Sustaining Innovation and Growth in Research-Intensive Industries: Early Stage Finance Issues and Approaches

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Executive Summary

Early stage finance in research-intensive industries is a critical but understudied issue in sustaining competitiveness and growth in the U.S. economy. In the post W.W. II period, the federal government and private industry funded the majority of national research and development. Among other important technological innovations, this research effort contributed to the development of the information technologies that are driving the current cycle of innovation and growth in the U.S. economy.[1] However, the recent downturn in federal spending for basic and applied research and the concomitant failure of private industry to pick up the slack raises serious questions about sustaining competitiveness and growth in the economy over time.[2]

There is some evidence that suggests that private venture capital funds, universities, and state governments are increasingly providing early stage finance to stimulate the commercialization of private and university-based research.[3] This support might substitute for the loss of federal and large-scale private sector funding, complement this funding, or meet a here-to-fore unrecognized financial need. Further information and analysis of the nature and extent of this funding is required to make this determination.

The path to appropriating economic benefits from research and development is also poorly understood. The available evidence indicates that it is long, circuitous, and perilous. Most research and development projects do not directly generate commercially viable products or processes. When commercially viable concepts do emerge from research and development, they are often the result of cumulative effort over a long time involving clusters of investigators working in multiple disciplines. Even a viable invention or application does not guarantee commercial success. Most business start-ups fail and these failures are often attributable to inadequate finance.[4]

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[1] Historically, advances in information technologies have rested upon a host of interrelated research and development activities. For example, advances in microwave technologies made it possible to transmit signals over the electromagnetic spectrum by microwave equipment and satellites. Advances in fiber optics made it possible to transmit signals through large coaxial cables, and advances in radio-based equipment made it possible to construct complex cellular networks. Developments in electronics technologies revolutionalized telephone switching and terminal equipment while creating demand for new voice, data, and record services. Electronic photo-imaging technologies made it possible to create facsimile machines that allow documents to be transmitted over telephone lines. Modems and a variety of other equipment make it possible to transmit data over telephone lines and link networks to telephone networks. Today, the emerging field of nanotechnology is fueling both product and process innovations that could result in disk drives capable of holding more than one trillion bytes of data (Markoff, 3/17/00). Each of these advances benefit from basic research in the engineering and physical sciences.

[2] For a detailed analysis of trends in basic and applied research funding in the federal government and private industry sectors, see McGeary and Merrill (1999) and Merrill and Cooper (1999). For an analysis of the implications of these trends, see Board on Science, Technology, and Economic Policy and National Research Council (1999).

[3] See for example the work of Gompers and Lerner (1998, 1999) and Kortum and Lerner (1998) on the role of private venture capital funds; Eisinger (1990), Sternberg (1996) and Feller (1997) on the role of state governments; Shane (2000) on the role of universities; Wessner (1999 a, 1999 b, and 1999 c) on government-industry partnerships.

[4] For an analysis of the economics of small business finance, see Berger and Udell (1998).

Developing a well-grounded understanding of effective policy alternatives for stimulating the kind of research and development that is associated with long-term competitive performance is itself quite challenging. The economic nature of research and development activities is complex. Markets, governments, and civil society each fail to consistently provide early stage finance in research-intensive industries. And while hybrid mechanisms such as partnerships and cooperative alliances are necessary complements to sectoral activities, these too are subject to serious limitations. Identifying the strengths and weaknesses of each of these mechanisms under different sets of political and economic conditions is a substantial policy challenge.

In short, considerable analytical work is required before we can determine whether or not we are not doing as much as we might to assure that the U.S. economy will continue to grow in the future and to evaluate alternative means to finance the achievement of this objective. At present, we might not be asking the right questions, producing and measuring the right data, or applying the right methodological tools to grapple effectively with these questions. The purpose of this paper is to identify key issues and outline a conceptual approach to developing a better understanding of early stage finance in research-intensive industries. The paper is organized as follows. The first section outlines key issues and develops analytical approaches for addressing these issues. The second section outlines a preliminary research agenda, and the third section concludes.

