International Studies in Entrepreneurship

David B. Audretsch
Albert N. Link *Editors*

Essays in Public Sector Entrepreneurship

Springer

International Studies in Entrepreneurship

Volume 34

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ISSN 1572-1922 ISSN 2197-5884 (electronic)
International Studies in Entrepreneurship
ISBN 978-3-319-26676-3 ISBN 978-3-319-26677-0 (eBook)
DOI 10.1007/978-3-319-26677-0

Library of Congress Control Number: 2016930669

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media (www.springer.com)

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Audretsch's research has focused on the links between entrepreneurship, government policy, innovation, economic development and global competitiveness. His recent books include *Everything in Its Place: The Strategic Management of Cities, Regions and States* with Oxford University Press, and *The Handbook of Local Competitiveness*, also with Oxford University Press. He is co-founder and co-editor of *Small Business Economics: An Entrepreneurship Journal*. He was awarded the 2001 Global Award for Entrepreneurship Research by the Swedish Foundation for Small Business Research. In 2008 he received an honorary doctorate degree from the University of Augsburg, and in September 2010 he received an honorary doctorate degree from Jonköping University. In 2011 he was awarded the Schumpeter Prize from the University of Wuppertal.

He is a member of the advisory board to a number of international research and policy institutes, including chair of the Deutsches Institut fuer Wirtschaftsforschung Berlin (German Institute for Economic Analysis Berlin), chair of the Stifterverband fuer die Deutsche Wissenschaft (Foundation for the Promotion of German Science), New York Academy of Sciences, the Swedish Entrepreneurship Forum and the Jackstädt Centre for Entrepreneurship in Wuppertal, Germany.

Pontus Braunerhjelm is professor in economics since 2005 and since 2012 head of the Department of Industrial Economics and Management at the Royal Institute of Technology, Stockholm. He is also research director at the Swedish Entrepreneurship Forum where he served as managing director between 2008 and 2014. Braunerhjelm earned his Ph.D. at the Graduate Institute of International Studies, Geneva, Switzerland, in 1994. His research focuses on the intersection between innovation, entrepreneurship, industrial dynamics and growth, covering both theoretical and empirical aspects. He has published extensively in that area, both in scientific outlets and outlets geared towards a wider audience. Institutions and their policy implications is a central theme in most of his academic work, and he has also been engaged in several policy-oriented projects of a more applied nature for the Swedish Government as well as internationally.

Between 2007 and 2009 he was general secretary of the Swedish Globalisation Council set up by the Swedish government. The objective of the Globalisation Council was to suggest economic policy reforms that enabled exploitation of the potential welfare effects associated with increasing globalisation and to broaden the national debate on issues related to globalisation. In May 2014 he was asked to serve as chairman of the Government Committee on Entrepreneurship Policy. The committee will present their results in October 2016. Braunerhjelm is also a member of the Royal Swedish Academy of Engineering Sciences (IVA) and a number of other boards and scientific committees.

James A. Cunningham is professor of strategic management at Newcastle Business School, United Kingdom. His research intersects the fields of strategic management, innovation and entrepreneurship. His research focuses on strategy issues with respect to principal investigators as scientific entrepreneurs and market shapers, university technology transfer commercialisation, academic and technology entrepreneurship, entrepreneurial universities and public sector entrepreneurship. His has papers published in leading international journals such as *Research Policy*, *Long Range Planning*, *Journal of Technology Transfer*, *International Entrepreneurship and Management Journal*, *International Journal of Technology Management* and the *Journal of Intellectual Capital*. He has published seven books on the themes strategy, entrepreneurship, technology transfer and technology entrepreneurship with leading publishers such as Oxford University Press and Palgrave MacMillan. He is currently a member of the editorial boards of the *Journal of Technology*

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In 2011–2014, he was a commissioned expert on the Swedish Government Committee on Business Taxation, and in 2015, he became a commissioned expert on the Government Committee on Entrepreneurship Policy. He has also written a number of books, studies and articles within the framework of Swedish policy discussions. He has experience in international banking and has served as an advisor in both the public and private sectors. Henrekson is a member of the Royal Swedish Academy of Engineering Sciences (IVA), and he has been a board member of two public companies, one high-tech start-up and the Swedish public service broadcasting company.

Albert N. Link is the Virginia Batte Phillips distinguished professor at the University of North Carolina at Greensboro. He holds a B.S. degree in mathematics (Phi Beta Kappa) from the University of Richmond and a Ph.D. in economics from Tulane University. Over the past several decades, he has distinguished himself as a leading scholar in fields related to entrepreneurship, technology and innovation policy, technology transfer and programme evaluation. He is editor in chief of the *Journal of Technology Transfer*, and he is a noted advisor to US and international government agencies. Most recently, he has consulted for the US Department of Energy, NASA and the National Institute of Standards and Technology, as well as for the National Academy of Sciences, the Canadian government, and The World Bank.

Link's publications in these areas are numerous. He has published in such academic journals as the *American Economic Review*, the *Journal of Political Economy*, the *Review of Economics and Statistics*, *Economica*, the *European Economic Review* and *Research Policy*. His recent books include *The Oxford Handbook of Local Competitiveness* (Oxford University Press), *The Chicago Handbook on University Technology Transfer* (University of Chicago Press), *Public Sector Entrepreneurship* (Oxford University Press), *Battery Technology for Electric Vehicles: Public Science and Private Innovation* (Routledge) and *Bending the Arc of Innovation: Public Support of R&D in Small, Entrepreneurial Firms* (Palgrave-Macmillan).

Vincent Mangematin is professor of strategic management and management of innovation and associate dean for research at Grenoble Ecole de Management, France. His research focuses on emerging processes (research, innovation, business model innovation) and quality assessment in fast-moving environment (signal, reputation, status). He published more than 50 papers in leading journals like *Strategic Management Journal*, *Research Policy*, *Long Range Planning*, *Journal of International Business Studies*, *Organization Studies*, *Technological Forecasting and Social Change*, *Technovation*, *Journal of Technology Transfer*, *International Journal of Technology Management* and *Small Business Economics*, 2 edited books on trust and over 20 book chapters and articles in professional journals. He serves on the editorial boards of *Organization Studies*, *Technovation* and *Long Range Planning*.

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Paul O'Reilly is head of research in the College of Business at Dublin Institute of Technology. His research activities are primarily on the role of PIs in public research systems. He was PI on the IRCHSS-funded project "An Appraisal of the Role of the Principal Investigator in their Delivery of Publicly Funded Research" and co-PI on the Food Institutional Research Measure project's "Development of a Technology Commercialisation Toolbox for Publicly Funded Food Research".

He has undertaken related consultancy assignments for Enterprise Ireland, European Commission, Forfas, Royal Irish Academy and Teagasc (Irish State agriculture and food research agency). He has served in an advisory capacity for the Irish Department of Agriculture on issues relating to technology transfer and is an external project evaluator for Teagasc. He has papers published in *Long Range Planning*, *Journal of Technology Transfer*, the *International Journal of Technology Management* and *Irish Journal of Management*.

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Chapter 1
Introduction

David B. Audretsch and Albert N. Link

Public sector entrepreneurship has been defined as the promulgation of innovative public policy initiatives that generate greater economic prosperity by transforming a status quo economic environment into one that is more conducive to economic units engaging in creative activities in the face of uncertainty (Leyden and Link, 2015). In today's economy, public sector entrepreneurship affects that transformation primarily by increasing the effectiveness of knowledge networks, that is, by increasing the heterogeneity of experiential ties among economic units and the ability of those same economic units to exploit such diversity. Through policy initiatives that are characterized by public sector entrepreneurship, there will be more development of new technology and hence more innovation throughout the economy.

We have assembled in this volume four essays that deal broadly with public sector entrepreneurship. Because innovation is the driver of economic growth and development, we believe that future policy initiatives that build on this premise will be cast within a public sector entrepreneurship framework. Thus, the following four essays may well represent the pillars on which future policies are developed.

In Chap. 2, Richardson, Audretsch, and Aldridge explore how US federal institutions influence innovation in the knowledge economy in an effort to ask if any US agencies or particular policies could be replicated in other countries. Three key US agencies are identified as having significantly contributed to innovation and growth: the Small Business Innovation Research (SBIR) program, the Advanced Technology Program (ATP), and the Defense Advanced Research Projects Agency (DARPA).

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D.B. Audretsch, A.N. Link (eds.), *Essays in Public Sector Entrepreneurship*,
International Studies in Entrepreneurship 34, DOI 10.1007/978-3-319-26677-0_1

Richardson et al. offer a view for understanding why and how search and development does not necessarily lead to innovation and economic activity. To become a successful innovation, ideas must first pass through a knowledge filter. The use of a knowledge filter, which may impede the development of potential innovations, implies that the evolution from ideas to innovations is neither linear nor does it imply that innovations will be successful. Therefore, government agencies are needed to help firms pass through the filter, or perhaps even through the valley of death, if the transformation from ideas to successful innovations is to be realized. Richardson et al. conclude that the SBIR program is the one US program that could conceivably be replicated in other countries to assist in the idea to innovation transformation.

In Chap. 3, Cunningham, O'Reilly, O'Kane, and Mangematin argue convincingly that publicly funded principal investigators (PIs) are core actors in knowledge-intensive economies. PIs are lead scientists responsible for delivering transformative publicly funded scientific programs. Becoming a publicly funded PI is a career enabler for scientists and carries significant peer prestige. However, the role and expected impact of PIs have grown substantially beyond traditional scientific activities. Publicly funded PIs must be adept in the areas such as technology transfer, strategy, management, entrepreneurship, brokering, negotiation, and mediation. They must engage with a broader range of stakeholders including scientific peers, technology transfer offices, industry, policy makers, nongovernmental organizations (NGOs), and regulators.

Publicly funded PIs, according to Cunningham et al., are critical agents in the delivery of transformative public sector entrepreneurship through the creation of scientific networks responding to broad opportunities directed by government scientific programs and associated publicly funding bodies. In the implementation of publicly funded scientific programs, PIs either directly or indirectly create technology transfer and commercial opportunities that can ultimately be exploited by third parties. The activities of publicly funded PIs can thus create transformative social scientific networks that can respond effectively to public sector entrepreneurship initiatives as well as contribute to creating economic activity and prosperity. Given the importance of the scientists as publicly funded PIs, Cunningham et al. contend that it is surprising that their roles and activities have received little empirical attention. Accordingly, the authors use Irish data of publicly funded PIs to focus on four themes with respect to publicly funded PIs. Their roles are as public sector entrepreneurship linchpins, as research strategists, as managers, and as agents of technology and knowledge transfer. The authors conclude with some practical implications and reflections with respect to future research agendas that seek to integrate the emerging literature on public sector entrepreneurship and that of publicly funded PIs.

In Chap. 4, Braunerhjelm and Henrekson build on the widely accepted premise that innovation has increasingly been acknowledged as a key factor in raising prosperity and securing sustainable long-term growth. They examine policy measures that foster the creation of innovations with high inherent potential and that simultaneously provide the right incentives for individuals to create and expand firms building on such innovations.

Previous research thus suggests that to facilitate and further enhance the role of entrepreneurs in the innovation process, policies should be expanded to areas other than education and R&D outlays. Despite these new insights, the links between microeconomic dynamics and macroeconomic growth are still neither well conceptualized nor adequately modeled. Mapping this analytically fragmented terrain in a comprehensive framework for growth and combining a dispersed and diverse microeconomic setting with the macroeconomic outcome basically remain unchartered territory.

Policies to boost innovation have thus primarily centered on R&D, whereas entrepreneurial processes, where existing (or new) knowledge is combined with individual abilities in the search for new market opportunities, tend to have been neglected. However, a policy discussion focusing on a limited set of instruments or areas is inadequate. A far more fruitful policy question, according to the authors, is the following: What policy measures (1) foster the creation of innovations with high inherent potential *and*, simultaneously, (2) provide the right incentives for individuals to create and expand firms that disseminate such innovations in the form of highly valued products?

Braunerhjelm and Henrekson propose an answer to this two-pronged question. They stress that recognizing the importance of diffusing and exploiting knowledge investments opens a complementary policy field related to entrepreneurs, the expansion of firms, and the competence structure of supporting agents (e.g., financial market actors in different phases of the life cycle of the firm, legal advisors, and management specialists).

Specifically, the authors suggest an innovation policy framework based on two complementary pillars:

- *The accumulation, investment, and upgrading of knowledge*. The policy areas involved in this pillar relate to the institutions that are needed to encourage high-quality education at all levels, to prompt internationally leading universities and their research, to establish links between academia and the commercial sector, and to fund universities.
- *The implementation of mechanisms that enable knowledge to be exploited such that growth and societal prosperity is encouraged*. These mechanisms involve a completely different set of institutions, such as tax policies, the regulatory burden, competition, and the formation of clusters. These mechanisms also include policies that create environments and incentives for individuals to undertake entrepreneurial efforts, innovations, and firm expansion.

Braunerhjelm and Henrekson go on to demonstrate what is required to integrate these two interdependent pillars in a coherent innovation policy framework. Without the accumulation, investment, and upgrading of knowledge, the second set of policies is likely to generate less value. Without the implementation of mechanisms that enable knowledge to be exploited, knowledge investments can be expected to yield little, if any, growth. Successful exploitation of knowledge and new ideas depends on many complementary agents and institutions. Thus, they argue that a coherent innovation policy framework must include tax policy, labor market regulation, savings channeling, competition policy, housing market regulation, and infrastructure to foster growth and future prosperity.

This collection of essays concludes with a Chap. 5 by Richardson, Audretsch, Aldridge, and Nadella. These authors note that there have been many studies measuring and analyzing technology transfer and knowledge spillovers from universities using data collected by the universities on the activities of the Technology Transfer Office (TTO). This chapter represents a methodological step forward. The authors examine university entrepreneurial activity by directly asking scientists in six fields of study, about their entrepreneurial involvement. While data from TTOs suggest that new firm start-ups from university research is an infrequent occurrence, this Richardson et al. study finds exactly the opposite. Furthermore, the authors report patterns with levels of entrepreneurial startups based on the scientific field, age, gender, and experience of the university scientists. Their evidence suggests that entrepreneurship is more prevalent among a broad spectrum of university scientists than had previously been identified in other studies that relied on TTO-provided data. The results from this pioneering effort suggest that knowledge spillovers from universities for commercialization, for innovation, and ultimately for economic growth, employment creation, and global competitiveness are substantially more robust than had previously been thought.

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Chapter 2
Motivating Entrepreneurship and Innovative Activity: Analyzing US Policies and Programs

Aileen Richardson, David B. Audretsch, and Taylor Aldridge

2.1 The Role of Innovation Policies in the United States[1]

2.1.1 Knowledge, Entrepreneurship, and Innovation

Government policy has undertaken a number of key initiatives, such as the Small Business Innovation Research (SBIR) program, the Advanced Technology Program (ATP), and the Defense Advanced Research Projects Agency (DARPA), with the goal of developing the innovative capacity and overall economic performance of the country. These agencies not only help firms innovate where they otherwise would most likely not have, but they also help to address the current and future needs of government agencies for innovative solutions. In order to understand how and why government intervention is needed, the chapter offers an explanation of why R&D and innovation necessitates governmental support.

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[1] This contribution is largely based on the JRC Scientific and Policy Report, written by David B. Audretsch and Taylor Aldridge, "The Development of US Policies directed at stimulating innovation and entrepreneurship." The report prepared for European Commission and edited by Itzhak Goldberg, Federico Biagi, and Paul Desruelle. 2014.

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D.B. Audretsch, A.N. Link (eds.), *Essays in Public Sector Entrepreneurship*,
International Studies in Entrepreneurship 34, DOI 10.1007/978-3-319-26677-0_2

2.1.2 The Role of Knowledge, R&D, and Innovation

In what Zvi Griliches (1979) formalized as the model of the knowledge production function, the firm is assumed to be exogenous. The strategies and investments of the firm are then modeled as choice variables generating innovative activity and are therefore modeled as being endogenous. Thus, the model of the firm knowledge production function starts with an exogenously given firm and examines which types of strategies and investments generate the greatest amount of innovative output. Griliches, in fact, suggested that it was investments in knowledge inputs that would generate the greatest yield in terms of innovative output.

Griliches' seminal article prompted a large number of studies, which attempted to empirically test the knowledge production function. These studies were confronted with numerous measurement concerns. The innovative output had to be measured and knowledge inputs had to operationalized. While the economic concept of innovative activity does not lend itself to precise measurements (Griliches 1990, 2002), scholars developed measures such as the number of patented inventions, new product introduction, share of sales accounted for by new products, productivity growth, and export performance as proxies for innovative output. Developing measures that reflect investments in knowledge inputs by the firm proved equally challenging. Still, a plethora of studies (Cohen and Klepper 1992a, b; Hausman et al. 1984) developed proxies of firm-specific investments in new economic knowledge in the form of expenditures on R&D and human capital as key inputs that yield a high innovative output.

2.1.2.1 Cohen and Levinthal's Absorptive Capacity Argument

The literature empirically tests the model of the knowledge production function generated as a series of econometrically robust results which substantiated Griliches' view that firm investments in knowledge inputs were required to produce innovative output. Cohen and Levinthal (1989) provided an even more compelling interpretation of the empirical link between firm-specific investments in knowledge and innovative output. According to Cohen and Levinthal, by developing the capacity to adapt new technology and ideas developed in other firms, firm-specific investments in knowledge such as R&D provide the capacity to absorb external knowledge, termed *absorptive capacity*. This key insight implied that by investing in R&D, firms could develop the absorptive capacity to appropriate at least some of the returns accruing to investments in new knowledge made externally by the firm. This insight only strengthened the conclusion that the empirical evidence linking firm-specific investments in new knowledge to innovative output verified the assumptions underlying the model of the knowledge production function.

2.1.2.2 The Individual Entrepreneur

Audretsch (1995) challenged the assumption underlying the knowledge production model of firm innovation by shifting the unit of analysis away from the firm to the individual. In this view, individuals such as scientists, engineers, or other knowledge workers are assumed to be endowed with a certain stock of knowledge. They are then confronted with the choice of how best to appropriate the economic returns from that knowledge. Thus, just the appropriability question, identified by Cohen and Levinthal (1989), confronts the firm; an analogous appropriability question confronts the individual knowledge or skilled worker.

The concept of the entrepreneurial decision resulting from the cognitive processes of opportunity recognition and ensuing action is introduced by Eckhardt and Shane (2003) and Shane and Venkataraman (2000). They suggest that an equilibrium view of entrepreneurship stems from the assumption of perfect information. By contrast, imperfect information generates divergences in perceived opportunities across different people. The sources of heterogeneity across individuals include different access to information as well as cognitive abilities, psychological differences, and access to financial and social capital.

2.1.2.3 The Geographical Dimension

Recognition of the role that firm-specific knowledge investments could play in accessing, absorbing, and transforming external knowledge, and therefore enhancing the innovative output of the firm, triggered an explosion of studies which focused on potential sources of knowledge that are external to the firm. Some studies examined the role of licensing, cooperative agreements, and strategic partnerships, all of which involve a formal agreement and a market transaction for the sale of knowledge. Thus, these all represent mechanisms by which a firm can access knowledge produced by another firm. As Cohen and Levinthal (1989) emphasized, presumably internal investments in knowledge are a prerequisite for absorbing such external knowledge even if it can be accessed.

A different research trajectory focused on flows of knowledge across firms where no market transaction or formal agreement occurred or what has become known as knowledge spillovers. The distinction between knowledge spillovers and technology transfer is that in the latter, a market transaction occurs, whereas in the case of spillovers, the benefits are accrued without an economic transaction (Acs and Varga 2005).

While Krugman (1991) and others certainly did not dispute the existence or importance of knowledge spillovers, they contested the claim that knowledge spillovers are geographically bounded. Their point was that when the marginal cost of transmitting information across geographic space approaches zero, there is no reason to think that the transmission of knowledge across geographic space will stop simply because it has reached the political border of a city, state, or country.

However, von Hippel (1994) explained how *knowledge* is distinct from *information* and requires geographic proximity in transmitting ideas that are highly dependent upon their context and inherently tacit and have a high degree of uncertainty. This followed from Arrow (1962), who distinguished economic knowledge from other economic factors as being inherently non-rival in nature so that knowledge developed for any particular application can easily spill over to generate economic value in very different applications. As Glaeser et al. (1992, p. 1126) have observed, "intellectual breakthroughs must cross hallways and streets more easily than oceans and continents."

Thus, a distinct research trajectory developed in the late 1980s and early 1990s, which tried to identify the impact of location on the innovative output of firms. These studies addressed the question "Holding firm-specific knowledge inputs constant, is the innovative output greater if the firm is located in a region with high investments in knowledge?" The answer to this question was provided in a series of studies, which shifted the unit of observation for testing the model of the knowledge production function from the firm to a spatial unit of observation, such as a city, region, or state. Furthermore, how does a region play a role in the public sector entrepreneurship and innovative capacity?

2.1.3 The Knowledge Filter

Because of the conditions inherent in radical innovation based on knowledge, high uncertainty, asymmetries, and transaction cost, decision-making hierarchies can decide not to commercialize new ideas that individual economic agents, or groups of economic agents, think are potentially valuable and should be pursued. The characteristics of knowledge that distinguish it from information include a high degree of uncertainty combined with nontrivial asymmetries, fused with a broad spectrum of institutions, rules, and regulations. These differences distinguish between radical innovation and incremental innovation. Thus, not all potential innovative activity, especially radical innovations, is fully appropriated within the firm, which made the investments to create that knowledge in the first place.

The ability of decision-makers to reach a consensus tends to be greater when it is based on more information and less knowledge, as information is easily transferable, put in context, and timely; therefore, it is more pertinent to decision-makers' incremental decisions. A decision's outcomes and their associated probability distributions are more certain when the decision is based on information and, by definition, less certain when it is based on knowledge, as knowledge is inherently more difficult to share and transfer. Radical innovation typically involves more knowledge and less information than does incremental innovation.

Various constraints on the ability of a large firm to determine the value of knowledge prevent the firm from fully exploiting the inherent value of its knowledge assets (Moran and Ghoshal 1999). In fact, evidence suggests that many large, established companies find it difficult to take advantage of all the opportunities emanating from their investment

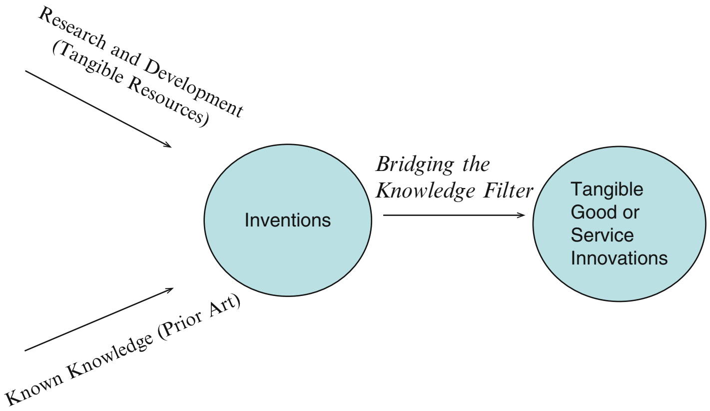

Fig. 2.1 The knowledge filter

in scientific knowledge (Christensen and Overdorf 2000). For example, Xerox's Palo Alto Research Center Incorporated succeeded in generating a large number of scientific breakthroughs (a superior personal computer, the facsimile machine, the Ethernet, and the laser printer, among others) yet failed to commercialize many of them and develop them into innovations (Smith and Alexander 1988; Chesbrough and Rosenbloom 2002). However, many incumbent firms have first-mover advantage, in that through their size and incremental innovation, they have the opportunity to acquire smaller firms, which tend to develop more radical innovations.

The knowledge conditions inherent in radical innovation impose what Audretsch et al. (2006a, b) and Acs et al. (2005) term *the knowledge filter* (see Fig. 2.1). The knowledge filter is the gap between knowledge that has potential commercial value and knowledge that is actually commercialized in the form of innovative activity. The greater the knowledge filter, the more pronounced the gap between new knowledge and commercialized knowledge in the form of innovative activity. An example of the knowledge filter which confronts a large firm is provided by the response of IBM to Bill Gates, who approached IBM to see if it was interested in purchasing the then struggling Microsoft. They weren't interested. IBM turned down "the chance to buy 10 % of Microsoft for a song in 1986, a missed opportunity that would cost $3 billion today."[2] IBM reached its decision on the grounds that "neither Gates nor any of his band of 30 some employees had anything approaching the credentials or personal characteristics required to work at IBM."[3]

Thus, the knowledge filter serves as a barrier impeding investments in new knowledge from being pursued and developed to generate innovative activity. In some cases, a firm will decide against developing and commercializing new ideas emanating from its knowledge investments even if an employee or group of

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[2] "System Error," *The Economist,* 18 September 1993, p. 99

[3] Ibid.

employees think they have a positive expected value. As explained above, this divergence arises because of the inherent conditions of uncertainty, asymmetries, and high transaction costs, which created the knowledge filter. While Griliches' model of the knowledge production function focuses on the decision-making context of the firm concerning investments in new knowledge, Acs and Audretsch (1994), Audretsch (1995) proposed shifting the unit of analysis from the firm to the individual knowledge worker (or group of knowledge workers). This shifted the fundamental decision-making unit of observation in the model of the knowledge production function away from the exogenously assumed firms to individuals such as scientists, engineers, or other knowledge workers—agents with endowments of new economic knowledge. Shifting the focus away from the firm to the individual as the relevant unit of observation also shifts the appropriation problem to the individual so that the relevant question becomes how economic agents with a given endowment of new knowledge can best appropriate the returns from that knowledge. If an employee can pursue a new idea within the context of the organizational structure of the incumbent firm, there is no reason to leave the firm. If, on the other hand, employees place greater value on their ideas than the decision-making hierarchy of the incumbent firm, they may forgo what has been determined to be a good idea. Such divergences in the valuation of new ideas force workers to choose between forgoing ideas and starting a new firm to appropriate the value of their inherent knowledge.

