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THE CENTER FOR **APPLIED ECONOMICS**

ENTREPRENEURSHIP, INNOVATION, AND TECHNOLOGICAL CHANGE

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TECHNICAL REPORT 07-0716

July 2007

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I. INTRODUCTION

There is growing interest among policy planners in both the public and private sectors about entrepreneurship and aspects of the consequences of successful entrepreneurship, namely innovation and technological change. This interest is a natural result of the shift towards a knowledge-based economy, as well as the substantial increase in public investment in knowledge-based institutions (e.g., universities), knowledge-generating public programs (e.g., the Small Business Innovation Research (SBIR) Program), and knowledge-sharing activities (e.g., public/private partnerships and research consortia).

Understanding the antecedents and consequences of entrepreneurship and innovation is critical because technological change has been shown to be related to improvements in economic performance at all economic levels – in the firm, among firms in industry, and at the regional and national levels. Relatedly, universities are increasingly being viewed by both themselves and policy planners as engines of regional economic growth and development because of their role in the commercialization of intellectual property through technology transfer. The primary commercial mechanisms for technology transfer are licensing agreements, research joint ventures, and university-based startups.

This report provides an overview of the burgeoning literature on entrepreneurship, innovation, and technological change with an emphasis on the nexus among these concepts and activities as related to regional economic growth and development.

Entrepreneurship, innovation, and technological change are not sequential concepts; each is a process that builds upon, as well as affects, the other two. The title of this report is not intended to suggest that entrepreneurial activity leads to innovation and then innovation leads to technological change. That may be the case – and many scholars have envisioned such a sequential process – but it may also not be the case. Entrepreneurship, innovation, and technological change are indeed interrelated

concepts but not necessarily related as a causal one-way process.

Several basic concepts are pervasive throughout this report. The first concept is entrepreneurship. As Hébert and Link (1988, p. 152) have written: “Throughout intellectual history as we know it, the entrepreneur has worn many faces and played many roles.” They define entrepreneurship as: “... someone who specializes in taking responsibility for and making judgmental decisions that affect the location, the form, and the use of goods, resources, or institutions” (1988, p. 155). Thus, broadly speaking, entrepreneurship refers to perception of opportunity and the ability to act on that perception. Individuals can be entrepreneurs, firms and organizations can act entrepreneurially, and governments can be entrepreneurs. Thus, entrepreneurship is a talent at all levels of analysis; at the firm and organizational levels there are nevertheless individuals that are the drivers. Being a talent, there is little that policy makers can do from a regional or state planning perspective.

Following Bozeman and Link (1983, p. 4): “Invention is the creation of something new. An invention becomes an innovation when it is put in use.” When innovation is conceptualized in a static sense, as in the quoted sentence just above, an innovation put in use is a new technology. When the innovation is the final marketable result, it is called a product innovation; when the innovation is applied in subsequent production processes, it is called a process innovation. More interesting is a dynamic view of innovation; that is, the process whereby an invention becomes an innovation – the so-called innovation process. Viewed as a process, there is a distinct role for entrepreneurship. When innovation is viewed as a process, the role of public policy also becomes clearer, namely the role becomes one of enhancing the innovation process.

As with entrepreneurship and innovation, the concepts of technology and technological change are varied. In a narrow sense, technology refers to a specific physical or

tangible tool – an innovation. In a broader sense, technology refers to intangible tools such as technological ethic or organizational technology; technological change describes an entire social process. Herein, technological change is discussed specifically as it relates to productivity and economic growth and development, and that is also the dimension in which most policy planners think of technological change.

II. THE ENTREPRENEUR AS INNOVATOR¹

From the perspective of the history of intellectual thought, one important role of an entrepreneur is as an innovator, an association made popular by Joseph Schumpeter. This section briefly sets forth a chronological trace of the entrepreneur as innovator in an effort to present the relevant intellectual history as well as to presage Schumpeter's contributions so as to enrich the analytical nexus between entrepreneurship and innovation.

A. SUPPLY-SIDE THEORIES OF ENTREPRENEURSHIP

A supply-side theory of entrepreneurship emphasizes the role of the entrepreneur in production and distribution of goods and services for which there is an independently determined demand. Such theories essentially address the question: Given the pattern of demand for existing goods and services, what role does the entrepreneur play in the market place? The earliest inquiries into the subject tended to focus on this question.

The term *entrepreneur* is a word of French origin that does not appear often in the pre-history of economics. Its common, though imprecise, use in the eighteenth century is corroborated by an entry in Savary's *Dictionnaire Universel de Commerce* (Paris, 1723) in which *entrepreneur* is defined as one who undertakes a project; a manufacturer; a master builder. An earlier form of the word, *entrepredeur*, appears as early as the fourteenth century. Throughout the sixteenth and seventeenth centuries the most frequent usage of the term connoted a government contractor, usually of military fortifications or public works.

The first significant writer to make frequent and obtrusive use of the term in a semblance of its modern form

was Richard Cantillon (1680-1734), an eighteenth-century businessman and financier. Cantillon's *Essai* is a watershed in the history of entrepreneurship because it establishes the entrepreneur as a central figure in the marketplace. Describing the nascent market economy of eighteenth-century Europe, Cantillon established the entrepreneur as the intermediary between landowners and hirelings. Landowners – the fashion leaders of society – established patterns of consumption in conformance with their individual tastes and preferences. Then, in turn, they relegated production of goods and services to entrepreneurs, who bore the risks associated with market judgments about production and distribution. Although Cantillon's entrepreneurs did not engage in the "creative destruction" of demand that Schumpeter described (discussed below), they nevertheless innovate in other ways befitting their intermediary status. For example, as they became aware that consumers are willing to pay a little extra in order to buy in small quantities rather than stockpile large quantities, they managed the circulation of goods accordingly.

Another way that Cantillon's entrepreneur can innovate is by arbitrage. An arbitrageur can create time and place utility by moving goods from low-valued use to high-valued use. Noting the opportunities for profit that existed between the countryside and Paris, Cantillon (1931, pp. 150-52) maintained that as long as they can cover their transportation costs, entrepreneurs "will buy at a low price the products of the villages and will transport them to the Capital to be sold there at a higher price."

