Going Green: Environmental Regulation and Collaboration Networks

Extended Abstract

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This paper contributes the literature on the determinants of eco-innovation, by investigating the impact of collaboration networks and environmental regulation, and of their interaction, on the generation of green technologies (GTs).

According to the general innovation theory, both technology push and demand-pull factors are key drivers of technological development and innovation activities. However, when considering environmental innovations there might be no clear economic incentives, due to the well-known double externality problem (Jaffe et al. 2005; Rennings 2000). Therefore, deployment policies and institutional factors may play an important role in the introduction of eco-innovations. Environmental regulation engenders the so-called regulatory push/pull effect, through the creation of new market niches for green technologies, which stimulates the advancement of knowledge in these fields. The derived demand of agents in downstream sectors is a powerful channel triggering eco-innovating efforts in those operating the upstream ones.

The analysis of the determinants of GTs has received increasing attention during the last decades. Several theoretical and empirical studies identified regulation as a key driver of environmental innovation. In this direction, a relatively large literature has focused on the relationship between environmental regulations and eco-innovation (Lanjouw et al. 1996; Brunnermeier et al. 2003; Popp 2003; Popp 2006; Arimura et al. 2007; Johnstone et al. 2010; Lanoie et al. 2011; Lee et al. 2011). On balance, these studies provide evidence of the positive relation between the regulatory framework and the generation of GTs. Other studies, instead, have explored the impact of environmental regulation on firm performance, providing contrasting evidence (Jaffe et al. 1997; Gollop et al. 1983; Berman et al. 2001; Lanoie et al. 2011), and, more recently, the effect of policy stringency on environmental performances (Ghisetti et al. 2017). However, relatively little is known on how the regulatory framework affect the knowledge generation process (Ghisetti et al. 2015; Arfaoui et al. 2015). The implementation of environmental policies is expected to engender an adaptation process in economic agents confronted with sudden changes in the regulatory framework. According to the induced innovation approach, agents are then expected to respond to such

perturbations by changing their relational structure. Therefore, the present study represents an attempt to understand the process through which the stringency of environmental regulation, by shaping the network of relations of firms, may spur technological innovation, stimulating advancement in GTs.

Prior research has long recognized the importance of inter-firm collaborations on firm innovation performances (Freeman 1991). Drawing upon the Schumpeterian vision of innovation as the result of a novel recombination of existing elements, a new approach to the analysis of knowledge production has emerged in the literature (Weitzman 1998). In the recombinant knowledge approach, the generation of new knowledge involves the novel recombination of existing "pieces" of knowledge (Fleming 2001). New technological knowledge is considered as the outcome of a collective process of active agents operating in context characterized by complementary sources of knowledge as well as frequent and qualified interactions. The recognition of the key role of external knowledge in the production of new knowledge, which is strongly complementary to internal knowledge (Cohen et al. 1990), makes clear that firms innovative success may extremely depends on the amount and the quality of their interactions. In this settings collaboration networks can become the locus of innovation (Powell et al. 1996) and then a network perspective enables the study of the mutual relations between the pattern of knowledge generation and firm collaborations.

A growing body of research has already assessed the importance of structural properties of collaboration networks and their effects on innovative outputs (Ahuja 2000; Uzzi et al. 2005; Schilling et al. 2007; Maggioni et al. 2007; Cantner et al. 2007; Maurseth et al. 2002). Only recently scholars have begun to follow a novel research path by studying the determinants of inter-organizational relationships and the consequent knowledge exchange between them. However, few studies adopted a dynamic perspective in order to explain the formation of inter-firm networks, how their structures evolve in time and how individual factors affect this process (Balland 2012; Balland et al. 2013; Ter Wal 2013). These works mainly focused on assessing the relative importance of proximity dimensions (i.e geographical, organizational, institutional, social and cognitive) in driving network formation. To our knowledge, empirical research has not yet examined the role of green technologies on the formation of collaboration networks and their evolution. Furthermore, social network studies have underlined the importance of getting a deeper understanding of relational structures and how these co-evolve with individual outcomes. In fact, as the network configuration changes in consequence of actor behavior and of endogenous network mechanisms, also the behavior of actors can change as a function of itself and of the network structure. The simultaneous estimation of collaboration network dynamics and the generation of green technologies can provide new evidence on the mutual dependence between the two processes, on how they influence each other and clarify how the environmental policy affects both.