Because radical innovative activity is based more on decisions involving knowledge and less on decisions involving information, it is accordingly more vulnerable to being impeded by the knowledge filter. By contrast, incremental innovation is based more on decisions involving information than knowledge and therefore is less vulnerable to being impeded by the knowledge filter.

By focusing on the decision-making context, which confronts the individual knowledge worker, the knowledge production function is actually reversed. Knowledge becomes exogenous and embodied in a worker. The firm is created endogenously in the workers' efforts to appropriate the value of their knowledge through innovative activity. Typically, an employee in an incumbent large corporation, often a scientist or engineer working in a research laboratory, will have an idea for an invention and ultimately for an innovation but will only act on the idea, or present it to the incumbent firm, if there is an expected return. Accompanying this potential innovation is an expected net return from the new product. The inventor would expect compensation for the potential innovation accordingly. If the company has a different, presumably lower, valuation of the potential innovation, the firm may decide either not to pursue its development or that it merits a lower level of compensation than that expected by the employee. In either case, employees will weigh the alternative of starting their own firm. If the gap in the expected return accruing from the potential innovation between the inventor and the corporate decision-maker is sufficiently large, and if the cost of starting a new firm is sufficiently low, the employee may decide to leave the large corporation and establish a new enterprise, such as the case with SAP.

The knowledge filter approach has important consequences concerning the role of policies. Particularly, Arrow (1962) identifies three types of market failure: those

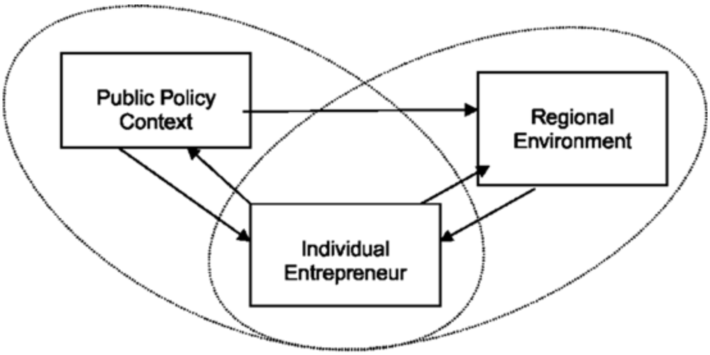

Fig. 2.2 The public policy/individual entrepreneur/regional environmental nexus. Source: Adapted from Feldman and Kelly 2001

associated with indivisibilities, inappropriability, and uncertainty. Public policies should try to correct for market failure associated with uncertainty, which demonstrates a problem with entrepreneurship. While in the classical knowledge production function approach, public policies are supposed to correct for failures in the market for the financing of innovation and for the positive externalities arising from the public good nature of R&D activities (which add to the stock of existing knowledge), according to the knowledge filter approach, public policies should also try to correct for the market failure associated with entrepreneurship Audretsch (2003) (see Fig. 2.2).

Such market failures might result in low levels of regional entrepreneurship capital that preempt scientists and other knowledge workers who perceive and recognize an entrepreneurial opportunity from actually pursuing that opportunity by starting a new firm and entering into entrepreneurship (not all regions, as a result of historical, institutional, and other reasons, are endowed with the same amount of entrepreneurial capital). Thus, public policies such as ATP and SBIR, but also regional and local policies, including science and technology parks and incubators, can serve to augment and enhance regional entrepreneurship capital, allowing companies, which require additional assets of capital, knowledge workers, or other missing ingredients, to develop their ideas into successful market innovations (more on this in Sect. 2.1.6).

Summarizing, when considering the different approaches, we have to recognize that each separate strand of literature focusing on technological innovation makes a distinct contribution to understanding the determinants of firm innovation. In particular, these different approaches to innovation suggest that four key units of observation are crucial in understanding the innovation process—the firm, the region, the individual, and the institutional/public policy context.

New-firm start-ups are important to innovation, because they embody a mechanism which facilitates the spillover of knowledge produced with one intended application in an incumbent corporation or university laboratory but which is actually commercialized by a new and different firm.

The individual matters to innovation because the individual scientists or engineers are confronted with a career trajectory decision—should they remain in a university laboratory or incumbent corporation or should they start a new high-technology enterprise? If no individual scientist or engineer makes the decision to start a new high-technology firm, there will be fewer spillovers and therefore less innovative activity, which will yield less economic activity.

Geography matters because the region provides the spatial platform in which knowledge spillovers are generated, absorbed, and ultimately commercially exploited and appropriated. A high density of high-technology firms, or highly skilled workers, forms a spatial cluster, where knowledge is more easily transferred between the similar groups of people over a small, clustered geographic space. The decision to start a new high-technology enterprise is shaped by the presence of knowledge and financial and other complementary assets that are available in the region.

2.1.4 Measuring and Identifying Innovative Firms

In order for an innovation agency to properly identify and award support to potential firms, a method of identifying innovation will be required. The section offers several different methods and concepts for identifying firms with potential market innovations.

2.1.4.1 Surveys and Expert Panels

One useful measurement technique for identifying innovations is the Community Innovation Survey (CIS). This survey is important in the EU context. Seven surveys were completed throughout Europe to understand how innovative specific fields were within the European context. Policy-makers and experts address needed improvements in innovative fields of technology use surveys to tailor their policy recommendations and responses.

There is also a long tradition of relying on industry experts to identify innovative activity. The first serious attempt to directly measure innovative output was by a panel of industry experts assembled by Gellman Research Associates (1976) for the National Science Foundation. The Gellman panel of international experts compiled a database of 500 major innovations that were introduced into the market between 1953 and 1973 in the United States, the United Kingdom, Japan, West Germany, France, and Canada. These innovations represented the “most significant new industrial products and processes, in terms of their technological importance and economic and social impact” (National Science Board 1975, p. 100).

A second and comparable database again involved an expert panel assembled by Gellman Research Associates (1982), this time for the US Small Business Administration. In this second study, Gellman compiled a total of 635 US innovations, including 45 from the earlier study for the National Science Foundation. The additional 590 innovations were selected from 14 industry trade journals for the

Table 2.1 Distribution of large- and small-form innovations according to significance levels (percentages in parentheses)

Innovation significance	Description	Number of innovations			
		Large firms		Small firms	
1	Establishes whole new categories	(0.00)	(0.00)	(0.00)	(0.00)
2	First of its type on the market in existing categories	50	(1.76)	30	(1.43)
3	A significant improvement in existing technology	360	(12.70)	216	(10.27)
4	Modest improvement designed to update existing products	2434	(85.53)	1959	(88.31)
Total		2834	(99.99)	2104	(100)

Source: Adapted from Acs and Audretsch (1990)

period 1970–1979. About 43 % of the sample was selected from the award winning innovations described in the *Industrial Research & Development* magazine.

The third data source that has attempted to directly measure innovation activity was compiled at the Science Policy Research Unit (SPRU) at the University of Sussex in the United Kingdom.[4] The SPRU data consist of a survey of 4378 innovations that were identified over a period of 15 years. The survey was compiled by writing to experts in each industry and asking them to identify "significant technical innovations that had been successfully commercialized in the United Kingdom since 1945, and to name the firm responsible" (Pavitt et al. 1987, p. 299).

Another study completed by Acs and Audretsch used 4938 innovations and an expert panel to apply four levels of significance (see Table 2.1): (1) innovation establishes an entirely new category of product; (2) innovation is the first of its type on the market for a product category already in existence; (3) the innovation represents a significant improvement in technology; and (4) the innovation is a modest improvement designed to update an existing product (Acs and Audretsch 1990).

Acs and Audretsch found that none of the innovations were at the highest significance level. However, they did find that small firms produced innovations which made up a considerable portion of the innovations within the field. There appeared to be little difference in the "quality" and significance of innovations between large and small firms.

The ex post approach of relying upon industry experts to distinguish between more and less significant innovations—that is, between radical and incremental innovations—has the advantage of being able to identify the extent to which a novel technological process is at the heart of the innovative process (Dewar and Dutton 1986). This approach is consistent with the view posited by Dutton and Thomas (1984) that technology is best defined in terms of the knowledge content.

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[4] The SPRU innovation data are explained in considerable detail in Pavitt et al. (1987), Townsend et al. (1981), Robson and Townsend (1984), and Rothwell (1989).

2.1.4.2 Codified Innovation: Patents

In the past 20 years, patents have become one of the most common means of measuring the degree to which an innovation is incremental or radical. Patents have become an important metric in the innovation literature because of the easy and open paper trail provided by patent citations and applications. This trail clearly defines the origin of ideas and represents a clear trajectory of where ideas go when they are cited in the future. This trajectory comes in two forms: forward citations and backward citations. The patent citations also attribute a clear economic value to start-ups and economic growth (Trajtenberg 1990).

2.1.4.3 Forward Patent Citation Radicalness

Forward patent citation involves future citations of a patent. These citations come from the US patent examiners.[5] Rosenkopf and Nerkar (2001) measure the degree of radicalness of forward patent citations by examining the computer disk industry and investigate the impact patents have on future citations in different domains of patent classification. Patent domains are maintained and categorized by the US Patent and Trade Office (USPTO). The authors show how incremental patents are often more narrowly cited within a certain domain of patents, and multiple domains of patents often cite radical patents, i.e., outside of their original domain.

The forward patent count that Rosenkopf and Nerkar (2001) use is, in many ways, comparable to forward citations in scholarly journals. There are, however, two detrimental differences when using citations. First, it is in the interests of patent inventors to cite as little as possible from previous work. The less previous work is cited in the patent application, the more IP monopoly is granted to the inventor. Second, a patent examiner is required to assign relevant patent citations to the patent application. For a greater understanding of deficiencies in the US patent examining process, see Graham and Harhoff (2006) and Graham et al. (2002). Drawing on patent citations creates other problems as well. As Rosenkopf and Nerkar (2001, p. 290) define radical innovation: "'radical' exploration builds upon distant technology that resides outside of the firm. The technological subunit utilizes knowledge from a different technological domain and does not obtain that knowledge from other subunits within the firm."

The above definition of radicalness holds innovation exogenous to the human capital and tacit knowledge of the firm. As Klepper and Graddy (1990) show, however, new and radical innovations can also come from subunits within the firm. The distant technology can often be found within the incumbent firm, though it may be unwilling to operationalize the potential radical innovation due to managerial disagreements. It may also be unwilling to commit resources to a new and uncertain venture.

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[5] These professionals cite the previous patent only when there is a legitimate reason to cite the previous patent's intellectual property.

2.1.4.4 Backward Patent Classification and Citations

Backward patent citations are citations given to prior work. Patent examiners cite previous patents and thereby give the citations, clear lines of intellectual property rights, and issue and examine these citations. Shane (2001) shows, through a unique data set from MIT inventors involving 1397 licensed MIT patents, that the more radical an invention is, the more likely it is to have been made by a small firm. Similarly, Acs and Audretsch (1990) find that small firms contribute a high share of innovations that could be classified as being more radical than incremental. These studies found that innovations emanating from small firms were more likely to be classified as radical than innovations from large firms. As Shane (2001, p. 208) explains, radical innovations tend to originate from newly established firms (typically small firms), whereas existing (and typically larger) firms have the competitive advantage in generating incremental innovations: "First, radical technologies destroy the capabilities of existing firms because they draw on new technical skills. Since organizational capabilities are difficult and costly to create (Nelson and Winter 1982; Hannan and Feeman, 1984), established firms are organized to exploit established technologies. Firms find it difficult to change their activities to exploit technologies based on different technical skills." Shane (2001) finds that research shows that radical patent citations and a lack of patent classification are positive to start-ups for the MIT-based patents. Joseph Schumpeter (1942) finds this *creative destruction* as an integral part of entrepreneurship and economic activity and growth.

2.1.5 Financing and Firm Size: How Small Firms Survive in Illiquid Capital Markets

One of the most consistent and compelling findings to emerge from a rich body of literature is that potential entrepreneurs with innovative ideas are frequently unable to attract adequate resources—financial, management, technical, and human capital—which impedes their ability to launch, sustain, or grow a new venture (Gompers and Lerner 2001). While this inability to attract resources has many names—financing constraints, liquidity constraints, or the infamous "valley of death" (Branscomb and Auerswald 2002)—all of them entail a high degree of uncertainty concerning the expected outcome valuation of a new idea, combined with asymmetries in information and knowledge.

Stiglitz and Weiss (1981) point out that, unlike most markets, the market for credit is exceptional in that the price of the good—the rate of interest—is not necessarily at a level that equilibrates the market. They attribute this to the fact that interest rates influence not only the demand for capital but also the risk inherent in different classes of borrowers. As the rate of interest rises, so does the risk of borrowing, leading suppliers of capital to rationally decide to limit the number and size of loans they make at any particular interest rate. The amount of information about an enterprise is generally not orthogonal to size. Rather, as Petersen and Rajan

(1994, p. 3) observe, “small and young firms are most likely to face this kind of credit rationing. Most potential lenders have little information on the managerial capabilities or investment opportunities of such firms and are unlikely to be able to screen out poor credit risks or to have control over a borrower’s investments.” If lenders are unable to identify the quality or risk associated with particular borrowers, credit rationing will occur and thereby create market failure (Burghof 2000). This phenomenon is analogous to the lemon argument put forth by George Akerlof (1970), where the market is unable to properly estimate the value of the start-up. This market failure leads entrepreneurs to bridge this “valley of death” in financing, team member employment, and advisor placement by other means than the commercial market clearinghouse for ideas.

The existence of asymmetric information prevents the suppliers of capital from engaging in price discrimination between riskier and less risky borrowers. But, as Diamond (1984) argues, the risk associated with any particular loan is also not neutral with respect to the duration of the relationship. This is because information about the underlying risk inherent in any particular customer is transmitted over time. With experience, a lender will condition the risk associated with any class of customers by characteristics associated with the individual customer.

Since potential entrepreneurs are left with the problem of how to finance, hire team members, and attract advisors for their entrepreneurial pursuits, other avenues of advancing their entrepreneurial interest must arise in the face of market failure. One potential answer may lie in their ability to create sufficient social capital with potential partners to overcome this market failure. If, for example, entrepreneurs are able to concentrate their efforts on interacting efficiently and quickly with a target group of investors, team members, or advisors, they may build enough social capital with the target group to form sufficient synergies for entrepreneurial success. Whether such concentrated efforts actually happen remains open to question by policy-makers and scholars due to the difficult nature of data collection.

Large incumbent firms with a proven track record can finance capital expenditures from their own internal resources, issuance of equity, or debt. By contrast, new entrepreneurial ventures have limited resources and are less able to issue equity. Since gathering information is costly, banks will expand their search for information until the expected marginal benefit of search equals zero. If the remaining information asymmetry induces a risk premium,[6] firms with fewer signaling opportunities will have higher costs of capital. The degree of information asymmetry depends on borrower characteristics such as firm size, firm age and governance, or legal form (Lehmann and Neuberger 2001). Typically, new and small firms provide less information to outside financiers than do their larger counterparts. This reflects the fixed costs of information disclosure or the absence of disclosure rules.

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[6] This compensation device has the drawback that rising loan rates aggravate moral hazard and adverse selection problems. Thus, the supply curve may bend backwards (Stiglitz and Weiss 1981). However, better information increases the ability to raise loan rates since the bank’s loan offer curver is less likely to bend backwards.

In addition, lack of reputation constrains the borrowing capacity of new entrepreneurial firms (Martinelli 1997). As firms age, information asymmetries decrease, and firms may earn a positive reputation through a proven credit history. As a result, new entrepreneurial ventures are often associated with higher loan rates and less access to financial resources.

It would be erroneous to suggest that venture capital finances most of the early stage ventures in the United States. In fact, as Table 2.2 makes clear, most of the venture capital in the United States is focused instead on expansion and later-stage growth, rather than early stage ventures. A different source of funding for small business is provided by the Small Business Investment Companies (SBICs). The SBICs provide financing to small firms by making available equity capital, long-term loans, and management assistance to qualifying small businesses.

An important and broadly accepted strand of literature suggests that small and new firms will be at a competitive disadvantage with respect to generating innovative activity in general and radical innovations in particular. However, small and new firms whose goal is to be acquired by an incumbent know that they will only be acquired if they produce the best radical innovation. The success rate of smaller firms is correlated by their rate of innovation. According to Griliches' (1979) model of the knowledge production function, innovative activity is the direct result of a firm making investments in knowledge inputs, such as R&D and human capital. Since larger firms generally invest significantly more in R&D than small and new firms, they would be expected to generate more innovative activity. Since radical innovation generates more value than incremental innovation, some scholars have assumed, and even developed elaborate theoretical models to explain why, large firms, which have large R&D departments, will generate more radical innovations than small and new firms, which are constrained by size in their ability to invest in R&D (Cohen and Klepper 1992a, b). Others, however, argue that incumbent firms will only have an incentive to invest in radical innovation if they can assure that they will produce the best and second-best radical innovation (Henkel et al. 2015).

Five factors favoring the innovative advantage of large enterprises have been identified in the literature. First is the argument that innovative activity requires a high fixed cost. As Comanor (1967) observes, R&D typically involves a "lumpy" process that yields scale economies. Similarly, Galbraith (1956, p. 87) argues, "Because development is costly, it follows that it can be carried on only by a firm that has the resources which are associated with considerable size." Second, only firms that are large enough to attain at least temporary market power will choose innovation as a means for maximization (Kamien and Schwartz 1975). This is because the ability of firms to appropriate the economic returns accruing from R&D and other knowledge-generating investments is directly related to the extent of that enterprise's market power (Levin et al. 1985, 1987; Cohen et al. 1987; Cohen and Klepper 1991). Third, R&D is a risky investment; small firms engaging in R&D make themselves vulnerable by investing a large proportion of their resources in a single project. However, their larger counterparts can reduce the risk accompanying innovation through diversification into simultaneous research projects. The larger firm is also more likely to find an economic application for the

Table 2.2 The US venture capital investment, financing stage, industry, and number of companies: 1995–2008 (millions of current dollars)

Financing stage/industry/ number of companies	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
All financing stages	**7628**	**10,840**	**14,364**	**20,172**	**52,016**	**101,767**	**39,308**	**21,250**	**19,278**	**22,117**	**22,922**	**26,334**	**30,639**	**28,077**
Seed/start-up	1244	1267	1309	1679	3571	3053	739	327	341	461	893	1194	1330	1494
Early	1694	2614	3430	5389	11,263	24,569	8387	3723	3455	3918	3830	4195	5686	5346
Expansion	3553	5340	7382	9999	28,720	58,138	22,248	12,063	9760	9086	8574	11,417	11,386	10,473
Later	1138	1619	2243	3105	8463	16,007	7935	5138	5723	8653	9626	9528	12,237	10,765
All industries	**7628**	**10,840**	**14,364**	**20,172**	**52,016**	**101,767**	**39,308**	**21,250**	**19,278**	**22,117**	**22,922**	**26,334**	**30,639**	**28,077**
Biotechnology	768	1156	1385	1520	2029	4057	3400	3183	3553	4145	3924	4504	5247	4410
Business products and services	177	377	409	691	2791	4560	1031	450	579	396	396	552	709	477
Computers and peripherals	324	383	377	372	897	1596	655	457	373	590	539	532	586	424
Consumer products and services	473	503	738	622	2534	3350	662	228	163	309	304	407	476	437
Electronics/instrumentation	125	193	260	227	282	773	381	314	236	351	438	722	563	574
Financial services	194	329	362	781	2202	4180	1380	338	410	520	918	462	558	526
Healthcare services	448	664	869	926	1368	1352	499	368	222	363	407	381	295	192
Industrial/energy	529	504	696	1407	1508	2479	1067	740	756	775	808	1925	3222	4576
Information technology services	178	430	655	1057	3958	8619	2391	1039	775	737	1063	1377	1707	1812
Media and entertainment	910	1074	956	1744	6560	10,299	2312	712	879	965	1149	1624	1962	1884
Medical devices and equipment	627	648	1016	1144	1511	2312	1997	1838	1602	1921	2186	2910	3872	3446

Networking and equipment	347	612	937	1360	4259	11,409	5543	2595	1737	1545	1517	1091	1378	735
Other	10	21	56	88	84	45	62	4	0	1	57	8	2	23
Retailing/distribution	314	257	303	609	2805	3067	321	151	65	174	207	201	365	235
Semiconductors	202	299	567	618	1290	3542	2391	1503	1764	2128	1923	2101	2080	1641
Software	1123	2218	3281	4367	10,295	24,012	10,141	5150	4462	5375	4803	4920	5423	5027
Telecommunications	880	1171	1498	2639	7642	16,116	5074	2180	1701	1822	2283	2618	2196	1659
Internet specific	505	1562	2359	4457	23,331	42,233	9848	3577	2388	2875	3336	4336	5176	4871
Clean technology	77	157	144	107	200	577	386	390	263	440	523	1458	2656	4023
Number of companies	**1539**	**2076**	**2537**	**2979**	**4404**	**6335**	**3786**	**2634**	**2461**	**2625**	**2708**	**3089**	**3301**	**3262**

Notes: The *seed/start-up* stage includes proof of concept (seed), research, product development, or initial marketing. *Early* includes financing for activities such as initial expansion, commercial manufacturing, and marketing. *Expansion* includes major expansion of activities or to prepare a company expecting to go public within 6–12 months. *Later* includes acquisition financing and management and leveraged buyout. *Internet specific* are companies whose business model is fundamentally dependent on the Internet, regardless of the company's primary industry category. *Clean technology* comprises companies that focus on alternative energy, pollution and recycling, power supplies, and conservation

Source: Adapted from National Science Board, *Science and Engineering Indicators 2010*

uncertain outcomes resulting from innovative activity (Nelson 1959). Fourth, scale economies in production may also provide scope economies for R&D. Scherer (1991) notes that economies of scale in promotion and distribution facilitate penetration of new products, enabling larger firms to enjoy greater profit potential from innovation. Finally, an innovation yielding cost reductions of a given percentage results in higher profit margins for larger firms than for smaller firms. There is also substantial evidence that technological change—or rather one aspect of technological change, R&D—is, in fact, positively related to firm size.

The empirical evidence from a plethora of studies suggests that, in terms of R&D inputs, large and more mature firms tend to make greater investments (i.e., R&D expenditures in absolute values) than do their smaller and younger counterparts. However, in terms of innovative outputs, the empirical evidence is very different. Younger and smaller enterprises contribute considerably more to innovative output than they do to R&D inputs and therefore account for a greater share of innovative activity than they do for R&D investments (Acs and Audretsch 2010). Moreover, as previously mentioned, newly established and small firms tend to generate more radical innovations, while established (and larger) firms focus more on incremental innovations.

2.1.6 Role of Public Support Programs in Reducing Market Failures in Financing of Small (and Young) Companies

The most predominant theory of innovation assumes that innovative opportunities are the result of systematic efforts by firms and the result of purposeful efforts to create knowledge and new ideas and subsequently to appropriate the returns on those investments through their commercialization (Chandler 1990; Cohen and Levinthal 1989; and Griliches 1979).

In what Griliches formalized as the model of the knowledge production function, (exogenously existing) firms (endogenously) create innovative output through purposeful and dedicated investments in new knowledge (R&D and human capital, for instance, through training and education). In this framework, an important point for thinking about (and also analyzing and evaluating the impact of) public policy on innovation is through focusing on the unit of observation of the firm. How does the firm change its activities, behavior, strategies, and output as a result of policy intervention? For example, can policy tools, such as the National Science Foundation funded research, help existing firms in generating new sources of knowledge? Moreover, are there specific policy institutions, such as the STTR, that can help facilitate these knowledge spillovers? Certainly, a minor army of scholars have put together a formidable body of literature which analyzes and evaluates the impact of various public policy instruments, including but not limited to the ATP and SBIR, on the innovative and economic performance of the firm (Branscomb and Auerswald 2002; Feldman and Kelley 2000, 2001; Powell and Lellock 1997; Silber and Associates 1996).

A stark contrast to this focus on the firm is provided by the intellectual tradition in entrepreneurship literature, where the focus is on the cognitive decision-making process of the individual to start a new firm and enter into entrepreneurship.

There is virtual consensus in the entrepreneurship literature that entrepreneurship revolves around the recognition of opportunities and the pursuit of those opportunities (Venkatraman 1997). But the existence of those opportunities is, in fact, taken as given. The focus has been on the cognitive process by which individuals reach the decision to start a new firm. This has resulted in a methodology focusing on differences across individuals in analyzing the entrepreneurial decision (Stevenson and Jarillo 1990). Krueger (2003, p. 105) has pointed out that, "The heart of entrepreneurship is an orientation toward seeing opportunities," which frames the research questions, "What is the nature of entrepreneurial thinking and what cognitive phenomena are associated with seeing and acting on opportunities?"

Thus, the traditional approach to entrepreneurship essentially holds the opportunities constant and then asks how the cognitive process inherent in the entrepreneurial decision varies across different individual characteristics and attributes (Carter et al. 2003; McClelland 1967). Eckhardt and Shane (2003, p 187) summarize this literature in introducing the individual-opportunity nexus (see Fig. 2.2): "We discussed the process of opportunity discovery and explained why some actors are more likely to discover a given opportunity than others." Some of these differences involve the willingness to incur risk; others involve the preference for autonomy and self-direction, while still others involve differential access to scarce and expensive resources, such as financial capital, human capital, social capital, and experiential capital.

