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Title

Technological variety in innovation systems: the role of actors, networks, resources and institutions

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Motivation and aim

Sufficient technological variety is an important condition for successful innovation (Van den Bergh, 2008; Faber and Frenken, 2009), it aids in preventing an early suboptimal technological lock-in and enables novel combinations that can lead to new innovations within a sector (Van den Bergh, 2008). Variety is defined as “the number of different technologies, products, processes and opportunities in a population of elements (Van den Bergh, 2008). It refers to the technological diversity from which alternatives that fit best with environmental demands can be selected (Rigby and Essletzbichler, 1997; Frenken et al., 1999).

Technological variety is usually created within an innovation system that co-evolves with the technology (see Nelson, 1994; Markard et al., 2009). This innovation system can formally be defined as *“the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technology.”* (Freeman, 1987). Innovation systems have been studied from a national (Freeman, 1995; Lundvall et al., 2002; Faber and Hesen, 2004), sector (Malerba, 2002), regional (Cooke et al., 1997) and technological perspective (Carlsson and Stankiewicz, 1991; Hekkert et al., 2007; Markard et al., 2009). Most studies that take a systemic approach focus on the performance of the innovation system as a whole (Carlsson et al., 2002), which can be assessed by looking at the extent to which certain system functions are fulfilled (Hekkert et al., 2007; Bergek et al., 2008) or by looking at specific outcome indicators, such as knowledge production, the number of innovations developed or innovation diffusion (Carlsson et al., 2002). On a more disaggregate level, innovation systems have been approached from a social network perspective where actors collaborate in innovation projects. Network ties between actors are then modeled as conduits for knowledge or resources (Leoncini et al., 1996; Ter Wal and Boschma, 2009). This idea links closely to studies from management about the performance of innovation networks (see for example Ahuja, 2000; Powell, Koput, & Smith-Doerr, 1996). Important research questions that arise from a network perspective are how an innovation network should look like in terms connectedness (Ahuja, 2000; Burt, 2004; Schilling and Phelps, 2007) and tie strength (Reagans and McEvily, 2003).

Until now, both innovation system and network scholars have dedicated most of their attention to the systemic or network relationships around new technologies and to a lesser extent to how this relates to quantities of innovative output. However, the concept of variety implies that technologies are often heterogeneous by nature. Within the innovation system, different technological varieties can be distinguished at different places in the in the system at any given moment in time. No studies have focused explicitly on the link between social networks and technological variety within the innovation system.

The aim of this research is to show how attributes of subsided innovation projects of collaborating actors within an innovation system network are related to the extent a projects adds to technological variety. We conceptualize the innovation system to consist of *networks* of *actors* in which *resources* are exchanged in an *institutional environment* (Carlsson and Stankiewicz, 1991). The attributes a project has with regard to its position in the innovation system are used to explain technological variety.

Empirically, we study the Dutch technological innovation system around biogas technology. This technology converts organic waste to sustainable energy and has been stimulated by the Dutch government during the past decades with various policy schemes that subsidize collaborative innovation projects. This has led to the build-up of a well-documented innovation system. The systematic data allows us to quantitatively explain technological variety.

Theoretically, our study is the first to link innovation systems to technological development using a quantitative approach. By making this link we enrich both the literature about technological trajectories and studies about innovation systems. We further complement those studies that looked at this particular technology using a more qualitative approach (see Raven, 2004; Geels and Raven, 2006; Negro et al., 2007, 2008; Markard et al., 2009). Finally, by enriching our model with actor diversity and resource exchange, next to more traditional factors such as structural holes in an innovation network (see Ahuja, 2000; Burt, 2004), we add to the social network literature in the context of innovation. Our results are also of interest to policy makers that wish to stimulate technological variety. We show which innovation system factors are important to variety creation. Policies that aim to stimulate this can be adjusted accordingly.

Approach

Technological variety has always been conceptualized on a system level. However, we are interested in explaining these varieties at different places within the system. This is done by looking at the different discrete paths that can be taken to develop a new product that fulfills a specific service or function (Saviotti and Metcalfe, 1984; Castaldi et al., 2009; Van Rijnsoever and Oppewal, 2012), in this case the conversion of organic waste to gas. This means that we delineate (see Carlsson et al., 2002; Bergek et al., 2008) the technological innovation system by the service that the final innovation fulfills. Drawing on Verspagen (2007) we conceptualize that the final goal of a technology (the fulfillment of a service) can be achieved through different technological routes. These can be compared to different paths on a map that all lead to the same destination. For some technologies, such as biogas, different components can be distinguished (Henderson and Clark, 1990), that each have potentially different paths. A technological route of a project is the combination of paths that is taken to reach the final destination. Given that there are multiple innovation projects within the innovation system, some routes are taken more often than others. More popular routes might eventually become the dominant design (see Utterback, 1996), while routes that are 'of the beaten path' lead to more variety. Variety of a project is the extent to which it's technology route differs from the average route that has been or is taken by other projects.

As mentioned above we attempt to explain technological variety of a project, using the attributes it has with regard to its position in the innovation system. Since innovation systems consist of an *institutional environment* in which *networks* of *actors* exchange *resources* (Carlsson and Stankiewicz, 1991), the project attributes in the innovation system we study are:

1. *Institutions* which is conceptualized as the type of policy instrument of which the project is a part. In this case these are subsidy schemes. We distinguish between two types of subsidies; research oriented subsidies and exploitation subsides.
2. The *number of network ties* of a project, which measures the extent to which a project is in contact with other projects through shared actors.
3. The *network clustering around the project*, which is the extent to which the neighbors of a network node are also connected to each other (Wasserman and Faust, 1994).
4. The *number of actors* collaborating within a project.
5. The *diversity of actor types* within a project. Several types of actors are distinguished: knowledge institutes, small & medium sized enterprises, large enterprises, government bodies and intermediary organizations.
6. *Resource diversity* in a project. Actors can contribute several resource types to a project. We distinguish between human, physical, and organizational capital. The more resources types there are in a project, the larger the resource diversity.

For each of these independent variables we formulate hypotheses to predict the influence on technological variety.

Using government data about than 404 subsidized biogas innovation projects, conducted by 416 separate actors between 2001 and 2012, we quantitatively map the development of this entire innovation system and the associated technological variety over time. This enables us to systematically study the influence of each variable on the technological variety of innovation projects in the system. To accomplish this we apply a combination of social network analysis and regression techniques. Social network analysis was used to calculate the network measures. Linear regression was used to actually test the hypotheses.

Results

Our preliminary results show that projects using research oriented subsidies are more likely to contribute to technological variety than projects using exploitation subsidies. Further, the diversity of actors and resources within a project are also positively related to technological variety. Network ties, clustering and number of actors within a project are negatively related to technological variety. This is in line with Burt (2004), who claims that redundant network connections can hamper the development of good ideas.

The results imply that to create technological variety, subsidy programs should stimulate the creation of small projects with diverse actors and resources. Projects that share actors with other projects tend to decrease technological variety. However, for a technological alternative to become successful, it is also required that it obtains sufficient critical mass within the system. It is debatable if the government should also intervene in selecting a technological alternatives, next to stimulating variety creation. It can also be argued that selection should be left to the market.

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