In this paper, the analyses are carried out on a newly constructed dataset of European firms, over the period 2005-2012. The panel includes all the publicly reported alliances between firms located in France, Germany, Italy, Spain and United Kingdom in the period considered. Alliance data have been collected via SDC Platinum database, including both joint ventures and strategic alliances agreements. The choice of studying the network structure of publicly reported partnership has been guided by the importance of strategic alliances and joint ventures as a mechanism for the sharing of knowledge among a wide range of firms and industries, as confirmed by previous research (Powell et al. 1996; Gulati 1998). The database has been then integrated with additional firm level data. Balance sheet information are gathered from the Bureau Van Dijk AMADEUS database. Great efforts have been spent in matching firms involved in alliances, as reported by SDC Platinum, with its corresponding record in Amadeus. The resulting dataset includes 4408 firms (of which 3312 successfully matches Amadeus-SDC) involved in 3561 alliances. We filled this dataset with the OECD Han Database information in order to extract the history of patent applications, submitted by each firm, available in REGPAT (since 1977). For matched firms presenting at least one patent application, we looked at their IPC codes in order to assign these patents to the green realm. Finally, to investigate role and effect of the environmental policies we used the OECD Environmental Policy Stringency Index (EPS), which measures, yearly, the stringency of the environmental policy at the country level.

The empirical analysis is articulated in two steps. As a first step, we empirically test the existence of a relationship between the stringency of environmental regulation, as measured by the OECD Environmental Policy Stringency index (EPS), and green technologies, proxied by patent applications. The second step involves the analysis of the structure of the collaboration network, built on Strategic Alliances and Join Ventures at the firm level, to estimate the importance of its structural properties. On this basis, we employ a dynamic network analysis model to explore the dual role of GTs both as determinant of the collaboration network and as outcome of the collaboration strategies of firms, providing new evidence on the role that the regulatory framework plays on the generation of new GTs.

The econometric estimation of the relationship between policy stringency and green technologies is performed through a zero-inflated negative binomial regression. Results confirm the existence of a strong and positive effect of the regulatory framework on the generation of new green technologies, controlling for sectoral and firm-level factors. Results also show that, when controlling for the structural properties of the collaboration network, the impact of environmental policy alone tends to disappear. Interestingly, the effect of operating in country characterized by stringent regulation and being embedded in an efficient local network structure is positive and significant.

Elaborating upon these results we run a static network analysis to explore the structural characteristics of the collaboration network. It reveals the presence of a highly skewed degree distribution (i.e the most of the actors in the network tend to have a very small number of connections, while very few organizations are the most active players, being involved in many alliances). Together with a very low density, a high clustering coefficient and relatively low geodesic distances, the analysis indicate that the network is characterized by a high overall connectivity with a strong hierarchical nature. Altogether, the structural description of our inter-firm network suggests that the structure itself contains a lot of information in terms of actors networking behavior. Therefore, structural aspect should be taken into account in modeling the determinants of inter-organizational partnerships, as they may engender relevant feedback mechanism not clearly identifiable in static or non-network approaches.

