An Introduction to the Analysis of Systems of Innovation: Scientific and Technological Interdependencies

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1. Introduction

Nowadays, most economists agree on the importance of learning and innovation for economic growth, notwithstanding the major differences in perspectives on the ways in which units (firms, sectors, regions, nations or even groups of nations) decide on investment in technology. Whatever the units taken into consideration, persistent differences in performance are often attributable to persistent differences in technological capabilities, irrespective of the specific performance indicator chosen (e.g. productivity, exports or market share). Consequently, the analysis of processes of the production and use of technology within such units has gained increasing attention. The concept of ‘systems of innovation’ is often used in such studies.

Depending on the type of units studied, one can speak of ‘national systems of innovation’ (Freeman, 1987; Lundvall, 1992; Nelson, 1993; Patel & Pavitt; 1994), ‘sectoral systems of innovation’ (Breschi & Malerba; 1997) or ‘regional systems of innovation’ (Saxenian, 1994; Cooke et al., 1997). Despite more than 15 years of research in the field, it is still difficult to find a comprehensive but practically useful definition of systems of innovations. In many cases, only enumerations of building blocks of such systems are offered by way of such a definition. These often emphasize the aspects of technology generation and adoption on which the specific study focuses. A broad definition of national systems of innovation, which apparently fits the majority of viewpoints, is given by Patel & Pavitt (1994, p. 79):

The national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change-generating activities) in a country.

With respect to institutions, Patel & Pavitt list four categories, i.e. business firms, universities, governments and (public or private) institutions that offer education and vocational training. In their definition, incentives refer to the way in which

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government support is organized, and the way in which intellectual property rights are protected (e.g. by patent laws). Competencies relate to the variety of products that can be produced, the requirements per unit of output for these products and the ability to adapt to future changes in the environment.

These are factors that have largely been outside the core of traditional input-output economics, although technology obviously has been a theme in this literature. As is well known (see, for example, Leontief, 1989), the columns of input-output tables can be viewed as a set of highly simplified descriptions of sectoral technologies. Differences between columns of input coefficients, be it between economies for a single period or between periods for a single economy, can be interpreted in many ways. For example, neoclassical economists may argue that changes in input coefficients will generally be due to price-induced factor substitution processes, whereas ‘believers’ in the non-substitutability of production factors will most likely attribute such changes to pure technological change.

Input-output economists have devoted much effort to analyses of the effects of differences or changes in input coefficients. In particular, structural decomposition analyses have often been applied to estimate the contribution of technological change (as reflected in changes of input coefficients) to changes in output levels (e.g. Chenery et al., 1962; Carter, 1970; Feldman et al., 1987), aggregate productivity levels (e.g. Wolff, 1985; Dietzenbacher et al., 2000), and levels of various forms of pollution (e.g. De Haan, 2001). It should be emphasized, however, that these studies take the rate and direction of technological progress for granted and focus on the effects, and that they tend to neglect the role of technology in changes in other parts of input-output tables (such as, for example, the impact of technology on exports and imports through the changes in technological competitiveness).

In a sense, the view on technology that underlies most structural decomposition analyses resembles the way in which neoclassical economists treated technological change in traditional ‘growth accounting’ studies (e.g. Solow, 1957). In the mid-1980s, neoclassical growth theory finally incorporated sources of technological change into its models. The so-called ‘endogenous growth theories’ (Romer, 1986; Grossman & Helpman, 1991) paid attention to the role of science, R&D expenditures, human capital formation and technology spillovers in growth processes. As such, some important aspects of evolutionary Neo-Schumpeterian thinking about growth (Nelson & Winter, 1982, is the classic reference) found their way into mainstream economics.

A similar, although perhaps less pronounced, trend has emerged in the field of input-output economics, and this special issue can be seen as a contribution to this expanding literature on intersectoral analysis of determinants of technological change. The special issue will take a broad view on the relations between technology and input-output economics. Hence, it will not be confined to studies into economic or technological linkages between sectors as usually defined, but will also take interrelationships between scientific entities as well as their relations to economic sectors into account. As such, it provides quantitative analyses of systems of innovation.

What could be the contribution of studies that apply input-output approaches to the literature on systems of innovation? Niosi et al. (1993) emphasize various links between the institutions that are later listed by Patel & Pavitt (1994). Four types of links are specified: financial flows (to finance costly innovative projects or purchase of high-tech capital goods), legal and policy links (intellectual property
laws, technology and procurement policy), *social flows* (mainly labour mobility between institutions), and *technological, scientific and informational flows* (formal and informal flows, market-driven or not). Traditional input-output analysis deals with commodity flows between sectors, but more recently other intersectoral links have also been analysed. In particular, the fourth category of links specified by Niosi *et al.* (1993) has been studied quite extensively.

This special issue follows in this tradition and takes these technological, scientific and informational flows as the point of departure. The novel aspect of the present papers is that they integrate the analysis of these flows into systems of innovation approach, and hence make this a central part of the analysis. We see this as a convergence of different parts of the literature that have largely been separated. In this respect, we point to the following three streams that have a central role in the papers in the special issue.

