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Technology, institutions, and innovation systems

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Abstract

There has been very little overlap or even interchange between scholars studying technological advance, and scholars in the field of cognitive science. Yet both fields of study are concerned with human know-how, the former at the level of society, and the latter at the level of the individual. Recent developments in cognitive science have made possible greater contact between the two fields. This essay reviews several of those developments, and points to a variety of interesting connections.

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1. Introduction

The development of the conception of an innovation system—national, regional, sectoral, or particular technology oriented—has largely been the work of economists and other scholars of technological advance who adhere to an evolutionary theory of economic growth (Freeman, 1988; Lundvall, 1988, 1992; Nelson, 1988, 1993; Carlsson, 1995; Edquist, 1997; Mowery and Nelson, 1999). From the time modern economic evolutionary theory emerged, it has been open to, indeed strongly drawn towards, embracing institutional analysis. The innovation systems idea is an institutional conception, par excellence.

The economists who have been active in the development of evolutionary growth theory have been motivated in large part by their perception that neoclassical economic growth theory, while assigning technological advance a central role in economic growth, is totally inadequate in its treatment of technological advance (Nelson and Winter, 1982). In particular, that theory represses the fact that efforts to advance technology are to a considerable extent "blind". This proposition does not deny the purpose, the intelligence, and the often powerful body of understanding the technique that those seeking to advance technology bring to their work. But it always seems to be the case that different inventors and R and teams lay their bets in different ways, and the winning technologies are determined to a considerable extent through ex-post competition. The broad notion that technological advance proceeds through an evolutionary process has been developed independently by scholars operating in a variety of different disciplines including historians (Constant, 1980; Rosenberg, 1976; Vincenti, 1990; Basalla, 1988; Petroski, 1992) as well as economists (Freeman, 1982; Rosenberg, 1976; Nelson and Winter, 1982; Soete and Turner, 1984; Silverberg et al., 1988; Metcalfe, 1998; Saviotti, 1996).

Sophisticated scholars of technological advance always have understood the important role of institutional structures in supporting and molding efforts to advance technology. Thus, institutions play a central place for example in David Landes' magisterial Unbound Prometheus (Landes, 1970), and Christopher

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Freeman's The Economics of Industrial Innovation (1982), and of course in the innovation systems literature.

However, to date formal evolutionary economic theory has been as limited in its incorporation of institutions as has been neo-classical economic theory, which it is designed to replace. Winter and I have argued that theorizing within a broad intellectual framework in economics tends to proceed at two different levels of abstraction. At the level of what we have called "appreciative" theory, which is close to the empirical subject matter, evolutionary theory has embraced and taken in institutions. At the formal level, it has not as yet. We also argued that the effective development of theory depended on a continuing dialectic interchange between formal and evolutionary theory. I am not alone in believing that further development of the innovation systems idea would be significantly facilitated if more formal economic evolutionary theory were able to take aboard institutional analysis.

Over the past several years, I have been working to develop a concept of institutions that fits conformably with the gist of formal evolutionary theory. This essay is a report on that work. If Winter and I are right about the importance of continuing dialogue between formal and appreciative theory, an important test of the value of the proposed view of institutions is whether or not it helps to sharpen up and advance the innovation systems idea.

2. Institutional analysis and evolutionary economic theory: the historical connections

First of all, I want to set the stage by proposing that, before modern neo-classical theory gained its present dominant position in economics, much of economic analysis was both evolutionary and institutional. Thus, Adam Smith's analysis (Smith, 1937, 1776) concerned with how "the division of labor is limited by the extent of the market" and, in particular, his famous pinmaking example, certainly fits the mold of what I would call evolutionary theorizing about economic change. Indeed, his analysis is very much one about the co-evolution of physical technologies and the organization of work, with the latter, I would argue, very much a notion about "institutions". In many other places in The Wealth of Nations, Smith is expressively concerned with the broader institutional structure of nations, in a way that certainly is consonant with the perspectives of modern institutional economics. Karl Marx of course was both an evolutionary and an institutional theorist. If you consider the broad scan of his writing, so too was Alfred Marshall. Thus, evolutionary growth theorizing that encompasses institutions in an essential way has a long and honorable tradition in economics.