The two approaches, the one focusing on existing firms and the other pointing to entrepreneurship, identify different sources for knowledge spillovers and market failures, and this generates different policy prescriptions. For instance, while Romer (1986), Lucas (1993), and others assumed that knowledge spillovers would automatically serve as the engine for innovation and economic activity and growth, Acs et al. (2005) and Audretsch et al. (2006a, b) suggest that the "knowledge filter" may actually impede the spillover and commercialization of knowledge. To the degree that the knowledge filter impedes or constrains the spillover and commercialization of knowledge, entrepreneurship can serve as the missing link to economic growth by providing a conduit for the spillover of knowledge that might otherwise never have been commercialized (Audretsch et al. 2006a, b). This could explain why, for example, in the European Union, we observe the simultaneous existence of high investments in new knowledge in the form of research and development (R&D), university research, and high levels of human capital, combined with stagnant rates of economic growth and high levels of unemployment (so-called European paradox). In fact, empirical evidence suggests that regions endowed with higher levels of entrepreneurship capital also exhibit stronger economic performance, suggesting that new-firm start-ups serve as an important conduit for knowledge spillovers and commercialization. Thus, public policies such as ATP and SBIR, and also regional and local policies, including science and technology parks and incubators, can serve to augment and enhance regional entrepreneurial capital. Indeed, as illustrated in Fig. 2.3, government programs can assist firms in their technology creation and technological development of their ideas.

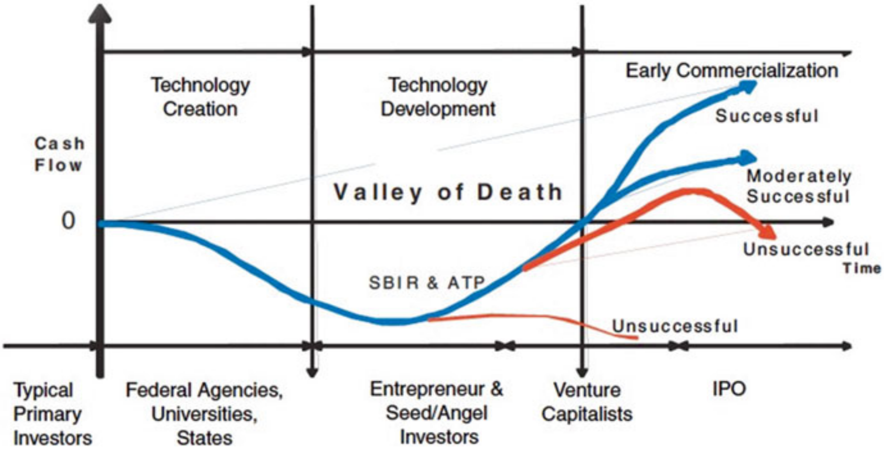

Fig. 2.3 The valley of death. Source: Adapted from Wessner, *An Assessment of the SBIR Program*, p. 30

This governmental assistance affords companies, which require additional assets of capital, knowledge workers, or other missing ingredients, the opportunity to develop their ideas into successful market innovations.

Innovative performance in the United States has been shaped by public policy. Examples of public policy instruments, which influence American innovative performance, range from immigration laws and enforcement to the R&D tax credit, Small Business Innovation Research (SBIR) program, and the Bayh-Dole Act. These instruments influence the ability of universities and university scientists to commercialize their research and ideas.

Immigration policy generally influences the supply of human capital, and particularly, the supply of scientists and engineers. The Hart-Cellar Act[7] established the basic immigration policy in the United States. High-skilled workers, including scientists and engineers, are permitted to enter into the United States and therefore become legally eligible for employment by high-technology companies, through the H-1, L-1, O-1, and TN visa categories. Under the H-1B visa, which is the most common, the foreign scientist may retain legal residence for a period of 3 years, which can be extended for up to 6 years. The L-1 visa applies to the intercompany transfer of international employees for employment in the United States by the same company. The O-1 visa is applicable for individuals with extraordinary ability. Immigrant visas, which are commonly referred to as the green card, are restricted to 145,000 annually. An E-2 visa enables an individual to enter and work inside the United States if he finances the start-up of a new firm. An EB-5 visa applies to foreigners creating or preserving at least ten jobs for US workers.[8]

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[7] See: http://library.uwb.edu/guides/usimmigration/79%20stat%20911.pdf.

[8] See: http://www.uscis.gov/USCIS/About%20Us/Electronic%Reading%20Room/Customer%20Service%20Reference%20Guide/Nonimmigrant_Empl.pdf

Another important policy instrument, which facilitates innovation in the United States, is the R&D tax credit. In 1981, the US Congress passed a new law authorizing a tax credit for companies investing in R&D. The tax credit stipulated a 25 % credit for R&D expenditures in excess of the average of a firm's R&D expenditure in a base period (generally, the previous 3 taxable years). Congress has renewed the R&D tax credit in subsequent years. Most OECD countries have also adopted the R&D tax credit in some form or another. While there were 12 OECD countries providing an R&D tax credit in 1996, by 2008, the number had grown to 21. Most states within the United States also have R&D tax credits or a similar measure to promote R&D investments at the state or local level.

While immigration policy and the R&D tax credit enhance investments in the innovative process, other instruments are designed to effectively penetrate the knowledge filter. In particular, the Bayh-Dole Act was enacted to facilitate the commercialization of research that might otherwise remain dormant and undeveloped for innovative activity in the laboratories of universities. Prior to the Bayh-Dole Act, the bureaucratic impediments of interacting between potential innovators and the governmental agencies seem to reduce the commercialization of many scientific projects at universities. The Bayh-Dole Act effectively transferred the property rights of federally financed research and scientific projects from the funding government agency to the university. This made the university responsible for deciding how best to manage the process of commercializing scientific knowledge and transforming it into innovative activity, rather than the funding government agency. Thus, the contemporary policy in the United States is clearly oriented toward penetrating the knowledge filter impeding the spillover of ideas created at universities into innovative activity.

A second example of innovation policy in the United States designed to facilitate penetration of the knowledge filter involves the Small Business Innovation Research (SBIR) program. As discussed in the previous sections, many nascent entrepreneurs and small firms are unable to procure sufficient funding to facilitate early stage finance of innovative ventures. The SBIR was created to provide such early stage funding and enable firms to cross what has become known as the "valley of death" or the financing constraints, which typically confront new and young firms, especially in knowledge-based and high-technology industries. As a result of the introduction of the SBIR, and its subsequent effect on American innovative activity, a plethora of states, cities, and regions have implemented more local policies designed to enable small and young firms to develop proposals for SBIR funding. As the next section will make clear, the SBIR has had a strong and positive impact on the innovative performance of the United States.

2.1.7 The Small Business Innovation Research Program (SBIR)

In the United States, the 1970s was characterized by sluggish growth, persistent high rates of unemployment, and inadequate rates of job creation. In response to these economic problems, the US Congress enacted the Small Business Innovation

Research (SBIR) program in 1982 explicitly to reinvigorate jobs and growth by enhancing the innovative capabilities of the United States. In particular, the mandate assigned by the Congress was to explicitly (1) promote technological innovation, (2) enhance the commercialization of new ideas emanating from scientific research, (3) increase the role of small business in meeting the needs of federal research and development, and (4) expand the involvement of minority and disadvantaged people in innovative activity.

The SBIR program functions through the 11 federal agencies,[9] which administer the program and award around $2.5 billion annually for innovative activity by small business. Qualifying small businesses are eligible to apply to the participating federal agencies of up to $150,000 for a Phase I award over a 6-month period. The Phase I objective for funding is to "establish technical merit, feasibility and commercial potential of the proposed R&D efforts to determine the quality of performance of the small business awardee organization"[10] prior to Phase II funding. Phase II funding is dependent on Phase I funding. Only Phase I awardees may apply for Phase II funding. If the results of the Phase I awardee clearly show scientific and technical merit, the Phase II funding awards an amount of up to $1,000,000 over a 2-year period. Phase III funding is more of a business construct where the SBIR no longer funds the business, and the small businesses must find funding in the private sector or other non-SBIR federal agency funding. To commercialize their product, small businesses are expected to garner additional funds from private investors, the capital markets, or from the agency that made the initial award.[11] In Fig. 2.4, the entire timeline from Phase I to Phase III and the time allocated to each phase are shown.

University scholars have analyzed the impact of the SBIR program in considerable detail in a series of meticulous studies undertaken by the Board on Science, Technology, and Economic Policy of the National Research Council of the National Academy of Sciences and also in a number of important studies (Fig. 2.5). There is compelling empirical evidence that the SBIR has generated a number of substantial benefits to the US economy. The country is no doubt more innovative and more competitive in the global economy and has generated more and better jobs as a result of SBIR. The studies assessing the impact of the SBIR program have generated robust findings. Studies with disparate methodologies, including case studies

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[9] The agencies consist of the Department of Agriculture, Department of Commerce (National Institute of Standards and Technology and National Oceanic and Atmospheric Administration), Department of Defense, Department of Education, Department of Energy, Department of Health and Human Services, Department of Homeland Security, Department of Transportation, the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Science Foundation.

[10] http://www.sbir.gov/faq/sbir#t25n66932

[11] National Research Council (US) Committee on Capitalizing on Science, Technology, and Innovation; Wessner CW, editor. SBIR and the Phase III Challenge of Commercialization: Report of a Symposium. Washington (DC): National Academies Press (US); 2007. I, Introduction: SBIR and the Phase III Challenge of Commercialization. Available from: http://www.ncbi.nlm.nih.gov/books/NBK11392/

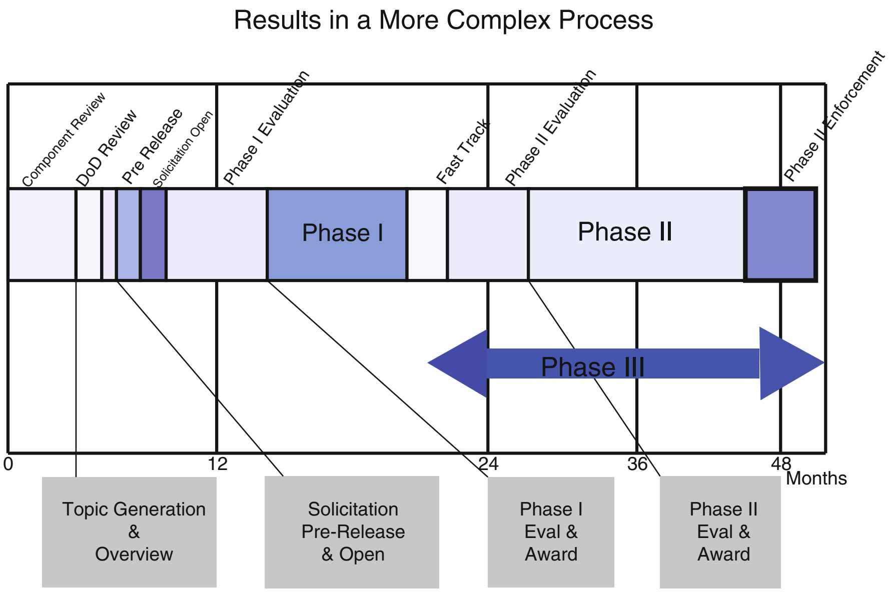

Fig. 2.4 The SBIR timeline

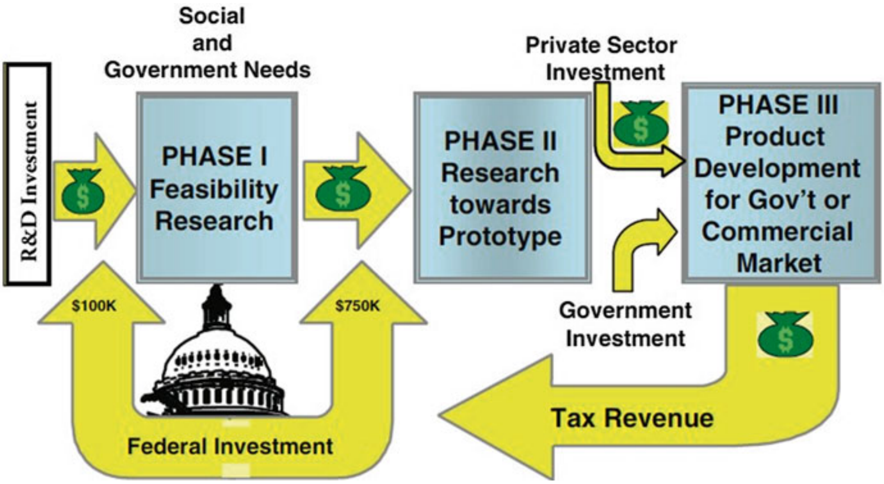

Fig. 2.5 The structure of the SBIR program. Source: Adapted from Wessner, *An Assessment of the SBIR Program*, p. 23

of recipient firms, interviews with program administrators at the funding agencies, systematic analyses of broad-based surveys of firms, and sophisticated econometric studies based on objective measures comparing the performance of recipient SBIR firms with control groups consisting of matched pairs that did not receive any SBIR support, all point to the same thing—the SBIR has made a key and unequivocal contribution to the innovative performance of the United States, especially in terms of technological innovation.

In particular, a number of key benefits emanating from the SBIR program can be identified from the literature. The key economic benefits accruing from implementation of the SBIR program are most compelling in terms of two of the objectives stated in the Congressional mandate—the promotion of technological innovation and increased commercialization from investments in research and development.

There is strong and compelling evidence that the United States is considerably more innovative as a result of the SBIR program than it would be without it.

- **Recipient SBIR firms are more innovative**: Existing small businesses are more innovative as a result of the SBIR program. A painstaking study undertaken by the National Research Council of the National Academy of Sciences found that around two thirds of the projects would not have been undertaken had they not received SBIR funding.[12] The same study also identified a remarkably high rate of innovative activity emanating from the SBIR-funded projects. Slightly less than half of the SBIR-funded projects actually resulted in an innovation in the form of a new product or service that was introduced into the market. Such a high rate of innovative success is striking given the inherently early stage and high-risk nature of the funded projects. A thorough review and summary of the empirical evidence testing the systematic impacts of the SBIR have concluded that (Audretsch 2010).
- **The SBIR has generated more technology-based start-ups**: The SBIR program results in a greater number of technology-based firms. One key study found that over one fifth of all recipient SBIR companies would not have existed in the absence of an SBIR award.
- **Recipient SBIR firms have stronger growth performance**: Studies consistently find that firms receiving SBIR awards exhibit higher growth rates than do control groups of matched pair companies.
- **Recipient SBIR firms are more likely to survive**: The early phase for technology entrepreneurial ventures has been characterized as *the valley of death*. The empirical evidence suggests that the likelihood of survival for young technology-based SBIR recipients is greater than for comparable companies in carefully selected control groups.
- **The SBIR has resulted in greater commercialization of university-based research**: Empirical evidence points to a high involvement of universities in SBIR-funded projects. One or more founders have been employed at a university in two thirds of the SBIR recipient firms. More than one quarter of the SBIR-funded projects involved contractors from university faculties.
- **The SBIR has increased the number of university entrepreneurs**: Studies find that scientists and engineers from universities have become entrepreneurs and started new companies, who otherwise might never have done so. Some of these university-based entrepreneurs are involved in firms that have received SBIR awards. Others have been inspired to become entrepreneurs as a result of learning about the efficacy

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[12] National Research Council, *An Assessment of the SBIR Program.* C. Wessner (ed.), Washington, D.C.: National Academies Press, 2008.

of becoming an entrepreneur from the observed success and experiences of their colleagues who have been involved with SBIR-funded companies.

Despite the compelling evidence of the strong and significant impact that the SBIR program has contributed to promoting innovation in the United States, are also a number of important qualifications and concerns about the impact of the SBIR. An important study by Gans and Stern (2003) found that many of the projects receiving SBIR funding would have been undertaken even in the absence of SBIR support. Their results cast at least some doubt that the SBIR generates innovative activity that otherwise would not have been undertaken. Similarly, a study by Lerner (1996, 2002) concludes that, while firms receiving support from the SBIR do exhibit higher rates of growth, having multiple awards does not contribute to higher firm growth rates. In addition, Wallsten (2000) concludes that firms receiving SBIR support do not significantly increase their investments in R&D and innovative activity. Other concerns have been expressed concerning the strong geographic concentration of the SBIR awards and the relatively low participation rates of females and minorities in procuring SBIR awards (Audretsch 2010).

Some agencies, such as the Department of Defense and NASA, select potential awardees on desired emerging potential technologies, while other agencies such as NIH and HHS select awards based on potential returns to society. SBIR and most public funds emphasize the importance of early stage financing, which is generally ignored by private venture capital. Some of the most innovative American companies received early stage financing from SBIR, including Apple Computer, Chiron, Compaq, and Intel.

The design of the SBIR program is as follows[13]:

2.1.7.1 Phase I

Federal agencies solicit contract proposals or applications for feasibility-related research with either general or narrow requirements as determined by the needs of that agency. Proposals are competitively evaluated on scientific and technical merit and feasibility, potential for commercialization, program balance, and agency requirements, and may require a Phase II proposal as a deliverable. Awarded efforts are further evaluated before consideration for Phase II funding. Agencies may select to fund multiple proposals for a given project or need.

2.1.7.2 Phase II

Phase II funding is awarded to selected Phase I-funded projects based on merit and commercial potential so that they can continue R/R&D efforts. Examples of commercial potential include a record of successful commercialization, private sector funding commitments, and Phase III follow-on commitments.

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[13] See: http://www.sbir.gov/faq/sbir#t25n66932

2.1.7.3 Phase III

Projects resulting from or concluding prior SBIR-funded efforts but that are funded by sources outside of the SBIR program may receive a Phase III award for commercialization of the resulting products, productions, services, research, and research and development.

In 2009, the SBIR program was budgeted more than $2.5 billion. The SBIR consists of the following three phases: Phase I is oriented toward determining the scientific and technical merit along with the feasibility of a proposed research idea. The award is for 6 months and cannot exceed $150,000. Phase II extends the technological idea and emphasizes commercialization. A Phase II award is awarded to the most promising of the Phase I projects based on scientific and technical merit, the expected value to the funding agency, company capability, and commercial potential. The award is for a maximum of 24 months and generally does not exceed $1,000,000. Phase I awards accounted for $47 million, Phase II, $194 million.[14]

As shown in Table 2.3, approximately 40 % of Phase I awards continue on to Phase II. Phase III involves additional private funding in various forms for the commercial application of a technology. Taken together, public SME funding is about two thirds as large as private venture capital, and the SBIR represents about 60 % of all public small- and medium-sized enterprise (SME) finance programs. In 1995, the sum of equity financing provided through and guaranteed by SME programs was $2.5 billion, which amounted to more than 60 % of the total money disbursed by traditional venture funds that year. Through the SBIR program, the National Institutes of Health (NIH) awarded $266 million to small firms for medical and biopharmaceutical research. As shown in Table 2.4, over $20.8 billion was disseminated to 11 different agencies from 1983 to 2006.

2.1.7.4 Selection Process of Wining Project and Criteria Needed to Select Awardees

The process for the selection of awardees is straightforward. From the time a solicitation is published on agency websites,[15] applicants generally have 2 months to apply. Awardees are selected on the basis of merit, which is determined by a panel of experts. This panel is generally a mix of agency experts and experts from outside of the government, who come from both the for-profit and nonprofit sectors. After submission, the respective agency generally takes 6 months to select awardees. The preconditions to apply for a Phase I funding are as follows:

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[14] The US Department of Defense also uses the SBIR program to fund firms, awarding more than $10,253 billion between 1983 and 2006.

[15] Coordination for all SBIR calls can be found on the US website https://www.fbo.gov/. This website is very similar to its European counterpart: ted.europa.eu/TED/main/HomePage.do All calls can also be found on the respective agency home pages with clear instructions on what a particular agency is currently interested in funding and how to apply.

Table 2.3 SBIR awards, by award phase: FY 1983–2006

SBIR			
Fiscal year	Phase I	Phase II	Total
1983	686	0	686
1984	999	338	1337
1985	1397	407	1804
1986	1945	564	2509
1987	2189	768	2957
1988	2013	711	2724
1989	2137	749	2886
1990	2346	837	3183
1991	2553	788	3341
1992	2559	916	3475
1993	2898	1141	4039
1994	3102	928	4030
1995	3085	1263	4348
1996	2841	1191	4032
1997	3371	1404	4775
1998	3022	1320	4342
1999	3334	1256	4590
2000	3166	1330	4496
2001	3215	1533	4748
2002	4243	1577	5820
2003	4465	1759	6224
2004	4638	2013	6651
2005	4300	1871	6171
2006	3835	2026	5861
Total	68,339	26,690	95,029

Source: Adapted from National Science Board, *Science and Engineering Indicators 2010*

1. The awardee must be a for-profit organization based in the United States with no more than 500 employees.
2. At least 51 % of the company must be US-based and for profit.
3. For-profit firms may not have direct investment with other foreign countries.
4. Generally, no more than three SBIR applications may be submitted at one time.
5. The proposal must, as in the case of NASA, "clearly and concisely (1) describe the proposed innovation relative to the state of the art; (2) address the scientific, technical and commercial merit and feasibility of the proposed innovation, and its relevance and significance to NASA's needs as described in Sect. 2.1.9: and (3) provide a preliminary strategy that addresses key technical, market and business factors pertinent to the successful development, demonstration of the proposed innovation, and its transition into products and services for NASA mission programs and other potential customers."[16]

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[16] http://sbir.gsfc.nasa.gov/SBIR/sbirselect2012/solicitation/chapter3.html

Table 2.4 SBIR award funding, by type of award and federal agency: FY 1983–2006 (in millions of current dollars)

Year	All	Phase I	Phase II	DOD	HHS	NASA	DOE	NSF	DHS[a]	USDA	DOT	EPA	ED	DOC
1983	44.5	44.5	0.0	20	7	5	5	5	NA	1	*	*	*	0
1984	108.4	48.0	60.4	45	23	13	16	7	NA	2	2	1	1	0
1985	199.1	69.1	130.0	78	45	29	26	10	NA	3	3	2	1	0
1986	297.9	98.5	199.4	151	57	36	29	15	NA	4	4	3	2	1
1987	350.5	109.6	240.9	194	67	32	28	17	NA	4	3	3	2	2
1988	389.1	101.9	248.9	208	73	47	30	17	NA	4	3	3	2	1
1989	431.9	107.7	321.7	233	79	52	33	19	NA	4	4	3	2	1
1990	460.7	118.1	341.8	241	84	62	39	20	NA	4	4	3	2	1
1991	483.1	127.9	335.9	241	93	69	39	22	NA	5	6	4	3	1
1992	508.4	127.9	371.2	242	102	79	43	23	NA	6	3	4	2	2
1993	698.0	154.0	490.7	385	126	86	50	29	NA	7	4	5	3	2
1994	717.6	220.4	473.6	354	133	116	53	34	NA	7	7	5	3	4
1995	834.5	232.2	601.9	414	181	118	70	42	NA	9	10	7	3	8
1996	916.3	228.9	645.8	479	189	114	62	41	NA	9	7	5	3	6
1997	1106.9	277.6	789.1	569	252	121	75	54	NA	10	8	6	4	7
1998	1066.7	262.3	804.4	540	267	96	76	53	NA	13	6	5	5	7
1999	1096.5	299.5	797.0	514	314	89	81	60	NA	13	6	5	5	7
2000	1190.2	302.0	888.2	549	355	93	86	65	NA	15	6	8	6	7

2001	1294.3	317.0	977.3	576	412	106	87	72	NA	16	6	6	7	7
2002	1434.7	411.4	1023.3	621	487	110	96	78	NA	17	6	6	8	7
2003	1670.3	455.3	1215.0	804	531	109	94	90	NA	17	3	6	8	8
2004	1867.6	498.8	1368.8	929	572	106	104	90	19	19	4	8	9	9
2005	1865.9	461.2	1404.7	926	580	113	100	79	22	19	4	6	8	9
2006	1883.2	411.2	1472.0	940	573	104	104	90	30	17	3	6	9	7
Total	20916.3	5485.0	15202.0	10253.0	5602.0	1905.0	1426.0	1032.0	71.0	225.0	112.0	110.0	98.0	104.0

Notes: Agency obligations based on information from Small Business Administration (SBA). Data do not necessarily contain subsequent-year revisions and may not add to total

NA = not available; * = ≤$500,000

DHS Department of Homeland Security, *DOC* Department of Commerce, *DOD* Department of Defense, *DOE* Department of Energy, *DOT* Department of Transportation, *ED* Department of Education, *EPA* Environmental Protection Agency, *HHS* Department of Health and Human Services, *NASA* National Aeronautics and Space Administration, *NSF* National Science Foundation, *SBIR* Small Business Innovation Research program, *USDA* US Department of Agriculture

[a] DHS, established by Homeland Security Act of 2002 and formed in January 2003, held the first SBIR competition in FY 2004

Source: Adapted from National Science Board, *Science and Engineering Indicators 2010*

The purpose of these conditions is simply to ensure that the resources dedicated to the awardee will remain in the United States and consequently benefit the US economy. Another aspect of the award is that most agencies attempt to select awardees where they feel a need for prospective innovations in their respective fields. Most agencies offer some sort of open evaluation checklist for applicants to consider, when they apply for an award. As shown in Table 2.5, one can clearly see how, in this case, the NIH weights its evaluations:

Table 2.5 Evaluation criteria for Phase I and II NIH awardees

In considering the technical merit of each proposal, the following factors will be assessed: *Factors for Phase I proposals*	*Weight (%)*
1. The soundness and technical merit of the proposed approach and identification of clear measurable goals (milestones) to be achieved during Phase I. (Preliminary data are not required for Phase I proposals.)	40
2. The qualifications of the proposed PDs/PIs, supporting staff, and consultants. For proposals designating multiple PDs/PIs is the leadership approach, including the designated roles and responsibilities, governance, and organizational structure, consistent with and justified by the aims of the project and the expertise of each of the PDs/PIs?	20
3. The potential of the proposed research for technological innovation	15
4. The potential of the proposed research for commercial application. The commercial potential of a proposal will be assessed using the following criteria: (a) Whether the outcome of the proposed research activity will likely lead to a marketable product or process (b) The offeror's discussion of the potential barriers to entry and the competitive market landscape	15
5. The adequacy and suitability of the facilities and research environment	10
Factors for Phase II proposals	*Weight (%)*
1. The scientific/technical merit of the proposed research, including adequacy of the approach and methodology, and identification of clear, measurable goals to be achieved during Phase II	30
2. The potential of the proposed research for commercialization, as documented in the offeror's commercialization plan and evidenced by (a) the offeror's record of successfully commercializing its prior SBIR/STTR or other research projects, (b) commitments of additional investment during Phase II and Phase III from private sector or other non-SBIR funding sources, and (c) any other indicators of commercial potential for the proposed research	30
3. The qualifications of the proposed PDs/PIs, supporting staff and consultants. For proposals designating multiple PDs/PIs is the leadership approach, including the designated roles and responsibilities, governance, and organizational structure, consistent with and justified by the aims of the project and the expertise of each of the PDs/PIs?	25
4. The adequacy and suitability of the facilities and research environment	15

2.1.7.5 Variation in the Role of Procurement Between Agencies

While there is some variation in how and what agencies fund, the role of procurement is generally driven by the mission of the particular agency, as mandated by the US Congress. Some of the federal agencies, such as the National Science Foundation, have a greater focus on their mission of promoting basic research. This fundamental mission to promote basic research is reflected in the type of awards and funding for the SBIR. By contrast, other agencies, such as the Department of Defense and NASA, have a greater priority on procurement that is consistent with their missions as mandated by the US Congress and less of a priority on basic research.