Another writer who developed a theory of entrepreneurship that anticipated future developments was Abbe Nicholas Baudeau (1730-1792), a clergyman. A member of the French school of economists that has come to be known as the Physiocrats, Baudeau believed in the primacy of agriculture. In depicting the agricultural entrepreneur as a risk bearer, he echoed Cantillon. But Baudeau established even more overtly than Cantillon the concept of the entrepreneur as innovator, one who invents and applies new techniques or ideas in order to reduce his costs and thereby raise his profit.

In his analysis of entrepreneurship, Baudeau emphasized and explored the significance of ability. He underscored

the importance of intelligence, the entrepreneur's ability to collect and process knowledge and information. Intelligence – knowledge and the ability to act – also gives the entrepreneur a measure of control, so that he is not a mere pawn to the capitalist. Hence, Baudeau (1910, p. 46) described the entrepreneur as an active agent: “Such is the goal of the grand productive enterprises; first to increase the harvest by two, three, four, ten times if possible; secondly to reduce the amount of labor employed and so reduce costs by a half, a third, a fourth, or a tenth, whatever possible.”

British classical economists paid little attention to the role of the entrepreneur in a market economy, choosing to elevate the capitalist or private business person to the top of the economic hierarchy. Jeremy Bentham (1748-1832), whose ties with France and its intellectual tradition were much stronger than those of his contemporaries, was an exception. Aside from the fact that Bentham was virtually alone among British classical economists in his repeated emphasis on the entrepreneur as an agent of economic progress, it is noteworthy that his arguments, especially as related to administrative arrangement of contract management, recast the entrepreneur in the position of government contractor, that is, a franchisee who undertakes financial risk in order to obtain an uncertain profit. Bentham also explicitly tied his notion of entrepreneur-contractor to the act of innovation. He defended contract management as the proper form of, following his example, prison administration on the ground that it is a progressive innovation and should therefore be rewarded accordingly, no less than an inventor is rewarded for his invention.

J.H. von Thünen (1785-1850) set forth an explanation of profit that clearly distinguished the function and reward of the entrepreneur from that of the capitalist. Thünen identified entrepreneurial gain as profit minus (1) interest on invested capital, (2) insurance against business losses, and (3) the wages of management. For Thünen, this residual is a return to entrepreneurial risk when he wrote (1960, p. 247):

He who has enough means to pay to get some knowledge and education for public service has a choice to become either a civil servant or, if

equally suited for both kinds of jobs, to become an industrial entrepreneur. If he takes the first job, he is guaranteed subsistence for life; if he chooses the latter, an unfortunate economic situation may take all his property, and then his fate becomes that of a worker for daily wages. Under such unequal expectations for the future what could motivate him to become an entrepreneur if the probability of gain were not much greater than that of loss?

Thünen clearly appreciated the difference between management and entrepreneurship. He maintained that the effort of an entrepreneur working on his own account was different from that of a paid manager, even if each has the same knowledge and ability. The entrepreneur takes on the anxiety and agitation that accompanies his business gamble; he spends many sleepless nights preoccupied with the single thought of how to avoid catastrophe, whereas the paid substitute, if he has worked well during the day and finds himself tired in the evening, can sleep soundly, secure in the knowledge of having performed his duty. As Thünen put it (1960, p. 248):

Necessity is the mother of invention; and so the entrepreneur through his troubles will become an inventor and explorer in his field. So, as the invention of a new and useful machine rightly gets the surplus which its application provides in comparison with an older machine, and this surplus is the compensation for his invention, in the same way what the entrepreneur brings about by greater mental effort in comparison with the paid manager is compensation for his industry, diligence, and ingenuity.

B. DEMAND-SIDE THEORIES OF ENTREPRENEURSHIP

A demand-side theory of entrepreneurship emphasizes the role of the entrepreneur in changing the nature of demand for existing goods and services by introducing new goods and services or new combinations of existing goods and services. Such theories essentially address the question: Given the pattern of supply for existing goods and services, what role does the entrepreneur play in the marketplace?

Economic thought in the late nineteenth and early twentieth centuries developed differently in Germany than it did in England, or throughout the rest of Europe. This was due in part to the influence on economic method of the German Historical School. The historicists believed that in order to understand man's economic behavior and the institutions that constrain it, economics must describe human motives and behavioral tendencies in psychologically realistic terms. Gustav Schmoller (1838-1917) represented the second generation of German historicists. He amassed mountains of historical data in order to analyze actual economic behavior. From his examination of these data he discovered a unique central factor in all economic activity – the enterprising spirit, the *Unternehmer*, or entrepreneur. Schmoller's entrepreneur was a creative organizer and manager whose role was innovation and the initiation of new projects. He combined factors of production to yield either new products or new methods of production. Schmoller's entrepreneur possessed imagination and daring. More significantly, Schmoller began to direct attention to the role of the entrepreneur on the demand side of economic activity.

Schmoller's ideas were extended by third-generation German historicists, Werner Sombart (1863-1941) and Max Weber (1864-1920). Sombart introduced a new leader who animates the entire economic system by creative innovations. This entrepreneur combined the powers of organization with a personality and ability to elicit maximum productivity from individuals engaged in the productive process. Whether he is a financier, manufacturer, or trader, Sombart portrayed the entrepreneur as a profit maximizer.

The German historicists characterized the entrepreneurial process as a breaking away from the old methods of production and the creation of new ones. This disequilibrating process was particularly emphasized by Weber. He sought to explain how a social system, as compared to an individual enterprise, could evolve from one stable form to another type of system. Historically, he identified such changes with a charismatic leader, or entrepreneur-like person.

Joseph Schumpeter (1883-1950) was schooled by the Austrian economists of the Vienna Circle but was heavily

influenced by Weber. He set out to develop a theory of economic development in which the entrepreneur plays a central role. By applying new combinations of factors of production, Schumpeter's entrepreneur becomes the motive force of economic change. He is thereby responsible for the rise and decay of capitalism. The talented few who carry out innovations by devising new technologies, discovering new products and developing new markets account for the short and long cycles of economic life. Schumpeter saw economic development as a dynamic process, a disturbing of the status quo. He viewed economic development not as a mere adjunct to the central body of orthodox economic theory, but as the basis for reinterpreting a vital process that had been crowded out of mainstream economic analysis by the static, general equilibrium approach. The entrepreneur is a key figure for Schumpeter because, quite simply, he is the *persona causa* of economic development.