First, one of the founding fathers of the concept of systems of innovation, Bengt-Åke Lundvall, stressed the learning interactions between producers and users of (product) innovations (e.g. Lundvall, 1988). In his view, inspired by Von Hippel (1988), innovation is mainly driven by an intense exchange of information between those who are aware of new technological opportunities (the potential innovators) and those aware of user wishes (the users of potential innovations). Most empirical evidence in support of this view on innovation emerged from case studies. DeBresson (1996) carried out studies at the national level, in search of more systematic support. By means of surveys, he collected data on the producer sectors of innovations and the most important user sectors. The results were tabulated in a matrix that could be called an innovation input-output table. Such tables were constructed for several countries, including Canada, Italy and China. Next, as a test of the ‘Lundvall-Von Hippel’ hypothesis, he attempted to correlate the cell values of the innovation input-output tables to cell values in conventional input-output tables. Some standard econometric tests suggested a strong positive correlation, which could be seen as indirect, but more systematic evidence in favour of the importance of interactive learning. Schnabl (1995) and Drejer (2000) explicitly studied characteristics of national innovation systems (and their evolution) by means of computations on input-output tables. They weighted commodity flows by R&D expenditures of supplying sectors in order to take interindustry differences in innovation potential into account. Cluster analysis then yielded insights into the sectors at the heart of national (sub)systems of innovation for Germany, Japan, the United Kingdom and the United States.

Secondly, many alternative technology-flow matrices were proposed to investigate the productivity effects of flows of either embodied or disembodied technology flows from one industry to another. Many of these methods found their way to earlier special issues of *Economic Systems Research* (vol. 9, issues 1 and 2). Good methodological surveys could be found in Mohnen (1996) and Van Pottelsberge de la Potterie (1997). In a major project initiated by Robert Evenson (see, for example, Johnson & Evenson, 1997), Canadian patents were assigned to industries-of-origin and industries-of-use, like Scherer (1982) did on a smaller scale for US patents. The matrix that could be made up of these data in an input-output fashion (the so-called Yale-matrix) can be viewed as an alternative to DeBresson’s innovation input-output matrices, obtained by means of a different innovation indicator. Contrary to these transaction-based technology flows, Verspagen (1997) introduced matrices based on classifications of the type of information contained in public patent documents. In this case, the focus is not on the origin and use of
a new or improved process or product, but on the origin and use of the public knowledge obtained during the innovation process. These matrices aim to measure disembodied technology flows. A similar disembodied technology perspective was chosen by Jaffe (1986), who suggested constructing measures of technological congruence between firms, based on the numbers of patents they have been granted in several patent classes. Goto & Suzuki (1989) extended this kind of analysis to the level of industries. Recently, Los (2001) proposed an R&D-driven dynamic input-output model with both commodity and technology flows between sectors. Calibration of such models could, among other things, indicate the potential growth-enhancing effects of strengthening the knowledge exchange between any pair of sectors.

The third approach is not necessarily limited to flows among business sectors. As stressed by contributions to the systems of innovation literature, many innovations are preceded by scientific developments that emerge within universities and other technological institutions that are not strongly tied to commercial firms. ‘Scientometrics’ has developed as a branch of science that attempts to quantify knowledge flows among scientific institutions, and between scientific institutions on the one hand and commercial firms on the other. Broadly speaking, two types of data are used (see Van Raan, 1988, for a relatively early comprehensive overview, and Grupp, 1996, and Verspagen, 1999, for typical contributions at the national and firm level, respectively). Scientific output is usually measured by the number of articles in scientific journals and the characteristics of these articles, such as the number and affiliations of authors, subject denominators, date of publication, and citations included. As measures of technological output, emphasis is put on the number of patents granted. Characteristics of these patents have also proven to be useful. In this respect, one could think of the affiliations and geographical localization of inventors and/or patent holders, patent class indicators, date of application and references to other patent documents and scientific papers. In view of the focus on non-business sectors, it is rather unsurprising that this type approach has not had a major impact on input-output analysis. The only proposal in this direction, to study interdisciplinary knowledge flows within science by means of input-output tools (Leontief, 1996), has never yielded ‘true’ contributions.

In the next section, the articles included in this special issue will be introduced and linked to this discussion of systems of innovation and their measurement.

2. Contributions to this Issue

The five papers that constitute this special issue were selected from more than 100 papers presented at the conference ‘The Future of Innovation Studies’, (21-23 September 2001) organized by the Eindhoven Center for Innovation Studies (ECIS) at Eindhoven University of Technology in the Netherlands. Together, they cover the broad spectrum of issues raised by the literature on systems of innovation quite well. The first three papers deal with quantitative descriptions of innovation systems, whereas the final two papers predominantly address the performance of these systems.

