as well as substitution of high- by low-carbon inputs. If such changes fail to achieve sufficient emissions reduction, e.g. as innovation takes a long time, prices of final goods will inevitably rise, in turn encouraging less consumption of high-carbon goods and services. In other words, carbon pricing regulates both demand and supply sides of the economy. For moderate to high carbon prices, the overall effect of all these impacts can therefore be substantial, contributing greatly to deep decarbonization provided such prices are active over a sufficiently long period of time. Under such conditions small emission-reduction effects per unit of time will translate into considerable long-term effects.

In fact, it is hard to imagine full market penetration of zero-carbon technologies and systems without getting the prices right. This does not mean other factors are not important, but one should not overlook the importance of relative prices. This is also confirmed by the literature on induced innovation and directed technological change (Acemoglu 2003; Popp et al. 2010; Acemoglu et al. 2012). It provides evidence for many technologies that higher relative prices of an input factor, whether the result of policy or market forces, tend to steer innovation in the direction of saving on the use of the (more expensive) factor. Moreover, the higher the price, the more such innovation is accelerated. Popp (2019) confirms these general findings in a recent overview of evidence for environment and energy. Of course, differences between sectors should be expected. A main exception where energy prices matter less is in energy conservation in the building sector, due to principal-agent problems limiting the impact of energy prices on energy use. This holds especially true for less visible technologies like insulation. However, even here, positive innovation effects of energy prices have been documented, notably for visible technologies like boilers and lighting (Noailly 2012). Of course, building norms and standards provide a good if not necessary complement.

The contribution of carbon pricing to deep carbonization is supposedly captured by LPB in the column for zero-carbon investment of Table 4. Here they list seven times "no effect" and 12 times "N/A". It is not clear, though, how they judged the "no effect" exactly—in fact, it seems to be the outcome of a very subjective assessment of the empirical evidence in the respective studies (the paper offers no details on it). Just as an example, LPB write "A set of articles, including all for British Columbia and one for Sweden, find strong emission reductions in the transport sector […] as Sweden and British Columbia have very low shares of electric cars and trucks in the investigated periods, we conclude that these results cannot be due to zero-carbon investment." But it remains unclear how the latter is related to the former. More generally, we do not understand how such a big issue of deep decarbonization, surrounded by complexity and uncertainty, can be so easily and with so little information judged by the authors. In particular, it is unclear what exact criterion LBP used to assess a significant impact on deep carbonization. We feel a more thorough, explicit and careful assessment approach would be needed.

3 Conclusions and Lessons

In summary, the review by LPB can be criticized on various accounts: creating too high expectations through use of the benchmark "complete decarbonization", not accounting seriously for low carbon prices in the past and—in line with this—failing to distinguish between relative or normalized effects, neglecting the relevance of the time period for observing induced-innovation impacts, overlooking many relevant studies with positive conclusions, downplaying positive findings of covered studies, and neglecting relevant older evidence for induced innovation by energy prices.

These multiple shortcomings mean that the overall conclusion of LPB lacks a firm foundation, and thus needs to be amended. As we demonstrated, there is a lot of evidence that carbon/energy pricing affects innovation, which should not come as a surprise since prices and associated costs are likely to affect deliberations about investment in innovation trajectories. This, of course, does not deny the relevance of other instruments to encourage innovation. Direct innovation support, such as through R&D subsidies, is needed next to carbon pricing to overcome short-term selection pressure against promising but still expensive technologies and to aid escape from lock-in of high-carbon technologies (Cowan and Hulten 1996). These insights are well supported in both environmental economics and innovation studies (Unruh 2002; Jaffe et al. 2005; Aldy et al. 2010; van den Bergh 2013; Popp 2019).

One may wonder why LPB arrived at such a strong conclusion that is clearly unsupported by the studies reviewed and not in line with other reviews (Tietenberg 2013; Martin et al. 2016; Popp 2019). An earlier article by two of its three authors (Patt and Lilliestam 2018), which was heavily criticized by Kirchner et al. (2019) for overlooking essential arguments in favour of carbon pricing, may provide some clarification. In this article, the authors expressed themselves very negatively about carbon pricing. This suggests that in their review they may have displayed confirmation bias (Nickerson 1998), that is, looked for and interpreted the evidence to support their initial beliefs about carbon pricing.

The eight considerations in our evaluation may be seen to provide the following lessons for undertaking more systematic and objective review studies of carbon-pricing impacts and related topics:

- Being as exhaustive as possible in searching and selecting studies, to avoid bias towards studies that are better known, more easily found, or confirm a desired outcome. One way to achieve this is conducting a systematic search through databases like Scopus or Web of Science using a wide set of suitable keywords. This will deliver an extensive list of potentially relevant studies. Next, one can go through the reference lists of the most recent studies found to identify additional relevant studies.
- Evaluating studies fairly and deriving relative or normalized effects. This is needed to clearly separate small from insignificant effects, instead of assuming that the first implies the second. This requires investing considerable time in the topic and the relevant literature as well as acquiring a good understanding of the primary data and methods used to analyse these.
- Using a fair and realistic conceptual benchmark, in the form of a future target for emissions reduction, consistent with the time period observed, to evaluate if changes are significant and reasonable given the relevant time frame.
- Interpreting empirical results of primary studies by adequately contextualizing policies in terms of their evolution over time (notably changing stringency) and geographical heterogeneity, as this allows to add moderator variables to the review, creating added value to the individual studies.
- Comparing insights with those from older empirical literature on similar topics, such as in this case the role of carbon versus energy prices in induced, directed technical change.

The possibility to quickly gather primary studies on a particular topic, through keyword searches in online databases, explains why we currently see so many review studies by authors with relatively little experience on the respective topic. As opposed, reviews traditionally were written by recognized experts, who often spent decades in a specific research area before writing down their extensive knowledge in the form of a literature review. Given the potential authority and influence of review studies, perhaps this means that in evaluating submissions of related papers, journals should be extra critical and involve more than the usual number of reviewers.

To acquire more evidence for the exact speed with which carbon pricing and other instruments can decarbonize the economy, it would be good if governments would be more open to experiment during certain periods with more stringent policy settings. In this respect, both those pro and contra carbon pricing might want to lobby with politicians and policy-makers to follow a more scientific approach of trial-and-error to learn about distinct policies, including policy mixes. This would also allow disentangling better the effects of price versus non-price interventions in directed technical change for a low-carbon economy (Popp 2019).

Our own assessment of the empirical literature is that carbon pricing has significant and relatively large normalized effects (i.e. accounting for the low level of prices so far), in terms of emissions reduction in general (through behavioural change, technology adoption and substitution) as well as pure innovation impacts. Nevertheless, it would be good to undertake more study of the relative contributions of each of these factors, as well as the moderating or synergetic role of complementary instruments (van den Bergh et al. 2021). Both represent ambitious research challenges as they require quantifying policies as well as effects of behaviours, technologies and inputs for both consumers and producers. Fortunately, environmental economics has shown to not be afraid of tackling difficult questions.

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