Yet, there are several agencies that differ in terms of procurement. The largest funder, the DoD, requires DoD liaisons between the SBIR office and the awardee. The liaisons' explicit role is to introduce the potential technologies into their acquisition program. For example, if an awardee successfully attains a Phase III designation, it is the role of the liaisons to report the potential benefits of the innovation to the DoD acquisitions. Due to the enormous scale of acquisitions conducted by the DoD, the agency desires that these awardees do not get "lost" among the large crowd of acquisition applicants and be therefore flagged as having a Phase III award designation. The DoD, however, is not required to purchase from Phase III awardees.[17]

Another agency, which differs in its procurement methods, is the NIH. Its solicitations are less determined by the procurement needs of the agency and are more consistent with pursuing the quality of the scientific contributions to basic research.

The recipient firm often owns the intellectual property generated from an SBIR award. An example of IP ownership remaining with SBIR awardees is given below:

> "NASA Select SBIR contracts will include FAR 52.227–11 Patent Rights Ownership by the Contractor, which requires the SBIR/STTR contractors to do the following. Contractors must disclose all subject inventions to NASA within 2 months of the inventor's report to the awardees. A subject invention is any invention or discovery, which is or may be patentable, and is conceived or first, actually reduced to practice in the performance of the contract. Once the contractor discloses a subject invention, the contractor has up to 2 years to notify the Government whether it elects to retain title to the subject invention. If the contractor elects to retain title, a patent application covering the subject invention must be filed within 1 year. If the contractor fails to do any of these within time specified periods, the Government has the right to obtain title. To the extent authorized by 35 USC 205, the Government will not make public any information disclosing such inventions, allowing the contractor the permissible time to file a patent."

2.1.7.6 Assessment

With over 90,000 awards given and 20.8 billion dollars distributed, two bothersome questions have been raised about measuring the success of SBIR (Buss 2001; Wallsten 2001). The first involves selection bias: SBIR may award firms that already

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[17] Unfortunately, no information could be found on how often DoD purchases products from Phase III funded SBIR awardees.

have the characteristics needed for a higher growth rate and likelihood of survival. The second suggests that SBIR recipients would have engaged in the same innovation projects and R&D investments in the absence of the SBIR funding and was raised in an important study by Wallsten (2000), who finds empirical evidence that being a recipient of an SBIR award does not result in greater R&D spending or innovative activity.

Although enhancing firm growth and survival is an important aspect of SBIR, it does not capture all of the program's benefits. SBIR may benefit the economy by changing the behavior of knowledge workers. For example, Audretsch and Stephan (1996) found that scientists starting biotechnology firms deviated from an academic path or career with a large pharmaceutical corporation. How to induce knowledge workers—particularly scientists and engineers—to change their behavior and take advantage of commercialization opportunities is at the center of the policy debate in European countries such as Germany and France. Although it is important to analyze the impact of a government research and development program such as the SBIR on the ability of firms to survive and grow, such programs may have even more fundamental impact on whether scientists and engineers start the firms in the first place (Audretsch 1995). Empirical evidence suggests that the SBIR has influenced the behavior of knowledge workers in at least two important ways. The first is that it may encourage entrepreneurship for some scientists and engineers who otherwise never would have tried to commercialize their knowledge. The second occurs when successful science-based entrepreneurs, who received SBIR support, influence the behavior of their colleagues by inducing subsequent commercialization. Much literature exists on the importance of learning, but it typically focuses on firms' learning. In contrast, this second aspect focuses on individual knowledge workers learning by observing the choices and outcomes of their colleagues. For example, Audretsch and Stephan (1996) attributed the clustering of scientists working with biotechnology firms in a particular location to the demonstration effect of seeing the success of their entrepreneurial colleagues. Thus, rather than focusing on the diffusion of particular processes, SBIR focuses on the diffusion of behavior (see Fig. 2.6 in Audretsch and Feldman 1996).

SBIR may have another key impact by altering the type of science undertaken. Specifically, Audretsch et al. (2002) have looked at the commercialization impact of SBIR through altering the career trajectories. The authors find that in over half of their case studies (55 % of the survey firms), SBIR induced individuals to start firms who otherwise would not. In one third of the case studies, SBIR induced other colleagues to start science-based firms through the demonstration effect.

In addition, there are indications that the experience of scientists and engineers in commercialization via a small business has an externality by spilling over to influence the career trajectories of colleagues. One quarter of the scientists interviewed in the case studies named specific examples of colleagues who were either starting a new firm or becoming involved in a small firm to commercialize their knowledge. The evidence from the broader survey generally confirms the findings from the case studies.

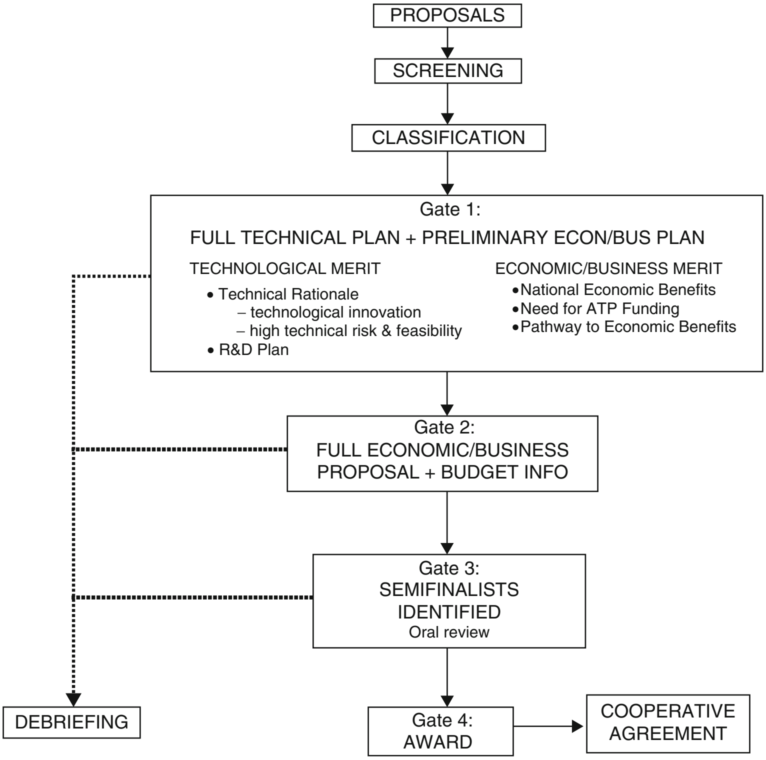

Fig. 2.6 Schematic overview of the ATP selection process. Source: Adapted from Wessner: *The Advanced Technology Program: Assessing Outcomes* (2001) p. 186

Both the policy-makers and scholarship provide the following consistent evidence that:

1. A significant number of the firms would not have been started without SBIR.
2. A significant number of the scientists and engineers would not have become involved in the commercialization process in the absence of SBIR.
3. A significant number of other firms were started because of the demonstration effect by the efforts of scientists to commercialize knowledge.
4. A number of other scientists altered their careers to include commercialization efforts as a result of the demonstration effect by SBIR-funded commercialization.

2.1.7.7 SBIR Cofinancing and Crowding Out

The SBIR program does not require cofinancing from awardees. The primary reason why there is no legal obligation for cofinancing is due to the aforementioned valley of death issue for small innovative firms. The US policy for funding potential innovative products has not addressed the issue of crowding out of potential private venture capitalists. To date, no scholarly research has addressed, in a systematic fashion, to what degree, if any, crowding out has occurred. Yet, at least on a theoretical level, one can assume that the SBIR program is simply a policy instrument designed to help potential entrepreneurs bridge the valley of death when they are unable to attract or find appropriate private venture capital. Due to the higher transaction costs of dealing with government and the lack of Phase III funding, one can assume there would be a clear preference for potential innovators to select private investment rather than public investment, which implies that the risk of crowding-out funding from private sources is likely to be small.

2.1.7.8 The Role of Phase III

Most of the agencies do not offer funding for Phase III awards. NASA and the Department of Defense may selectively offer small funding for Phase III awards, but the primary purpose of the award is simply to serve as a signal that the SBIR awardee has successfully completed Phase I and II and is therefore at the potential stage of production. This signal can play an important role in that the awardee works almost exclusively with one agency, such as NASA, and therefore has an understanding of the agency's operating procedure and the institutional norms necessary to successfully complete a potential project.

In fact, there are also institutional problems in federal procurement of Phase III products. Federal procurement rules are generally very rigid and cost intensive for selling products. Procurement regulations require many new firms to have higher compliance and overhead, which therefore give incumbent firms a competitive cost advantage when acquiring federal contracts. Indeed, the 11 agencies that are authorized to acquire products may also have a bias against SBIR firms due to the aforementioned mandated 2.5 % R&D budget allocation going to SBIR firms.[18]

Many of the Phase II awardees have asked the question, what is Phase III good for? (Wessner 2006). Yet, many feel that the recognition of being a Phase III awardee, having been independently selected by an agency, adds a degree of legitimacy to any potential procurement bid they elect to submit. However, most of the Phase III awardees believe that there is a missing element of large-scale finance which they require in order to become profitable.

2.1.8 The Advanced Technology Program (ATP)

During the late 1980s, the United States faced increasing competition from highly innovative Japanese firms. Policy-makers concluded that some sort of policy instrument was needed in response to the advancing Japanese technologies, such as the electronic or automotive industry, which were outcompeting the United States. In response to this innovation gap between the United States and Japan and also to the

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[18] Procurement officers may view this mandate as a loss of resources on the particular agency and therefore would be less willing to buy the final product that their agency has been mandated to fund.

recession in 1990, policy-makers and the congress decided to enact legislation which would enable private firms to acquire funding to help them commercialize ideas with market potential.

In 1991, special legislation created the Advanced Technology Program (ATP), which was designed to help industry develop ideas into innovations and serve as a governmental conduit between the research laboratory and the commercial market. ATP's express mission is to help manifest ideas into commercially applicable innovations. The National Institute of Standards and Technology (NIST), US Department of Commerce, ran ATP. As shown in Table 2.6, ATP supported 1581 different participants with over $4,614,000,000 of funding. ATP belonged to the National Institute of Standards and Technology, a subsection of the Department of Commerce, during its program life from 1991 to 2007. Due to its $136 million budget in 2006, the George W. Bush administration terminated the program in 2007. A new Technology Innovation Program (TIP) established by the 2007 America COMPETES Act (Public Law 110–69) succeeded the ATP program.

Table 2.6 Advanced Technology Program projects, number of participants, and funding: FY 1990–2007

Project funding (current $millions)						ATP			Industry		
Fiscal year	Projects	SA	JV	Participants	Total	All	To JV	To SA	All	From JV	From SA
1990	11	6	5	35	98	46	38	8	52	45	7
1991	28	18	10	83	202	93	65	28	109	83	26
1992	21	18	3	32	97	48	19	29	49	19	30
1993	29	24	5	50	118	60	19	41	58	20	38
1994	88	50	38	211	640	309	216	93	331	233	98
1995	103	62	41	318	827	414	304	110	413	340	73
1996	8	6	2	12	37	19	9	10	18	10	8
1997	64	49	15	101	304	162	75	87	142	81	61
1998	79	52	27	168	460	235	143	92	225	157	68
1999	37	26	11	57	212	110	61	49	102	64	38
2000	54	39	15	95	274	144	70	74	130	74	56
2001	59	46	13	88	286	164	79	85	122	81	41
2002	61	51	10	79	289	156	59	97	133	61	72
2003	67	55	12	104	257	154	49	105	103	51	52
2004	59	48	11	78	270	155	62	93	115	66	49
2005	0	0	0	0	0	0	0	0	0	0	0
2006	0	0	0	0	0	0	0	0	0	0	0
2007	56	47	9	70	243	139	47	92	104	50	54

Notes: For multiyear projects, total funding was attributed to the year award was made. Participants include SAs, JV leaders, and JV members and exclude subcontractors and informal collaborators. Beginning in 2000, funding and number of awards were based on the year recipient received funding, not on competition year

ATP Advanced Technology Program, *JV* joint ventures, *SA* single applicants

Source: Adapted from National Science Board, *Science and Engineering Indicators 2010*

During its 17-year life, the program's uniqueness attracted considerable attention from both policy-makers and scholars. It was seen as one of the first attempts by policy-makers to deliver a governmental organization which could help firms in a knowledge economy context, after an industrial era, the latest from World War II to the fall of the Berlin Wall in 1989.

From a policy prospective, the ATP not only served as a bridge but also tried to identify the positive externalities of innovation. For example, a US-based firm may be unwilling to invest its resources in a potential *idea* due to its perceived lack of return, but the potential *innovation* would have positive benefits to the economy as a whole if commercialized. While this innovation may have produced highly positive benefits to the economy as a whole, its benefit to the particular firm would be unrealized and therefore remain dormant. ATP's mission therefore was to view R&D projects from a macro- rather than a microperspective, i.e., can this idea benefit the nation, not just the company? ATP's design was to share relatively high risks of developing technologies, which potentially had a broad range of new commercial opportunities. The ATP mission differed from other government R&D programs in that:

- "ATP projects focused on the technology needs of American industry, not those of government. Research priorities for the ATP are set by industry, based on their understanding of the marketplace and research opportunities. For-profit companies conceive, propose, co-fund, and execute ATP projects and programs in partnerships with academia, independent research organizations and federal labs.
- The ATP had strict cost-sharing rules. Joint ventures (two or more companies working together) had to pay at least half of the project costs. Large, *Fortune 500* companies participating as a single firm had to pay at least 60 % of total project costs. Small- and medium-sized companies working on single-firm ATP projects had to pay a minimum of all indirect costs associated with the project.
- The ATP did not fund product development. Private industry bears the costs of product development, production, marketing, sales, and distribution.
- The ATP awards were made strictly on the basis of rigorous peer-reviewed competitions. Selection was based on the innovation, the technical risk, potential economic benefits to the nation, and the strength of the commercialization plan of the project.
- The ATP's support did not become a perpetual subsidy or entitlement—each project had goals, specific funding allocations, and completion dates established at the outset. Projects were monitored and could be terminated for cause before completion."[19]

2.1.8.1 ATP Design

The ATP partnered with companies of all sizes, universities, and nonprofits, encouraging them to take on greater technical challenges with potentially large benefits that extended well beyond the innovators—challenges they could not or would not

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[19] Adapted from: http://www.atp.nist.gov/atp/overview.htm

face alone. For smaller, start-up firms, early support from the ATP could spell the difference between success and failure. More than half of the ATP awards went to individual small businesses or to joint ventures led by a small business. Large firms worked with the ATP, especially in joint ventures, to develop critical, high-risk technologies that would have been difficult for any one company to justify because, for example, the benefits were spread across the industry as a whole.

Universities and nonprofit independent research organizations played a significant role as participants in ATP projects. Out of 768 projects selected by the ATP from its inception, well over half of the projects included one or more universities as either subcontractors or joint-venture members. All told, more than 170 individual universities and over 30 national laboratories participated in ATP projects.

ATP awards were selected through open, peer-reviewed competitions. All industries and all fields of science and technology were eligible. Proposals were evaluated by one of several technology-specific boards that were staffed with experts in fields such as biotechnology, photonics, chemistry, manufacturing, information technology, or materials. All proposals could be sure of an appropriate, technically competent review even if they involved a broad, multidisciplinary mix of technologies. As shown in Fig. 2.6, the schematic overview of the ATP selection process clearly illustrates the degree to which proposals were properly screened and identified for potential positive externalities to the economy.

2.1.8.2 Assessment of ATP

A rich and compelling literature has been generated which identifies and analyzes the impact of specific public policy programs and instruments, such as ATP, on the economic and technological performance and strategies of firms. Branscomb and Auerswald (2002), for example, found that ATP awards help bridge a funding gap left by venture capitalists, what the authors refer to as *the valley of death*. Feldman and Kelley (2002) find that ATP fosters knowledge spillovers leading ATP-funded projects to produce not only firm-specific benefits but broad national economic benefits as well. The same study shows that, in the absence of ATP awards, firms are not likely to proceed with any aspect of their proposed project on their own. Studies evaluating the impact of ATP have also shown that an ATP award creates a halo effect, also known as reputation effect, for participating firms, increasing their chances of attracting additional funding from other sources (Feldman and Kelley 2000, 2001; Powell and Lellock 1997). Other studies have assessed the impact of federal programs like ATP, DARPA, and SBIR in terms of their effect on firm growth and productivity, employment size, number of patents secured, R&D cycle time, and other related metrics (Advanced Technology Program Economic Assessment Office 2004; Silber and Associates 1996).

This literature has been guided by the most prevalent theory of firm innovation in economics—the model of the knowledge production function. This was formally introduced by Griliches (1979) and links innovative outputs to knowledge inputs. Just as this theory takes the firms as given, or exogenous, and then analyzes their innovative and economic performance as a result of purposeful and targeted investments to create and commercialize new knowledge, the impact of public policy has generally been analyzed by examining the performance of existing firms. While the exact nature and magnitude of public policy on firm performance varies somewhat depending upon the particular type of policy and study, the focus and therefore the return accruing from public policies such as ATP and SBIR have been largely restricted to improvement in the economic and technological performance of recipient firms.

2.1.9 The DARPA Program

The Defense Advanced Research Projects Agency (DARPA) is an agency with a long history of advanced technology development for the US Department of Defense. With the increasing threat of Soviet Union military hegemony in the late 1950s, the US Congress and military created a program to prevent technological surprises, like Sputnik, and to induce technological advancement in the Space Race in the 1960s. While its original mission was meant to develop space age technologies, DARPA increased the scope and scale of its mission from the 1960s to the 2000s. Today, DARPA employs over 300 people and has an annual operating budget of $3.2 billion. Over the course of the past 50 years, the agency is widely regarded as having developed computer networking, hypertext, graphical user interface, stealth technology, and drone networking.

The agency's current budget for 2015 is 2.92 billion dollars. Around 140 technical scientists work for the agency, which is headquartered in Arlington, Virginia. The agency is explicitly mandated to advance the US military technology and works closely with all areas of the US military service to coordinate and develop existing technological needs. DARPA is widely considered to have the highest R&D investment per scientist in the world.

Today, the agency is considered to be one of the most advanced and secretive institutions in the US government. Indeed, this agency is often cited as similar to something from the Men in Black movie series, where a select few people develop future technologies unknown to the public or private market. For example, some of the projects selected, which are currently or were funded, include the "Transformer" where the goal is to create a flying armored car, "Human Universal Load Carrier" where the goal is to create a battery-powered human exoskeleton, or "EATR" where the goal is to create a robotic soldier.

The structure of DARPA is best described as a group of small organized teams with short-term goals. Given the enormous budget, one would expect some degree of hierarchy; yet, there is little. The self-described motto of DARPA is "100 geniuses connected by a travel agent." Their technological goals are set within a 2–4-year time frame, and they are given almost complete autonomy to complete their projects as they see fit. The primary measure of success for these small groups is whether they have created radical technological innovations during their tenure, during which they had an almost unlimited budget.

DARPA maintains six different program offices, which are dedicated to choosing the best and brightest scientists and project bids every 4–6 years and overseeing and coordinating 140 scientists in their respective fields. The DARPA director is routinely changed to ensure fresh and new ideas are introduced into the agency paradigm.

While DARPA has advanced a plethora of US military technologies, it remains to be seen to what degree these advancements have crossed the knowledge filter barrier and have actually entered the commercial market. Due to the top-secret nature of these advancements, patents are not for public use, nor for competing countries, and the private market has no knowledge of how to endogenize these radical innovations.

DARPA is designed to remain independent from the military's more traditional R&D programs. The distinguishing factor between these two types of military program is that DARPA's explicit mission is to fund and deliver radical innovations for the US military. There are, however, several problems in evaluating DARPA's contribution to the US innovation. Due to the secrecy surrounding military inventions, the returns on this significant investment remain relatively enigmatic. One should note the strong relationships to universities committed to basic research. The MIT, University of Alabama, Carnegie Mellon University, Harvard University, and University of California system receive substantial funding for military research.

Another interesting aspect of DARPA is that during the budget cuts in the mid-1970s, DARPA made significant cuts to its computer networking program. These cuts resulted in several key scientists to start up computer network companies and create private research labs such as the Xerox Palo Alto Research Center, Incorporated. Unlike SBIR and ATP, DARPA's structural design is much more like a lab of creativity and innovation and less like a typical bureaucratic organization. DARPA assigns funding to 2–4-year projects where there is a high degree of potential radical innovations. These projects are overseen by highly educated DARPA staffs who, in conjunction with university scientists and industry research labs, attempt to create advanced military applications.

2.1.10 The Role of Other US Agencies in Innovation

2.1.10.1 Technology Innovation Program (TIP)

The Technology Innovation Program (TIP) was established by the 2007 America COMPETES Act, at the National Institute of Standards and Technology (NIST), US Department of Commerce. Its mission is to assist US businesses and universities to support, promote, and accelerate innovation in the United States through high-risk, high-reward research Technology Innovation Program (2011). Its stated mission is to promote projects which:

- **Have a novel purpose**: addressing societal challenges not being addressed in areas of critical national need with benefits that extend significantly beyond proposers
- **Offer solutions to societal challenges**: concentrating on those challenges that justify government attention

- **Have scientific and technical merit**: supporting innovative high-risk, high-reward research
- **Promise transformational results**: focusing on ideas with a strong potential to advance state-of-the-art and contribute to the US science and technology base
- **Involve rich teaming**: funding small- and medium-sized businesses, academia, national labs, nonprofit research institutions, and other organizations
- **Fulfill a clear government need**: addressing problems that require government attention because the magnitude of the problem is large and no other sources of funding are reasonably available
- **Provide funding**: single company projects up to $3 M over a maximum of 3 years, joint venture projects up to $9 M over a maximum of 5 years
- **Share costs**: requiring proposers to cover at least 50 % of the costs[20]

2.1.10.2 Small Business Technology Transfer Program (STTR)

The Small Business Technology Transfer (STTR) program is in many ways identical to the SBIR program. However, its core mission is to fund small companies, which work in collaboration with universities. Another difference is that instead of the 2.5 % reserved for SBIR funding by the 11 different agencies, STTR requires that five agencies[21] reserve 0.3 % of their budget for STTR funding. A total of $1.3 billion was awarded to over 6000 projects from 1994 to 2006. Each awarded project required a university partner and was awarded Phase I and Phase II awards, according to the SBIR scheme.

2.1.10.3 Hollings Manufacturing Extension Partnership (MEP)

The Hollings Manufacturing Extension Partnership (MEP) is a national network of 60 centers across the United States. This agency, unlike other federal agencies, is run at state level. The purpose of these centers in all 50 states is to focus R&D efforts on technology acceleration, supplier development, sustainability, and workforce improvement. Its explicit purpose is to help manufacturers develop and create new markets and products, thus giving a competitive advantage to US firms.

2.1.11 Lessons that Can Be Learned from These Programs

The previous sections of this report have established that there is empirical evidence that the main innovation programs in the United States—the SBIR, ATP, and DARPA—have generally exerted a positive influence on innovative activity. While

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[20] See: http://www.nist.gov/tip/factsheets/upload/tip_at_a_glance_2011.pdf

[21] The Department of Defense, the National Science Foundation, The Department of Energy, NASA, and Health and Human Services

there is no reason to conclude that these programs in any way constitute an optimal policy to promote innovative activity, competitiveness, and ultimately economic growth, the empirical evidence does suggest they have had a positive impact on the innovative performance of the United States.

This section considers the adaptability of these programs to other countries from two perspectives. The first is whether the actual delivery and administration of the programs can be replicated. The second is whether others can achieve similar capabilities and outcomes from the programs.

From the first perspective, the authors of this chapter believe that the answer to whether US innovation programs can be applied to other countries (i.e., duplicating the exact programs and administration) is improbable. This is because of the central role played by US federal institutions in the design and administration of the US innovation programs. The SBIR, in particular, depends on the main federal agencies allocating a share of their research budgets to small innovative firms. Administered by federal agencies such as the US Department of Defense, the SBIR enjoys support from a mission-oriented approach to innovation.

Other countries have no agencies that are equivalent to, say, the US Department of Defense, either in terms of size or scope. Taken from the first perspective, this would seemingly preclude the applicability of the US innovation policy approach to other countries.

