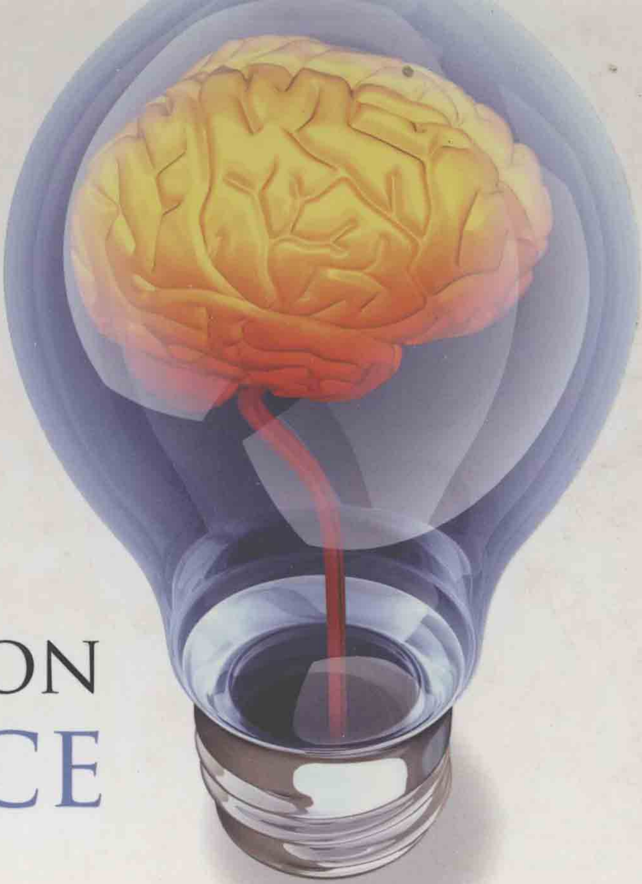

STUDIES ON SCIENCE AND THE INNOVATION PROCESS

Selected Works by

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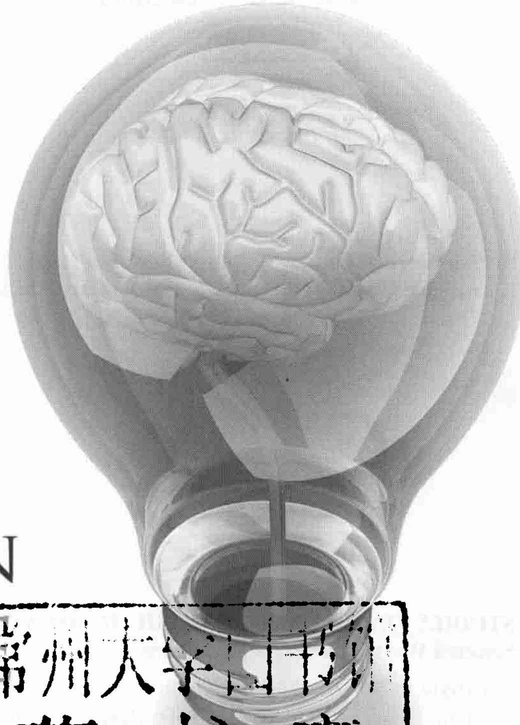

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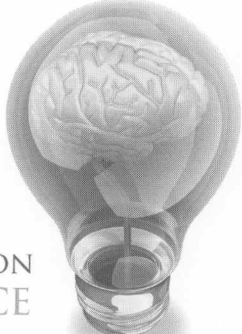

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Schumpeter and The Endogeneity of Technology

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Technology and the Pursuit of Economic Growth (with David Mowery)

Paths of Innovation (with David Mowery)

How the West Grew Rich (with L. E. Birdzell, Jr.)

The Britannia Bridge: The Generation and Diffusion of Technological Knowledge (with Walter Vincenti)

Prologue

This book brings together a cluster of studies that have a common denominator: that is to say, they may shed some light on the forces that have contributed to long-term economic growth. It is hard even to conceive of such growth (i.e., the substantial rise in incomes per capita) without the innovation process. The more specific focus is the performance of the American economy in the last two hundred years which, obviously, never existed as an isolated entity. Attention will be devoted to the larger global context. Frequent comparisons will be made to differences in national institutions and powerful economic incentives, that have shaped the innovation processes in industrialized countries.