As neo-classical economic theory became dominant in economics, and increasingly narrowed its intellectual scope, both the institutional and the evolutionary strands of economic analysis came to become "counter-cultures". In some cases, they were intertwined. Thus, they certainly were in Veblen and Hayek.

However, there was a tendency for the dissonant strains of institutional economic theorizing, and evolutionary economic theorizing, to take their own separate paths. Thus, in the United States, Commons (1924, 1934) helped to define the American institutional school. Commons' analysis was not very evolutionary. Nor was the perspective of Coase (1937, 1960) who, later, had a major shaping role on "the new institutional economics". While it seems to me that Williamson's kind of institutional analysis (1985) cries out for an express evolutionary formulation, to date Williamson has been reluctant to go along this route. On the other hand, Schumpeter (1942), whose work arguably has provided the starting point for modern evolutionary economics, is seldom footnoted by self-professed institutionalists, despite the fact that Schumpeter was very much concerned with economic institutions.

Thus, what has been called the "new institutional economics", and the new evolutionary economics, have different immediate sources and their focal orientations have been different. The orientation of institutional economics is toward the set of factors that mold and define human interaction, both within organizations, and between them. In contrast, much of modern evolutionary economic theorizing is focused on the processes of technological advance.

However, in my view at least, recent developments have seen the two strands coming together again, as Hodgson (1988, 1993) and Langlois (1989) long have argued should be the case. Thus, Douglass North (1990), perhaps today's best known economic "institutionalist", gradually has adopted an evolution-

ary perspective regarding how institutions form and change. And, as I noted earlier, many of the scholars who did the early work on the new evolutionary economics recently have become focused on such subjects as "national innovation systems", which is an institutional concept par excellence.

There certainly are strong natural affinities, in the form of common core assumptions and perceptions, between institutional economists, at least those in the school of North, and modern evolutionary economists. There also are very strong reasons more generally why they should join forces.

Both camps share a central behavioral premise that human action and interaction needs to be understood as largely the result of shared habits of action and thought (the language is Veblen's). In both, there is a deep-cutting rejection of "maximization" as a process characterization of what humans do. There also is a rejection of the Friedmanian notion that, while humans do not go through actual maximizing calculations, they behave "as if" they did, and therefore, that behavior can be predicted by an analyst who calculates the best possible behavior for humans operating in a particular context. Thus, for scholars in both camps, patterns of action need to be understood in behavioral terms, with improvements over time being explained as occurring through processes of individual and collective learning. For economic evolutionary theorists, this exactly defines the nature of an evolutionary process.

Scholars in both camps share a central interest in understanding the determinants of economic performance, and how economic performance differs across nations, and over time. Modern evolutionary theorists focus centrally on what they tend to call "technologies". For evolutionary theorists, a country's level of technological competence is seen as the basic factor constraining it's productivity, with technological advance the central driving force behind economic growth. As noted, increasingly evolutionary economists are coming to see "institutions" as molding the technologies used by a society, and technological change itself. However, institutions have not as yet been incorporated into their formal analysis.

On the other hand, institutional economists tend to focus exactly on these institutions. Many would be happy to admit that the influence of a countries institutions on it's ability to master and advance technology is a central way that institutions affect economic performance. However, institutionalists have yet to include technology and technological change explicitly into their formulation.

The arguments for a marriage I think are strong. Below I map out what a marriage might look like.

3. Routines as a unifying concept

I begin by noting the essential function, the notion of a "routine", or an equivalent concept, plays in modern economic evolutionary theory. A routine is a way of doing something, a course of action. As Sidney Winter and I have developed the concept (1982), the carrying out of a routine is "programmatic" in nature, and like a program tends largely to be carried out automatically. Like a computer program, our routine concept admits choice within a limited range of alternatives, but channeled choice. Almost always, there will be a set of understandings or beliefs associated with a particular routine, which explicates or rationalizes why it is appropriate in a particular context, and often, which provides an explanation of why and just how it works. But the key operative concept is the routine itself. It is the routine used that determines what is accomplished, given the context in which it is employed.

As noted, most of the writing by evolutionary economists has focused on "physical" technologies as routines. However, under the proposal that Winter and I put forth, business practices tend to be routines. There are routines for setting prices, ordering new inventory, hiring new workers, deciding whether or not to promote them, etc.