However, it should be emphasized that the policy approach to the US innovation programs is a second-best approach. The SBIR, ATP, and DARPA programs promote and facilitate entrepreneurial innovation indirectly in that the administering agencies do not have commercialization and innovation as their primary and explicit mandates. This approach was not adopted in the United States because it was considered to be the most effective way to promote innovation, competitiveness, and growth but rather as a second-best option. It was not considered politically feasible to create new agencies and programs that directly promote innovation. Thus, the current approach in the United States was adopted because it was considered to be politically feasible and not because it was considered to be the best way to foster innovative activity.

Thus, it may be the second perspective that is the most relevant and important in considering the applicability of the US programs to other contexts. Here, the focus is not on exactly duplicating the exact programs and administration but rather on achieving similar capabilities and outcomes. The capabilities would be in terms of innovative capabilities of the local firms and the outcomes would be in terms of the innovative performance of the local firms.

Rather than administer such innovation programs indirectly through existing ministries and agencies already mandated with a different mission, as is the case in the United States, other countries have the potential to establish agencies and ministries with a main mandate to promote innovation. Such an approach would consist of three phases—feasibility, research, and commercialization. Applicant firms and nascent entrepreneurs would make an application based on these three phases. The applications would be subjected to a competitive assessment.

The first phase would focus on the feasibility of the idea. The second phase would include those ideas developed in the first phase that are the most innovative and embody the greatest potential commercial impact. The funding in the second phase would be to develop the idea into a workable prototype. The third phase would involve actual commercialization. In this third phase, the firm would actually introduce the innovative product, conceptualized during the first phase and developed into a prototype in the second phase, onto the market.

During the first two phases, the innovative activity would be funded entirely by the relevant innovation-funding agency. However, the resulting intellectual property would remain with the company undertaking the innovative activity. This is a form of pre-commercial procurement that policy can deploy for innovative activity in priority areas. For example, specific social issues could be assigned a high priority by the relevant agency. In the third phase, both the firm and the funding agency could share funding. This approach to innovative programs could fit the institutional context of other countries that do not have the equivalent of large US mission-oriented agencies.

2.2 The Role of Local Institutions (Universities and Regions/States)

This section illustrates the importance of local institutions in R&D and innovation. Given that over one third of *total* R&D is allocated to universities, it is imperative to understand what institutions are likely to facilitate growth. Moreover, are certain individuals more likely to be inclined to transform ideas into innovations for the local region? If so, how can local institutions, laws, and incentives create more innovation in the knowledge economy context?

2.2.1 The Relevance of Universities and Regions/States in Fostering the Knowledge Economy

Why will scientists choose to combine their scientific creativity with entrepreneurial creativity? There are a number of theories and hypotheses as to why some scientists choose to commercialize research while others do not, and some compelling insights have been garnered through previous empirical studies. These include the scientist life cycle which highlights the role of reputation, the knowledge production function which highlights the role of scientific human capital and resources, and the regional and university contexts which highlight the role of geographically bounded spillovers and institutional incentives.

A large body of literature has emerged focusing on what has become known as the appropriability problem. The underlying issue revolves around how firms, which invest in the creation of new knowledge, can best appropriate the economic returns from that knowledge (Arrow 1962). Audretsch (1995) proposed shifting the unit of observation away from exogenously assumed firms to individuals—agents with endowments of new economic knowledge. When the focus is shifted away from the firm to the individual as the relevant unit of analysis, the appropriability issue remains, but the question becomes, "How can scientists with a given endowment of new knowledge best appropriate the returns from that knowledge?" Levin and Stephan (1991) suggest that the answer is "It depends—it depends on both the career trajectory as well as the stage of the life-cycle of the scientist."

The university or academic career trajectory encourages and rewards the production of new scientific knowledge. Thus, the goal of the scientist in the university context is to establish *priority*. This is done most efficiently through publication in scientific journals (Stephan and Audretsch 2000). By contrast, with a career trajectory in the private sector, scientists are rewarded for the production of new economic knowledge, or knowledge, which has been commercialized in the market but not necessarily new scientific knowledge per se. In fact, scientists working in industry are often discouraged from sharing knowledge externally with the scientific community through publication. As a result of these different incentive structures, industrial and academic scientists develop distinct career trajectories.

The appropriability question confronting academic scientists can be considered in the context of the model of scientist human capital over the life cycle. Scientist life-cycle models suggest that early in their careers, scientists invest heavily in human capital in order to build a scientific reputation (Levin and Stephan 1991) that signals the value of their knowledge to the scientific community.

With maturity, scientists seek ways to appropriate the economic value of the new knowledge. Thus, academic scientists may seek to commercialize their scientific research within a life-cycle context. The life-cycle model of the scientist implies that, *ceteris paribus*, scientist reputation should play a role in the decision to commercialize.

An implication of the knowledge production function formalized by Griliches (1979) is that those scientists with greater research and scientific prowess have the capacity to generate greater scientific output. But how does scientific capability translate into observable characteristics that can promote or impede commercialization efforts? Because the commercialization of scientific research is particularly risky and uncertain (Stephan and Audretsch 2000), a strong scientific reputation, as evidenced through vigorous publication and formidable citations, provides a greatly valued signal of scientific credibility and capability to any anticipated commercialized venture or project. This suggests a hypothesis which links measures of the quality of the scientist, or his/her scientific reputation as measured by citations and publications, to commercialization.

Scientist location can influence the decision to commercialize for two reasons. First, as Jaffe (1989), Audretsch and Feldman (1996), Jaffe et al. (1993), and Glaeser et al. (1992) show, knowledge tends to spill over within geographically bounded regions or clusters. This implies that scientists working in regions with a high level of investments in new knowledge can more easily access and generate new scientific ideas. This suggests that scientists working in knowledge clusters tend to be more productive than their counterparts who are geographically isolated from other sources of knowledge.

A second component of externalities involves not the technological knowledge but rather behavioral knowledge. As Bercovitz and Feldman (2003) show in a study based on the scientists' commercialization activities at Johns Hopkins and Duke University, the likelihood of a scientist engaging in commercialization activity, which is measured as disclosing an invention, is influenced by the commercialization behavior of the doctoral supervisor in the institution where the scientist was trained. The commercialization behavior and attitudes exhibited by the chair and peers at the relevant department also have an effect.

Thus, the locational and institutional contexts can influence the propensity of scientists to engage in commercialization activities by providing access to spatially bounded knowledge spillovers and by shaping the institutional setting and behavioral norms and attitudes toward commercialization.

Globalization has triggered a shift in the comparative advantage of leading developed countries away from the factor of capital and toward knowledge. For the factor of knowledge to be effective in generating employment, economic growth, and international competitiveness, it must spill over to become commercialized (Acs and Audretsch 2003; Siegel et al. 2003b). As Acs et al. (2005) and Audretsch et al. (2006a, b) emphasize, such knowledge spillovers are not automatic and cannot be assumed to exist. Thus, in terms of Richard Florida's insights about creativity, investments in scientific creativity need to be combined with commercial creativity to facilitate knowledge spillovers that can ultimately contribute to economic growth Florida (1999). Scientists who choose to commercialize their research can combine such scientific creativity with commercial creativity.

This report has identified why some scientists choose to combine scientific and commercial creativity while others do not. In particular, the human capital and reputation of the scientist play an important part, as does the context, in terms of location and particular type of institution where the scientist is employed. The evidence suggests that scientists with the most knowledge have a higher propensity to commercialize their research. However, the type of university and the region habituates scientist commercialization.

2.2.2 Complementarities between Centrally vs. Locally Based Policies

2.2.2.1 The Role of Universities and the Bayh-Dole Act in Economic Growth and Innovation

When the Bayh-Dole Act was passed in 1980, it was a direct response to the US international competitiveness crisis of the 1970s. The Bayh-Dole Act shifted intellectual property rights created through federally funded research from the government to the university. As Senator Birch Bayh pointed out, "A wealth of scientific talent at American colleges and universities—talent responsible for the development of numerous innovative scientific breakthroughs each year—is going to waste as a result of bureaucratic red tape and illogical government regulations… What sense does it make to spend billions of dollars each year on government-supported research and then prevent new development from benefiting the American people because of dumb bureaucratic red tape?"[22]

One important aspect of such technology infrastructure in the United States involves both the passage of the Bayh-Dole Act and its application. The Bayh-Dole Act has not only provided the requisite infrastructure to enable entrepreneurial activity to emerge out of universities, but it has also enabled "other actors," and in particular university scientists, to participate in the innovation process, when previously they might have been excluded.

The Bayh-Dole Act paved the way for the widespread diffusion of the university technology transfer office (TTO), which has served as a mechanism, or instrument, to facilitate the commercialization of university scientific research and to harness the ensuing revenue streams for the university. In fact, examples of technology transfer offices existed prior to 1980, but some three decades subsequent to the act's passage, virtually every major US university now has a TTO. The main mission of the TTO is to collect the intellectual property disclosed by scientists to the university and to encourage commercialization where deemed feasible and appropriate Siegel and Phan (2005).

The Association of University Technology Managers (AUTM) collects and reports a number of measures reflecting the intellectual property and commercialization by its member universities. A voluminous and growing body of research has emerged which documents the impact of TTOs on the commercialization of university research. Most of these studies focus on various measures of output associated with university TTOs (see Chap. 5, Richardson, Audretsch, Aldridge, and Nadella.) By most accounts, the impact of the TTO on facilitating the commercialization of university science research was so impressive that by the turn of the century, the Bayh-Dole Act was being celebrated as an unequivocal success: "Possibly the most inspired piece of legislation to be enacted in America over the past half-century was the Bayh-Dole Act of 1980."[23] With amendments in 1984 and augmentation in 1986, this act unlocked all the inventions and discoveries that had been made in laboratories throughout the United States with the help of taxpayers' money. More than anything, this single policy measure helped to reverse America's precipitous slide into industrial irrelevance. "Before Bayh-Dole, the fruits of research supported by government agencies had gone strictly to the federal government. Nobody could exploit this research without tedious negotiations with the federal agency concerned. Worse, companies found it nearly impossible to acquire exclusive rights to a government-owned patent. And without that, few firms were willing to invest millions more of their own money to turn a basic research idea into a marketable product."[24]

In an even more enthusiastic assessment of the Bayh-Dole Act, *The Economist* (2002) gushed, "The Bayh-Dole Act turned out to be the Viagra for campus innovation.

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[22] Statement by Birch Bayh, April 13, 1980, on the approval of S. 414 (Bayh-Dole) by the US Senate on a 91-4 vote, cited from AUTM (2004, p. 16), and introductory statement of Birch Bayh, September 13, 1978, cited from the Association of University Technology Managers Report (AUTM) (2004, p. 5)

[23] "Innovation's Golden Goose," *The Economist*, 12 December 2002.

[24] "Innovation's Golden Goose," *The Economist*, 12 December 2002.

Universities that would previously have let their intellectual property lie fallow began filing for—and getting—patents at unprecedented rates. Coupled with other legal, economic and political developments that also spurred patenting and licensing, the results seems nothing less than a major boost to national economic growth."[25]

Despite the generally giddy assessments of Bayh-Dole, Mowery (2005, pp. 40–41) has argued for a more cautious and balanced perspective: "Although it seems clear that the criticism of high-technology start-ups that was widespread during the period of pessimism over US competitiveness was overstated, the recent focus on patenting and licensing as the essential ingredient in university–industry collaboration and knowledge transfer may be no less exaggerated. The emphasis on the Bayh-Dole Act as a catalyst to these interactions also seems somewhat misplaced."

However, there are compelling reasons to suspect that not all of the intellectual property created through the university is commercialized through the TTO (Thursby and Thursby 2005). In particular, a university's TTO may be overwhelmed with intellectual property disclosures, forcing it to select and focus on only a subset of the most promising projects. Shane (2004, p. 4) suggests that by resorting to what he refers to as the backdoor, scientist commercialization does not always proceed through the implicit front door of the technology transfer, Shane (2004, p. 4) finds that, "Sometimes patents, copyrights and other legal mechanisms are used to protect the intellectual property that leads to spin-offs, while at other times the intellectual property that leads to a spin-off company formation takes the form of know how or trade secrets. Moreover, sometimes entrepreneurs create university spin-offs by licensing university inventions, while at other times the spin-offs are created without the intellectual property being formally licensed from the institution in which it was created. These distinctions are important for two reasons. First it is harder for researchers to measure the formation of spin-off companies created to exploit intellectual property that is not protected by legal mechanisms or that has not been disclosed by inventors to university administrators. As a result, this book probably underestimates the spin-off activity generated when exploiting inventions that are neither patented nor protected by copyrights. This finding also underestimates the spin-off activity that occurs 'through the back door': that is, companies founded to exploit technologies that investors fail to disclose to university administrators."

There is little empirical evidence to support Shane's admonition that relying upon the data collected by the TTOs and aggregated by AUTM will obscure the extent to which scientists resort to backdoor commercialization. Field studies (Siegel et al. 2003a and Link et al. 2007) and research from a survey (Thursby and Thursby 2002), along with two university case studies (Bercovitz and Feldman 2006), clearly highlight the vigorous propensity of some scientists to resort to informal and backdoor activities rather than front door activities through the TTO for commercializing their research. As shown in Fig. 2.7, the American University

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[25] Cited in Mowery 2005 D. Mowery, The Bayh-Dole Act and High-technology Entrepreneurship in US Universities: Chicken, Egg, or Something Else? Colloquium on Entrepreneurship Education and Technology Transfer, University of Arizona (2005) (21–22 January). Mowery (2005, p. 64).

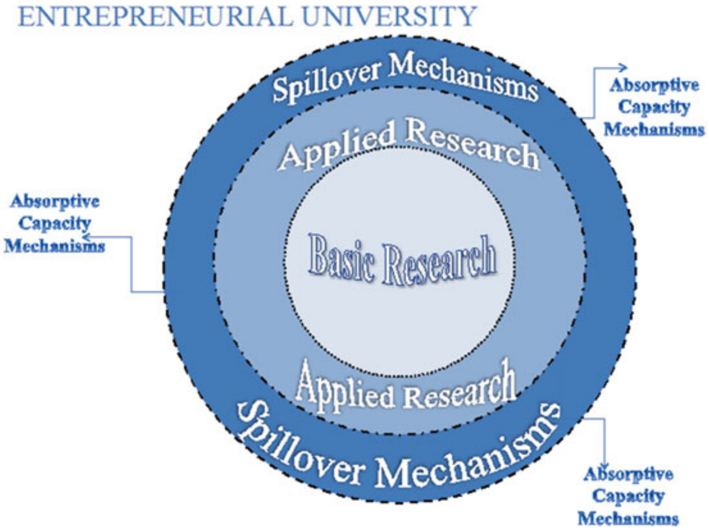


Fig. 2.7 The entrepreneurial university

innovation ecosystem has developed significantly over the past 30 years as to where part of a universities primary mission is knowledge diffusion and profit maximization of its intellectual property.

One empirical analysis of the implemented of the Bayh-Dole Act in Europe and other countries describes the abolishment of the “professor privilege” conducted by Czarnitzki et al. (2011). The paper finds that the abolishment of the “professor privilege” led to an acceleration of the decline in patent forward citations. Due to the structural change in Germany, professors no longer had to bear the cost of funding patent applications, and the cost was borne by the professor’s institution. The authors find that the overall quality of forward citations declined after the introduction of the German Bayh-Dole Act. To a large degree these findings are rather unsurprising for several reasons. For example, prior to the “professor privilege,” one would expect only the most certain and potentially successful patents to be registered by the professor, since he/she would have to bear not only the cost of the patent application, but also be responsible for commercializing the potential innovation, i.e., only the most certain patents with a very high general quality would be issued. After the abolition of the “professor privilege,” the cost of a patent application was less for a university scientist, thereby increasing the number of patents filed. This therefore lowered the average general quality of total patents issued by university professors.

It is important to understand, when dealing with the entrepreneurial university, that whatever a patent has created, there must be proper institutional mechanisms for it to become an active innovation. As Aldridge and Audretsch (2010, 2011) demonstrate, US professors are starting companies in far greater numbers than previously recorded, and they also tend to not register their “best” quality patents with their respective universities.

2.2.2.2 Role of Regions/States in Fostering the Knowledge Economy and Growth

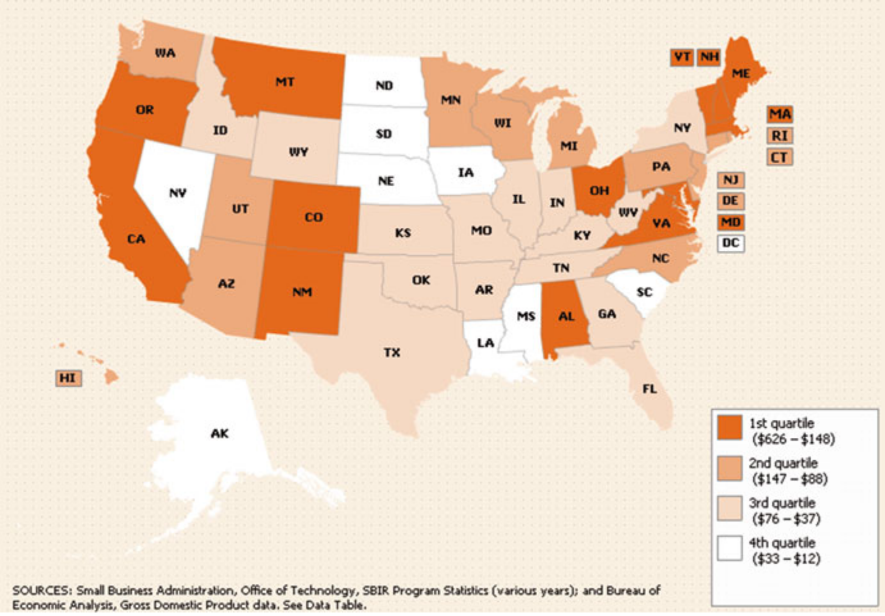
Recognition of the role that firm-specific knowledge investments could play in accessing and absorbing external knowledge, and therefore enhancing the innovative output of the firm, triggered an explosion of studies focusing on potential sources of knowledge that are external to the firm. Some studies examined the role of licensing, cooperative agreements, and strategic partnerships, all of which involve a formal agreement and a market transaction for the sale of knowledge. Thus, these all represent mechanisms by which a firm can access knowledge produced by another firm (but this might require previous internal investments in knowledge that are a prerequisite for absorbing such external knowledge, see Cohen and Levinthal 1989).

Compelling and consistent evidence provided first by Jaffe (1989), but later confirmed by Acs et al. (1992, 1994), Feldman (1994a, b), Jaffe et al. (1993), and Audretsch and Feldman (1996), suggested that, in fact, the presence of external knowledge sources in geographically bounded regions increased the innovative output of firms located in those regions. Thus, there was clear and compelling econometric evidence suggesting that external investments in clustered regions would yield an increased level of innovative output by the firms located in that region as a result of knowledge spillovers.

The new findings from the studies on spatially bounded knowledge spillovers supported the knowledge production model of firm innovation in two main ways. First, the firms were still assumed to be exogenous, and second, knowledge inputs were still found to be important determinants of innovative output. The main distinction lies in the unit of analysis. Because of knowledge spillovers, the link between knowledge inputs and firm innovative output was found to be more important for spatial units of observation than at the level of the firm.

The geography of firms has important implications on the spatial distribution of the impact of public policies directed at stimulating innovative behavior. It is already well documented that not only university research, venture capital, scientists and engineers, high-technology firms, and start-ups tend to cluster in spatial agglomerations (Saxenian 1994), but federal support of innovation, such as the ATP and SBIR (Fig. 2.8), also tends to be spatially concentrated in exactly these areas (Audretsch et al. 2002).

The spatial correlation of knowledge assets, high-technology programs, and federal programs such as ATP and SBIR suggests that a “winner takes all” policy may be emerging across regions. Those regions that have already established a successful high-technology cluster are able to generate knowledge spillovers, attract firms, scientists, and engineers, as well as draw a high share of federal support for innovation to their regions. By contrast, regions that have been technologically disadvantaged or have not yet developed knowledge-based clusters tend to experience difficulties in procuring a high share of federal support for innovation (see Fig. 2.8



SOURCES: Small Business Administration, Office of Technology, SBIR Program Statistics (various years); and Bureau of Economic Analysis, Gross Domestic Product data. See Data Table.

Fig. 2.8 Average annual federal SBIR funding per $1 million of gross domestic product: 2006–2008

and Table 2.7). This raises the question about the relative contribution made by public policies at the federal level that have a local impact: *Is there greater impact in existing successful high-technology agglomerations, where the technology firms are already established and knowledge spills over without being impeded by a filter, or would public policy at the federal level have a greater, or at least different, impact in regions that have not yet established viable high-technology agglomerations?*

2.3 Lessons from the US Programs

This section offers several key policy implications, which can be drawn from the US programs to fit the context of other countries. The primary problems of replicating a SBIR-type institution are identified and addressed.

There is little doubt that the US public innovation system has provided robust and significant contributions to the economic growth of small- and medium-sized enterprises (Wessner 2011). To what degree can this contribution be replicated in other countries' institutional mechanisms remains an open question, given that the US system is predicated on several consistent and important features.

Table 2.7 Advanced Technology Program, ongoing/completed projects, project-level award amounts ($M), summed by the state

State	Number of projects	ATP awards ($M)	Industry share ($M)	Total ($M)
Alabama	1	$3.3	$3.5	$6.8
Arizona	5	$16.6	$14	$30.6
California	120	$360.7	$353.6	$714.3
Colorado	8	$15	$8.5	$23.5
Connecticut	19	$55.3	$55.5	$110.8
Delaware	5	$9.4	$7.6	$17
Florida	7	$28.7	$29.8	$58.5
Georgia	6	$12.3	$7.2	$19.5
Illinois	21	$71.3	$75.7	$147
Indiana	2	$3.6	$3.2	$6.8
Iowa	2	$2.6	$1.4	$4
Louisiana	2	$3.8	$3.1	$6.9
Maryland	16	$50	$45	$95
Massachusetts	48	$96.2	$78.1	$174.3
Michigan	41	$182.4	$192.2	$374.6
Minnesota	17	$60.9	$70.3	$131.2
Missouri	1	$2	$1.4	$3.4
Nebraska	1	$2	$0.9	$2.9
New	2	$4	$1	$5
New Jersey	26	$88.1	$95.5	$183.6
New Mexico	1	$2	$1.8	$3.8
New York	29	$72.1	$73.7	$145.8
North Carolina	7	$34.4	$33.1	$67.5
Ohio	17	$70.6	$71.6	$142.2
Oklahoma	2	$3.5	$3	$6.5
Oregon	8	$18.9	$17.7	$36.6
Pennsylvania	18	$57.1	$61.8	$118.9
Rhode Island	3	$4.4	$2.6	$7
South Carolina	3	$41.4	$48	$89.4
Texas	18	$59.7	$53.1	$112.8
Utah	8	$15.2	$12.9	$28.1
Virginia	10	$31.1	$23.3	$54.4
Washington	2	$3.9	$1.4	$5.3
Wisconsin	5	$9	$6.1	$15.1
State count	Project count	Total ATP ($M)	Total industry ($M)	Grand total ($M)
34	481	$1491.5	$1457.6	$2949.1

Source: Adapted from Wessner, *The Advanced Technology Program: Assessing Outcomes* (2001)

2.3.1 *Does US Public Intervention Have a Positive Impact?*

2.3.1.1 Crowding Out/Crowding In: Halo Effect

Most research on the US system has focused on whether or not there is potential crowding out from private sector finance. There is no clear consensus on whether there is, indeed, a crowding-out effect. However, research by Hall, David et al. (1999) suggest that the effect is, at a minimum, negligible for private finance. They also note that there is potential opposite effect of "crowding in." This effect, which is also termed the "halo effect," is thought to be associated with private investors who see the potential awards as a signal of quality and consequently are willing to invest more time and effort in a potential awardee, rather than treat the awardee as an unknown quantity.

There are qualitative differences in awards that need to be considered by potential investors. For example, receiving an SBIR I award may not add additional interest to the VC market. However, if an awardee receives an SBIR III award, this signals to the market that the firm has not only produced a potential product but also that this product is something the US government may wish to purchase in an opening bidding contest.

SBIR III awards may serve to provide high-quality information between investor and entrepreneur. Uncertainty for investors is one of the most negative factors in their decision as to whether to invest in a potential firm or not. If the investor believes the SBIR award system to be of high quality, this removes an important degree of uncertainty.

2.3.1.2 Geographical Diversification

The second important aspect is that in other countries, venture capital markets are not as advanced or geographically disperse as in the United States. Venture capital in other countries is generally centralized in the most concentrated hubs such as in Europe, London, Paris, Milan, or Munich. Other countries also tend to focus more on innovation from medium and large firms than on innovation from small firms. The introduction of an SBIR system could help to lower the sunk costs for potential venture capital, which would allow capital markets to diversify their portfolio into larger percentages of small-firm ventures.

As shown in Table 2.8, the US venture capital market for early stage start-ups rose from 2.6 billion dollars in 1996 to 5.3 billion dollars 12 years later. Indeed, there is a wide diversity of venture capital for a broad range of industries. While there are central clusters of venture capital for specific technologies, such as biotech venture capital in Silicon Valley, there are also venture capital markets spanning the United States. A lack of venture capital outside of the hubs remains an obstacle for economic innovation and activity.