Martin Meyer argues that academic and industrial research have become more alike. Commercial firms increasingly hire their own scientists to carry out fundamental research, while governmental research grants have become steadily
more conditional on the probability of results with a clear societal relevance. Both tendencies imply an increasing importance of the question ‘how productive is science in enabling firms to bring innovations to the market?’. Meyer discusses three classes of indicators that might give clues to answers to this question and discusses their advantages and drawbacks. The theoretical discussion is followed by an empirical illustration for the Finnish innovation system. This system is an interesting case, in particular because of its recent success in the telecommunications sector.

Koen Frenken’s contribution investigates whether the recent European integration, almost omnipresent, is also likely to yield a true European system of innovation. To this end, it studies national and international collaborations that yielded articles in scientific journals. Frenken argues that an indicator that has become a valuable tool in information theory might well be useful in scientometrics as well. The indicator is applied to a very recent and comprehensive dataset. One of the main conclusions derived from this study is that a tendency towards international collaboration within the EU is observed, but that the vast amount of research collaborations within member countries suggests a continued role for national systems of innovation.

Finn Valentin & Rasmus Lund Jensen provide an in-depth study of (supra) national subsystems of innovation related to a specific technology, the use of ‘lactic acid bacteria’ in the food industry. Based on relevant patent data, they use network analysis to identify several systems of innovation, each of which is concentrated in a geographical sense. The database is also used to test theoretical notions with respect to the development of systems of innovation over time. Valentin and Lund Jensen find that systems are indeed different during three stages of the lactic acid bacteria technology. Finally, the authors propose answers to the question of why some systems of innovation have been much more successful than others in this specific technology.

Ina Drejer’s analysis focuses on institutions that have received much attention in the literature on recent systems of innovation—knowledge-intensive business service firms. These firms can enhance productivity of other sectors in a number of ways. Examples of such mechanisms are improved transmission of specialized knowledge and easier outsourcing of activities that do not belong to the ‘core’ of a firm’s operations. The objective of Drejer’s paper is not to provide a description of the position knowledge intensive business service firms have in systems of innovation, but rather to estimate the effects of the use of these specialized services on output growth of other sectors. A panel database of Danish sectors for the time span 1970–95 is analysed. The econometric framework allows for differences between sectors that belong to different classes in the well-known ‘Pavitt-Soete-Miozzo-taxonomy’. Such differences are indeed found and interpreted.

Finally, Erik Dietzenbacher & Bart Los argue that systems of innovation-related policy changes aimed at specific sectors will also have consequences for other sectors. Their emphasis is on the effects of traditional input-output linkages, which can be studied by extensions of the well-known concepts of backward and forward multipliers. Backward R&D multipliers are shown to give an indication of the economy-wide increases in R&D expenditures that are related to an increase in final demand for a single commodity. Procurement by governments, one of the above-mentioned important flow types within systems of innovations, is a source of such final demand increases. Dietzenbacher & Los argue that forward R&D multipliers give an indication of the economy-wide short-run price increases due
to increased R&D costs in a single sector. These price increases (and the implied worsening of international competitiveness) are interpreted as a negative externality of R&D. The analytical framework is used for an empirical study of the United States in the period 1977-90.

3. Outlook

A synthesis between the essential ideas of the systems of innovations literature and the analytical rigor pertaining to intersectoral economic analysis is only in its early stages. This special issue presents a number of papers that set the first steps in what might eventually become a fruitful new tradition of analysis. At a general level, the ideas from both streams of literature match quite well. The distinct feature of input-output analysis is its emphasis on differences between sectors and the interdependencies between them. Both issues are also at the heart of systems of innovation studies. If we try to think beyond the obvious and imagine how a further convergence might contribute to the understanding in both fields, which issues may emerge as important?

In the input-output literature, the identification of key sectors has gained quite some attention. Clear methodologies have emerged to identify these key sectors. These studies, however, have largely remained restricted to the analysis of economic flows between sectors. In studies of innovation systems, a more diverse set of methods has been devised to describe interfirm or intersectoral networks and to find the most important elements in such networks. However, economic relations have generally remained unexplored. In addition, quantifying the relations has been difficult. We think that more interaction between both branches of economics would prove mutually beneficial, in terms of broadening the scope of input-output economics and simultaneously providing quantitative guidance to the innovation systems perspective.

Convergence may also lead to fruitful new theoretical directions in both literatures. On the one hand, in the systems of innovation literature, we can foresee a clearer focus on performance of the system emerging, by using the consistent statistical framework of input-output economics. This yields data at relatively low levels of aggregation and opens up opportunities for applying econometric methods. On the other hand, a greater emphasis on the endogenous nature of innovation might well prove to be an important development in input-output economics. This could possibly shed new light on ‘old’ questions, such as those surrounding the construction and analysis of dynamic input-output models. To conclude, we hope that this special issue offers sufficient inspiration to scholars in both fields to investigate mutual interests and to enlarge the literature on the theme of this special issue.

References

Introduction


