COMPLEXITY AND TECHNOLOGY

Loet A. Leydesdorff
University of Amsterdam, The Netherlands

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Summary

Contrary to biological species technologies are not given in nature, but man-made constructs. Technological innovations are the products of cultural evolution and technologies feed back on the social development, as in a coevolution. Technology, society, and culture increasingly shape one another by innovative recombination of materials, principles derived from the sciences, and solutions to problems.

Innovations can be appreciated differently in terms of their economic value, in terms of their significance to research traditions, and with reference to problem management. The various actors involved (e.g., engineers, managers, economists, adopters, and policy makers) can be expected to use different definitions of technology. These definitions and perspectives, however, are basic to the discursive traditions studying technology and its relevant contexts. Three reflexive perspectives are distinguished: (1) the economics of industrial innovation, (2) the history of technology and the sociology of science, and (3) science and technology policy analysis and research and development management.

While technologies are continuously evolving, the definitions and relevant perspectives also change. The combination of the perspectives challenges us to consider technology as a subject of complexity studies. From this combined perspective, the role of technological change in reshaping the relations between nature, culture, and society in a knowledge-based economy can further be specified.

1. Introduction

The study of technology is itself a complex issue. First, contrary to biological species technologies are not given in nature, but man-made constructs; they are the products of cultural evolution. The various actors involved may use different definitions of technology. Furthermore, technologies are continuously evolving. With the further development of technologies, their definitions and relevant perspectives may also have to change. These definitions and perspectives, however, are basic to the discursive traditions studying technology and its relevant contexts.

I distinguish three main perspectives in the study of technology: (1) economics, (2) the history of technology and the sociology of science, and (3) an orientation towards normative control in science and technology (S&T) policy analysis and management. I shall argue that the combination of these three perspectives challenges us to consider technology as a subject of complexity studies. From this combined perspective, I then proceed to specify the role of technological change in reshaping the relations between nature, culture, and society in a knowledge-based economy.

2. Prevailing Perspectives

2.1. Technology as a Subject of Economics

The primary function of markets is to resolve imbalances so that differences between supply and demand can be equalized by the price mechanism. Market clearing operates dynamically, yet at specific moments in time. Accordingly, economic theorizing initially focused on technological developments in terms of (so-called) comparative static analysis; or, how can the resulting configuration be compared with one or more prior configurations? One convenient way to model the operation of the market in the case of a choice among (available) technologies has been provided by the production function. The production function represents the relation of output to input factors (e.g. labor, capital, raw materials). When prices change, an entrepreneur is able to substitute among input factors using different techniques. Thus, the model assumes a single optimum given factor prices. The production function can be represented as a hyperbole given two input factors (e.g., Output = c*Capital*Labor) (See Figure 1).

The optimal technology at a certain moment in time can be found by drawing the tangent of this hyperbole with the straight line representing the current ratio between factor prices. However, technological innovation and development allow for the same output using fewer inputs. Therefore, economists distinguish analytically between shifts along the production function indicating factor substitution, and shifts of the production function towards the origin, as an indicator of technological development.

Although technological developments are also driven by economic factors (e.g., factor prices), this distinction has been fruitful both for empirical research and for theoretical developments. The shifts of the production function, however, could not be explained in neo-classical economics. From this perspective, technological progress had to be considered as an external given or a residual factor.

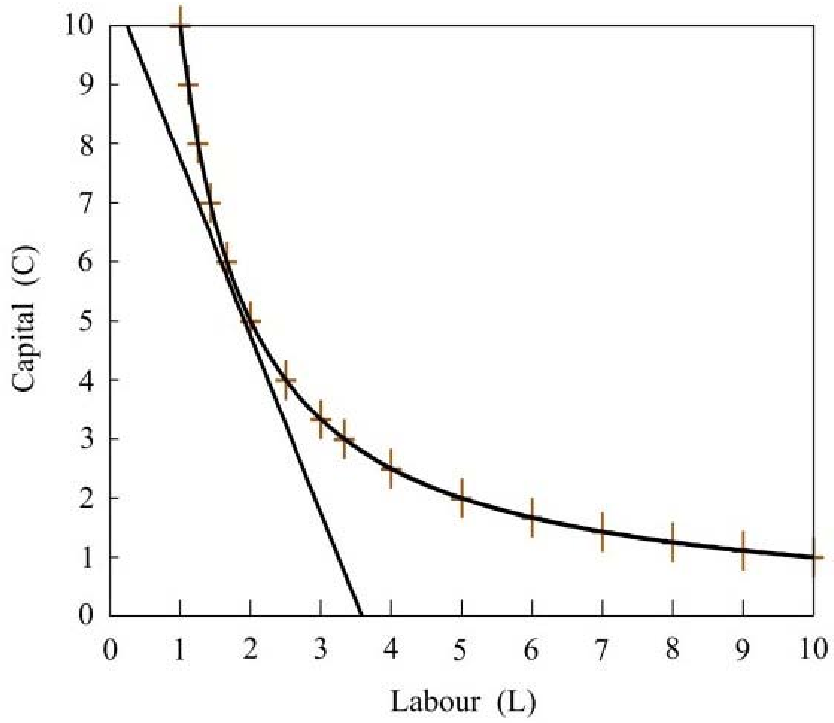

Figure 1: Cobb-Douglas production function (Q = K * L)

In a seminal study, Nelson and Winter proposed in 1982 to make technological developments endogenous to economic theorizing by using so-called Markov chain models. These authors, however, also changed the unit of analysis. While the (neo-classical) price mechanism and (Joseph Schumpeter's) innovative dynamics had analyzed the economy as a system, technological developments are now explained in terms of longitudinal developments in *firm behavior*. From this perspective, firms become the carriers of technologies and the driving force behind innovation.