And I would like to note here, for elaboration later, that the notion of a routine fits very well with the conceptualization of many institutional economists, if the concept is turned to characterize standardized patterns of human transaction and interaction more generally. Indeed, if one defines institutions as widely employed "social" technologies, in the sense I will develop shortly, it is easy to take institutions on board as a component of an evolutionary theory of economic growth.

In order to see what I am suggesting, it is useful to reflect a bit on some important characteristics of productive routines. A routine involves a collection of procedures which, taken together, result in a predictable and specifiable outcome. Complex routines

almost always can be analytically broken down into a collection of subroutines. Thus, the routine for making a cake involves subroutines like pour, mix, and bake. These operations often will require particular inputs, like flour, sugar, and a stove. In turn, virtually all complex routines are linked with other routines that must be effected in order to make them possible, or to enable them to create value. Thus, a cake-making routine presupposes that the necessary ingredients and equipment are at hand, and the acquisition of these at some prior date requires its own "shopping" routines. And still further back in the chain of activity, the inputs themselves needed to be produced, in a form that meets the requirements of cake-makers.

A key aspect of productive routines that I want to highlight here is that, while the operation of a particular routine by a competent individual or organization generally involves certain idiosyncratic elements, at its core almost always are elements that are broadly similar to what other competent parties would do in the same context. By and large, the ingredients and the equipment used by reasonably skilled bakers are basically the same as those used by other skilled cake-makers. And the broad outline of the steps generally can be recognized by someone skilled in the art as being roughly those described in The Joy of Cooking, or some comparable reference.

There are two basic reasons why productive routines tend to be widely used by those who are skilled in the art. The first is that great cake-recipes, or effective ways of organizing bakeries, or for producing steel or semiconductor, tend to be the result of the cumulative contributions of many parties, often operating over many generations. This is a central reason why they are as effective as they are. Widely used routines are widely used because they are effective, and they are effective because over the years they have been widely used. To deviate from them in significant ways is risky, and while the payoffs may be considerable, there also is a major chance of failure.

The second reason is that particular routines tend to be a part of systems of routines. This systemic aspect forces a certain basic commonality of ways of doing particular things. The needed inputs tend to be available, routinely, for widely known and used routines. If help is needed, it generally is easy to get help from someone who already knows a lot about what is needed, and to explain the particulars in common language, if the routine involved is widely known and practiced. In contrast, idiosyncratic routines tend to lack good fit with complementary routines, and may require their users to build their own support systems.

4. Social technologies and institutions

In an earlier paper (Nelson and Sampat, 2000) where Bhaven Sampat and I developed many of these notions, we proposed that, if one reflects on the matter, the program built into a routine generally involves two different aspects: a recipe that is anonymous regarding any division of labor, and a division of labor plus a mode of coordination. We proposed that the former is what scholars often have in mind when they think of "physical technologies". The latter we called a "social technology", and proposed that social technologies are what many scholars have in mind when they use the terms "institutions". North and Wallis (1994) have proposed a similar distinction between physical and social technologies.

I propose that the conception of institutions as widely employed social technologies squares very well with the most widely used definitions of institutions put forth in the literature, although the flavor is different than some. It fits with Veblen's notion of institutions as "general habits of action and thought". Social institutions certainly are defined by and define "the rules of the game", the concept of institutions employed by many scholars, including North. Social technologies also can be viewed as widely employed "modes of governance", which is Williamson's notion (Williamson, 1985) of what institutions are about. And in the language of transaction costs, which is widely employed in the institutional literature, generally used "social technologies" provide low transaction cost ways of getting something done. As this discussion indicates, the concept of social technology is broad enough to encompass both ways of organizing activity within particular organizations—that is, the M form of organization is a social technology—and ways of transacting across organizational borders. Thus, markets define and are defined by "social technologies". So too are widely used procedures for collective choice and action.

This formulation naturally induces one to see prevailing institutions not so much as "constraints"

on behavior, as do some analysts, but rather as defining the effective ways to get things done when human cooperation is needed. To view institutions as "constraints" on behavior is analogous to seeing prevailing physical technologies as constraints. A productive social technology (an institution) or a physical technology is like a paved road across a swamp. To say that the location of the prevailing road is a constraint on getting across is basically to miss the point. Without a road, getting across would be impossible, or at least much harder.