Issues and Approaches

The extant literature on innovation and growth generates five distinct sets of questions related to early stage finance in research-intensive industries:

1. What is the existing system for providing and producing technological innovation and how does it work?
2. What is the nature of the innovation process and what is the relationship between this process and early stage finance?
3. Given the nature of the innovation process, how well does the existing system work? Are there better ways to supply early stage finance?
4. Which types of policies are most likely to stimulate an optimal supply of innovations across industries over time and which sectors should be involved at different stages?
5. How can these policies be implemented and sustained?

The issues surrounding these questions as well as approaches for addressing them are elaborated in the sections that follow.

The Existing System

The first set of questions has to do with how the U.S. political-economic system provides and produces early stage finance for technology-intensive industries. It involves analyzing how we have done so in the past, how we are doing so at present, how the system is changing and the implications of these changes for future funding. This analytic project is quite complex: the current system for providing early stage finance in the U.S. is polycentric, involving many independent centers of overlapping activity in the government, private, and civil society sectors, which are sometimes competing and sometimes cooperating. Research and development finance is provided by the federal government through multiple agencies and programs, state governments, corporations, individuals, private foundations, and venture capital funds. A taxonomy of these elements is outlined in Table 1.

Polycentric systems permit a high degree of relatively low-risk experimentation and hence exhibit remarkable flexibility and adaptability. However, transaction costs are high and they are rife with coordination problems, which increase the social costs of adaptation and change. In order to understand the strengths and vulnerabilities of the existing innovation system, it is essential to discover who is doing what, how this differs for different research disciplines and for different industries, the institutional structures in which these activities are embedded, the incentives created by these institutional structures, how coordination occurs, and the nature and extent of coordination failures.

Similarly, a variety of independent but overlapping decision mechanisms are used to allocate finance to early stage research and development including public budgetary processes, private budgetary processes, and public and private capital markets. Each of these allocation mechanisms is embedded in a particular institutional structure and is subject to different types of political and economic influences. Developing an understanding of how each of these mechanisms functions under different sets of political and economic conditions is also important for understanding coordination and allocation processes.

The Innovation Life Cycle

Building on the first set of questions, a second set of questions focuses on the relationship between research and development, commercialization, and sources of finance. Understanding the relationship between these elements requires mapping the process of innovation from basic scientific investigation through commercial success. At present, this process is not well understood for most types of research and development in most industries. Realistic models of technological innovation in different industries are needed.

To illustrate this set of questions consider the general model illustrated in Figure 1. The innovation process is modeled as a life cycle using an exponential function that reaches a maxima, sustains this point for a period of time, and then begins to decay. Changes in revenues, r, generated from the innovation are depicted along the vertical axis. Changes in the stages of development of a particular innovation and potential sources of finance in each of these stages over time, t, are depicted on the horizontal axis.

The model in Figure 1 provides a framework for drawing analytical distinctions between different stages of research and development activities in different research areas and in different industries. In each stage, each of which requires further elaboration, there are fundamental differences between types activities, types of participants, levels of risk and uncertainty, the appropriability of knowledge, organizational and policy requirements for successful progress, and feasible sets of financing mechanisms.

Optimal Innovation

A third set of policy questions relates to the optimal supply of innovation and the best way to provide early stage finance in research intensive industries. All other things being equal, what are the best ways to provide and produce innovation? Addressing this issue requires developing an understanding of the economic nature of research and development activities in different industries and different types of finance mechanisms.

At the most basic level of analysis, research and development is a process for producing innovation, or more generally, knowledge. Knowledge and the activities that produce knowledge are typically characterized as public goods or services. Using a conventional taxonomy of types of goods and services, this implies that the consumption of knowledge activities is nonrival and nonexcludable. This implication leads to the conclusion that absent concerted intervention, knowledge will be underprovided in the economy.

The assumption that knowledge activities are pure public goods rests on the implicit assumption that knowledge is static. However, knowledge, particularly in research intensive industries, is not static but evolves over time.[5] The research and development process transforms general knowledge into unique knowledge (innovation). Under the U.S. intellectual property rights system, unique knowledge as well as the economic value of unique knowledge is appropriable through patenting and is thus contestable. Once a patent is granted, knowledge that was once a public good is transformed into a private good.