The empirical dynamic network analysis on the co-evolution of the collaboration network and new green technologies is performed through a Stochastic Actor Oriented Model (SAOM), implemented in the R package SIENA (Simulation Investigation for Empirical Network Analysis). SIENA models are able to statistically estimate the effect on the dynamics of network structure (macro structure) of a large variety of micro-mechanisms (at the actor level), which may operate simultaneously. They also allow us to develop a "selection and influence stochastic model" where the dependent variables consist in both the network and the relevant actor's behavior variable. Hence, the two processes are estimated simultaneously, controlling one effect for the other. The results on the network dynamics show that there is a strong tendency of firms to set up formal partnerships with firms who are already partner of one of their partners (transitive closure). Also, firm have a preference to collaborate with firm operating in same sector and sub-sector of activity as well as with those located in the same country, while regional proximity does not play a significant role. Concerning the firm performance indicators, the effect of size is positive and significant, indicating that larger firms are able to manage a greater number of collaborations at the same time, searching for partners with high and similar level of profitability. The results also demonstrate that innovative outputs play an important role on the collaboration dynamic: firms with a poor knowledge base in green technologies tend to form relationship with firm already involved in the generation of high levels of green technologies (and viceversa). Lastly, the strong and positive effect of environmental regulation indicates that a stringent regulatory framework stimulates firms to set-up more collaboration. Results on the behavior dynamics highlight that large firms and firm with a high degree have a higher probability of generating new green technologies. A key role is also played by the experience of a firm partner in the generation of GTs. In fact, there is an average positive reciprocal influence of connected firms, which drives firm toward the development of new GTs. The direct effect of the

environmental stringency is not significant. All in all, these results confirm our hypothesis that the regulatory framework has not a direct effect on GTs, rather it stimulates firm to search for new qualified collaborations. Then, it is the nature of these collaborations and structure of the local interactions that encourages firms to generate new green technological knowledge.

References

Ahuja, Gautam (2000). "Collaboration networks, structural holes, and innovation: A longitudinal study". In: *Administrative science quarterly* 45.3, pp. 425–455.

Arfaoui, Nabila et al. (2015). *Eco-innovation and Regulatory Push/Pull Effect in the Case of REACH Regulation: Empirical Evidence from Survey Data*. Tech. rep. Groupe de REcherche en Droit, Economie, Gestion (GREDEG CNRS), University of Nice Sophia Antipolis.

Arimura, Toshi, Akira Hibiki, and Nick Johnstone (2007). "An empirical study of environmental R&D: what encourages facilities to be environmentally innovative". In: *Environmental policy and corporate behaviour*, pp. 142–173.

Balland, Pierre-Alexandre (2012). "Proximity and the evolution of collaboration networks: evidence from research and development projects within the global navigation satellite system (GNSS) industry". In: *Regional Studies* 46.6, pp. 741– 756.

Balland, Pierre-Alexandre, Mathijs De Vaan, and Ron Boschma (2013). "The dynamics of interfirm networks along the industry life cycle: The case of the global video game industry, 1987–2007". In: *Journal of Economic Geography* 13.5, pp. 741–765.

Berman, Eli and Linda TM Bui (2001). "Environmental regulation and productivity: evidence from oil refineries". In: *Review of Economics and Statistics* 83.3, pp. 498– 510.

Brunnermeier, Smita B and Mark A Cohen (2003). "Determinants of environmental innovation in US manufacturing industries". In: *Journal of environmental economics and management* 45.2, pp. 278–293.

Cantner, Uwe and Andreas Meder (2007). "Technological proximity and the choice of cooperation partner". In: *Journal of Economic Interaction and Coordination* 2.1, p. 45.

Cohen, Wesley M and Daniel A Levinthal (1990). "Absorptive capacity: A new perspective on learning and innovation". In: *Administrative science quarterly*, pp. 128–152.

Fleming, Lee (2001). "Recombinant uncertainty in technological search". In: *Management science* 47.1, pp. 117–132.

Freeman, Christopher (1991). "Networks of innovators: a synthesis of research issues". In: *Research policy* 20.5, pp. 499–514.

Ghisetti, Claudia and Francesco Quatraro (2015). *Regulatory push-pull effects on innovation: an evaluation of the effects of the REACH regulation on patents in the chemical sector*. Tech. rep. WWWforEurope Working Paper.

