Green Innovation in Production Networks: Empirical Evidence from the Auto Industry

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Any significant progress in reconciling economic activities with environmental goals requires technological change. Designing effective policies to foster green transitions relies on understanding the subtleties of the long and often non-linear processes leading to the development of new technologies. Most of the economic literature on induced green technological change has modelled environmental innovations as changes in the *process* through which goods are produced, either as a decrease in the cost of abatement technologies (e.g., Goulder and Mathai 2000; Jaffe et al. 2003) or as an improvement in clean intermediate inputs making dirty technologies less attractive (e.g., Acemoglu et al. 2012; Fischer and Newell 2008)[2]. Less research has been devoted to the drivers and barriers of green technological change when the change required involves creating a new *product*, such as zero-emission vehicles or zero-energy buildings.

In this project, we propose to empirically investigate how inter-firm relationships in production networks impact firms' ability to develop green product innovations. Our motivation rests on two observations. First, most products are nowadays complex combinations of several components and innovations offering significant "green potential" typically involve changing several components. Second, such changes and product redesigns must happen in the context of production networks where the manufacturing or assembling of parts is outsourced to different firms (Timmer et al. 2014). Vertically integrated firms are rarer than a few decades ago (Feenstra 1998), and final producers depend on a large number of suppliers that are often globally distributed. Importantly, some of these suppliers are highly embedded in the network and supply most if not all final producers.

In a previous theoretical paper (Dugoua and Dumas 2019), we identified how such suppliers could act as bottlenecks for innovation by reducing the level of ambition in product changes. Here, we aim to empirically test whether producers contracting with more shared suppliers are less ambitious in their innovations. We focus on the case of the automotive sector and the shift to alternative fuel vehicles. We also document how firms' innovation output has varied over time and across the global automotive production network in the course of this secular shift towards alternative fuel vehicles.

We combine data on supply-chain networks from FactSet Revere and patent data from the USPTO. The supply-chain data report the existence of relationships with suppliers, customers, R&D collaborations, and competitors for a large number of public and private firms, globally and from 2003 to 2017. The USPTO data contains every patent application between 2001 and 2017. Methodologically, we leverage recent advances in computer sciences to extract useful information from large quantities of text. The social sciences literature here is burgeoning, but no paper has yet to apply the methods to inform industrial policy or to the study of green innovation. Specifically, we apply text analysis algorithms to the full text of patents to find a representation of the technological space. We then locate the research portfolio of each firm in any given year in this technological space.

From there, we focus on two different aspects of a firm's patenting output. The first is novelty which we define as an unusually large change in the location of the firm's patents relative to 1) the firm's own past innovations (measuring what is a novel direction for the firm) and 2) the overall sector's past innovation activity (measuring what is a novel direction for the sector as a whole).

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[2]For reviews of both the empirical and theoretical literature on induced green innovation, see Popp et al. (2010).

The second aspect of firms' patenting output that we study is the extent to which firms engage in innovations that are complementary to those of other firms in their network. This indicates that the firm is investing in innovations that rely on complementary investments by other firms. We measure this by identifying patents between firms located in different parts of the supply-chain that cite each other (because they build on each other), yet are located in different parts of the technological space (they are not substitutes, but complements).

The first goal of our empirical investigation is to describe how the structure of a firm's supply-chain network correlates with these measures of innovation. We examine how a firm's reliance on very central actors, in particular shared suppliers, correlates with their level of ambition. We also describe how the distance between the innovation portfolios of buyers and suppliers changes over time as the sector as a whole moves from a focus on combustion engines to alternative fuel vehicles. The second goal is to identify a causal effect between network structure and R&D ambition. We will use variation in fusion and acquisition of firms that can be argued to be exogenous from the firms' patent portfolio and which affects a producer's degree of reliance on shared suppliers.

Findings will help understand the conditions enabling product innovation in mature industries with established players and relationships like the automotive industry. We complement the induced technological literature's focus on technology-push and demand-pull policy mechanisms with a focus on the coordination problems that arise in the process of innovation due to inter-firm relationships. We thus contribute to the literature on green industrial policy which often emphasizes public institutions to coordinate actors and catalyse technological change (Aghion et al. 2009; Alic et al. 2003; Mazzucato 2011; Rodrik 2014).

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