Schumpeter combined ideas from many earlier writers, but the demand-side emphasis that marked the Germanic tradition dominated his treatment of entrepreneurship. His entrepreneur is a disequilibrating force. For Schumpeter the concept of equilibrium that dominated twentieth-century economics served as a mere point of departure. The phrase he coined to describe this equilibrium state was the circular flow of economic life. Its chief characteristic is that economic life proceeds routinely on the basis of past experience; there are no forces evident for any change of the status quo. Schumpeter (1934, pp. 42-43) described the nature of production and distribution in the circular flow in the following way:

[I]n every period only products which were produced in the previous period are consumed, and . . . only products which will be consumed in the following period are produced. Therefore workers and landlords always exchange their productive services for present consumption goods only, whether the former are employed directly or only indirectly in the production of consumption goods. There is no necessity for them to exchange their services of labor and land for future goods or for promises of future consumption goods or to apply for any "advances" of present consumption goods. It is simply a

matter of exchange, and not of credit transactions. The element of time plays no part. All products are only products and nothing more. For the individual firm it is a matter of complete indifference whether it produces means of production or consumption goods. In both cases the product is paid for immediately and at its full value.

Within this system, the production function is invariant, although factor substitution is possible within the limits of known technological horizons. The only real function that must be performed in this state is "... that of combining the two original factors of production, and this function is performed in every period mechanically as it were, of its own accord, without requiring a personal element distinguishable from superintendence and similar things" (Schumpeter 1934, p. 45). In this artificial situation, the entrepreneur is a nonentity. "If we choose to call the manager or owner of a business 'entrepreneur'," wrote Schumpeter (1934, pp. 45-46), then he would be an entrepreneur "without special function and without income of a special kind."

For Schumpeter, the circular flow is a mere foil. The relevant problem is not how capitalism administers existing structures, but how it creates and destroys them. This process of creative destruction is the essence of economic development. In other words, development is a disturbance of the circular flow. It occurs in industrial and commercial life, not in consumption. It is a process defined by the carrying out of new combinations in production. It is accomplished by the entrepreneur.

Schumpeter realized that the essential function of the entrepreneur is almost always mingled with other functions, such as management. But management does not elicit the truly distinctive role of the entrepreneur, making decisions however does. In Schumpeter's theory, the dynamic entrepreneur is the person who innovates, who makes new combinations in production.

Schumpeter described innovation in several ways. Initially he spelled out the kinds of new combinations that underlie economic development. They encompass the following: (1) creation of a new good or new quality of good; (2) creation of a new method of production; (3)

the opening of a new market; (4) the capture of a new source of supply; (5) evolvement of a new organization of industry (e.g., creation or destruction of a monopoly). Over time, of course, the force of these new combinations dissipates, as the new becomes part of the old (circular flow). But this does not change the essence of the entrepreneurial function. According to Schumpeter (1934, p. 78), "everyone is an entrepreneur only when he actually 'carries out new combinations,' and loses that character as soon as he has built up his business, when he settles down to running it as other people run their businesses."

Alternatively, Schumpeter (1939, p. 62) defined innovation by means of the production function. The production function, he said, "describes the way in which quantity of product varies if quantities of factors vary. If, instead of quantities of factors, we vary the form of the function, we have an innovation." Mere cost-reducing adaptations of knowledge lead only to new supply schedules of existing goods, however, so this kind of innovation must involve a new commodity, or one of higher quality. However, Schumpeter recognized that the knowledge supporting the innovation need not be new. On the contrary, it may be existing knowledge that has not been utilized before.

In Schumpeter's theory, successful innovation requires an act of will, not of intellect. It depends, therefore, on leadership, not intelligence, and, it should not be confused with invention. On this last point, Schumpeter (1934, pp. 88-89) was explicit:

To carry any improvement into effect is a task entirely different from the inventing of it, and a task, moreover, requiring entirely different kinds of aptitudes. Although entrepreneurs of course may be inventors just as they may be capitalists, they are inventors not by nature of their function but by coincidence and vice versa. Besides, the innovations which it is the function of entrepreneurs to carry out need not necessarily be any inventions at all.

The leadership that constitutes innovation in the Schumpeterian system is disparate, not homogeneous. An aptitude for leadership stems in part from the use of

knowledge, and knowledge has aspects of a public good. People of action who perceive and react to knowledge do so in various ways; each internalizes the public good in potentially a different way. The leader distances himself from the manager by virtue of his aptitude. According to Schumpeter (1928, p. 380), different aptitudes for the routine work of static management results merely in differential success at what all managers do, whereas different leadership aptitudes mean that “some are able to undertake uncertainties incident to what has not been done before; [indeed] . . . to overcome these difficulties incident to change of practice is the function of the entrepreneur.”

The simplicity and power of Schumpeter’s theory is summed up in his own words: “The carrying out of new combinations we call ‘enterprise’; the individual whose function it is to carry them out we call ‘entrepreneurs’” (Schumpeter 1934, p. 74).

III. INNOVATION AND TECHNOLOGICAL CHANGE

If technology is an innovation put into use, then in a broad sense technology is the physical representation of knowledge. Any useful device is, in part, proof of the knowledge-based or informational assumptions that resulted in its creation.

The information embodied in a technology varies accordingly to its source, its type, and its application. For example, one source of information is science, although scientific knowledge is rarely sufficient for the more particular needs entailed in constructing, literally, a technological device. It could be useful in this regard to think of science as focusing on the understanding of knowledge and technology as focusing on the application of knowledge. Other sources of knowledge include information from controlled and random experimentation, information that philosophers refer to as ordinary knowledge, and, information of the kind that falls under the rubrics of creativity, perceptiveness, and inspiration.

Regarding perceptiveness, an entrepreneurial characteristic, Fritz Machlup argued that formal education is only one form of knowledge. He asserted that knowledge is also gained experientially and is gathered and processed at different rates by each individual (1980, p. 179):

Some alert and quick-minded persons, by keeping their eyes and ears open for new facts and theories, discoveries and opportunities, perceive what normal people of lesser alertness and perceptiveness, would fail to notice. Hence new knowledge is available at little or no cost to those who are on the lookout, full of curiosity, and bright enough not to miss their chances.

