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What drives innovation? Evidence from economic history☆

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ABSTRACT

An unresolved issue in innovation studies is to what extent and how innovation is affected by changes in the economic environment of firms. This study elaborates on a theoretical framework that unites theories of innovation as creative response and the economics of complexity. In the empirical section, results from a new micro-based database on Swedish product innovations, 1970–2007, are introduced. Applying the theoretical framework, both quantitative evidence and collected innovation biographies inform of the historical impulses that have shaped innovation activity in the Swedish economy in two broad surges during the 1970s and 1990s. The study shows that, rather than being the result of continuous efforts, most innovations were developed as a response to discrete events, history-specific problems and new technological opportunities. It is also suggested that patterns of creative response are industry-specific and associated with the radicalness and complexity of innovation processes.

1. Introduction

There is today a sizeable body of literature on the determinants of innovation activity. While a wide range of economic, social and technological incentives have been suggested as driving forces of innovation, there is hardly a consensus on how and to what extent innovation activity is the response to changes in the social or economic environment. In fact, modern research may be read to convey the message that a plethora of factors may matter and that there are large differences on a case to case basis, so that a universal theory of innovation appears unrealistic. Yet, it is hard to find comfort in such an outlook, perhaps because the perspective one takes on the driving forces of innovation carries large stakes for our view of major technology shifts and the long run evolution of economies, not least evidenced in the lengthy and still ongoing debate on the driving forces of the industrial revolution and the origins of industrial capitalism (Crafts, 1985, 1995; Mokyr, 1990, 2009; Allen, 2009; Bottomley, 2014).

Upon examination, many theoretical accounts opt for emphasizing either a set of 'positive' driving forces to innovation, e.g. private returns to innovation and market demand, or 'negative' factors, sometimes summarized in the, somewhat vague, claim that "necessity is the mother of invention". In the canonical economic models, innovation is motivated by expected private returns to innovation, which are ensured to varying degrees by intellectual property rights, e.g. patent laws (see Nordhaus, 1969; Scotchmer, 1991; Moser, 2005, 2013) or induced by increasing market demand and user initiatives (Schmookler, 1962; Lundvall, 1985, 1988; von Hippel, 1994). Other frameworks view innovation as resulting from advances in the stock of knowledge (Arrow, 1962; Romer, 1990; Aghion and Howitt, 1992), useful knowledge (Mokyr, 2002), new technological opportunities (Klevorick et al., 1995) and the diffusion of general purpose technologies (Bresnahan and Trajtenberg, 1995; Lipsey et al., 2005). Emphasizing negative pressure, a strand of literature points to factor-price inducement (Hicks, 1932; Binswanger et al., 1978; Popp, 2002), declines in profits (Antonelli, 1989; Greve, 2003b) and innovation as resulting from problem solving activity, or the overcoming of imbalances and technical obstacles (Dahmén, 1942; Dahmén, 1988; Rosenberg, 1969; Sahal, 1985; Dosi, 1988).

Along these lines, authors have also proposed competing hypotheses about the 'when' of innovation, ever since Schumpeter (1939) suggested the arrival of innovations in cycles of different length. Some authors have proposed that basic innovations are likely to be spurred by the adversities of economic crises (Archibugi and Filippetti, 2011; Berchicci et al., 2014) or the downturns of long waves (Mensch, 1979; Kleinknecht, 1987). Others have proposed that innovations are more likely to be spurred by increasing demand (Geroski and Walters, 1995; Brouwer and Kleinknecht, 1999), and positive prospects in the recovery from deep downturns (Clark et al., 1981; Freeman et al., 1982; Freeman and Perez, 1988).

The gist of the problem is that while neither of these views have a hard time finding support in economic history, neither of the views are exempt from criticism. Moreover, micro- or macro-econometric tests of relationships between innovation and economic activity (see e.g. Geroski and Walters, 1995) are typically only able to give support to one or the other hypothesis, while in fact innovation is likely to be simultaneously affected by a number of factors. Such issues have led

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some recent contributions to argue for the development of an inclusive approach which spans both negative and positive factors, acknowledging both external driving forces and the "internal" impact of innovations on the course of technological development (Arthur, 2007; Antonelli and Scellato, 2011; see also Mokyr, 2010). Turning this suggestion into an empirical research strategy, such an inclusive approach requires that factors behind innovation be studied both systematically (i.e. assembling large amounts of data) and in their proper historical setting (i.e. accessing the minute details of history). However, historical studies of the driving forces of innovation have mostly been carried out in terms of case studies.

This paper carries out, for the first time, a long-term study of the driving forces of innovation in Sweden during the third industrial revolution, 1970–2007. A first aim of this study is to give a systematic description of the historical driving forces of innovation and an account of the 'when' and 'how' of innovation. More specifically, we inquire into what driving forces explain patterns of innovation activity, and in turn, what factors and historical processes explain the prevalence of certain types of creative response across industries and over time.

Since the first stumbling block of a comprehensive empirical analysis is to distinguish analytically between different driving forces within an inclusive consistent framework, a second aim of this study is to synthesize ostensibly conflicting claims in previous literature into a coherent framework. Hence, Section 2 is devoted to the elaboration of a theoretical approach based on the view of innovation as an adaptive combinatorial search process and the view of innovation as a creative response to particular events and discrete inducements (Schumpeter, 1947; Antonelli, 2015). This framework amounts to suggesting four types of sources of incentives to innovation: "problems", "technological opportunities", "market opportunities" and "institutionalized search for improved performance".