The literature on innovation and growth suggests that the knowledge transformation process is quite complex.[6] Knowledge is not transformed directly from a public good to a private good. Moreover, knowledge activities have spillover effects that

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5 This insight can be traced to Arrow (1962), who argues that technological change can be ascribed to learning from experience.

generate even more knowledge. Successful commercialization in research-intensive industries appears to emerge from knowledge clusters that agglomerate in particular places.[7] The presence of these clusters suggests that in the process of evolving from a pure public good to a pure private good, knowledge takes the form of a club or toll good in which the consumption of knowledge is nonrival but potentially excludable.

Thus far we have knowledge evolving from a public good to a club good and then to a private good. However, under the U.S. system, patents expire after a fixed period of time. At this point, private (patented) knowledge returns to the public domain. Hence the complete cycle of the evolution of knowledge is from public good to club good to private good and finally, to public good. The research and development process and the property rights systems within which it is embedded, structures the flow of knowledge much like a funnel structures the flow of liquids.[8]

A related consideration in analyzing the economic nature of research and development activities is the appropriation of economic value. As the economic nature of a stream of knowledge changes, the appropriability of the knowledge stream changes as well. Except under perverse circumstances, economic value cannot be appropriated from general knowledge. However, the process of refining and applying a general knowledge stream to meet economic demand generates economic value, which is delimited by the intellectual property rights system.

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6 Evidence on the biotechnology industry illustrates the point. See for example, Audretsch and Stephan (1996), Lerner and Merges (1998) and Lerner and Tsai (2000). Audretsch (1995) provides evidence on innovation and industry evolution more generally.

7 See for example, Audretsch and Feldman (1996), Audretsch and Stephan (1996), Audretsch (1998), and Feldman and Audretsch (1999).

8 Note that the efficacy of this structure depends critically upon a host of conditions including the enforceability of institutions, e.g., in some settings, the R&D "funnel" might function more like a sieve.

The dynamic nature of knowledge appropriation can be modeled as a discontinuous function in which the economic value of knowledge, *v*, begins at zero at time *t*(0), increases exponentially to a maxima as general knowledge is transformed into unique knowledge, sustains this level for a period of time that is determined by the nature of demand as well as the skill of the patent-holder in exploiting the innovation to meet demand, and then plummets to zero as the knowledge embodied in the innovation returns to the public domain. Aggregating across differences in individual capabilities, the specific form of this function depends critically upon the type of knowledge that is being developed, the intellectual property rights system, the form of commercial organization, and market conditions.

Given the evolutionary nature of knowledge, sustained economic growth requires investments in continuous knowledge production and appropriation. Research and development for the next generation of innovations must begin prior to the point at which maximum economic value has been appropriated from a current innovation. This implies that basic research and development activities are inextricably linked with appropriation activities. Figure 2 illustrates this concept.

Summing up, the best way to stimulate and finance innovation depends upon the extent to which knowledge is appropriable in a particular industry under a particular set of conditions, the amount of effort and the period of time required to do so, and the amount of risk and uncertainty involved. Investment must support the provision and production of general knowledge that is not appropriable as well as that of specific knowledge, which is appropriable. Moreover, because the economic nature of research and development activities evolves over time, there is no single best means to stimulate and finance these activities. Instead, the means of finance must evolve in concert with the nature of research and development activities.

The principle that the public sector should take the lead in funding basic research and development activities and that the private sector should take the lead in funding the development of commercial applications is well developed in U.S. public policy. However, in practice, it is difficult to apply this principle to financing research and development because basic and applied activities cannot be separated easily. Moreover, as research and development proceeds, the economic value of these activities becomes increasingly contestable. The strategic character of knowledge appropriation is an additional confounding factor in estimating the optimal supply of innovation and early stage finance.

Policy Design and Implementation

The final set of questions connected to innovation and early stage finance in research intensive industries relates to policy design and implementation. Which types of policies are most likely to create incentives for individuals and organizations to produce a continuous supply of innovations across industries over time? Which sectors should be involved at which stages of appropriability? Once developed, how can policies be implemented and sustained?

The analysis thus far places research and development in a relatively sparse environment. However, the innovation life cycle and early stage finance practices are the result of interacting combinations of economic conditions, physical and technological conditions, social norms, management strategies, and institutional arrangements. These factors influence the behavior of those who are involved in research, development, and early stage finance, and function as enabling and constraining conditions. Good policy design and effective policy implementation requires developing an understanding of these factors and their potential influence on behavior as well as the outcomes of behavior.[9]

Research Agenda

In order to make strategic policy decisions that affect competitive advantage, policy makers need to understand where innovative activities are located in political-economic space, who is in this space, how this space will change over time, and what they can do to influence the configuration of this space. Standard approaches have failed to deal with the complexity and the dynamic nature of sustained innovation and growth.