Table 2.8 US venture capital investment, financing stage, industry, and number of companies: 1995–2008 (millions of current dollars)

Financing stage/industry/ number of companies	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
All financing stages	7628	10,840	14,364	20,172	52,016	101,767	39,308	21,250	19,278	22,117	22,922	26,334	30,639	28,077
Seed/start-up	1244	1267	1309	1679	3571	3053	739	327	341	461	893	1194	1330	1494
Early	1694	2614	3430	5389	11,263	24,569	8387	3723	3455	3918	3830	4195	5686	5346
Expansion	3553	5340	7382	9999	28,720	58,138	22,248	12,063	9760	9086	8574	11,417	11,386	10,473
Later	1138	1619	2243	3105	8463	16,007	7935	5138	5723	8653	9626	9528	12,237	10,765
All industries	7628	10,840	14,364	20,172	52,016	101,767	39,308	21,250	19,278	22,117	22,922	26,334	30,639	28,077
Biotechnology	768	1156	1385	1520	2029	4057	3400	3183	3553	4145	3924	4504	5247	4410
Business products and services	177	377	409	691	2791	4560	1031	450	579	396	396	552	709	477
Computers and peripherals	324	383	377	372	897	1596	655	457	373	590	539	532	586	424
Consumer products and services	473	503	738	622	2534	3350	662	228	163	309	304	407	476	437
Electronics/instrumentation	125	193	260	227	282	773	381	314	236	351	438	722	563	574
Financial services	194	329	362	781	2202	4180	1380	338	410	520	918	462	558	526
Healthcare services	448	664	869	926	1368	1352	499	368	222	363	407	381	295	192
Industrial/energy	529	504	696	1407	1508	2479	1067	740	756	775	808	1925	3222	4576
Information technology services	178	430	655	1057	3958	8619	2391	1039	775	737	1063	1377	1707	1812
Media entertainment	910	1074	956	1744	6560	10,299	2312	712	879	965	1149	1624	1962	1884
Medical devices and equipment	627	648	1016	1144	1511	2312	1997	1838	1602	1921	2186	2910	3872	3446

Networking equipment	347	612	937	1360	4259	11,409	5543	2595	1737	1545	1517	1091	1378	735
Other	10	21	56	88	84	45	62	4	0	1	57	8	2	23
Retailing/distribution	314	257	303	609	2805	3067	321	151	65	174	207	201	365	235
Semiconductors	202	299	567	618	1290	3542	2391	1503	1764	2128	1923	2101	2080	1641
Software	1123	2218	3281	4367	10,295	24,012	10,141	5150	4462	5375	4803	4920	5423	5027
Telecommunications	880	1171	1498	2639	7642	16,116	5074	2180	1701	1822	2283	2618	2196	1659
Internet specific	505	1562	2359	4457	23,331	42,233	9848	3577	2388	2875	3336	4336	5176	4871
Clean technology	77	157	144	107	200	577	386	390	263	440	523	1458	2656	4023
Number of companies	1539	2076	2537	2979	4404	6335	3786	2634	2461	2625	2708	3089	3301	3262

Notes: Seed/start-up includes proof of concept (seed), research, product development, or initial marketing. Early includes financing for activities such as initial expansion, commercial manufacturing, and marketing. Expansion includes major expansion of activities or to prepare a company expecting to go public within 6–12 months. Later includes acquisition financing and management and leveraged buyout. Internet specific are companies whose business model is fundamentally dependent on the Internet, regardless of the company's primary industry category. Clean technology comprises companies that focus on alternative energy, pollution and recycling, power supplies, and conservation

Science and Engineering Indicators 2010

Source: PricewaterhouseCoopers/National Venture Capital Association, MoneyTree™ Report (data provided by Thomson Reuters), https://www.pwcmoneytree.com/MTPublic/ns/index.jsp, accessed 23 October 2009

2.3.2 *Does US Public Intervention Show Characteristics that Drive Its Positive Impacts?*

2.3.2.1 Agreeing on Innovation Targets

US R&D differs from other countries' R&D in several ways. The first difference is simply investment. The United States can target strategic R&D investment on a far greater scale. Specifically, the United States can coordinate at federal, state, and agency levels. For example, to place a "man on the Moon" within 10 years, the United States was able to concentrate its ability on a specific goal at all levels of government. This focus is concentrated from the executive office and allows the United States to have an economy of scale effect when strategically targeting specific innovative goals. In other countries, similar concentration usually requires that multiple large agencies have to deal with a higher level of compliance costs, which also takes time, in order to form a consensus on a particular goal.

The second area of difference is that the United States places an explicit goal of R&D transfer into the commercial market. As shown in Table 2.9, US agencies not only have to allocate 2.5 % of their funding to SBIR but they must also actively seek partners to transfer newly developed technology into the market. Indeed as one notes, all US agencies are active in commercializing their intellectual property for commercial application.

In general, national agencies are not required by legislation, such as the Bayh-Dole Act or SBIR in the United States, to make the necessary and important knowledge transfers. This legislation proved vital for innovative success in the United States and it would be equally in any other context.

2.3.2.2 Creating Innovation Clusters

In addition to the agency spillover, the United States also created technology and knowledge clusters which are now associated with some of the best innovative firms in the field. As shown in Table 2.10, for example, Oak Ridge National Laboratory is a world leader in nuclear energy and has led to a myriad of very successful spillover companies.

These specialized knowledge centers also attract needed venture capitalists to help facilitate these transfers. As one notes in Table 2.10, in the United States most of these federally funded hubs are based in either California or the Washington, DC, area. These consolidated hubs require federal clustering for venture capital markets to move into the area.

2.3.2.3 Coordination of Public Intervention

The United States is considered a world leader in transferring new technology to the market. However, it would be wrong to associate this success with a formula, which can be easily replicated by other countries or regions. The US government is a

Table 2.9 Federal laboratory technology transfer activity indicators, by selected US agency: FY 2007

Technology transfer activity indicator	Total	DOD	HHS	DOE	NASA	USDA	DOC
Invention disclosures and patenting							
Inventions disclosed	4486	838	447	1575	1268	126	32
Patent applications filed	1824	597	261	693	105	114	7
Patents issued	1406	425	379	441	93	37	4
Licensing							
All licenses, total active	10,347	460	1418	5842	1883	339	217
Invention licenses	3935	460	915	1354	461	339	217
Other intellectual property licenses	6405	0	460	4488	1422	0	0
Collaborative relationships for R&D							
CRADAs, total active	7327	2971	285	697	1	230	2778
Traditional CRADAs	3117	2383	206	697	1	184	154
Other collaborative R&D relationships	9445	0	0	0	2666	4084	2695

Notes: Other federal agencies not listed but included in total: Department of the Interior, Department of Transportation, Department of Veterans Affairs, and Environmental Protection Agency. Department of Homeland Security expected to provide technology transfer statistics starting in FY 2008. Invention licenses refers to inventions that are/could be patented. Other intellectual property refers to intellectual property protected through mechanisms other than a patent, e.g., copyright. Total active CRADAs refer to agreements executed under CRADA authority (15 USC. 3710a). Traditional CRADAs are collaborative R&D partnerships between a federal laboratory and one or more nonfederal organizations. Federal agencies have varying authorities for other kinds of collaborative R&D relationships

CRADA cooperative research and development agreement, *DOC* Department of Commerce, *DOD* Department of Defense, *DOE* Department of Energy, *HHS* Department of Health and Human Services, *NASA* National Aeronautics and Space Administration, *USDA* US Department of Agriculture

Science and Engineering Indicators 2010

Source: National Institute of Standards and Technology, Federal Laboratory Technology Transfer, Fiscal Year 2007, Summary Report to the President and the Congress, January 2009, http://patapsco.nist.gov/ts/220/external/index.htm, accessed 6 May 2009. See appendix Table 4-43

unique organization, in terms of scale and scope of its executive legislative powers. The United States also has world leading private and public universities and the sheer ability to drain the best and brightest talent from the rest of the world. These factors represent considerable competitive advantages and must be considered when trying to replicate innovative mechanisms from the United States.

Other countries' systems are far from being able to coordinate on a scale similar to the United States. However, that should not deter them from adopting successful mechanisms from the US innovation model. There are several areas (e.g., crossing the valley of death) where, with proper coordination and efficient funding, other countries could produce innovation which otherwise might not exist.

Table 2.10 R&D expenditures at federally funded research and development centers: FY 2007 (thousands of dollars)

FFRDC	All expenditures	Federal	Sponsoring agency	Location
All FFRDCs	13,820,767	13,396,861	na	na
University-administered FFRDCs	**5,855,193**	**5,654,952**	**na**	**na**
Ames Laboratory	25,254	25,254	DOE	Ames, IA
Argonne National Laboratory	489,684	445,096	DOE	Argonne, IL
AUI National Radio Astronomy Observatory	129,000	128,158	NSF	Green Bank, WV
Fermi National Accelerator Laboratory	337,306	336,927	DOE	Batavia, IL
Jet Propulsion Laboratory	1,717,203	1,717,203	NASA	Pasadena, CA
Lawrence Berkeley National Laboratory	503,775	443,273	DOE	Berkeley, CA
Lawrence Livermore National Laboratory	1,353,980	1,298,044	DOE	Livermore, CA
Massachusetts Institute of Technology Lincoln Laboratory	618,011	613,858	DOD, Department of the Air Force	Lexington, MA
National Astronomy and Ionosphere Center	13,591	13,375	NSF	Arecibo, PR
National Center for Atmospheric Research	144,293	132,375	NSF	Boulder, CO
National Optical Astronomy Observatory	53,608	46,624	NSF	Tucson, AZ
Plasma Physics Laboratory	75,720	75,488	DOE	Princeton, NJ
Software Engineering Institute	80,566	67,657	DOD, Office of the Secretary of Defense	Pittsburgh, PA
Stanford Linear Accelerator Center	231,960	231,960	DOE	Stanford, CA
Thomas Jefferson National Accelerator Facility	81,242	79,660	DOE	Newport News, VA
Industry-administered FFRDCs	**4,780,586**	**4,693,399**	**na**	**na**
Idaho National Laboratory	248,322	235,506	DOE	Idaho Falls, ID
Los Alamos National Laboratory	2,046,260	2,029,056	DOE	Los Alamos, NM
NCI Frederick Cancer R&D Center	339,800	339,800	NIH	Frederick, MD
Sandia National Laboratory	2,031,309	1,974,142	DOE	Albuquerque, NM
Savannah River Technology Center	114,895	114,895	DOE	Aiken, SC

Nonprofit-administered FFRDCs	**3,184,988**	**3,048,510**	**na**	**na**
Aerospace Corporation	36,490	16,930	DOD, Department of the Air Force	El Segundo, CA
Arroyo Center	25,195	25,195	DOD, Department of the Army	Santa Monica, CA
Brookhaven National Laboratory	510,212	491,138	DOE	Upton, NY
C3I FFRDC	46,368	46,368	DOD, Office of the Secretary of Defense	Bedford, MA/ McLean, VA
Center for Advanced Aviation System Development	7290	7290	FAA	McLean, VA
Center for Naval Analyses	99,993	89,721	DOD, Department of the Navy	Alexandria, VA
Center for Nuclear Waste Regulatory Analyses	17,007	16,519	NRC	San Antonio, TX
Homeland Security Institute	25,370	25,370	Department of Homeland Security	Arlington, VA
Institute for Defense Analyses Communications and Computing	59,500	59,500	National Security Agency	Alexandria, VA
Institute for Defense Analyses Studies and Analyses	141,500	141,500	DOD, Office of the Secretary of Defense	Alexandria, VA
Internal Revenue Service FFRDC	7101	7101	IRS	McLean, VA
National Defense Research Institute	38,152	38,152	DOD, Office of the Secretary of Defense	Santa Monica, CA
National Renewable Energy Research Laboratory	190,874	183,812	DOE	Golden, CO
Oak Ridge National Laboratory	1,083,509	1,031,919	DOE	Oak Ridge, TN
Pacific Northwest National Laboratory	851,512	823,080	DOE	Richland, WA
Project Air Force	39,315	39,315	DOD, Department of the Air Force	Santa Monica, CA
Science and Technology Policy Institute	5600	5600	NSF	Washington, DC

na not applicable, *DOD* Department of Defense, *DOE* Department of Energy, *FAA* Federal Aviation Administration, *FFRDC* Federally Funded Research and Development Center, *IRS* Internal Revenue Service, *NASA* National Aeronautics and Space Administration, *NCI* National Cancer Institute, *NIH* National Institutes of Health, *NRC* Nuclear Regulatory Commission, *NSF* National Science Foundation

2.3.2.4 Cost-Efficient Management of Programs for Beneficiaries

The importance to expedite and efficiently turn over potentially highly esoteric SBIR award applications without placing a burden on small firms is imperative for innovative success. Small firms operate on small budgets, usually with just enough cash flow to last from several months to a year. If potential awardees invest their limited resources in an SBIR program application, it is important that they are not burdened by unnecessary costs.

2.3.2.5 University Technology Transfer Mechanisms

In Europe, for example, one of the greatest achievements in the past 10 years was the improvement in the quality of its university research. Costly investment led to increased publications and quality of accepted research. Indeed, one may imagine future scholars reviewing the past 10 years as a period of "European University Renaissance." As shown in Tables 2.11 and 2.12, the EU has now significantly surpassed the United States in terms of journal articles published and is relatively close in terms of top-quality journal citations.

Table 2.11 S&E journal articles produced by selected regions/countries: 1988–2008 (thousands)

Year	The United States	EU	Asia-10	Japan	China	Asia-8	Rest of world
1988	169.97	146.37	50.74	33.86	4.63	12.26	92.29
1989	177.72	153.95	55.85	36.98	5.48	13.39	97.09
1990	181.25	157.92	58.27	38.35	6.10	13.82	99.23
1991	187.12	162.69	61.80	40.66	6.23	14.91	99.11
1992	187.52	171.22	65.48	42.54	6.75	16.19	97.65
1993	190.54	180.66	69.80	44.39	7.60	17.82	96.01
1994	192.93	190.29	74.54	47.07	8.05	19.42	99.11
1995	193.34	195.90	76.18	47.07	9.06	20.05	99.23
1996	193.16	203.95	83.29	50.35	10.53	22.41	101.37
1997	189.75	208.90	87.48	51.46	12.17	23.85	102.36
1998	190.43	214.76	93.80	53.84	13.78	26.18	103.44
1999	188.00	217.19	99.56	55.27	15.72	28.57	105.46
2000	192.74	222.69	106.47	57.10	18.48	30.89	108.55
2001	190.59	220.41	110.90	56.08	21.13	33.68	107.46
2002	190.50	221.72	115.46	56.35	23.27	35.84	110.71
2003	196.43	224.85	125.56	57.23	28.77	39.57	114.88
2004	202.08	230.48	135.58	56.54	34.85	44.20	120.50
2005	205.52	235.09	144.84	55.50	41.60	47.73	124.73
2006	209.24	242.79	157.58	54.46	49.58	53.55	130.66
2007	209.70	245.85	165.83	52.90	56.81	56.12	136.77
2008	198.84	232.94	165.68	47.80	60.98	56.90	130.54

Table 2.12 Share of region's/country's papers among world's most cited S&E articles: 2007 (percent in category)

Citation category	The United States	EU	Asia-10
Top 1 %	1.64	0.82	0.41
2–5 %	6.03	3.87	2.36
6–10 %	6.20	4.64	3.22
11–25 %	14.95	13.04	10.04

As mentioned in previous chapters, a keynote for US innovation, however, is its ability to transform ideas into innovation, i.e., the knowledge filter. Yet, if one of the primary pistons of US growth is found in regions rich with university technology transfer mechanisms, such as Silicon Valley, Route128, and the Research Triangle, an open and important question for the EU remains: how to adapt the European University Renaissance of ideas and transform these significant investments into innovation? If other countries do not implement proper mechanisms such as the Small Business Technology Transfer (STTR), for example, they will be unable to exploit these new and important ideas and may continually lag behind its competitors with better mechanisms of knowledge transfer.

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Chapter 3
Publicly Funded Principal Investigators as Transformative Agents of Public Sector Entrepreneurship

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3.1 Introduction

National governments consistently implement an array of public sector entrepreneurship policies and activities, seeking to generate further economic activity and create new networks and market opportunities that reduce market risks and uncertainties for market-based technology exploiters. This means that scientists taking on the role of being a publicly funded principal investigator (PI) is at the nexus of science, government and industry, and can have a significant influence and impact on shaping and delivering outcomes of public sector entrepreneurship policies and activities. Within the emerging public sector entrepreneurship literature (see Leyden and Link 2015; Link and Link 2009), we argue that publicly funded PIs as key public sector entrepreneurship transformative agents, through scientific novelty and originality involving some creative and innovative processes that can be exploited for opportunities with good market or societal potential. Publicly funded PIs are key agents of what Leyden and Link (2015:14) define as public sector entrepreneurship:

> Innovative public policy initiatives that generate greater economic prosperity by transforming a status-quo economic environment into one that is more conducive to economic units engaging in creative activities in the face of uncertainty.

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D.B. Audretsch, A.N. Link (eds.), *Essays in Public Sector Entrepreneurship*,
International Studies in Entrepreneurship 34, DOI 10.1007/978-3-319-26677-0_3

For innovative science technology and entrepreneurship-orientated public policy initiatives, publicly funded PIs are key assets, and the combination of their novel efforts and their capability to meet the expanding PI role means that they are a core and critical player in transforming scientific, economic and societal environments.

The implementation of public sector entrepreneurship policy agendas supporting basic and applied research has seen publicly funded PIs becoming the linchpin of this transformation process, as they shape novel research avenues, articulate and coordinate players within scientific programmes and bridge academia and industry. They play a specific role in the new governance of research and design novel scientific research programmes and projects in response to public sector entrepreneurship research funding opportunities and initiatives. When successful, they manage the implementation of these typically large-scale, publicly funded research programmes. While policymakers and funding agencies specify and prioritise scientific targets, publicly funded PIs interpret public policies and programmes; they articulate scientific research avenues, scientific programmes and priorities, firms' expectations and their own anticipation of where science is going. This can involve the mobilisation of scientific and industry networks nationally and internationally to create consortia that can compete to secure funding by means of scientific and increasingly now also commercial peer review processes.

Being an excellent scientist is only one aspect of the publicly funded PI role, which has now become multidimensional. The role has evolved from providing research leadership to research management. Some key tasks of publicly funded PIs include leading a research programme, overseeing the day-to-day management of the project, supervising and mentoring staff conduct, signing off on the budgets and financial management, ensuring that all deliverables and deadlines are met and submitting technical documentation and progress reports. The multidimensional publicly funded PI role also now involves coordinating with multiple organisations, including industry partners, scientific partners, technology transfer (TT) specialists, lawyers and innovation specialists. Publicly funded PIs need to be constantly spanning boundaries in their dealings with a wide variety of stakeholders inside and outside their institution. They also operate within the dual sets of control mechanisms and bureaucracies prescribed by their own institution and that of the public funding agency. Moreover, the role of publicly funded PIs is more important and policy-relevant with regard to the development, implementation and delivery of public sector entrepreneurship policy.

For most academic researchers, taking on the role of lead researcher on a research project as PI represents an important landmark in their research career. From the researcher's perspective, it marks a point in their career at which they have assumed intellectual leadership of their research efforts and are providing leadership for others in this endeavour. From a research system perspective, it also identifies a point in time when the academic researcher can be entrusted to successfully deliver a funded research project on behalf of the funding agent. Responding to public sector entrepreneurship policies through open funding calls requires scientists to strategise and develop novel scientific research programmes that meet and exceed the expectations of relevant stakeholders and 'that generate greater economic prosperity' (Leyden and Link 2015:14). Inherent in this PI strategising is transformative intent with regard to different environments—scientific, industry, regulatory, etc. Despite the importance of publicly funded PIs, little is understood about the various aspects of the role and activities.

We begin our chapter by examining definitions of PIs that attempt to illuminate the various facets and responsibilities of the role. We then consider as agents of public sector entrepreneurship policies that PIs need to become ambidextrous and boundary-spanning in their activities and this creates new challenges and tensions. While our research into publicly funded PIs has focused on many themes, for the purposes of this chapter we concentrate on three: the publicly funded PI as research strategists, as managers and as agents of technology and knowledge transfer. Implicitly inherent in each of these PI activities is the intentional transformation of different environments. We conclude the chapter with reflections and recommendations in addition to suggestions for future research, integrating emerging research into public sector entrepreneurship and publicly funded PIs.

3.2 A Question of Definition: A Scientist, Administrator, Manager or Research Leader?

The term "principal investigator" is commonly used within academia and has different institutional interpretations. Despite the common use of PI among researchers and in the organisational arrangements for public research, the term itself has limited usage in the academic literature on research management. There does not appear to be a universal definition of the role and responsibilities of a PI. However, the term is commonly used in the research policies of universities and publicly funded institutions. It is a role with responsibilities in addition to those that researchers already hold. Academic institutions can prescribe the role and responsibilities. In their standard contractual requirements from host institutions and the lead scientist—the principal investigator— the funding agencies may outline very specific roles, responsibilities and requirements. For example, funding agencies can contractually require the PI to devote a certain percentage of his or her time to the funded project.

In the absence of a universal definition of PIs, we conducted a small review of US Ivy League research policies in search of PI role definitions. From this small review there was a universal commonality with regard to these descriptions. They all agree that the PI has total responsibility for all aspects of a funded project. For example, the University of Pennsylvania[1] defines the PI as follows:

> The principal investigator is an individual designated by the University and approved by the sponsor to direct a project funded by an external sponsor.

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[1] www.upenn.edu/researchservices/faq.html

Columbia University's[2] definition is simple:

> The full administrative, fiscal and scientific responsibility for the management of a sponsored project resides with the Principal Investigator named in the award.

Princeton University's[3] definition is broader and includes a number of individuals as co-PIs:

> The principal investigator is an individual judged by the University to have the appropriate level of authority, expertise, and responsibility to direct a research project or program supported by a grant. There also may be multiple individuals serving as co-PIs who share the authority and responsibility for leading and directing the project, intellectually and logistically. Each PI/co-PI is responsible and accountable to the University for the proper conduct of the project or program. PIs are responsible for mentoring students involved in the project. They are also responsible for fulfilling the programmatic, management, and other requirements of the sponsoring organization.

Stanford University's research policy notes that the PI plays a privileged role with limited availability and that the post-holder is:

> Responsible for determining the intellectual direction of the research and scholarship, and for the training of graduate students.

We found that the predominant managerial focus of the Ivy League PI role descriptions we reviewed was internal. Various aspects of managerial planning, organising, leading and controlling formed part of this internal managerial focus.

Funding agencies are the other institutional bodies that have provided definitions of PIs. A review of the main research funding agencies in the USA, Europe and Ireland highlights a more expansive interpretation of the PI role. These definitions emphasised different aspects of scientific research management and leadership. We found from reviewing these funding agency descriptions that they clearly laid out the primary fiduciary responsibilities of PIs and ensured that they strictly adhered to the terms and conditions of their grant award. For example, the Economic Social Research Council[4] in the UK gives the following definition:

> The principal investigator is the individual who takes responsibility for the intellectual leadership of the research project and for the overall management of the research. He/She will be the Council's main contact for the proposal. The nature of the role includes making a significant contribution to the design, project management, scientific leadership, impact activities, and overall supervision of staff conduct/responsibilities.

The European Research Council[5] simply defines the role as follows:

> The Principal Investigator is the individual that may assemble a team to carry out the project under his/her scientific guidance

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[2] www.columbia.edu/cu/compliance/pdfs/PI_Quick_Guide.pdf

[3] www.princeton.edu/…/PI%20Request%20for%20Website%20-%20Final.pdf

[4] See ESRC RTD Enquiries Service.

[5] See EUROPE DIRECT Contact Centre/Research Enquiry Service.

However, the National Science Foundation[6] in the USA defines the PI role as:

> The individual designated by the grantee, and approved by NSF. Responsible for the scientific or technical direction of the project for carrying out the research within the funding limits awarded and in accordance with the terms and conditions of the award.

Other responsibilities enshrined in the PI role by the funding agencies include:

- Acting as the primary conduit between the project organisation or team and the funder
- Leading the scientific and technical direction of the project
- Ensuring compliance with the intellectual property requirements of the award
- Maintaining proper conduct on the project and the appropriate use of funds
- Assembling and coordinating the project team
- Designing project management structures

In general, the definitions used by universities and funding agencies to explain the role and responsibilities of PIs do little to appreciate the full extent of the expanded responsibilities and practices embodied in it. These definitions tend to be designed from a contractual perspective with an emphasis on project management, administration and fiduciary responsibilities—scientific and financial. They do little to reflect the complexity and strategic importance of the role in the context of the implementation of public sector entrepreneurship policies that are carried out in a multilayered institutional setting, and that involve industrial partners across international research systems. The reality for publicly funded PIs is they are expected to be the agents for implementing public sector entrepreneurship policies, programmes and initiatives. This involves overseeing the day-to-day management of a research project or research programme, supervising and mentoring researchers, conducting and signing off on the financial arrangements of the research project, ensuring that all deliverables and deadlines are met and submitting technical documentation and progress reports to both the funding agency and their own institution.

Given the expanding array of activities and responsibilities of publicly funded PIs, they are expected to take on more significant management roles, including designing and scheduling the research project, coordinating and directing a research team, liaising with stakeholders and acting as a primary contact point for the funding agency and flagging and responding to institutional or project issues. Significantly, however, the responsibilities associated with the position of PI are somewhat heightened, with the added expectations that they develop and maintain their own status and expertise in the field, demonstrate intellectual leadership, set the scientific direction, deliver technical success and oversee the project's impact activities following completion. In addition to these conditions, there is also the increased imperative for publicly funded PIs to incorporate industry partners into their research, to meet the expectations of these partners and to contribute towards TT targets set by funding agencies. All of this is to be achieved within as many as three layers of control mechanisms, including their own institution, the public funding agency and the project-specific controls.

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[6] http://www.nsf.gov/pubs/2002/nsf02151/gpm2.jsp#210

Fig. 3.1 Key responsibilities of publicly funded principal investigators (PIs)

By considering the different definitions of the PI role, we define PIs as scientists who orchestrate new research projects, combine resources and competencies, deepen existing scientific trajectories or shape new ones that are transformative in intent, nature and outcome, and that can be exploited for commercial ends and/or for the common good of society. We have identified and mapped ten core responsibilities of public funded PIs (Fig. 3.1).