A central theme, inevitably, is innovation, even in contexts where that term was not explicitly invoked. I should immediately admit to how I came to this usage. I was trained in economics, surely an indispensable discipline in the examination of the process of industrialization. Over the years, however, I became increasingly dissatisfied with the inability of economic analysis, *by itself*, to shed much light upon the growing role of technological change in the course of the twentieth century. Gradually, my interests shifted to historical-empirical perspectives. From such perspectives, it became increasingly apparent that a growing industrial economy was immensely diverse from sector to sector, and from one period to another, and that economic performance was being powerfully re-shaped by changes in the surrounding institutions of education, scientific research and, of course, government. It should not have taken me quite so long, as it did, to arrive at these conclusions. This became increasingly obvious in the course of my research. Ultimately, the innovation process, in all its diversities, has had to be approached historically.[1] On this fundamental issue, I eventually came to conclude

[1] For further expansion of this statement, see Nathan Rosenberg, *Inside the Black Box* (Cambridge University, 1982), Chapter 1, "The historiography of technical progress," and Chapter 7, "How exogenous is science?"

that Joseph Schumpeter, a distinguished economist, should serve as an appropriate guide to understanding the process of long-term economic growth. To explain my reasons for this view, I have included, as the last chapter of this book, a lecture that I presented to an Italian audience a few years ago.

Nathan Rosenberg
Stanford
March 2009

Acknowledgments

Since Stanford University has been my home for more than 35 years, my first acknowledgment must inevitably go to a magnificent institution that has been highly innovative in the intellectual realms of both teaching and research. The Economics Department, my departmental home, has provided immediate access to a diverse and immensely distinguished group of economists. In terms of the specific issues that I have addressed in this book, Moses Abramovitz, Paul David, Kenneth Arrow, Gavin Wright and Victer Fuchs have been, at various stages, simply indispensable.

Elsewhere at Stanford, Walter Vincenti and Steve Kline opened my windows, allowing me to peer into the realms of engineering disciplines with two superb guides. Ralph Landau was a visitor to Stanford for a number of years after a spectacular career as an innovator in chemical industries, who taught me much about chemical engineering. Marvin Chodorow, a well-known physicist, introduced me to Felix Bloch, the great physicist and the first Nobel Prize winner at Stanford. Chodorow later took me by the hand and guided me through the world of the emerging growth of Silicon Valley. Leonard Herzenberg, Professor of Genetics, provided me with multiple insights into the nature, as well as the changes, in the direction of frontier research in the biomedical world. Herzenberg was the primary force in the development of a powerful scientific instrument, the FACS (Fluorescence-Activated Cell Sorter). It is widely accepted that the FACS machine has transformed the field of flow cytometry. By the end of the 1990s, there were approximately 30,000 of these sophisticated devices in use throughout the world.

My invisible college outside of Stanford University has, happily, become more numerous along with the innovative processes that gave birth to the World Wide Web and to creative firms such as Google (which was initiated by two Stanford graduate students). In my invisible college, I must at least mention the names of a few distant colleagues who have been unusually helpful in my various research activities. They included Richard Nelson, David Mowery, Edward Steinmueller, Douglass North, Joel Mokyr, Annetine Gelijns, Vernon Ruttan, L.E. Birdzell, Stanley Engerman, Manual Trajtenberg, and Bronwyn Hall.

Returning to Stanford, I must extend my deepest thanks to the Stanford Institute for Economic Policy Research, in which I have been a Senior Fellow. This institute has provided me with a variety of resources and facilities without which my sizeable research projects would have been far more modest. I cannot close without my deepest thanks to Dafna Baldwin, a staff member of SIEPR. Dafna solved numerous difficulties that have emerged between me and publication deadlines that I could not have fulfilled had it not been for the alacrity with which Dafna moved into the "breach" and fulfilled commitments that I thought were no longer possible. Dafna has confirmed my long-standing conviction that the most powerful contributions to the rise in measured economic productivity in the last half of the twentieth century was the innovation that we call "the deadline."

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Contents

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Introduction

In view of the prominence played by universities in the papers that make up this book, it seems appropriate to provide some of the background conditions that have shaped institutions of higher education in the course of American history. Indeed, this recourse to history is inevitable, not only in understanding the introduction of new forms of educational institutions or new academic disciplines. Innovations are hardly ever subjects that can be well-illuminated with only the assistance of sweeping generalizations or abstract theories.