While there has been considerable progress in developing dynamic theories of innovation and growth that are sensitive to particular contexts, much work remains to make this work useful for policy analysis and design. Progress depends upon developing a deep understanding of the determinants and processes of sustained innovation and growth in the U.S. economy.

Developing an understanding of these foundations requires new sources of data, cross-disciplinary approaches, and a mix of formal and qualitative methods including econometric studies, case studies, decision-theoretic studies, experimental studies, and simulations. A preliminary research agenda would include the following:

- Empirical studies of the factors associated with innovative activity in U.S. industries that generate quantifiable inputs to dynamic models of innovation and growth as well as qualitative information that contributes to understanding

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[9] For a systematic approach to policy analysis and design that incorporates these considerations, see Polski and Ostrom (1999).

how social, political, economic, and institutional arrangements structure behavior.[10]

- Theoretical models of innovation life cycles in U.S. industries and empirical tests of these models.
- Empirical studies of the economic value generated by research and development activities in U.S. industries.
- Theoretical models of the evolution of appropriable knowledge in U.S. industries and empirical tests of these models.

Conclusion

This paper outlines several key research issues and approaches related to developing a well-grounded understanding of innovation and growth under different sets of economic, technological, and institutional conditions. These issues are a logical extension of recent work on the competitive performance of U.S. industry undertaken by the Board on Science, Technology, and Economic Policy (1999). Based upon this study, the Board concluded that four issues merit further attention: 1) the adequacy of measures and statistical data on research and innovation; 2) the adequacy of human capital to sustain the recent resurgence in the U.S. economy; 3) the implications of the continued expansion of intellectual property rights protection for research, innovation, and technology diffusion; and 4) divergent trends in public an private investment in R&D and infrastructure. The Board further noted that absent supporting institutions, strong short-term performance does not necessarily signify sustained performance. Not only are the issues outlined in this paper pertinent to the Board's concerns, formally addressing these

[10] For an interesting effort to develop an understanding of the relationship between social networks and

issues is a prerequisite for addressing the Board's concerns. Accordingly, the final point of this paper is to urge the Board on Science, Technology, and Economic Policy to take a leadership role in promoting cross-disciplinary research on the micro foundations of innovation and growth in the U.S. economy.

early stage finance in research-intensive industries, see Shane and Cable (2000).

Table 1: Taxonomy of Early Stage Finance in Research Intensive Industries

Private
Corporate retained earnings, equity, or borrowings
Inventor's savings or borrowings
Inventor's friends' and families' savings or borrowings
Angel
Incubator
Venture capital

Public
Federal research laboratories
Research grants from federal research budgets
R&D seed funds
Small business loan programs

Civil Society
Philanthrophic grants
University research grants

Public/Private Partnerships
Technology parks
Technology incubator programs
Economic development programs