This informational view of technology implies that technology *per se* is an output that arises from a formal, rational, purposively undertaken process. Such an idea – the production of technology – highlights the role of knowledge and research produces knowledge in the generation of technology – as well as the role of entrepreneurship in terms of perception and action. And, the concept of research underscores the myriad sources available from which knowledge can be acquired. Technologies can thus be distinguished, albeit imperfectly, by the amount of embedded information. More concretely, research and development (R&D) activities and related investments – wherever they are based – play a large role in creating and characterizing new technologies.

Economists have often evaluated the effect of technological change on production in terms of changes in the amount of capital and labor used in production. The simplest classification scheme assumes that technological change alters the input mix for a given level of output. For a given level of output and input-to-price ratio, a labor-saving technological change results in a higher capital-to-labor ratio; a capital-saving technological change results in a lower capital-to-labor ratio; and a neutral technological change results in an unchanged capital-to-labor ratio.

This factor-saving conceptualization of technological change implicitly assumes that technology leads to cost-reducing changes in the production process, rather than to new or improved quality products. Very simply, this factor-saving conceptualization highlights the distinction between a process innovation and a product innovation. This notion also highlights one difference between economic and management scholars who study technological change.

Economists have long emphasized cost reduction, perhaps, and this is somewhat speculative, because it is the dual of profit maximization and profit maximization is a fundamental theoretical premise of the discipline. Management scholars have emphasized product enhancement, perhaps, and this again is somewhat speculative, because it relates to the behavior assumptions of managers and to their strategy for maximizing shareholder wealth.

Much of the early literature on the economics of technological change was based on production function models in which the output (Q) of an economic unit (a plant, a firm, an industry, or a nation) is represented simply as a function of capital (K) and labor (L):

$$(1) \quad Q = A(t) F(K, L)$$

where $A(t)$ is a disembodied time-related shift factor. Changes in K and/or L affect Q . Changes in other factors can also affect Q through the shift factor $A(t)$. It follows mathematically that the impact of technological change on productivity growth can be approximated in terms of the growth rate of $A(t)$.

There is a vast literature in economics and public policy, which began in the early 1960s, in which researchers estimated empirically, based on representations of production as in equation (1), the impact of investments in R&D on productivity growth under the implicit assumption that R&D is an input into innovation and innovation leads to technological change. The findings support the conclusion that investments in R&D matter at all levels of aggregation – at the firm level, at the industry level, and at the aggregate level;² increases in R&D in both the private and public sectors are associated, with a lag, with increases in technological change and hence productivity growth.

The workhorse model within this body of literature is based upon mathematical variants of the production function in equation (1). These models reduce to a simple relationship between total factor productivity (TFP) and the ratio of R&D to output.³

TFP measures output per a combination of units of both K and L , and thus from equation (1):⁴

$$(2) \quad TFP = Q / F(K, L) = A(t)$$

The fundamental model that results from the production function in equation (1) and the definition of TFP in equation (2) is:⁵

$$(3) \quad \text{Percentage Change in TFP} = a + b (R\&D/Q)$$

and, the estimated value of b is the marginal rate of return to R&D.

Implicit in the empirical estimation of equation (3) is that changes in R&D intensity ($R\&D/Q$) effect the percentage change in total factor productivity (TFP) contemporaneously. This is certainly counterintuitive, and the assumption is driven more by data than by reality. Nevertheless, this stringent assumption does not affect the theoretical foundation of causality that is embodied in equation (3), a point reiterated in Section VI below. There is certainly a lag between R&D investments in period t and total factor productivity in period $(t+1)$.

In addition, the model in equation (3) understates the impact of technology diffusion. For example, R&D investments in period t by firm A, will, after a lag, affect total factor productivity in period $(t+1)$ in firm A. If the realization of firm A's R&D in period t is also a technology advanced product or process in period $(t+1)$, and if firm B purchases that product or process in period $(t+2)$, that product or process may not have an effect on firm B's total factor productivity until period $(t+3)$, etc. In other words, technologies diffuse across firms in the form of enhanced capital, K .⁶

The same diffusion concept is relevant if a firm or firms in one industry develop(s) a more advanced technology product or process, and then firms in another industry will adopt that advanced technology product or process slowly over time. Some firms in the second industry will be early adopters, while other will be slower waiting to see the effect of the new technology on the early-adopting firms.

The economics and public policy literature reports estimated values of b in equation (3) that are numerically greater than the rate of return that is normally earned on comparable investments. This finding suggests that firms are under investing in R&D, from a social perspective, because, among other things, firms are not able to appropriate all of the returns from R&D.⁷ Many of the

economic returns from investments by a firm in R&D spill over to other firms, such as firms that purchase R&D-embodied goods and services.

IV. R&D BY CHARACTER OF USE

Vannevar Bush (1945) is credited for first using the term basic research. In his 1945 report to President Roosevelt, *Science—the Endless Frontier*, Bush used the term and defined it to mean research conducted without thought of practical ends. Since then, policy makers have been concerned about definitions that appropriately characterize the various aspects of scientific inquiry that broadly fall under the label of R&D and that relate to the linear model that Bush proffered.

Definitions are important to the National Science Foundation because it collects expenditure data on R&D and attempts to ensure reporting consistency over time. For those data to reflect accurately industrial and academic investments in technological advancement, and for those data to be comparable over time, there must be a consistent set of reporting definitions.

The classification scheme used by the National Science Foundation for reporting purposes was developed for its first industrial survey in 1953-1954. While minor definitional changes were made in the early years, the concepts of basic research, applied research, and development have remained much as was implicitly contained in Bush's 1945 linear model that described, at that time, the progress of research within a firm:

Basic Research → *Applied Research* → *Development*

The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind. Basic research is defined as research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest. Much of the scientific research that takes place at universities and colleges is basic research.

Applied research is aimed at gaining the knowledge or understanding to meet a specific recognized need. Applied research includes investigations oriented to discovering new scientific knowledge that has specific com-

mercial objectives with respect to products, processes, or services.

Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes.