3.2.1 From an Agent of Science to an Agent of Economic Transformation: The Ambidextrous PI

In Europe over the last 15 years there has been an increasing emphasis on the generation of commercial outcomes from publicly funded research, although until recently, research commercialisation or TT was not a mainstream activity for research and publicly funded PIs. Public sector entrepreneurship research programmes seeking to generate economic activities are now requiring publicly funded

PIs and their host institutions to deliver a research impact, including technology and knowledge transfer that will have a tangible impact on local, regional and national economies. This research system objective presents challenges at various levels. Universities and public research institutions are undergoing a significant transformation in terms of how research is managed at an institutional level (see Kang 2004; Park et al. 2010). Universities have responded to these changes by investing in signature research centres, thereby concentrating research and scientific activities and resources on supporting transformation- and impact-orientated research. Technology transfer offices (TTOs) have seen their mission, role and influence expanded beyond protecting intellectual property of the university (see Fitzgerald and Cunningham 2015; Gubitta et al. 2015). TTOs are involved in the marketing and promoting of technology, supporting the creation of start-up and spin-off firms and encouraging the faculty to exploit technology (see Friedman and Silberman 2003; Muscio 2010). This has meant that TTOs have had to develop and shape dual identities—scientific and business—and building such legitimacy for TTOs can be challenging for academics (O'Kane et al. 2015). Funding agencies and governments are expecting greater returns for their research investment (see Bessette 2003; Hertzfeld 2002; Link and Scott 2004). They now need to demonstrate to society the economic value of public investment in science, innovation and technology.

These contextual drivers and changes have had significant implications for publicly funded PIs as they seek to develop research programmes that exploit public sector entrepreneurship transformation programmes seeking to generate economic prosperity. Therefore, scientists taking on a publicly funded PI role need to have an ambidextrous mindset to move between scientific and commercial environments and the capabilities that convert transformative intent to action and measureable outcomes. Ambos et al. (2008:1425) describe this as something of an extraordinary challenge where researchers are:

> Not simply required to switch from one (single-handed) activity to another, but to develop the simultaneous capacity for two activities (academic rigour and commercialisation).

They also note that few studies have examined the capacity of researchers to handle what they describe as conflicting demands and the tensions created by this requirement. For many scientists there is a firm conviction that academic research and commercial research are fundamentally different. Some highlight the notion that engagement in TT is insufficiently valued in their institutions, particularly in relation to scientific publishing activity (Markman et al. 2005b). Indeed, there may even be reluctance on the part of some senior faculty to alter a system that has provided the basis for their own success. Other scientists simply lack the competence to undertake commercial activities or engage in TT initiatives (Clarysse and Moray 2004). For publicly funded PIs the new paradigm is that they are transformative scientific and economic agents for public sector entrepreneurship policy programmes. This requires an ambidexterity and effective boundary-spanning abilities to influence and shape scientific and economic directions that generate economic prosperity.

The boundary-spanning perspective is particularly important as it introduces key dimensions to the role. First of all, as boundary-spanners, publicly funded PIs are bridging different areas, from academia and higher education to policymakers and enterprises. They play a role in articulating different objectives, time frames, logics and cultures. They also play a role within academia in creating a dialogue between disciplines, shaping research avenues and combining different approaches and instruments to propose solutions. Finally, emphasising the boundary spanner role obliges scholars of research management to reconsider the definition of publicly funded PIs and their characteristics, and to question their role in academic science, not only in the light of their productivity, but also taking into account their ability to implement multi-environment transformative visions and to share expectations, particularly as agents of public sector entrepreneurship policies.

3.2.2 Some Challenges and Tensions Facing Publicly Funded PIs

From the definitions and role descriptions proffered by funding agencies and universities, our understanding of the activities and practices of PIs has emphasised their role as project managers and administrators (Birnbaum-More et al. 1990; Frestedt 2008). More recently, the role of research leaders as boundary-spanners taking on different points of view and logics to solve problems has been considered (see Alder et al. 2009; Comacchio et al. 2012; Jain et al. 2009). These changes have created new challenges and tensions for publicly funded PIs. Ambiguities regarding the definition of the role of PIs reflect these tensions and include:

Scientific versus Economic Activities and Impact: Scientist formation and training predominantly focuses on being trained to be an excellent researcher, to write academic papers, to participate in international scientific communities and to learn how to mentor and support. The publicly funded PI role means that they now have to act as a transformative conduit between science and industry. This involves PIs becoming knowledge brokers, playing a role that was not common in decades past. For this role they typically receive little professional training and learn on the job. Moreover, as part of securing public funding, PIs are required to elaborate on the economic impact of their research proposal, such as the number of jobs created etc. The proposal needs to be transformative in intent. Again, PIs receive little formal professional support and rely on the professional support within their network and in their institution to meet these growing demands. As research projects evolve and mature, the competing scientific and commercial agendas create more tensions for the PI between economic and scientific activities.

Governance and Fiduciary Responsibilities: The governance requirements and broader fiduciary responsibilities that publicly funded PIs now face are growing. Most publicly funded PIs at least have to deal with institutional and funding control mechanisms. Moreover, funding agencies require even more of an overview regarding the scientific progress of funded projects, and with regard to financial and project management. These additional requirements can be demanding for publicly funded PIs and their institutions. The real challenge and tension created for publicly funded PIs is achieving the appropriate balance between research leadership and research management. Thus, for public sector entrepreneurship policies, the overall challenge is to achieve the appropriate balance between loose and tight administrative controls that enables them to realise transformational intent in multiple environments.

Market-Shaping Expectations: Public funding agencies are increasingly requiring scientists to articulate the commercial and economic impact of their proposed scientific proposals that have the potential to be market-shaping. Such an articulation may include outlining a clear technology management and transfer strategy, forecasts such as the potential size of market opportunities and supported market research and analysis that further validate the economic and financial case for the proposed project. The challenge for the PI is how they form these projections and expectations, while allowing for manoeuvrable change, if, for example, anticipated market opportunities change or if the scientific progress is not achieved. Furthermore, another challenge is making credible linkages and claims between the anticipated scientific programme and potential market opportunities that is substantially transformative, to secure funding through public sector entrepreneurship programmes and subsequent market support.

Taken together, these tensions provide a framework for studying the role of the PI. We observe that the effective publicly funded PI is required to have the ambidextrous qualities that enable them to lead highly complex and technically advanced research programmes, while having the dexterity to simultaneously manage a set of relationships that extends to their institution, industry partners, research funders, government agencies and research team members. Setting aside the obvious scientific competencies required to lead research efforts, they must also be:

A *research strategist*, where they envision transformative scientific trajectories and design scientific programmes

A *manager*, where they lead a research team and manage a diverse stakeholder network to realise transformation intent in multiple environments

A *TT agent*, where they create a bridge between science and industry and support the knowledge transfer and application of their research outputs

3.3 Study Framework

Given that there is little empirical focus on scientists in the publicly funded PI role with the support of funding from the Irish Research Council,[7] the research team, comprising researchers from NUI Galway, the Dublin Institute of Technology, the University of Otago in New Zealand and Grenoble Ecole de Management in France, undertook quantitative and qualitative investigations and analysis of a range of issues with regard to publicly funded PIs in science, engineering and technology. Our data collection had two elements—a large-scale survey of publicly funded PIs and in-depth interviews and documentary analysis.

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[7] Formerly known as the Irish Research Council for Humanities and Social Science

3.3.1 Large-Scale Survey

We undertook a full population survey of publicly funded PIs in science, engineering and technology in Ireland. This included publicly funded PIs from public funding agencies such as Science Foundation Ireland, Enterprise Ireland, the Health Research Board, the Programme for Research in Third-Level Institutions (PRTLI), Food Institution Research Measure, SafeFood, the Environmental Protection Agency and EU Framework Programmes. Across these programmes, a dataset comprising 1,391 individual publicly funded PIs was compiled and surveyed. Our survey response rate was 32 %. The survey had a project focus and addressed PI issues such as activities and practices as they designed, led and managed publicly funded research projects. Areas of activity surveyed included project design, project management, collaboration strategies, stakeholder management and TT activities. Some 82 % of the respondents were based in universities, 9 % were based in public research organisation (PROs) and the remainder at institutes of technology (IoTs).[8]

3.3.2 In-Depth Interviews

Thirty case studies of publicly funded PIs were undertaken using in-depth interviews and documentary analysis. The selection criteria required case subjects to have been the publicly funded PI for multi-annual and collaborative (preferably with industry) research projects with a minimum funding value of €250,000. The final sample was refined to include an appropriate diversity of discipline areas, genders, age and stage of career of the PI. It was also refined to suitably reflect the host research institutions in Ireland (i.e. universities, PROs and IoTs. Thirty semi-structured interviews of approximately 90 min each were undertaken (amounting to just over 400 pages of transcripts). A second phase of data collection included an analysis of documentation collected before, during and after the interview that was relevant to both the project and the CV of the PI.

3.3.3 Our Focus

Our data collection focused on a variety of themes, given the dearth of empirical research on publicly funded PIs. In the findings section of this chapter, we focus and report on three themes of the publicly funded PI as a strategist, a manager and a knowledge and TT agent based on the research we have undertaken to date. Publicly funded PIs are transformational agents of public sector entrepreneurship; thus, there is a need to understand their strategic behaviours, their managerial challenges and

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[8] For more information about the project and other large-scale survey findings, see www.topik.ie

what barriers or stimuli they face with regard to technology and knowledge transfer given their central role in designing, leading and delivering publicly funded programmes in science, innovation and technology.

3.4 Findings

3.4.1 The Publicly Funded PI as Research Strategist

Within the evolving research environment, PIs are key strategic and transformational players. As scientists, they design and orchestrate new research projects, which involves combining resources and competencies with other researchers, research organisations and enterprise partners (Kidwell 2014). To varying degrees they seek to deepen scientific trajectories and shape new areas (Casati and Genet 2014). Despite this important strategic aspect to their roles, surprisingly little is understood regarding the strategic orientation of researchers or indeed their approach to strategising in relation to their role as leaders in national and international research systems.

3.4.1.1 Strategic Behaviours of Publicly Funded PIs

To examine the strategic behaviours that underpin the research activities of publicly funded PIs, we identified two key constructs that inform their strategic behaviours and applied them to 30 case studies of publicly funded PIs (see O'Kane et al. 2015). First, we drew on the theory of exploration and exploitation in organisational adaptation and learning to describe the strategic posture of PIs as being more 'reactive' or 'proactive'. Second, we explored the effects of strategic conformance on PI research development trajectories. We grounded conformance in funding applications in literature detailing the influence of peer review funding on research creativity and originality. Together, our constructs reflect how choice of research line in science must balance curiosity and opportunity boundaries (see Bozeman and Mangematin 2004; Fisher 2005; Franzoni 2009; Porac et al. 2004).

After examining the strategic posture of publicly funded PIs and how they are more proactive or reactive, and mapping that against their level of conformance in funding applications, four distinct categories of PI strategic behaviours became apparent—*research designers*, *research adapters*, *research supporters* and *research pursuers*.

Research Designer: These publicly funded PIs are highly purposeful, passionate and committed, with clearly focused and novel research agendas. They have challenging ambitions and long-term intentions and combine projects to build their own trajectory, shaping the scientific field. These publicly funded PIs do not attain their deliberate planned objectives through single stand-alone projects and are highly selective when choosing public funding opportunities to pursue. Moreover, they are more driven by the originality of their research and how funding opportunities are compatible with their broader research objectives.

Research Adapters: These publicly funded PIs have a broad research focus, are not overly committed to a focused or long-term research agenda, take a reactive and broad focus so that they maintain some career and research competitiveness, and being in a position to respond to the emerging opportunities. Like the research designer, they are less conformist in relation to funding applications and have the confidence to convey to funding bodies their research intentions. We found this category of PI to have a varied professional ranking and that they are constantly adapting their research trajectory and activities to fit their external environment.

Research Supporters: These publicly funded PIs are deliberate planners and have a clearly defined long-term research focus that they proactively pursue, and build upon existing scientific trajectories rather than opening up new ones. They are less of a risk-taker when it comes to pursuing their research objectives, are heavily reliant on funding and concentrate on conformity.

Research Pursuers: This type of publicly funded PI is in the short term focused on a poorly defined or absent research agenda and is less reliant on original research. Research pursuers are highly tactical and build on existing research by making adjustments to meet the threshold expectations of funding opportunities. They also have a reactive research posture, a broad research focus and short-term and fluid research intentions. They are less focused on building originality and more concerned with meeting the expectations of the funding body.

3.4.2 PIs as Managers

Our review of the definitions of PIs demonstrated both implicit and explicit notions that the scientist, in taking on the publicly funded PI role, accepts managerial responsibility. In becoming a publicly funded PI, an individual scientist assumes managerial responsibilities that are associated with the successful delivery of the project. The publicly funded PI has to manage the budget, select and recruit the research team, set up the management structure for the project, engage with stakeholders and provide leadership for the whole project team. For large-scale multi-partner projects, management and leadership by the publicly funded PI is significantly complex. We examined the managerial nature of the publicly funded PI role, as there has been little empirical focus on this topic.

3.4.2.1 The Managerial Nature of the PI Role

Publicly funded PIs have to ensure that the work programme articulated in their successful proposal is implemented. They have to ensure that the project is effectively coordinated to ensure delivery of project objectives. Effective organisation and allocation of resources is essential to meet the needs of the different work packages within a project. The project team, partners and funders require the scientist in the role of PI to lead, to deal with unanticipated events and to adhere to his or her own institutional policies and the terms and conditions of the funding agency.

The PI has to balance project leadership and management responsibilities with other teaching and service demands, and they need to manage their time effectively (Link et al. 2008). In addition to their scientific excellence, PIs have to be effective managers to deliver multi-environment transformation. Acquiring managerial skills for PIs is learnt on the job (Kidwell 2013). One recent study of research centres established by the US National Science Foundation found that some PIs demonstrated managerial capabilities and some did not (Boardman and Ponomariov 2014). Boardman and Ponomariov (2014) suggested that managerial capabilities matter with regard to how research gets done effectively. Managerial capabilities are also essential for dealing with inter-organisational relationships, such as industry collaborators (Boehm and Hogan 2014).

3.4.2.2 Managerial Challenges

Addressing the deficit of empirical studies on managerial issues facing PIs, from the qualitative phase of our study, we focused on the managerial challenges experienced by publicly funded PIs. We found three main categories of managerial challenges—*project management, project adaptability and project network management* (see Cunningham et al. 2015).

3.4.2.2.1 Project Management

The managerial challenges experienced by PIs in our study demonstrate a focus on operational tasks.

Talent Recruitment and Management: How to attract, recruit and manage the best research team for a funded project was the most significant management task for publicly funded PIs. Developing a productive work environment was essential in maintaining the research team and ultimately in delivering against expected project outcomes.

Supervision: How best to supervise research teams, ensuring scientific quality and monitoring any project partner delivery were key managerial challenges for publicly funded PIs. The key challenge for publicly funded PIs is balancing operational day-to-day activities with the strategic responsibilities of delivering project objectives against the conditions of the funding agency.

Maintaining Project Focus and Alignment: How to balance a shared vision for the overall project with all project participants against individual partner objectives that could be in conflict with the overall project objectives. This requires publicly funded PIs to build effective relationships with project partners and with internal and external stakeholders to maintain project focus and alignment.

Managing Across Disciplines: How to create a common project language, vision and objectives when dealing with cross-disciplinary teams to ensure project delivery. Managing across disciplines can be an on-going managerial challenge for publicly funded PIs; therefore, having open dialogue and garnering shared ideas among the project partners can be effective management mechanisms.

Managing Cultural Diversity: There is cross-cultural diversity within publicly funded project teams. How best to manage this cultural diversity against different layers of institutional and funding agency control is managerially challenging. Publicly funded PIs need to have an understanding and appreciation of cross-cultural and institutional differences to manage effectively for the duration of the project.

Performance Management: How best to deal with project partners who do not deliver is a key managerial challenge and concern for publicly funded PIs. Reported responses in dealing with non-performance included, individual meetings, exposure of underperformers or project partner removal.

3.4.2.2.2 Project Adaptability

We found another significant set of managerial challenges centred on project relevance that we termed "project adaptability". A constant concern for the publicly funded PI was to ensure that their funded project had temporal relevance and if it did not, how it could be shaped to achieve this.

Environmental Scanning: How best to balance scientific and market perspectives to ensure consistent relevance of the project. For example, during the course of a publicly funded project, external market changes and external scientific breakthroughs may occur that may lessen the potential market attractiveness of projects. To deal with this managerial challenge, if possible, the publicly funded PIs used a dedicated work package on environmental scanning or building to report processes to have consistent market intelligence within the project to ensure temporal relevance.

Maintaining Project Agility: The focus of markets and funding agencies can shift; thus, the key managerial challenge for PIs is to adapt project activities and outcomes to reflect these changes. The shift towards economic and social outcome for projects is an on-going managerial challenge.

3.4.2.2.3 Project Network Management

The final managerial challenge detailed how PIs had to interact with key parties in both their internal and external project networks.

Internal Network Management: How do deal with control systems, bureaucracy and host institutional units such as TTOs can be a difficult managerial challenge for publicly funded PIs. We found that publicly funded PIs of large-scale research programmes tended to have a structured relationship with TTOs to deal with or overcome any difficulties effectively. For publicly funded PIs early in their career, a major challenge is balancing publishing against initial invention disclosures, as required by host institutions and TTOs.

External Network Management: As publicly funded PIs, boundary-spanning activities are expanding; they are engaging with industry, regulatory bodies, research funders and governments as key external stakeholders. The managerial challenge is balancing this external networking effectively against the other demands and responsibilities of the PI role.

3.4.3 PIs as Agents of Technology and Knowledge Transfer

When taking on the role of PI for a publicly funded project means that a scientist becomes an agent of technology and knowledge transfer. Nearly all publicly funded research programmes require PIs to proactively disseminate their project outcomes through traditional knowledge transfer mechanisms, such as scientific papers, conferences etc. They now also require PIs to be actively involved in TT based on project outcomes through licensing, material transfer agreements and spin-out and spin-in companies. The PI has become an agent of technology and knowledge transfer. In essence, they have to contribute to scientific and economic environments and where appropriate, society. When considering these issues, we first assess more general demands and some of the conditions for TT before presenting our study findings in relation to prevalent technology and knowledge transfer activities, and factors inhibiting and stimulating TT.

3.4.3.1 Demands and Some Conditions for TT

An increasing feature of national and international publicly funded programmes is a requirement for projects to transfer technology and knowledge to external stakeholders that can be exploited by firms and/or have public good outcomes. Publicly funded programmes may also require engagement with citizens with regard to building up their awareness and knowledge of different aspects of science and technology.

This growing demand is being shaped by the way in which the key stakeholders of business, academia and government in many domains are collaborating and co-creating together in advanced scientific programmes. Transformative innovation and research development that can be exploited in markets now require multiple players. In addition, many businesses are using open innovation strategies to expand their research and development capabilities. Rapid advances in ICT have meant that open economies and R&D activities can be undertaken in multiple locations across the globe (see Cunningham and Harney 2006:7–9). Other factors increasing the demand for public research commercialisation include increasing national competitiveness, scientific costs and budgetary pressures, competition for human resources and funding, and open access and open research data.

Increasing numbers of universities have adopted third mission activities focused on technology and knowledge transfer. This has led to the creation of the TTOs within universities to protect, manage and exploit university intellectual property. US University TTOs have become the model for many institutions worldwide

(Grimaldi et al. 2011). Some universities are adopting the characteristics of an entrepreneurial university where the culture of institutions means that ideas can be explored and exploited for economic and social return through engagement in a wide range of university networks and relationships (Guerrero and Urbano 2012; Guerrero et al. 2014). The easier the access between businesses and universities, the easier it will be to foster university–business R&D collaborations. The conditions for effective technology have been the focus of much empirical study. The research quality of the affiliate university increases the likelihood of researchers participating in commercialisation (see Di Gregorio and Shane 2003; O'Shea et al. 2005). The presence of formal TT mechanisms is generally positively related to commercialisation (see Markman et al. 2005a, b; Phan and Siegel 2006). Research has also found local peer effects, which means that academics are more likely to be entrepreneurial if departmental colleagues of the same rank are entrepreneurial (Bercovitz and Feldman 2008), and disciplinary affiliation, which is an important variable informing engagement with industry. Scientific disciplines affect the selection of knowledge transfer channels from university to firms (Bekkers and Bodas Freitas 2008). For example, for biomedical and chemical engineering the most important channels are patents and licensing, scientific output, student placements, informal contacts and contract research. For researchers in computer science, patents and licenses do not seem a relevant transfer channel, whereas they are very important for material scientists. The scientist in the role of PI is a central player in technology and knowledge transfer.

3.4.3.2 Prevalent Technology and Knowledge Transfer Activities

The most prevalent TT activities among publicly funded PIs in our study are peer publications, research symposiums, end-of-project reports, collaborative research with industry and industry workshops (Fig. 3.2). Notably, all of the commercially orientated activities (licensing, spin-offs, consulting and contractual research) are less prevalent than the other TT activities. Peer publication (48 %), research symposiums and colloquiums (17 %) and end of project reports (12 %) are the top three dissemination and TT activities reported by publicly funded PIs in our survey.

Technology transfer activities in their order of prevalence, broken down by institution type, show that collaborative research with industry, licensing of intellectual property and consulting are more likely to take place at universities (Table 3.1); industry workshops and contractual research are more likely to take place at both universities and PROs; and spin-off enterprise is more likely to take place at IoTs, and even more frequently at universities.

Table 3.2 shows the TT activities in order of prevalence, broken down by the size of the project budget. Peer publications dominate as the main mechanism for knowledge and TT. For projects with a budget of less than €500,000 collaborative research with industry, industry workshops and research symposiums were the predominant mechanisms reported by publicly funded PIs in our survey. On the other hand, for projects with budgets greater that €500,000, research symposiums and colloquiums and end-of-project reports have been used.

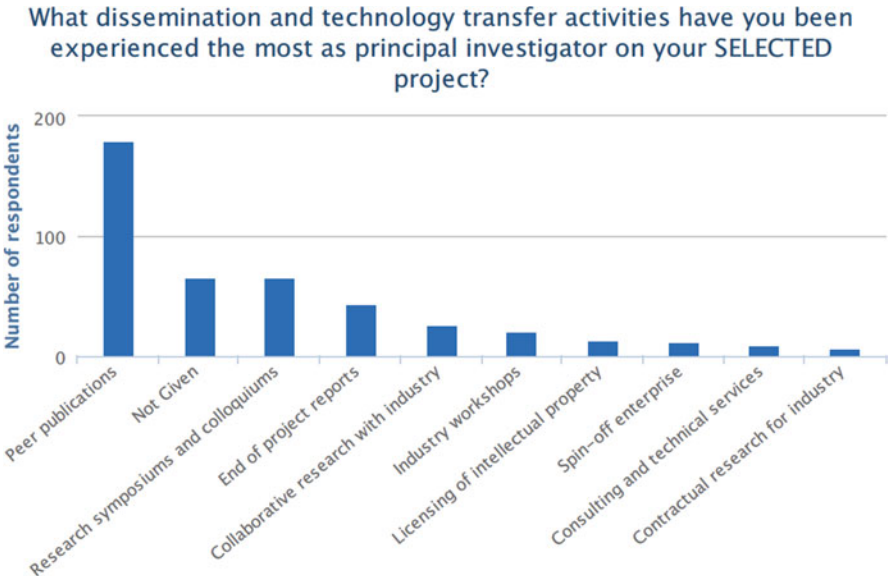

Fig. 3.2 Publicly funded PI dissemination and technology transfer activities

Table 3.1 Knowledge and technology transfer (TT) by institution type

	University	Public research organisation	Institute of technology
Knowledge and TT by institution	*n*	*n*	*n*
Peer publications	158	9	13
Research symposiums and colloquiums	55	7	2
End of project reports	35	4	4
Collaborative research with industry	23	1	2
Industry workshops	7	10	3
Licensing of intellectual property	10	1	2
Spin-off enterprise	8	0	3
Consulting and technical services	8	0	0
Contractual research for industry	4	3	0

3.4.3.3 Factors Inhibiting TT

The top factors that inhibit TT are lack of funding for bringing research to market (24.14 %), lack of commercialisation opportunities, lack of available time, weak links with industry and lack of personal motivation. From our analysis of our qualitative data, we found inhibiting factors that were directly or indirectly related to TT. Overall, we found three main inhibiting factors: political and environmental, institutional and project-based (see Cunningham et al. 2014).

Table 3.2 Knowledge and TT by size of the project budget

Knowledge and TT mechanism	Budget value	
	<€500,000	€500,000+
Peer publications	37	143
Research symposiums and colloquiums	12	53
End of project reports	8	36
Collaborative research with industry	17	9
Industry workshops	13	8
Licensing of intellectual property	7	6
Spin-off enterprise	5	6
Consulting and technical services	4	5
Contractual research for industry	4	3

- *Political and Environmental Factors*: These factors relate to TT policy, particularly in relation to project direction and focus, stakeholder demands and IP valuation.
- *Institutional Inhibitors*: These factors relate to TT support, tailored support for the PI role and human capital support. It should be noted that all the organisations of the PIs in our study had centralised administration services, such as finance, human resources and TT.
- *Project Inhibitors*: We found several project level inhibitors that had an impact on publicly funded PIs and their projects, the most significant among all PIs in our study being administration, lack of dedicated professional development support for publicly funded PI roles and the power of industry partners.

3.4.3.4 Factors Stimulating TT

Institutional provision of TT activities, strong links with industry and clearly defined commercialisation opportunities are the top three factors that stimulate TT among the publicly funded PIs in our study (Table 3.3). When factors that stimulate TT are broken down by institution, the order of prevalence is somewhat different for universities, with institutional provision of TT services, strong industry links and accessibility of support being the top three factors among publicly funded PI respondents.

