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Analysis

Investigating the impacts of technological position and European environmental regulation on green automotive patent activity

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ABSTRACT

Using patents data on environmental road transport technologies filed by 355 assignees over the period 1999–2010, the paper investigates under what conditions the European environmental transport policy portfolio and the intrinsic characteristics of assignees' knowledge boost worldwide green patent production. The findings suggest that post-tax fuel prices, environmental vehicle taxes, CO_2 standards and European emission standards, introduced into the empirical model through an innovative methodology based on Self-Organising Maps (SOM) (Kohonen, 1990, 2001), positively influence the creation of environmental inventions. Most importantly, the paper highlights that assignees anticipate the introduction of regulatory instruments (*i.e.* European emission standards and CO_2 targets) by filing patents before the effective implementation of regulations when legislation is announced. Furthermore, the paper provides evidence that in a technological space (which measures the applicants' technological proximity), closely located assignees enhance their patent output through the exploitation of technological knowledge produced by others. This means that the greater the proximity between assignees, the higher their likelihood of gaining advantage from this potential spillover pool. Finally, the paper observes that dynamic changes in assignees' patent portfolios spur inventive performances.

1. Introduction

In a complex framework such as long-term climate policy analysis, market failures play a pivotal role by threatening the achievement of environmental and innovation objectives. One of these objectives is the development and exploitation of eco-innovation, defined as 'the production, assimilation or exploitation of a product, production process, service or management or business method that is novel to the organisation (developing or adopting it) and which results, throughout its life cycle, in a reduction of environmental risk, pollution and other negative impacts of resources use (including energy use) compared to relevant alternatives' (Kemp and Pearson, 2007; pp.7). However, an absence of interventions by policy makers to create the incentives to internalize and share the costs of pollution encourages firms to pollute too much and innovate too little with respect to the social optimum (Johnstone et al., 2010).

Although the literature on environmental policy-induced innovation has provided evidence that green policy spurs eco-innovation (see Popp et al. (2010) for a detailed survey), environmental regulation is only part of the story. In fact, interacting market failures associated with both environmental pressure and the creation of new technologies may bias policy analysis.

Since those market failures arise from both the negative environmental impact of economic activities and the positive externalities of knowledge creation, the majority of studies lack investigation of what influences technological change from a combined institutional and technological perspective that may fill the gap in the understanding of endogenous technological change.[1] Thus, the study of this dynamic interaction appears important because investments in technological knowledge are exposed to uncertainty, high costs, information asymmetry, and positive externalities (*i.e.* other firms may benefit without incurring all the development costs) (Jaffe et al., 2005), all of which may reduce innovative performances even if environmental policies have been properly designed.

Using patents as a proxy for invention, the present paper delves into what triggers green invention development. It includes both the European environmental policy portfolio and the intrinsic characteristics of knowledge (*i.e.* the potential spillover pool and dynamic knowledge compositeness) in the analysis.

To this end, the paper focuses on those automotive technologies that allow for a reduction in the environmental impacts of the road transport sector, this being one of the main sectors most responsible for different environmental externalities (*e.g.* greenhouse gas (GHG) emissions) (Timilsina and Dulal, 2011), and one of the major R&D investors in Europe (Ploder, 2011).

This paper makes manifold innovative contributions. First, it 'unpacks the box' of environmental inventions by distinguishing among several sub-fields of inventive activities that compose the environmental patent data set related to passenger cars (see Section 3.1).

[1] Popp (2002) and Aghion et al. (2012) are exceptions.

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For this purpose, it employs the so-called Self-Organising Map (SOM) (Kohonen, 1990, 2001). This is an unsupervised Neural Network (NN) technique able to detect similarities in multidimensional data and represent them in a two-dimensional map where an overall order is achieved. That is, through an iterative process, this technique measures the Euclidean distance (ED) between the multidimensional input data and the interconnected lattice of nodes, *i.e.* the SOM. Once the winning map node (*i.e.* the node with the lowest ED) has been detected, the learning process creates a map similar to the input data by shrinking the nodes located in the neighbourhood towards the winning node (Kohonen, 2013). Thus, in the output map similar items are placed closer to each other, whereas less similar ones are mapped further away (Kohonen, 2013).

The added value of this methodology is that it makes it possible to create distance-based maps where the patents, assignees, or emission standards are mapped in relation to specific and relative characteristics of their multidimensional input data. That is, the learning process allows each map node to become more similar to the assigned input data. Moreover, the other map nodes move closer to each selected node, undergoing or causing the shrinking of the neighbour nodes.

Most importantly, the distance between the mapped items can be measured, used as a proxy for the similarity of input data and employed in empirical analysis. Indeed, in the first application of this technique patents and their technological classes were employed to build a distance-based patent map that identified the technological domains that characterised the automotive technology space.[2] The distance between patents was then used as a proxy for their technological relatedness in order to obtain clusters of technologies. In the second application, we ran the SOM using as input data the distribution of patents filed by each assignee in each specific technological field defined in the previous SOM exercise. The distance among assignees was used as a proxy for the similarity of assignees' knowledge base. Finally, in the third application the input data were maximum thresholds of pollutants allowed by European emission standards and CO_2 targets. In this case, the distance among the items mapped was used as a proxy for the stringency of generic regulatory instruments.