This conception has an enormous advantage if one's theory of the processes of economic change is evolutionary. The institutions that an actor works with are directly relevant to that actor's performance. While the processes through which new institutions arise, and are modified over time, usually are complex, and involve much more than simple "innovation" on the part of particular firms, and selection based directly on how well those firms do, these processes do seem to be amenable to the kind of general "evolutionary" analysis that I and kindred scholars are trying to develop.

5. Institutions in an evolutionary theory of economic growth

The question of how institutions fit into a theory of economic growth of course depends not only on what one means by institutions, but also on the other aspects of that theory. I suggest that the concept of institutions as social technologies fits into evolutionary theories of economic growth very nicely.

While these days, almost all scholars studying economic growth see technological advance as a large part of the story, evolutionary theorists put special weight on technological advance. The reason is that, while neo-classical theory sees economic actors as facing a spacious choice set, including possible actions that they never have taken before, within which they can choose with confidence and competence, evolutionary theory sees economic actors as at any time bound by the limited range of routines they have mastered. Each of these has only a small range of choice. Further, the learning of new routines by actors is a time consuming, costly, and risky thing. Thus, while neo-classical growth theory sees considerable economic growth as possible simply by "moving along the production function", in evolutionary theory there are no easy ways to come to master new things.

Put more positively, from the perspective of evolutionary theory, the economic growth we have experienced needs to be understood as the result of the progressive introduction of new technologies which were associated with increasingly higher levels of worker productivity, and the ability to produce new or improved goods and services.

I want to put forth the empirical proposition that the advance of physical technologies is the key driving force. My reading of economic history suggests that, in the normal flow of events, new social technologies, new "institutions", often come into the picture as changes in the modes of interaction—new ways of organizing work, new kinds of markets, new laws, new forms of collective action—that are called for as the new technologies are brought into economic use. In turn, the institutional structure at any time has a profound effect on, and reflects, the technologies that are in use, and which are being developed.

6. Some particular cases

I do not offer the particular relationships between the evolution of physical and social technologies that I have just sketched as a general theory of institutional evolution, but I propose that it does fit a number of cases. More generally, I believe that the concept of institutions as social technologies, the routines language for describing them, and the particular context-dependent theory sketched above of how institutions and institutional change are bound up with the advance of physical technologies in the process of economic growth, becomes more powerful, the closer the analysis gets to describing actual social technologies in action. Thus, I turn now to two important particular developments in the history of experienced modern economic growth: the rise of mass production industry in the United States in the late 19th century, and the rise of the first science based industry—synthetic dyestuffs—in Germany at about the same time. Given space constraints, the discussion must be very sketchy, but I hope to provide enough detail so that one can see the proposed conceptualization in action.

6.1. The rise of mass production

As Alfred Chandler (1962) and other business historians tell the story, during the last parts of the 19th century and the first half of the 20th century, manufacturing industry in the United States experienced rapid productivity growth, associated with the bringing into operation of methods of production—new technologies or routines—that came to be called "mass production". The primary initial driving force was the development of certain new "physical" technologies, in particular, the development of the railroad and telegraph. These developments opened the possibilities for firms to sell on a much larger market than before, and thus to exploit potential economies of "scale and scope". At the same time, the advance of machine tool technology facilitated the design and production of specialized capital equipment that would enable these opportunities to be exploited.

The exploitation of these opportunities required that firms operate at much larger scale than before, and was associated with rising capital intensity of production, and the employment of professional management, often with education beyond the secondary level. However, these latter increases in "physical and human capital per worker", and in the scale of output, should not be considered as independent sources of growth, in the sense of growth accounting; they were productive only because they were needed by the new technologies. At the same time, it would be a conceptual mistake to try to calculate how much productivity increase the new technologies would have allowed, had physical and human capital per worker, and the scale of output, remained constant. The new production routines involved new physical technologies which incorporated higher levels of physical and human capital per worker than the older routines they replaced. To operate the new routines efficiently required much larger scales of output than previously.

