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TWENTY-FIVE CENTURIES OF TECHNOLOGICAL CHANGE

Joel Mokyr

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An Historical Survey

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An Historical Survey

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Introduction to the Series

Drawing on a personal network, an economist can still relatively easily stay well-informed in the narrow field in which he works, but to keep up with the development of economics as a whole is a much more formidable challenge. Economists are confronted with difficulties associated with the rapid development of their discipline. There is a risk of "balkanization" in economics, which may not be favorable to its development.

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Twenty-Five Centuries of Technological Change: An Historical Survey

JOEL MOKYR

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1. INTRODUCTION

One of the most pervasive and pernicious half-truths economists teach their students is the hackneyed aphorism that there is no such thing as a free lunch. It is the purpose of this essay to highlight the greatest counterexample to this statement.[1] Economic History is full of examples of free lunches, as well as (more frequently) very cheap lunches. At the same time, there are endless instances of very expensive meals that ended up inedible and in some cases lethal. Progress and growth are the subjects of this essay, but human history is laden with waste and inefficiency; the past has rarely been an example of economic efficiency. To phrase it differently, technological change is primarily the study of outward shifts of the production possibility frontier. Yet often societies have not been on the frontier, but at a point far from any economic optimality.

This monograph has benefitted throughout its long period of creation from the wisdom and wit of F. Michael Scherer. The additional comments of William Baumol, Reuven Brenner, Julia Burns, Charles Calomiris, Jan De Vries, Karl deSchweinitz, Stefano Fenoaltea, Jack Goldstone, C. Knick Harley, Dan Headrick, Jonathan R. T. Hughes, David Hull, Eric L. Jones, William McNeill, Cormac Ó Gráda, and William N. Parker, on earlier drafts have resulted in innumerable improvements. Mrs Barbara Karni provided her usual peerless editorial expertise. All remaining errors are mine and my sources' alone.

[1] For a similar statement, rare amongst economists, see Kamien and Schwartz (1982), p. 216. Kamien and Schwartz, too, regard technological change as a "trick" that makes it possible to avoid a choice and have "both" when faced with Samuelson's famous query "which one." Their analysis is cast largely in terms of a modern market in which research and development are embarked upon in a systematic way.

Roughly speaking, economic growth can occur as a result of four basic causes:

a) Growth that derives from capital deepening, or Solovian Growth (named after Robert Solow, who laid the foundation of the theory of modern economic growth). Because output per capita depends on the capital–labor ratio, net capital formation at a rate faster than population growth leads to economic growth, defined as an increase in output per capita. This type of growth involves no free lunch: in principle, all future benefits are paid for by abstinence in the present.

b) Growth that derives from commercial expansion leading to a more efficient allocation of resources. Any economist can show how the emergence of exchange (of goods or factors of production) can be beneficial to all partners involved, whether the gains are from international or local trade. A finer division of labor leads to productivity growth through specialization and the adaptation of skills to tasks. This process may be termed "Smithian Growth" (following Parker (1984)). Abstracting from the cost of transacting, the emergence of Smithian growth is a good example of a free lunch. It is, however, not the kind of free lunch I shall be much concerned with below.

c) Growth that derives from scale effects other than the division of labor. It is sometimes maintained that population growth can lead to per capita income growth, e.g. Simon (1977) and Boserup (1981). Such scale effects may clash with the economist's intuition of diminishing returns, but up to some point at least there are fixed costs and indivisibilities such as roads, schools, property-rights enforcement agencies, and so on, which can be deployed effectively only for large populations.

d) Growth that derives from increasing the stock of human knowledge, which includes technological progress proper, as well as changes in institutions. By technological progress, I mean any change in the application of information to the production process resulting either in the production of a given output with fewer resources (i.e., lower costs), or the production of better or new products. Again following Parker, I shall refer to this type of process as "Schumpeterian Growth." The choice of the words "application of information" is deliberate: much growth is derived from the employment of previously available information rather than the generation of new knowledge (Rosenberg (1982), p. 143). Traditionally, economists have distinguished between "invention" (the creation of new information) and its implementation, usually referred to as "innovation". Innovation is followed by "diffusion" in which more and more producers gain access to the new technique. In practice, these distinctions are not very helpful. During the implementation stages, inventions were usually improved, debugged, and modified in ways that qualify for the invention label. Diffusion, too, often required adaptation to local conditions and often implied further productivity gains due to learning by doing. Moreover, inventions that were not implemented remain little more than curiosa, of interest to intellectual but not economic historians. Some societies, such as the Hellenistic Mediterranean, were not especially technologically creative although they were capable of inventing. Their inventions for the most part remained amusing toys and had little or no economic impact. On the other hand, major gains in economic welfare were achieved due to exposure effects that occurred when previously disjointed civilizations came into contact with each other and learned to use each other's technologies. It is not really material, then, whether the information applied is entirely new even if a proper definition of what "new" exactly means here could be agreed upon. In what follows, the main focus is on technological creativity, defined as novel ways to apply knowledge so as to improve production techniques, a shift outward of the supply curve. Some societies have a remarkable record of technological creativity. Most have not.