– (2017). "Green Technologies and Environmental Productivity: A Cross-sectoral Analysis of Direct and Indirect Effects in Italian Regions". In: *Ecological Economics* 132, pp. 1–13.

Gollop, Frank M and Mark J Roberts (1983). "Environmental regulations and productivity growth: The case of fossil-fueled electric power generation". In: *Journal of political Economy* 91.4, pp. 654–674.

Gulati, Ranjay (1998). "Alliances and networks". In: *Strategic management journal*, pp. 293–317.

Jaffe, Adam B and Karen Palmer (1997). "Environmental regulation and innovation: a panel data study". In: *The review of economics and statistics* 79.4, pp. 610–619.

Jaffe, Adam B, Richard G Newell, and Robert N Stavins (2005). "A tale of two market failures: Technology and environmental policy". In: *Ecological economics* 54.2, pp. 164–174.

Johnstone, Nick, Ivan Haščič, and David Popp (2010). "Renewable energy policies and technological innovation: evidence based on patent counts". In: *Environmental and resource economics* 45.1, pp. 133–155.

Lanjouw, Jean Olson and Ashoka Mody (1996). "Innovation and the international diffusion of environmentally responsive technology". In: *Research Policy* 25.4, pp. 549–571.

Lanoie, Paul et al. (2011). "Environmental policy, innovation and performance: new insights on the Porter hypothesis". In: *Journal of Economics & Management Strategy* 20.3, pp. 803–842.

Lee, Jaegul, Francisco M Veloso, and David A Hounshell (2011). "Linking induced technological change, and environmental regulation: Evidence from patenting in the US auto industry". In: *Research policy* 40.9, pp. 1240–1252.

Maggioni, Mario A, Mario Nosvelli, and Teodora Erika Uberti (2007). "Space versus networks in the geography of innovation: A European analysis". In: *Papers in Regional Science* 86.3, pp. 471–493.

Maurseth, Per Botolf and Bart Verspagen (2002). "Knowledge spillovers in Europe: a patent citations analysis". In: *The Scandinavian journal of economics* 104.4, pp. 531–545.

Popp, David (2003). "Pollution control innovations and the Clean Air Act of 1990". In: *Journal of Policy Analysis and Management* 22.4, pp. 641–660.

– (2006). "International innovation and diffusion of air pollution control technologies: the effects of NOX and SO 2 regulation in the US, Japan, and Germany". In: *Journal of Environmental Economics and Management* 51.1, pp. 46–71.

Powell, Walter W, Kenneth W Koput, and Laurel Smith-Doerr (1996). "Inter-organizational collaboration and the locus of innovation: Networks of learning in biotechnology". In: *Administrative science quarterly*, pp. 116–145.

Rennings, Klaus (2000). “Redefining innovation—eco-innovation research and the contribution from ecological economics”. In: *Ecological economics* 32.2, pp. 319– 332.

Schilling, Melissa A and Corey C Phelps (2007). “Interfirm collaboration networks: The impact of large-scale network structure on firm innovation”. In: *Management Science* 53.7, pp. 1113–1126.

Snijders, Tom AB, Gerhard G Van de Bunt, and Christian EG Steglich (2010). “Introduction to stochastic actor-based models for network dynamics”. In: *Social networks* 32.1, pp. 44–60.

Ter Wal, Anne LJ (2013). “The dynamics of the inventor network in German biotechnology: geographic proximity versus triadic closure”. In: *Journal of Economic*

Geography 14.3, pp. 589–620. Uzzi, Brian and Jarrett Spiro (2005). “Collaboration and creativity: The small world

problem”. In: *American journal of sociology* 111.2, pp. 447–504. Weitzman, Martin L (1998). “Recombinant growth”. In: *Quarterly journal of Economics*, pp. 331–360.