The theoretical approach is subsequently applied in a study of driving forces to innovation during the third industrial revolution, drawing on a new micro-database containing in its entirety more than 4000 significant product innovations commercialized in Sweden between 1970 and 2007 (Sjöö et al., 2014; Sjöö, 2014; Taalbi, 2014; the empirical sections are further elaborations on chapter 4 in Taalbi, 2014). Data on innovation output has been collected from the screening of 15 trade journals covering the manufacturing sector, enabling both a quantitative study of innovation launches as well as detailed textual evidence on innovation biographies. This data is put to use to assess the patterns in the aggregate rate of innovation in the Swedish manufacturing sector and to classify and describe innovations according to economic, social and technological factors that have led to or contributed to their development. The underlying methodology is described in Section 3. Sections 4 and 5 present a statistical and historical analysis of the driving forces conveyed by this database. The statistical analysis examines the driving forces to innovation and carries out basic tests of cross-industry differences and other covariates to explain patterns of creative response. To assess the relationship between innovation activity and cycles in economic activity, a bandspectrum regression is employed. The historical analysis details the specific economic, social and institutional circumstances that explain the basic patterns of innovation as creative response. Section 6 concludes.

2. A framework of innovation as creative response

To a student of technology wishing to approach the empirical subject-matter of the driving forces of innovation, the available literature can be quite overwhelming. Arguably, there is an apparent need for a coherent framework for analysis of the driving forces of innovation, which covers a broad range of both positive and negative factors. Common ground for the diverse accounts of the evolution of technology can certainly be found in Schumpeter's "The creative response in economic history" (1947), distinguishing between 'adaptive response' and 'creative response' (see also Antonelli, 2015). The former term denotes measures taken within the "existing practice" of an economy, industry or firm, whereas the latter denotes measures taken "outside of the range of existing practice", viz. innovation (Schumpeter, 1947, p. 150). Schumpeter wrote that creative response rarely, if ever, is fully understood *ex ante*, i.e. cannot be predicted from "pre-existing facts". The 'how' of the mechanisms behind creative response "must therefore be investigated in each case" (Schumpeter, 1947, p. 150). An understanding of innovation as creative response should thus leave plenty of room for history. The aim of the current endeavors is therefore to elaborate a theoretically grounded classification of sources of innovation that can be put to use in empirical analysis.

The view proposed here recognizes first of all that technological objects are combinations of other technological objects and that innovation is a *new* combination (Schumpeter, 1911; see also Weitzman, 1998, Fleming and Sorenson, 2001 and Arthur, 2009). Accordingly, not only does any innovator face a more or less complex combinatorial problem, but the evolution of technology must be thought of as the evolution of a complex system. The full implication of this principle is a relational outlook where technologies must be viewed as (co-)evolving in greater or smaller constellations forming technological systems (Gille, 1978; Hughes, 1983, 1987; Nelson, 1994) or development blocks (Dahmén, 1950; Dahmén, 1988), in which opportunities, pressures and imbalances emerge.

Of course, the possible combinations of technological objects are ample, unfathomably so, and innovations can in principle be discovered by any agent that engages in search. But the question of interest is under what circumstances there are incentives to take the risk of deploying resources into such search activity. On this matter, we accept the basic formulation of Schmookler (1962, p. 19), that "the incentive to make an invention, like the incentive to produce any other good, is affected by the excess of expected returns over expected costs". This is to say that economic agents search for new combinations only when they have reason to believe that returns from innovation exceed the costs of search. This makes the incentives to innovation a question of information, typically limited and imperfect. In general, *depending on the complexity* of the combinatorial problem, let alone market and product uncertainty, innovators can to a higher or lower extent predict the consequences of their choices. Typically, innovators are acting under fundamental uncertainty (Alchian, 1950) and are boundedly rational and myopic (Cyert and March, 1963; Simon, 1991). For this reason, firms use focusing devices (Rosenberg, 1969) and procedures (Nelson and Winter, 1982) to make the choice of when and how to innovate.

Since the degree to which innovators respond to economic factors is fundamentally linked to the complexity of the combinatorial problem, this study proposes, following some recent contributions (see e.g. Arthur, 2007, 2009; Antonelli, 2011) to combine insights from the economics of complexity, with the notion of innovation as responding to changes in economic data.

To this end this framework builds on the nowadays standard NK-model, originally introduced to describe adaptive genetic evolution on fitness landscapes (Kauffman and Levin, 1987; Kauffman, 1993), but subsequently applied to e.g. economics of innovation to describe how search strategies – local search or distant search, exploitation or exploration – are afflicted by the complexity of the space of combinations (cf March, 1991; Levinthal, 1997; Frenken, 2000). Recent research has remarked that the NK-model is an apt tool for understanding how complexity shapes search strategies of firms, but that notions such as problemistic search and negative feedback have not been properly included (Gavetti et al., 2012; Billinger et al., 2013). The current endeavors examine a way to link the NK-model to the notion of innovation as a creative response to changes in economic data.

2.1. Opening up the black box

How can we understand the process through which agents find

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