The historical record of technological change displays an uneven and spasmodic character. Some brief spans in the history of a nation, like Britain between 1760 and 1800, are enormously rich in technological change. These peaks are followed by periods during which technical progress peters out. Why does that happen? Economists, sociologists, and historians have written extensively about this question, and they have found that its explanation is far from easy (Heertje (1983)). This essay is one more exploration in that direction. Most of what follows, however, is more of a historical description than an explanation. The reader interested in making a point about the history of technological change is offered a grab-bag of examples taken from the records ranging between 500 B.C. and 1914. The richness of technological history is such, however, that almost any point can be contradicted with a counterexample. Picking up empirical regularities in this massive amount of qualitative and often very uncertain information is hazardous and must be deferred (Mokyr, 1989a, 1989b).

The literature produced by modern economists on technological change is vast.[2] It has not, however, been very successful in explaining why some societies are technologically more creative than others. It is rarely informed by economic history, confining itself mostly to the post 1945 period. It is rarely informed by technological history. When technological historians such as A. P. Usher are cited, it is more for his interesting but speculative application of *gestalt* psychology to invention than for his enormous knowledge of how machines actually evolved over time (see for instance Thirtle and Ruttan (1987), pp. 2–5). Economists typically approach the explanation of technical change by considering the relation between demand and supply variables, research and development, and productivity growth. In so doing, they implicitly treat technology as a input, albeit one with peculiar features, that is produced and sold in the market for research and development. Such a market may or may not be a useful description of the post-1945 period (Jewkes, Sawers, and Stillerman (1969)). It is clear, however, that for an explanation of the diffusion of windpower in medieval Europe or the adoption of intensive husbandry in seventeenth century Britain, such a framework is inappropriate. Technological change throughout most of history can hardly be regarded as the consequence of an orderly process of Research and Development. It possessed few elements of planning and precise cost-benefit calculation. How, then, to explain it?

Once the economist ventures outside the safe realm of traditional microeconomics and agrees to consider extra-economic factors, he or she often discovers that events are hopelessly overdetermined. Theories of technical change based on geographic, political, religious, military, and scientific factors are typically easy to concoct and hard to reject. Many explanations make sense. But are they

[2] For recent surveys see Thirtle and Ruttan (1987); Baldwin and Scott (1987); Coombs, Saviotti and Walsh (1987); Wyatt (1986).

likely to be correct? This way of posing the question may not be very useful; perhaps it would be better to ask whether they are persuasive. Can we amass enough evidence to show that a particular theory is supported by facts in addition to logic? In what follows below I shall try to follow this kind of methodology.

By focussing on Schumpeterian growth I am not abandoning other forms of economic growth. Technological change unaccompanied by other forms of growth is rare. The four forms of growth aid and abet each other in many complex ways. For example, the embodiment hypothesis maintains that much technological change is contained in new capital goods. Thus in the absence of capital accumulation, technological change would be slow. Scale effects spurred by demographic growth lead to technological change, according to Simon (1977), because a large population implies a larger probability of a clever inventor being born. Schumpeterian growth in shipping leads to increased gains from trade by reducing transportation costs. The main focus here will be on technological change proper. The other forms of economic growth will be dealt with only insofar as they touch upon it directly. Technological change has a *macro* as well as a *micro* aspect. Even though the processes of invention and adoption are usually carried out by small units (individuals or enterprises), growth itself is an aggregate process. The economic historian is therefore directed to the macrofoundations of technological creativity, that is to say, what kind of environment makes individuals innovative, what kind of stimuli, incentives, hopes, and fears create an economy that encourages technological creativity?

It may turn out, as Heertje (1983, p. 46) has put it, that technological change cannot be explained. By that he means, I think, that standard economic theory faces a dilemma in dealing with technological creativity. It deals, after all, with rational choices subject to known constraints. Technological change involves an attack by an individual on a constraint everybody else takes as given. Yet most of the literature in the economics of technological change has viewed it as a process in which certain inputs (research and development) are transformed into an output called "productivity growth". As a result, the economics of technological change has been side-tracked by secondary questions such as its direction (factor saving biases) and the effect of cyclical variation in demand on the rate of patenting.