Based on National Science Foundation data (2006), approximately 62 percent of national R&D is development, with almost 19 percent of R&D being allocated to applied research and the same approximate percentage to basic research. Different sectors contribute disproportionately to the Nation's funding and performance of these R&D component categories. Applied research and development activities are primarily funded by industry and performed by industry. Basic research, however, is primarily funded by the federal government and generally performed in universities and colleges. Industry funds the 84 percent of its own basic and over 88 percent of its applied research; the federal government funds nearly 65 percent of basic research at universities and colleges and 54 percent of the applied research performed there. Nearly 89 percent of all development is funded by industry and performed by industry.

With reference to the model in equation (3) from which researchers have estimated the returns to R&D, or alternatively stated, the contribution of R&D to productivity growth, estimates are that the contributions from basic research are significantly greater than from applied research or development. From a statistical perspective, the estimated value of b in equation (3) is numerically greater when basic research per unit of output is the independent variable compared to when applied research or development per unit of output are the independent variables. The logic of these empirical findings is that investments in basic research are the foundation for further research, and that foundation is critically important to economic growth. Because the lion's share of basic research occurs in the academic sector, it is reasonable to focus policy attention on the continued health of university and college research activity, as Bush did in his 1945 report.

V. AN ILLUSTRATION: THE DEVELOPMENT AND COMMERCIALIZATION OF BIOTECHNOLOGIES

The development and commercialization of biotechnology in the United States represents a phenomenon that illustrates well the interrelationship among the concepts of entrepreneurship, innovation, and technological change.

The historical process of the development and commercialization of biotechnology is one that can be viewed as beginning with relevant science funded by government agencies.⁸ The application of that science was exploited by academic and industrial entrepreneurs. That exploitation led to biological innovations, and subsequently these innovations brought about technological change and attendant economic growth (regional growth as well as national growth).

Biotechnology is, according to the U.S. Department of Commerce (2003, p. 3), "... the application of molecular and cellular processes to solve problems, conduct research, and create goods and services." It is important to emphasize that it is not the goods and services associated with biotechnology that are its defining characteristics, but rather, biotechnology is defined with regard to the techniques or fundamental technologies used to develop products and processes. Cells contain genetic material, DNA that acts like a blueprint for the function and structure of the cell. Through biotechnology, the genetic blueprint can be isolated, copied, and rearranged at the molecular level to alter or manipulate the function and structure of the cell.⁹

The number of new so-called biotech firms has increased over the past two decades in all industrial nations, albeit erratically over time in a given nation as well as over time across nations. As opposed to defining the biotechnology industry in terms of application industries or areas, one possible alternative is to think about the biotechnology industry in terms of the sectors from which those organizations involved in the overall value added process come. Thus, one could argue that the biotechnology industry has three distinct segments. The first segment includes universities and colleges and research institutes

where the underlying bioscience base upon which the technology is created; the second segment includes dedicated biotechnology firms (DBFs) which rely on the underlying science base and, building upon it, develop new technological procedures and techniques; and the third segment includes user firms which apply the technological procedures of DBFs to application areas, and these firms are often referred to as biotechnology commercializing firms (BCFs).

The biotechnology industry began with breakthroughs in the biosciences.

- In 1953, Watson and Crick discovered the double helix structure of DNA.
- In 1957, Kornberg revealed how DNA is replicated through the discovery of the enzyme DNA polymerase I.
- In 1973, Cohen and Boyer developed the recombinant DNA (r-DNA) technique.
- In 1975, the first monoclonal antibodies were discovered.

It is important to point out that the above four chronological events, which reflect knowledge diffusion over time, are the precursor events to the development of the underlying bioscience. While they are, indeed, events that occurred in the United States at U.S. universities and colleges, the resulting knowledge has public good characteristics that thus represented at that time and now the building blocks for world wide applications.

The scientists involved in these events were entrepreneurs. They not only perceived an opportunity but also they acted upon it, and their actions results in a discovery and a patented invention. Federal funding of their research did not create their entrepreneurial talent; such funding, in the form of research grants, did speed up the realization of their entrepreneurial talent and the ensuing commercialization of their inventions. Subsequently, others perceived the importance of these discoveries and patented inventions and acted upon that knowledge to create related products and processes – innovations. The application of those products and processes brought about technological change and improved firm performance, and in turn it affected economic growth.

The four dated bioscience breakthroughs bulleted above were used – perceived and acted upon – very quickly by DBFs to develop biotechnologies (and certainly not all DBFs adopted the bioscience breakthroughs at the same time but rather they diffused over time), and, not surprisingly, these DBFs located initially near the bioscience breakthroughs in San Francisco and nearby Silicon Valley and in Cambridge, MA:

- In 1976, Genentech (a DBF) was founded in San Francisco by venture capitalist Robert Swanson of Kleiner Perkins and professor Herbert Boyer of the University of California at San Francisco. The goal of the new company was to use bioscience to synthesize human insulin. This was accomplished in 1978.
- In 1978, Biogen (a DBF) was founded in Cambridge, MA, by Harvard professor Walter Gilbert, among others, including MIT professor Phillip Sharpe. These formations of clusters are evidence of the impact of the technology on regional economic growth and development.¹⁰

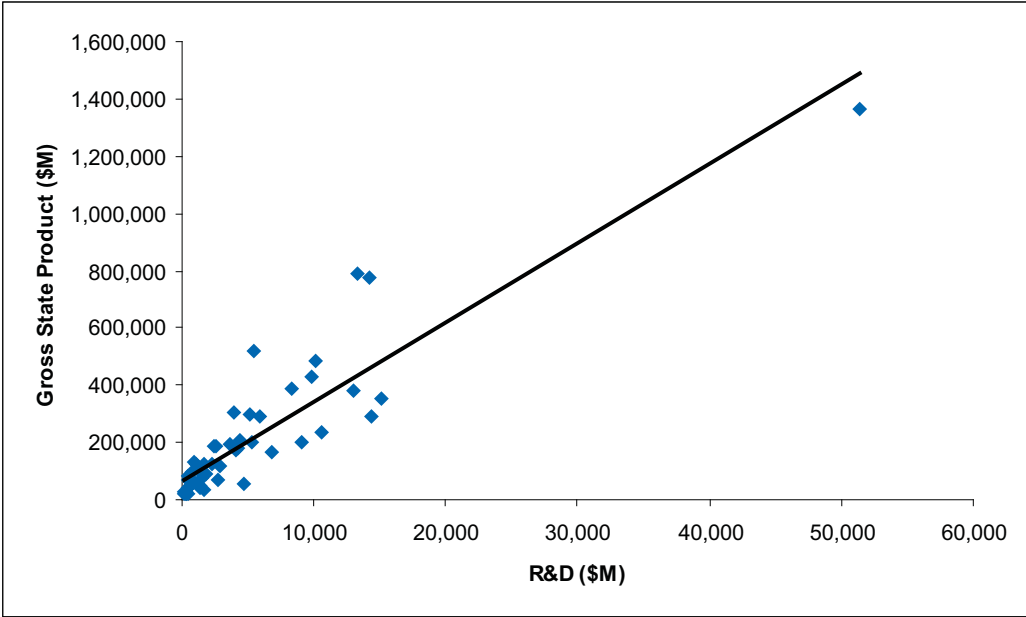
There have not yet been any empirical studies based on equation (3) above that estimate the returns to biotechnology-focused R&D.