And they also involved new "social technologies". Chandler's great studies are largely about the new modes of organizing and managing business that were required to take advantage of the new opportunities for "scale and scope". The scale of the new firms exceeded that which owner-managers plus their relatives and close friends could deal with, either in terms of governance or finance. The growing importance of hired professional management, and the diminished willingness of the original family owners to provide all the financial capital, called for the development of new financial institutions and associated markets. In turn, these called into existence new bodies of law. The need for professional managers also pulled Business Schools into being. More generally, the new industrial organization profoundly reshaped shared beliefs of how the economy worked, and came to define the concept of modern capitalism.

I would like to call attention to the fact that some of the institutional innovations associated with mass production could be implemented by firms on their own volition. Others, however, required cooperative decision, and some needed the actions of government. The development of mass production proceeded especially rapidly in the United States, in part at least because of the large size of the American market, but also because the associated new institutions grew up rapidly in the new world. In general, Europe lagged. On the other hand, the rise of new institutions to support science based industry occurred first in Europe.

6.2. The development of science based industry: the case of dyestuffs

Advances of understanding of organic chemistry, which occurred during the last half of the 19th century, led to the development of the first technology and industry with close links to formal science: those concerned with the development and production of synthetic dyestuffs. See Murmann, 1998, for a detailed account of what I sketch below. Academic chemistry provided the knowledge, the techniques, and the persons trained to use them, that firms needed to be successful in this new business.

A very important consequence was that the creation of new products in this business required a very different kind of persons than those who were engaged in the activities of day-to-day production and marketing, although at least a few trained chemists were needed on those fronts as well. Research and development (to use the modern term) became a highly specialized activity, that could and in general should proceed quite independently of day-to-day commercial operations. This posed a challenging problem of devising an appropriate "social technology".

German firms pioneered in the new social technology, or institution, that met the new opportunities and

needs, through developing the industrial research laboratory. The new industrial research laboratories were owned and funded by chemical product firms operating in the dyestuffs business, and staffed by university trained chemists employed by the firm and charged with creating new synthetic dyestuffs the firm could sell. German patent law was reformed to enable firms to own the chemical formulas for the new products.

There also was significant institutional innovation in the broader system supporting the new developments. German university chemistry departments adjusted their policies and expectations to the new fact that a large share of their students would go into industry. The German Lander governments were persuaded by the German chemical industry to increase their support for academic research and training in organic chemistry.

German firms were initially advantaged in this new science based technology for reasons that, in an evolutionary analysis of the developments in question, might well be regarded as exogenous, the German university system was initially well ahead of the rest of the world in research and training of chemists. However, German firms were quick to invent and put in practice the industrial research laboratory system, and the university system accommodated relatively quickly to the new context. The developments I have sketched above resulted in the domination of this new industry by German firms that lasted more than half a century.

7. Innovation systems

The reader undoubtedly can see the "innovation system" conception in the two accounts given above. The Chandler story stresses more the institutional structures needed to take advantage of technological innovation than the structures needed to support technological innovation of particular sorts. However, as Teece (1993) has pointed out, by the 1920s almost all of Chandler's corporations had put in place industrial R&D laboratories. The Murmann account focusses on the broader institutional structures supporting technological innovation, including universities, and government funding programs, and well as corporate labs. This is very much an "innovation systems" idea, as that concept has come to be articulated.

The interdependencies between the evolution of physical and social technologies that is so clear in these two accounts has been argued to hold on a larger canvas by Perez (1983), and more recently by Freeman and Louca (2001). The basic proposal there is that different economic eras are driven by the development of particular clusters of technologies, and that the institutional strictures needed to exploit and support these clusters can vary significantly. The innovation systems idea is clearly apparent here.

I believe, the conception of institutions as defining or shaping standard social technologies which I have articulated in this essay is coherent, and consistent with the innovation systems conception. I think, it provides a concrete theoretical base for its further development and articulation.

In my view, at least, the advance of physical technologies continues to play the leading role in the process of economic growth. In the example of the rise of mass production, social technologies enter the story in terms of how they enable the implementation of physical technologies. In the case of the rise of the industrial R&D laboratory, new social technologies are needed to support activities that create new physical technologies. Perhaps, a useful way of looking at this obvious interdependence is to posit, or recognize, that physical and social technologies co-evolve, and that this co-evolutionary process is the driving force behind economic growth. I take it that this conception is what the innovation systems idea is mostly about.

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