The different trajectories taken by American universities, as compared to those in Europe, owed a great deal to the political systems in which they were developed. After the Napoleonic Wars, higher education in much of continental Europe became public institutions. In effect, they were nationalized, with extensive centralized control as the inevitable accompaniment of centralized funding. University faculties in Europe became, essentially, civil servants.

The status of higher education in the United States was shaped by a very different set of political forces, the most distinguishing feature of which was an aversion to the centralization of power. The federation of the country in the last two decades of the eighteenth century translated into the localization of decision making as well as financial support of the educational system. This hostility to centralization has had its reflection in the fact that, to the present day, there is no major research university located in the nation's capital, in spite of numerous proposals over the years as well as the availability of superb library and archival collections. Support for establishing a national university in Washington, D.C. goes back to Hamiltonian proposals that were advanced almost immediately after the American Revolution, but they were rejected out of a fear of the possibility of concentrating excessive power in a centralized authority. Perhaps even more pertinent is the fact that the US has never had a ministry of education!

In the absence of a reliable source of revenue, a prerequisite for the success of an American university has always been its ability to raise funds, and the leadership of universities has therefore required a critical entrepreneurial skill: fund raising. In a small number of cases, some of America's most eminent universities were founded with substantial endowments by entrepreneurs who had already acquired considerable wealth. Johns Hopkins University, Cornell University, Vanderbilt University, Stanford University, Carnegie-Mellon University and the University of Chicago. The University of Chicago was, of course, founded with abundant Rockefeller money, but it was thought to be unwise at the time (1891) to prejudice the future of a newly born university with the name of a "robber baron". But, for the vast majority of private institutions, and even for institutions that started life with sizeable benefactions, a university president has had to be a skillful and determined fundraiser.

In this context, the older, elite American universities paid little attention to more "practical" concerns, such as science and engineering, until the incentive of a private endowment was eventually forthcoming, which led to the establishment of the Lawrence Scientific School as a branch of Harvard in 1847. Yale created the Sheffield Scientific School in response to a gift by a private entrepreneur in 1858. MIT was established on April 10th 1861, through the leadership of a group of Boston industrialists (two days before Fort Sumter was bombarded and the Civil War begun).[1]

State universities might, on first consideration, appear to have been exempted from the need for entrepreneurial leadership, but this has not been the case. The Morrill Act, passed by the US Congress in 1862, was the enabling "land grant" legislation that gave rise to a national network of state universities, with decentralized control and the subsequent financing of these universities left in the hands of each state. Since there were many states, it was never obvious why a public institution of higher

[1] UNIDO (2005). *Capability Building for Catching-up*, UNIDO, Vienna, p. 46. See also Karl Wildes and Nilo Lindgren, *A Century of Electrical Engineering and Computer Science at MIT, 1882–1982*, pp. 378–379.

education was necessary in each state, to be supported by revenues raised by the taxpayers of each state. Thus, in order to persuade state legislators to appropriate the necessary tax revenues, it was essential to demonstrate that the state university was providing uniquely valuable services to the business, agricultural and industrial interests of each state. And this required considerable entrepreneurial skills of a political and perhaps rhetorical sort.

State universities therefore came to specialize both their teaching curricula and their research activities in ways that would accommodate the changing needs of local industry and business. The Merrill Act referred to the need for these new institutions to advance the interests of "agriculture and the mechanic arts." The subsequent Hatch Act, passed by Congress in 1887, established state agricultural experiment stations that have subsequently played a crucial role in the development of improved agricultural technologies. As the country expanded westward and underwent industrialization, university teaching and research programs expanded in terms of their diversity and their extent of specialization. Indeed, the ease with which these activities could be altered became, and has remained, an essential feature that distinguished American universities from their European counterparts.

Thus, after the first World War, a college of engineering might offer undergraduate degrees in a bewildering variety of highly specialized engineering subjects, specializations of somewhat doubtful social benefit. In Illinois, a state heavily dependent on railroads, an engineering student at the University of Illinois found that he might take an undergraduate degree in architectural engineering, ceramic engineering, mining engineering, municipal and sanitary engineering, railway electrical engineering, and railway mechanical engineering. As one observer wryly observed at the time, "Nearly every industry and government agency in Illinois had its own department at the state university in Urbana-Champaign."[2]

American universities, especially state universities, have been a cornucopia of useful technologies for local industry. The Babcock test,

[2] David Levine. *The American College and the Culture of Aspiration, 1915–1940*, 1986.