Evolutionary economists have developed the discipline during the 1980s using concepts like trajectories and regimes. Models from evolutionary theorizing like predator/prey models (Lotka-Volterra) have been applied to economic phenomena. More recently and during the 1990s, evolutionary economists have focused on the network level of the adopters of a technology, rather than on individual firms. The utility of using a particular technology increases with the number of adopters. Therefore, standardization can emerge spontaneously, leading to the "lock-in" of one technology. This phenomenon has been related to the emergence of dominant designs in the history of various industries.

One well-known example of a "lock-in" is the QWERTY keyboard. This keyboard was engineered in order to optimize typing speed in the case of mechanical typewriting. It had been designed so that the typebars have a minimum chance of jamming given the character frequency distribution in the English language. Since mechanical typewriting is out of use, the QWERTY keyboard has become suboptimal. However, one is no longer able to break out of the lock-in given learning curves and network externalities resulting in the continued dominance of the QWERTY keyboard.

2.2. History of Technology and the Sociology of Science

Historians, scientists, and engineers with a common interest in the social contexts of the development of science and technology have provided us with a wealth of source materials about technologies and innovations. How are technologies shaped historically? How exogenous have technologies been to the development of the sciences? Or, from a very different perspective: How are user interests represented in the development of technological artifacts?

The period 1870-1910 is sometimes characterized as the "scientific-technological revolution" in industrial production. While technologies before this time were mainly embodied in artifacts (e.g., the steam engine), corporations from then onwards were generated on the basis of engineering activities (e.g., Thomas Edison); and, vice versa, large corporations began to develop their own research and development facilities (e.g., in the German chemical industry).

Patent legislation was a necessary complement to this development. The further development of the interface of science, technology, and markets has led to the emergence of a so-called "technostructure" both within large corporations and in state apparatuses during the first half of the 20th century. "Scientific management" feeds into the division between white-collar work concentrated within the technostructure and blue-collar work on the shop floor. In this configuration, technological developments remained relatively shielded from immediate consumer interests and oriented towards the longer-term planning of investments.

Sustained and institutionalized mutual interactions between markets and sciences change the codes in these communications. Braverman, for example, noted that "the key innovation is not to be found in chemistry, electronics, automatic machinery, aeronautics, atomic physics, or any of the products of these science-technologies, but rather in the transformation of science itself into capital." Conversely, the absorption of science by capital has gradually transformed the latter: the productive forces are no longer necessarily linked to the managerial decisions and instrumental actions of real people engaged in a labor process. One has to account increasingly for the interaction terms.

2.3. Technology Policy Analysis

Mission orientation in the development of science-based technologies has become a mode of operation since the Manhattan project in World War II. Under peaceful conditions it took the Sputnik shock (1957-1960) to generate science and technology policy analysis as a separate field of scholarly work. Policy analysts share with social historians of science and technology their orientation towards the dynamics of the systems under study, but they share with economists a focus on choices in terms of present strengths and weaknesses.

The Organization for Economic Cooperation and Development (OECD) in Paris has had a leading role in shaping science and technology policies since the 1960s. One of the main results of these efforts has been that one has for analytical reasons to differentiate among various sectors in society, disciplines of science, national cultures, and so on. The issue is complex in terms of the subject matter.

The differentiation between strategy and operational structure has been appreciated as constitutive of technology management. Knowledge-intensive production processes cannot be managed using a single criterion (like for example, prices or growth figures) since optimization in different dimensions has to be traded off. For example, technological alternatives can be compared in terms of price/performance *ratios*. Economic selections can be discussed in terms of representations (e.g., utility functions); and scientific reflections and technological constraints can no longer be considered as exogenous to the economic system.

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Biographical Sketch

Loet A. Leydesdorff reads Science and Technology Dynamics at the Amsterdam School of Communications Research (ASCoR), University of Amsterdam. He is the author of numerous articles and books in the area of technological development. His books include *The Knowledge-Based Economy: Modeled, Measured, Simulated* (2006); *A Sociological Theory of Communication: the Self-Organization of the Knowledge-Based Society (2001); The Challenge of Scientometrics: The Development, Measurement, and Self-Organization of Scientific Communications (1995); Universities and the global knowledge economy: a triple helix of university - industry - government relations*, with Henry Etkowitz, (1997) and *Evolutionary economics and chaos theory: new directions in technology studies*, with Peter van den Besselaar (1994).