VI. PUBLIC POLICIES TOWARD R&D AND ECONOMIC GROWTH

Reflecting on the conclusions discussed in Section III, namely that investments in R&D matter at all levels of aggregation – at the firm level, at the industry level, and at the aggregate level – and therefore increases in R&D in both the private and public sectors are associated with increases in technological change and hence productivity growth, a number of public policy initiatives have been promulgated to enhance private-sector R&D activity. These initiatives came to the fore in response to the productivity slowdown in the United States – and in most industrialized nations – in the mid-1960s into the early 1970s and then again in the late 1970s and early 1980s; productivity growth is a fundamental contributor to overall economic well-being.

The economics and public policy literature that developed related to the productivity slowdown focused on a

Figure 1
Gross State Product and State R&D Investments, 2002



Source: National Science Foundation (2006), Table 8-26.

number of explanations for it and on only a few target variables for policy responses. Culprits for the slowdown included:

- cyclical shocks or patterns that exist in an economy that results in uneven uses of resources,
- declining capital investments that directly affect productivity growth,
- inflation and energy prices that cause economy uncertainty and thus waning investment spending,
- government regulations that redirect productivity-enhancing investments toward compliance to regulations (e.g., environmental) that are not correlated with measured productivity growth,
- unionization activities that dampen labor productivity, and
- entrepreneurial and managerial myopia reflecting the inability of many business people to deal with cyclical disequilibria because of a focus on short-term activities.

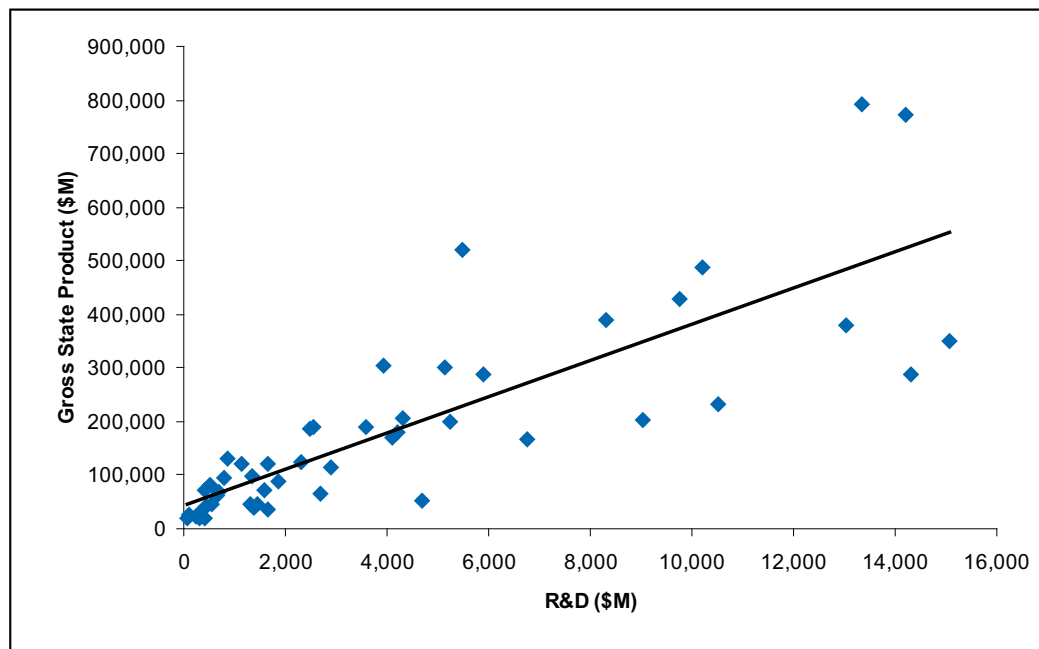
Industrial R&D had been declining in the United States from the early-1950s until the mid-1960s, and many pointed to this decline as a, or perhaps the, driving force behind the productivity slowdown. As one Department of Commerce (1990, p. 47) report noted:

As a [N]ation ... we no longer are totally self-sufficient in all essential materials or industries required to maintain a strong national defense. Consequently, we must identify requirements carefully and assess them against our industrial base capabilities. We must develop [R&D-based] strategies that enable us to meet security needs

In response to the productivity slowdown and to growing awareness of the role of R&D in technological advancements, a number of policy responses were initiated in the early 1980s with the realization that there is a lag between R&D activity and technological advancements and productivity growth. These initiatives included tax incentives for R&D through the R&E Tax Credit of 1981;¹¹ the leveraging of R&D activity in small firms

Figure 2

Gross State Product and State R&D Investments, 2002 (less California)



Source: National Science Foundation (2006), Table 8-26.

(which may not benefit from tax credits) by the creation of the Small Business Innovation Research (SBIR) through the Small Business Innovation Development Act of 1982; and through antitrust indemnification from research collaborations from the National Cooperative Research Act of 1984.

The logic of the R&E Tax Credit and direct R&D support through the SBIR program is that lowering the marginal cost to a firm from conducting additional R&D – presumably the more risky R&D – will provide an incentive for firms to expand their margin and re-evaluate the marginal returns from their own investments. The logic of the National Cooperative Research Act is that through collaboration in R&D, redundancy in research efforts will be lessened and the overall research process will be shortened thus leading to a shortened time to the commercialization of new discoveries.