Figure 1

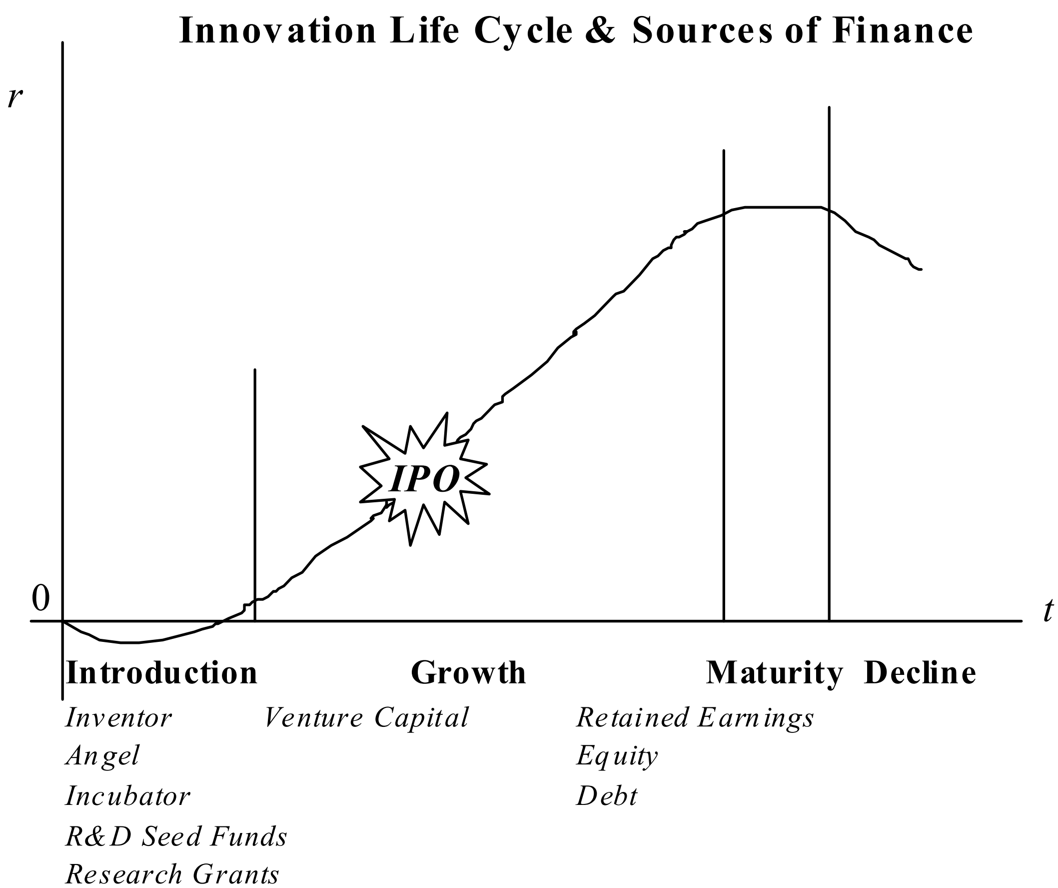
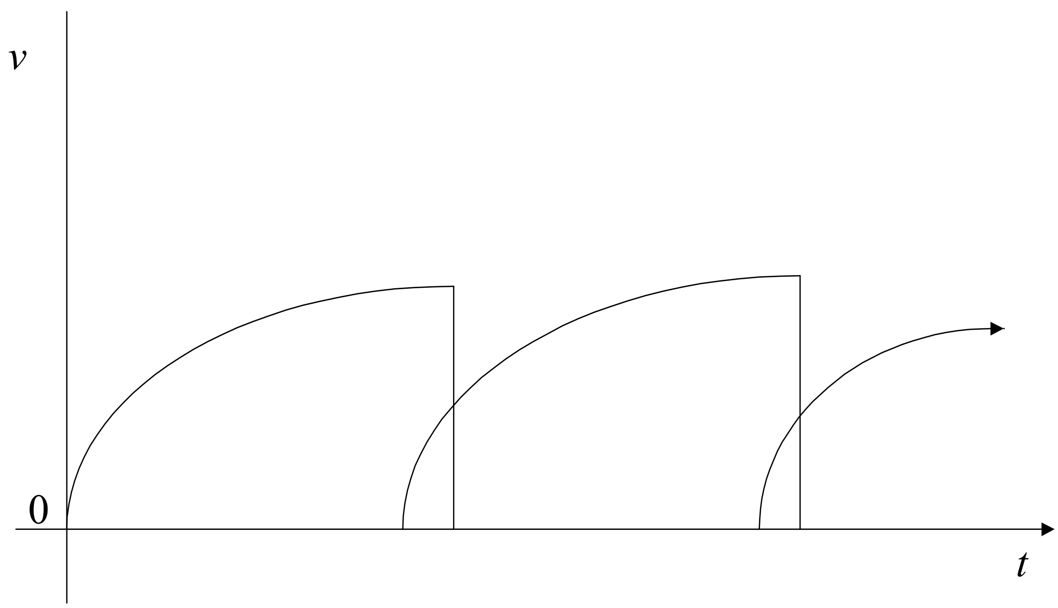

Innovation Life Cycle & Sources of Finance
r
0
t
IPO
Introduction
Growth
Maturity
Decline
Inventor
Angel
Incubator
R&D Seed Funds
Research Grants
Venture Capital
Retained Earnings
Equity
Debt

Figure 2

Continuous Knowledge Appropriation



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