Furthermore, we investigated whether assignees are able to anticipate the effective introduction of mandatory environmental policies by developing inventions when regulations are announced.

Finally, we shed light on the effect of European regulation on foreign inventive activities carried out to comply with the European regulatory system. Differently from those studies that investigate innovation diffusion, this paper makes use of 'prior' patents (*i.e.* earliest patent applications within a patent family whose priority country is European), to test whether the geographical context impacts on assignees' responses to regulatory changes.

The paper is structured as follows: Section 2 presents the literature on both the innovation impact of environmental policy instruments and the knowledge characteristics that spur innovative performances. Section 3 describes the methodological framework through which the independent variables were built. Subsequently, Section 4 introduces the empirical model and Section 5 describes the results. Finally, Section 6 concludes.

2. Theoretical Background and Provable Hypotheses

2.1. Environmental Policies and Innovation

In recent decades, several scholars have investigated the relationship between environmental policies and technological change, with results that provide evidence of a positive impact of the former on the latter (Green et al., 1994; Porter and Van der Linde, 1995; Kemp, 1997; Rennings, 2000).

Popp et al. (2010) surveyed empirical studies on policy-driven innovation. The results of this branch of literature depend, at least in part, on the kind of data used to proxy innovation and environmental policies, and on the sector analysed. For example, Jaffe and Palmer (1997) found a positive correlation between pollution abatement control expenditures (PACE) (used to proxy regulatory stringency) and R&D spending, but they did not observe any effect of this policy instrument on patent activity. By contrast, Brunnermeier and Cohen (2003) highlighted a positive relationship between green patents and PACE.

In a recent comparative study between the automotive and energy sector, Bergek et al. (2014) have explored whether different environmental policy instruments support different types of innovations. The paper builds upon an environmental policy classification that groups regulations into four main groups. On the one hand, green regulation differs in the prescriptiveness of the instruments, *i.e.* economic *vs.* regulatory (mandatory). On the other hand, instruments diverge according to their technological neutrality, *i.e.* specific or general. Bergek et al. (2014) have observed that general economic instruments (*e.g.* CO_2 taxes, ETS, *etc.*) boost incremental innovation, while general regulatory instruments (such as emissions regulation) trigger modular innovation. Finally, technology-specific instruments are suitable for spurring the development of radically new technologies.

Economic instruments provide the incentives to adopt and develop environmentally-sound technologies. Such incentives take the form of economic compensation for the avoided social cost of pollution (Bergek et al., 2014). The literature on general economic instruments in the automotive industry has mainly examined the effect of fuel prices on boosting the development of environmental technologies. Aghion et al. (2012) analysed the effect of tax-inclusive fuel prices on patent activities across worldwide firms. The results evidenced a positive relationship between fuel price, used as a proxy for carbon tax, and environmental innovation.

Due to the fact that fiscal policies also comprise environmental taxes other than fuel taxes (*i.e.* environmental vehicle taxes) (Timilsina and Dulal, 2011), the literature has explored what spurs innovation beyond fuel prices. This class of polices (*e.g.* registration taxes, purchase taxes and subsidies, *etc.*) have been scrutinised by Klier and Linn (2012), who discussed the role of such instruments in promoting car registrations and average vehicle CO_2 emission rates. While it was found that these taxes had a significant negative effect on new vehicle registration, the analysis provided little evidence on the decrease in long-run vehicle emission rates.

Furthermore, the literature acknowledges that, together with economic instruments, regulatory environmental policies can be implemented to boost technological change. This broad range of regulatory policies influences firms' actions by prescribing specific technological solutions (technology standards), by establishing upper thresholds to emission levels (emission standards), or by imposing maximum limits of emissions per unit of output (performance standards) (Bergek et al., 2014).

In the automotive industry, the main general regulatory instruments are performance-based standards such as fuel economy, CO_2 and noxious emission standards. As regards the former, Clerides and Zachariadis (2008) found that the introduction or adoption of more stringent fuel economy standards and fuel prices improved new-car fuel efficiency. In addition, the authors observed that in Europe and Japan fuel economy standards have a greater impact than fuel prices. In another noteworthy study, Hascic et al. (2009) analysed how fuel prices, emission standards and on-board diagnostic systems of one country affect automotive green patent activities in the others. The results of their study showed that green inventions have been impacted in a greater and more positive way by foreign regulation than by domestic standards.

Lee et al. (2011) underlined the positive effect of US technology-forcing auto emission standards on innovation in the automotive industry between 1970 and 1998. They found a positive effect:

[2] Section 3.1 and Appendix B show the technicalities of the SOM. Appendix C reports the results of the clustering process and the main key words that characterise each cluster.