VII. R&D AND ECONOMIC PERFORMANCE AT THE STATE LEVEL

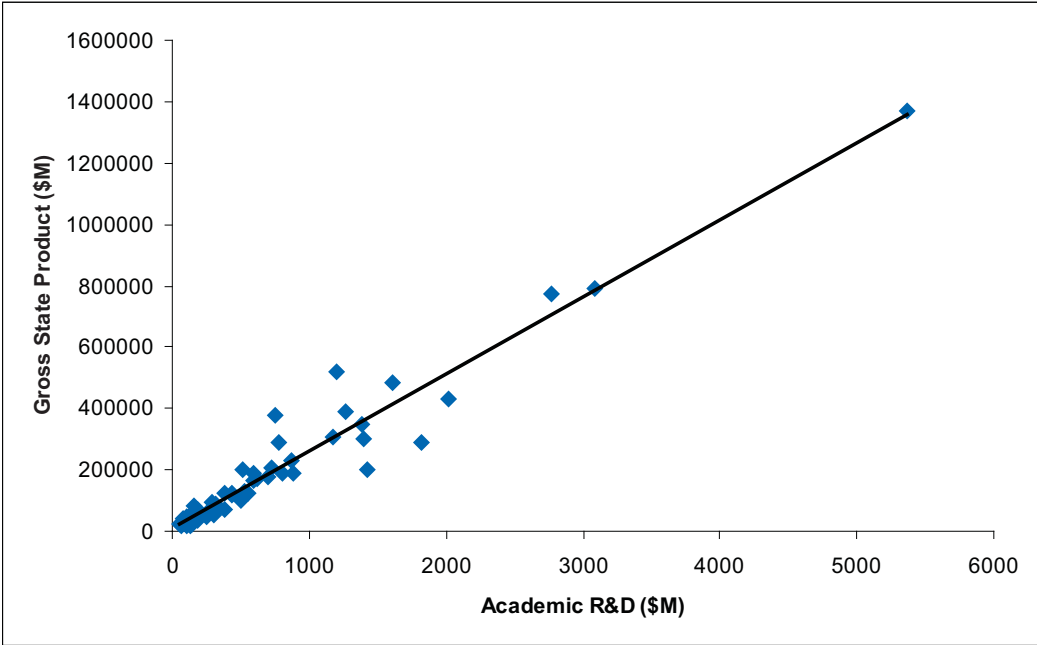
Estimates from the model in equation (3), or variations in the model, have historically been important to justify

from an economic perspective, continued national policy support for public initiatives toward R&D, as discussed above. The rationale is that firms under invest in R&D, from a social perspective, so incentives, broadly defined, to encourage more private-sector R&D are in the public good.

Technology-based economic growth and development at the state level has attracted attention in recent years because many state economies have been waning as traditional industries have either downsized or moved offshore. Many states are looking to their universities to be engines of growth. Universities are being viewed as magnets to attract in the future new technology-based firms, as they have been in the past with regard to biotechnology clusters, and the formation of university research parks are one venue to accomplish this.

Do to data limitations, models like that in equation (3) above have not been estimated at the state level primarily because the concept of total factor productivity at that level of aggregation is not meaningful and surrogate data are not available. Were such models able to be esti-

Figure 3
Gross State Product and State Academic R&D Investments, 2003



Source: National Science Foundation (2006), Table 8-30.

mated, and were the results able to show that firms in states are under investing in R&D, public policies, like those at the national level, could be considered to stimulate growth and could be justified on economic grounds. Nevertheless, there are data available to demonstrate at the state level, the importance of R&D, and these data are suggestive, rather than definitive, that state R&D policies may be a viable growth and development tool. And, because these data do reflect the theoretical concepts that underlie equation (3), and the vast empirical literature supports those theoretical concepts, the behavioral patterns in the following three figures can be thought of as causal relationships absent issues of time lags. As such they do represent at the state level prescriptions for economic growth and development.

Figure 1 shows graphically the relationship between R&D investments and Gross State Product in 2002, the most recent year of National Science Foundation data.¹² Clearly, there is a positive relationship between R&D investment and Gross State Product as evidenced by the trend line imposed on the data. To the extent that Gross State Product is an indicator of economic growth and development, then one might infer that R&D is a policy target variable at the state level (e.g., as state R&D increases, Gross State Product increases). Noticeable in Figure 1 is the outlier data point – the state of California with a Gross State Product of \$1,367,785 million and R&D investments of \$51,388 million. Figure 2 is a replot of the data in Figure 1 less the California data point. The positive correlation remains, and it appears visually to be stronger in smaller R&D states.¹³

Figure 3 shows the relationship between Gross State Product and academic R&D investments, as a component of total R&D. The positive correlation is again evi-

dent from the trend line imposed on the data, and this finding reinforces the importance of academic research on economic growth and development at the state level.¹⁴

Table 1 highlights the R&D investment activity in Kansas. The range of investment activity is large. For total R&D, the range in 2002 was \$80 million (Wyoming) to \$51,388 million (California), and for academic R&D, the range was \$50 million (South Dakota) to \$5,363 million (California). In terms of both total R&D and academic R&D, Kansas is just below the middle of the rankings for all states. Kansas ranked 24th from the bottom in terms of total R&D and 19th from the bottom in terms of academic R&D.

VII. CONCLUDING OBSERVATIONS

Entrepreneurship, innovation, and technological change are important contributors to economic growth and development. From a regional or state planning perspective, however, policy makers can do little to enhance entrepreneurship. As the evolution of thought about the entrepreneur reviewed in Section II makes clear, entrepreneurship is in part a talent rather than the outcome of purposive training. Public funding, at any level, of researchers will not create entrepreneurial talent; it will likely speed up the realization of the existing talent.

Fundamental to the innovation process, given the level of entrepreneurial talent in a state or region, is the level of R&D investment activity – in total and especially academic R&D. As discussed in Section VI there are several public policies that were initiated in the early 1980s to stimulate R&D, industrial R&D in particular. The R&E Tax Credit benefits firms in all states. There is little that a state could reasonably do to enhance that effect unless a state initiated a state tax credit as well. Similarly,

Table 1

Quintile Distribution of States by Range of R&D Investments

Quintile	Range of Total R&D (\$M, 2002)	Range of Academic R&D (\$M, 2003)
1	\$80 - \$524	\$50 - \$141
2	\$542 - \$1,435	\$155 - \$324 (<i>Kansas: \$310</i>)
3	\$1,572 - \$3,935 (<i>Kansas: \$1,865</i>)	\$378 - \$600
4	\$4,096 - \$8,310	\$618 - \$1,205
5	\$9,030 - \$51,388	\$1,269 - \$5,363

the National Cooperative Research Act indemnified all firms involved in collaborative R&D, regardless of state, so again there is little that a state could do to enhance indemnification. And, the SBIR program is a national program, and firms in all states are eligible to apply to a particular funding agency.

However, with regard to the national SBIR program, a number of states have initiated policies to encourage firms to participate in that program. For example, North

Carolina initiated a program in 2005 that matches up to 100 percent (up to \$100,000) of the amount that a firm received as an initial SBIR award (called a Phase I award). Other states have similar programs, such as Indiana, Oklahoma, Hawaii, Michigan, and most recently Kentucky.¹⁵ This is a policy tool that states could consider for stimulating R&D, especially R&D in small firms, and that R&D will impact favorable economic growth and development.

ENDNOTES

- 1 This section draws from the ideas in Hébert and Link (1988, 2006) and the references therein.
- 2 This literature is reviewed in Link and Siegel (2003).
- 3 If the analysis is at the firm level then output is usually measured as sales; if the analysis is at an industry level, then output is usually measured as value added, and if the analysis is at the aggregate level then output is usually measured as Gross Domestic Product.
- 4 Output per unit of K is capital productivity and output per unit of L is labor productivity.
- 5 This model is based on Solow (1957). See Link and Siegel (2003) for a complete derivation.
- 6 Economists refer to this as capital-embodied technological change.
- 7 A fundamental principle in economics is diminishing marginal returns. The returns to additional investments in a particular research activity decrease as that activity becomes over researched.
- 8 On the one hand, one could argue that through such funding the government acted as an entrepreneur by perceiving opportunities for scientific breakthroughs; but on the other hand most basic science is funded across many fields based on scientific merit rather than commercialization potential. Thus, this may not be a viable example of government as entrepreneur.
- 9 Definitions aside, the term biotechnology industry remains somewhat misleading to academics, although the term is casually and widely used by public policy makers as well as the popular press. One possible reason for this lack of definitional clarity about the bounds or dimensions of the industry is that there is in the United States, for example, as well as in other industrialized nations, no single group of homogeneous firms or organizations that clearly defines such an industry.
- 10 The San Diego biotechnology area developed similarly to the San Francisco and Cambridge areas. The Salk Institute was founded in 1955, followed by the Scripps Research Institute in 1960 and the University of California at San Diego (UCSD) in 1964. The Burnham Institute was founded in 1976 by William H. Fishman and his wife Lillian Fishman. Fishman spent his research career at Tufts University School of Medicine. The Foundation originally focused on cancer research but today its focus is much broader. Hybritech was founded in 1978 and was San Diego's first DBF; it was acquired by Eli Lilly in 1986. Hybritech became the anchor firm in the San Diego area.
- 11 Experimentation (E in R&E) is defined to be more narrow than Development (D in R&D) to help to ensure that the credit applies to those investments that are most likely to stimulate technological advance as opposed to technological modifications.
- 12 Gross State Product is the sum of value added by industries in a state for a given year. It is the state-based counterpart to Gross Domestic Product.
- 13 Figure 1 and Figure 2 can be thought of in terms of equation (3) where Gross State Product, at the state level, is equivalent to total factor productivity at the firm level.
- 14 Figure 3 can be thought of in terms of equation (3) where Gross State Product, at the state level, is equivalent to total factor productivity at the firm level, and where academic R&D is a subset of total R&D.
- 15 The North Carolina program is modeled after the Oklahoma program, and the Kentucky program mirrors the North Carolina program.

REFERENCES

- Baudeau, Nicolas (1910), *Premiere introduction a la philosophie economique*, edited by A. Dubois. Paris: P. Geuthner [originally 1767].
- Bozeman, Barry and Albert N. Link, (2003), *Investments in Technology: Corporate Strategies and Public Policy Alternatives*, New York: Praeger Publisher.
- Bush, Vannever (1945), *Science—the Endless Frontier*, Washington, DC: U.S. Government Printing Office.
- Cantillon, Richard (1931), *Essai sur la nature du commerce en general*, edited and translated by H. Higgs, London: Macmillan.
- Hébert, Robert F. and Albert N. Link (1988), *The Entrepreneur: Mainstream Views & Radical Critiques*, second edition, New York: Praeger Publishers.
- Hébert, Robert F. and Albert N. Link (2006), “The Entrepreneur as Innovator,” *Journal of Technology Transfer*, pp. 589-97.
- Link, Albert N. and Donald S. Siegel (2003), *Technological Change and Economic Performance*, London: Routledge.
- Machlup, Fritz (1980), *Knowledge and Knowledge Production*, Princeton, NJ: Princeton University Press.
- National Science Foundation (2006), *Science and Engineering Indicators*, Arlington, VA: National Science Foundation.
- Schumpeter, Joseph A. (1928), “The Instability of Capitalism,” *Economic Journal*, pp. 361-86.
- Schumpeter, Joseph A. (1934), *The Theory of Economic Development*, translated by R. Opie from the 2nd German edition [1926], Cambridge, MA: Harvard University Press.
- Schumpeter, Joseph A. (1939), *Business Cycles*. New York: McGraw-Hill.
- Solow, Robert M. (1957), “Technical Change and the Aggregate Production Function,” *Review of Economics and Statistics*, pp. 312-20.
- U.S. Department of Commerce, (1990), *Emerging Technologies: A Survey of Technical and Economic Opportunities*, Washington, DC: U.S. Department of Commerce, Technology Administration.
- U.S. Department of Commerce, (2003), “A Survey of the Use of Biotechnology in U.S. Industry,” Washington, DC: U.S. Department of Commerce, Technology Administration.



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