For PROs the top three factors that simulate TT reported by publicly funded PI respondents are strong links with industry, institutional provision of TT services and facilitation of researcher involvement in the process.

For publicly funded PIs in IoTs strong industry links, institutional provision of TT services, facilitation of researcher involvement in the process and clearly defined commercialisation opportunities (ranked joint third) are the top three factors that stimulate TT. When examining stimulants by project budget the top stimulating factor for project budgets of less than €500,000 is institutional provision of TT support, but for project budgets of more than €500,000 strong links with industry are most important.

Table 3.3 Ranking of factors that stimulate TT among publicly funded principal investigators (PIs)

Stimulating factor	% of Respondents
Institutional provision of TT activities	16.46
Strong linkages with industry	14.64
Clearly defined commercialisation opportunities	11.60
Accessibility of TT office support	11.60
Own department leadership and commitment	10.09
Facilitation of researcher involvement TT	9.90
Realistic expectations of commercial returns from TT	7.35
Professional development initiatives to enhance TT	5.47
Financial rewards for researchers	4.68
Positive experience in relation to TT	4.50
Clearly defined and documentedTT policies	3.71

3.5 Discussions and Implications

3.5.1 Publicly Funded PI Strategic Behaviour

Our research found that the strategic behaviours of publicly funded PIs fall into four categories—research designer, research adapter, research supporter and research pursuer—and that these categories are influenced by strategic posture and conformance. How these agents respond and the capabilities they possess do matter in the delivery of public sector entrepreneurship policies. This has implications for practising PIs, policy-makers, research funding agencies and research organisations as scientists in the publicly funded PI roles are transformation agents in multiple environments progressing from intent to action.

We found that proactive publicly funded PIs seek to enact their environment whereas reactive PIs respond to research funding opportunities that arise. We suggest that proactive publicly funded PIs with the appropriate institutional support and research environment might have the capability to deliver transformative research that has the potential to enable direct and indirect economic spillovers of public sector entrepreneurship policies. Such publicly funded PIs promise to shape scientific direction and market opportunities that can be transformational in both environments. This requires publicly funded PIs to reflect on what strategic posture is best aligned to their long-term research ambitions.

For funding bodies and policymakers devising and implementing public sector entrepreneurship policies and initiatives greater consideration needs to be given as to the type of publicly funded PIs that are truly transformational agents and that have the potential to contribute to greater economic wealth. The strategic behaviour of publicly funded PIs contributes to the success of public sector entrepreneurship policies. Selecting the appropriate mix of PIs is necessary so that they are enabled to be transformational with regard to scientific endeavours and in creating potentially sustainable market opportunities. Moreover, funding agencies need to recognise that the selection mechanisms of research strategies are interwoven with the pro-reactive posture of strategic players and conformance. When the publicly funded PI selection programmes and processes are based on conformance, it discourages proactive exploration strategies and encourages conformity. Resource allocation must promote an appropriate balance of research exploration and research exploitation activities, hence the need for the different strategic behaviours of publicly funded PIs in a research system to realise economic potential, which is transformational.

For research organisations such as universities, IoTs and PROs, which provide the environment in which publicly funded research is carried out, their institutional strategies and policies (HR and IPR) and their organisational cultures have an important influence on the strategic behaviours of publicly funded PIs. To deliver on their missions relating to research exploration and exploitation, it is necessary for these institutions to have an awareness of the strategy postures of their publicly funded PIs and to maintain appropriate research environments that support the strategic behaviours of publicly funded PIs.

3.5.2 Managerial Responsibilities of Publicly Funded PIs

Our study has found that publicly funded PIs are heavily involved in the operational management of their project and active in the project compliance of their funding awards. It also highlights the totality of the managerial burden and extent of the managerial work that publicly funded PIs have to deal with in the role. It is more extensive and has a compliance focus. The publicly funded PI role endows scientists and their institution with a certain prestige; however, the role involves greater managerial responsibilities than anticipated or estimated by the publicly funded PIs in our study. The managerial role has a low status among publicly funded PIs, but it remains an intensive part of their engagement with research.

The PIs are involved in all managerial functions (planning, leading, organising and controlling), which are challenging and complex. We suggest that the ability of publicly funded PIs to effectively manage and lead in multiple environments might ultimately determine the extent of economic and transformational outcomes of public sector entrepreneurship policies. This issue requires more empirical investigation to assess how critical the managerial capabilities of publicly funded PIs are in delivering large-scale, multi-partner, multi-impact, cross-discipline, publicly funded research programmes.

Our research indicates that publicly funded PIs learn the PI role on the job. They face multiple and contradictory demands and expectations, particularly in dealing with the project focus, cross-cultural, cross-disciplinary and under-performance aspects. In responding to these managerial challenges they use a variety of managerial approaches (see Cunningham et al. 2015). More empirical research is required to understand the managerial approaches used by publicly funded PIs in different organisational contexts and the hybrid role identities—scientific, managerial, economic—they adopt in different environments in the role of a publicly funded PI.

In designing public sector entrepreneurship programmes policymakers need to consider the managerial burden that is actually being placed on the publicly funded PIs and the real institutional supports that are available to them. If they are over burdened with managerial responsibility and do not have appropriate organisational support, this has implications regarding whether such public sector entrepreneurship programmes are sufficiently attractive to secure the right mix of publicly funded PIs engaged in programmes that seek to generate economic prosperity and be transformational in nature.

3.5.3 Knowledge and TT

There is a clear need for all publicly funded PIs to have the knowledge and developing expertise to effectively undertake knowledge and TT activities. The demands for TT from all national and international public research programmes are growing and therefore scientists need to hone their own knowledge and skills so that they can implement them in a PI role.

Research quality and excellence is the basis for effective knowledge and TT. Consequently, publicly funded PIs need to ensure that within projects research quality is maintained and that a strategic relationship with TTOs is developed to ensure that the appropriate knowledge and TT strategy is in place to maximise the impact of the public research programme.

Within institutions, having role models, a culture of academic entrepreneurship and good provision of TT support is essential if publicly funded PIs are to be supported as agents for technology and knowledge transfer in public sector entrepreneurship programmes. Also, institutions need to customise their provision of TT for different scientific domains.

In designing public sector entrepreneurship programmes, policymakers and funding agencies can shape the desired knowledge and TT outcome that have the potential to contribute to economic prosperity and underpin the development of new sustainable market opportunities that can be exploited by the relevant players.

3.6 Recommendations and Final Reflections

Our research on the PI role and the experiences of scientists as publicly funded PIs highlights increasing levels of complexity and the need for further empirical research. We conclude with some key reflections and recommendations for PIs, host institutions, funding agencies and government policymakers. In summary, publicly funded PIs are the linchpins of the public sector entrepreneurship programme-based organisation of science and technology policies. This needs to be more widely recognised. PIs are not only instruments but also facilitators of the public sector entrepreneurship policy.

3.6.1 Publicly Funded PIs: Strategising, Competencies and Skill Mix

3.6.1.1 Strategising

The PIs have a vision of what should be done, and they have their own goals and expectations about how to leave a footprint in academia. They strategise their action, they resource their strategy and they shape organisations to reach their goals. For the individual scientist, our research highlights the need to have a clear scientific vision that has transformational intentions and to use a resourcing strategy to secure resources and collaborations. Publicly funded PIs are strategising themselves and using the program-based organisation of science and technology to resource and nurture their own strategy. PIs need to be proactive and selective about their resourcing strategy and consistently strategise about realising their scientific vision. Resourcing means convincing colleagues to collaborate with them and funding bodies to fund them, building alliances with other teams or researchers and investing in academic and/or industrial communities.

3.6.1.2 PI Competencies and Skill Mix

The skills a PI requires to be effective encompass managerial, leadership and strategic skills. Being an excellent scientist is just one competency that a PI requires. Effective boundary-spanning skills and being able to network effectively with a wide variety of stakeholders are essential and critical. PIs should look at ways of developing their managerial skills of planning, leading, organising and controlling that compliment their scientific skills. The combination of scientific and managerial skills and the knowledge of markets is necessary for publicly funded PIs to devise and implement public sector entrepreneurship policies.

3.6.2 Role Supports

3.6.2.1 Recognition of the Managerial Nature of the Publicly Funded PI Role

Among funding agencies and host institutions there needs to be a greater recognition of the managerial nature of the publicly funded PI role in the allocation of workloads, additional resources and for project evaluations. For scientists, the publicly funded PI role involves consistently acknowledging and highlighting the extent of the managerial tasks and challenges that they face within their own institution and to funding agencies. Also, scientists in the submission phase of competitive project proposals need to be realistic and understand the management challenges they will face and factor the necessary supports into project proposals. Moreover, they need to be unafraid to articulate credible transformative project ideas because of the more pervasive managerial constraints imposed by host institutions and funding agencies.

3.6.2.2 Structured PI Professional Development

To deal with the growing managerial demands of the publicly funded PI role, scientists require more structured and customised training and must be able to operate effectively in multiple environments. Such structured training with regard to business, entrepreneurship, knowledge and TT should also be a consistent feature of the educational transformation from undergraduate to doctoral level. Moreover, scientific training is mostly on the job and through companionship with mentors and senior scientists. Better identifying other practices and connecting these to personal scientific strategies contribute to the recognition of PIs as a transformational agent of public sector entrepreneurship within academia. Moreover, it ensures that as agents of public sector entrepreneurship, they can respond to and have the necessary tools to be effective in the realisation of outcomes.

3.6.2.3 Research Administration and Support

Recognising the necessity for project administration, greater consideration should be given by funding agencies and host institutions with regard to reporting templates, information needs, timing, etc. and having in place dedicated research support as part of projects. Publicly funded PIs are focused on complying with funder requirements; however, the rationale for transforming scientists into administrators is not obvious. To realise the potential of public sector entrepreneurship policies publicly funded PIs need appropriate levels of research support. Less optimal levels of research support have the potential to diminish project outcomes—scientific and economic and the potential common benefits for society.

3.6.2.4 Organisational Flexibility

The challenge for universities and other host institutions is how best to support high-performing and high-potential publicly funded PIs. How does an institution provide sufficient flexibility to publicly funded PIs to conduct their research projects and to implement their research programmes, while at the same time trying to implement its own scientific policy or to cope with accountability concerns.

While we talk about the craft of research management and leadership for the publicly funded PI, there may also be a craft to research management and administration for university research support professionals. This craft is required to manage the tensions between conformance and administration commitments, while maintaining a flexible university or institutional research environment. Further exploration of the characteristics that contribute to this craft is required.

3.6.3 Knowledge and TT

3.6.3.1 Effective TT Support

Publicly funded PIs need effective access to appropriate knowledge TT support. This access aids TT support. Without adequate and appropriate provision of TT services, publicly funded PIs can be significantly hindered in fulfilling their knowledge and TT project objectives that are necessary in realising potential economic prosperity.

3.6.3.2 Industry Links

Before taking on the role of PI, scientists should be encouraged to build local, national and international relationships with industry and this should be recognised in workload, career planning and promotion. In the mobilising of players to respond to public sector entrepreneurship policies, PIs are enabled to create scientific and industry networks that can effect potential economic prosperity and realise new sustainable market opportunities.

3.6.3.3 Resources for TT

Time and funding are the two major inhibitors of TT for PIs. Institutions can mitigate the time factor by providing publicly funded PIs with, for example, better levels of research support and allocations of workload. In terms of funding, systematic analysis should be undertaken to identify funding opportunities at the beginning of projects for publicly funded PIs. Also, it is necessary to identify appropriate public sector entrepreneurship instruments that will financially support different forms of knowledge and TT.

3.6.4 Funders and Policymakers

For policymakers the diversity of publicly funded PIs and their role in the implementation of public sector entrepreneurship science and technology policy objectives calls for ex ante differentiation of supporting schemes. It is important to design public sector entrepreneurship programmes where there are targeted research projects. Such programs may explore scientific bottlenecks, technological conditions to innovate, or methodological advances that benefit the whole community. It is also critical in the design of public sector entrepreneurship programmes to leave space for publicly funded PIs to take risks, to propose and discuss ambitious research programmes and to support unconventional ideas. This also involves high levels of risk and uncertainty, but also great transformational potential. Encouraging, developing, leveraging and managing such unconventional and original thinking from publicly funded PIs should further influence public sector entrepreneurship policy direction setting. This may require a new way of engaging with stakeholders collectively about the direction setting of public sector entrepreneurship programmes. As critical agents of public sector entrepreneurship, the voice and input of publicly funded PIs are vital. Each publicly funded PI has the potential to realise many of the desired outcomes of public sector entrepreneurship expected by funders and policymakers. We suggest that they need to be allowed and provided with more systematic means and consistent opportunities to become co-designers of public sector entrepreneurship programmes. They are the agents upon whose scientific originality public sector entrepreneurship programmes consistently rely, and have the potential to provide a sufficient transformational basis that can contribute to economic prosperity. Furthermore, in encouraging publicly funded PIs to develop their projects for different environments (scientific, TT, training, etc.), it is important to support publicly funded PIs to lead research teams with additional personnel to manage and administer projects effectively, delivering or exceeding expectations.

3.6.5 Opportunities for Future Research

We see that combining the emerging fields of research on public sector entrepreneurship and PIs holds great promise in unearthing a new understanding of publicly funded PIs as transformative agents of public sector entrepreneurship. More research is necessary into the themes explored in this chapter on publicly funded PIs—strategic behaviours, managerial challenges and knowledge and TT. Future research that focuses on what influences and shapes the thinking of public sector entrepreneurship policymakers in the areas of science, innovation, technology, enterprise and education is warranted and cross-country studies to examine the extent of the replication of "successful" public sector entrepreneurship policies, such as the SBIR programme from the USA. Furthermore, taking established research themes from the fields of strategic management and entrepreneurship such as entrepreneurial effectuation, entrepreneurial orientation, value creation, business models, strategic leadership, and applying these to emerging fields, public sector entrepreneurship and PIs have real potential in yielding new theoretical and empirical insights, and providing evidence that policymakers, PIs and supporting institutions can use in supporting scientists in the PI role who are shaping, influencing and implementing public sector entrepreneurship. Moreover, further research on how PIs scan in multi-environmental settings and what factors influence their transformational intent, activities and actions is necessary. We suggest that taking PIs as a unit of analysis for future studies might be an integral part of the development of empirical studies of public sector entrepreneurship.

Finally, in their concluding observations on public sector entrepreneurship Leyden and Link (2015:206) cite Vanneaver Bush (1945:2) with regard to scientific progress and pioneers:

> Science offers a largely unexplored hinterland for the pioneer who has the tools for his task.

Viewing publicly funded PIs as the contemporary pioneers suggests that more empirical research might be required to really understand if they have the "tools", as Bush describes, as transformational agents to realise fully the potential of public sector entrepreneurship programmes. Further empirical research on the impact of public sector entrepreneurship will provide a better understanding of how it influences the PIs as "pioneers" and the "tasks" they undertake as transformational agents of public sector entrepreneurship.

Acknowledgements The authors wish to acknowledge the funding support of the Irish Research Council and the Irish Social Sciences Platform funded under the Programme for Research in Third Level Institutions Cycle 4, administered by the Higher Education Authority and co-funded by the European Regional Development Fund (ERDF). We also wish to thank all of the PIs who participated in the study, either by completing the survey or participating in interviews conducted for the case studies. Finally, we wish to acknowledge the research support of Dr. Agnes Maciocha, Brendan Dolan and Chris Young for different aspects of this research programme.

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Chapter 4
An Innovation Policy Framework: Bridging the Gap Between Industrial Dynamics and Growth

Pontus Braunerhjelm and Magnus Henrekson

4.1 Introduction

> Often, in their eagerness to get to the "fun stuff" of handing out money, public leaders neglect the importance of setting the table, or creating a favorable environment.[1]

Innovation is increasingly considered the key to elevating prosperity and securing sustainable long-term growth. The last few decades have also witnessed a refinement of previous growth models to include investments in education by individuals and R&D by firms. Better educated individuals and increased expenditure on R&D are shown to result in increased innovation and accelerated growth in endogenous growth models. This finding has spurred policy makers, most recently the OECD, the European commission, and other organizations, to design innovation strategies to meet future growth and welfare challenges. Such strategies have also trickled down to the country level.

Financial support from Karl-Adam Bonniers Stiftelse, the Jan Wallander and Tom Hedelius Foundation, and the Marianne and Marcus Wallenberg Foundation is gratefully acknowledged. We are grateful for useful comments and suggestions on earlier versions of this paper from Bettina Peters, Scott Stern, and the participants at the ZEW Conference National Systems of Entrepreneurship in Mannheim, November 20–21, 2014.

[1] Lerner (2009, p. 12).

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D.B. Audretsch, A.N. Link (eds.), *Essays in Public Sector Entrepreneurship*,
International Studies in Entrepreneurship 34, DOI 10.1007/978-3-319-26677-0_4

Similar to the theoretical advances in modeling growth, an increasing number of empirical observations suggest that irrespective of modest R&D investments, small, entrepreneurial firms substantially contribute to aggregate innovation (Scherer 1965; Klienknecht 1989; OECD 2010). These empirical observations indicate that, such firms may exploit existing knowledge in different ways compared with older, more mature incumbents.[2] Moreover, these entrepreneurial firms increasingly emanate from industries that are traditionally considered less innovative, i.e., the service sector. Innovation among service sector firms generates new knowledge that is not necessarily reflected in aggregate R&D figures, such as new business models and new ways of organizing production, but is of considerable economic significance and rapidly adopted by other firms. Ikea, Starbucks, Ryanair, Virgin, and Walmart, as well as Apple and Microsoft in their early years, are obvious examples of innovative firms that have had a strong impact on the organization of other companies without being heavily committed to research, even though some of them have sizeable design and development departments. This new knowledge is sometimes produced independently and sometimes collaboratively with other firms and organizations. But the innovation process in start-ups radically differs from that in large, R&D-investing firms (Carlsson et al. 2009). In particular, these findings suggest that innovation and entrepreneurship, whether in incumbents or new start-ups, are inseparable phenomena.

Despite these new insights, the links between microeconomic dynamics and macroeconomic growth are still neither well conceptualized nor adequately modeled. At the micro level, a patchwork of research contributions stress that entrepreneurship and innovation critically depend on institutions relating to, such as education (Kuratko 2005; Béchard and Grégoire 2005), the labor market (Poschke 2013), taxes (Henrekson and Sanandaji 2016), and regional dimensions (Saxenian 1994), but this research neglects growth effects.[3] Mapping this analytically fragmented terrain in a comprehensive framework for growth and combining a dispersed and diverse microeconomic setting with the macroeconomic outcome remains unchartered territory. A constructive attempt to narrow this research gap is provided by Feldman et al. (2015), who distinguish between economic growth and economic development. Economic development, which is claimed to be associated with prosperity and quality of life, is considered a necessary condition for growth. Government policies can support economic development by acting as a "capacity builder" in different dimensions, including in entrepreneurial and innovative aspects. We find the distinction between growth and development promising and side with the view that providing a well-balanced support structure is imperative for entrepreneurship, innovation, and growth. Our approach,

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[2] As shown by Almeida and Kogut (1997) and Almeida (1999), small firms also innovate in relatively unexplored fields of technology. See also Rothwell and Zegveld (1982), Baumol (2004), and Ortega-Argilés et al. (2009).

[3] Ample evidence from previous research also suggests that small and new firms provide most of the new jobs and terminate fewer employees than large firms in downturns and that a positive correlation exists between entrepreneurship/small firms and growth (e.g., Braunerhjelm et al. 2010; Thurik and Tessensohn 2012; Haltiwanger et al. 2013).

however, is considerably more applied, emphasizing how incentives at the individual and firm levels influence macro level growth in advanced economies where basic institutions such as the rule of law and secure property rights are already in place.

Previous research thus suggests that to facilitate and further enhance the role of entrepreneurs in the innovation process, policies should be expanded to areas other than education and R&D outlays. Obviously, scientific findings or inventions have little value per se. The policy focus on R&D to boost innovation tends to neglect entrepreneurial processes where existing (or new) knowledge is combined with individual abilities in the search for new market opportunities. The entrepreneur is thus likely to play a potentially important role in transforming knowledge to growth, but for entrepreneurs to play such a role, the individual-opportunity nexus must be acknowledged in the design of policies (Acs et al. 2009; Braunerhjelm et al. 2010).

Consequently, a policy discussion focusing on a limited set of instruments or areas is inadequate. A far more fruitful policy question is the following: What policy measures (1) foster the creation of innovations with high inherent potential *and*, simultaneously, (2) provide the right incentives for individuals to create and expand firms that disseminate such innovations in the form of highly valued products?

This essay aims to provide an answer to this two-pronged question. This requires a broad approach; a narrow focus on knowledge creation (i.e., education and R&D) is insufficient. New knowledge is not automatically disseminated or transformed to innovations, expanding firms and valuable goods and services. Rather, this is conditional on institutions (regarding both policies/rules of the game and organizations) and incentives that promote productive entrepreneurship. A limited number of core policies thus seem critically important.

We stress that recognizing the importance of diffusing and exploiting knowledge investments opens a complementary policy field related to entrepreneurs, the expansion of firms, and the competence structure of supporting agents (e.g., financial market actors in different phases of the life cycle of the firm, legal advisors, and management specialists). This area of policy has been neglected in a growth context, but it is crucial for understanding the innovation process and the ensuing implications for growth policies (Braunerhjelm 2010).

Drawing on findings in other areas of economics, e.g., monetary and fiscal policies, we emphasize that innovation policies also require a credible and long-term framework that combines different areas of economic policies. Specifically, we suggest an innovation policy framework based on two pillars:

- *The accumulation, investment, and upgrading of knowledge*. The policy areas involved in this pillar relate to the institutions that are needed to encourage high-quality education at all levels, to prompt internationally leading universities and their research, to establish links between academia and the commercial sector, and to fund universities.
- *The implementation of mechanisms that enable knowledge to be exploited such that growth and societal prosperity is encouraged*. These mechanisms involve a completely different set of institutions, such as tax policies, the regulatory burden, competition, and the formation of clusters. These mechanisms also include policies that create environments and incentives for individuals to undertake entrepreneurial efforts, innovations, and firm expansion.

We will demonstrate what is required to integrate these two interdependent pillars in a coherent innovation policy framework. Without the accumulation, investment, and upgrading of knowledge, the second set of policies is likely to generate less value. Without the implementation of mechanisms that enable knowledge to be exploited, knowledge investments can be expected to yield little, if any, growth.

The remainder of the paper is organized as follows. In Sect. 4.2, we discuss why present models do not satisfactorily capture the forces that drive innovation and growth. In Sect. 4.3, we argue that growth must be connected to institutions and therefore that the challenge is to provide an institutional framework that connects knowledge and entrepreneurial effort in promoting growth. In Sect. 4.4, we identify the different agents with complementary competencies that are needed to initiate and sustain an innovation-driven growth process. In Sect. 4.5, we discuss what we consider to be the most important institutions and policy measures in this respect. Section 4.6 concludes.

4.2 What Drives Economic Growth?

We will draw on three research fields in explaining why present models do not satisfactorily capture the forces that drive innovation and growth. First, we will refer to previous and current growth models that have dominated in providing a basis for policy prescriptions. Second, the insights from the evolutionary economic models will be utilized. Finally, we consider the systems of innovation (SI) approach. Based on insights from these three areas, we will synthesize the findings regarding the institutional inferences that can be extracted concerning knowledge, innovation, and growth.

4.2.1 Past and Current Mainstream Growth Paradigms

Despite its advantages with respect to tractability and clarity, the original neoclassical growth model suffered from a major disadvantage: weak empirical support. The limited explanatory power was attributed to the accumulation of capital and labor; instead, an unexplained residual factor was identified as the main driver of economic growth, assumed to consist of new knowledge, both technological and organizational (Solow 1957; Denison 1968). Obviously, this is an unsatisfactory feature of the neoclassical model because the commercial exploitation of (scientific) ideas always requires resources. Since knowledge exploitation was viewed as "manna from heaven," policy prescriptions focused on optimizing the relationship between capital and labor to obtain equilibrium growth.

Romer (1986, 1990) endogenized investments in knowledge and human capital. Although firms invest in R&D to obtain a competitive edge, some of this knowledge spills over to a societal knowledge stock that augments productivity in all firms.

However, technology is not a pure public good; although a non-rival good, it is partially excludable. Even if capital and labor remain constant, increases in knowledge result in more rapid growth. Policy recommendations center on tax incentives and subsidies to increase knowledge (R&D) investments, even though empirical support is ambiguous. Rather, empirical studies indicate that knowledge is one, but far from the only, factor driving growth (Barro 1999; Jones 1995, 2011).[4]

Whereas the Romer model starts with a monopolistic market structure, much of the subsequent literature adopts a (temporary) monopoly framework where firms engaged in R&D races to create the next new product, which would give them a monopoly until the next race produced a new monopoly product. In Romer's stylized setting, firms introduce new varieties of goods, diluting profits and decreasing each firm's market share, whereas in the so-called neo-Schumpeterian models, the introduction of new varieties of goods with higher quality implies that firms have captured the entire market.[5] The monopoly position that firms attain if they succeed allows them to sell their products at prices higher than their production costs and to thereby recover their research outlays.

In the most recent vein of knowledge-based growth models, the focus is narrowed and better defined. Specifically, these models focus on the effects of technology-based entry on the innovativeness and productivity of incumbents and the implications of firm heterogeneity on creative destruction and growth (Aghion and Griffith 2005).[6]

Although the most recent models acknowledge the impact of factors such as competition and entry regulations, innovation is still considered a process where R&D is converted to new products, often in markets that are characterized by oligopoly or monopoly. Knowledge-based growth models are a sizeable step forward in understanding growth. However, the precise microeconomic mechanisms are still constrained by strong assumptions regarding how to define innovations and how innovations are connected to R&D investment.

4.2.2 The Evolutionary Economic Models

Nelson and Winter (1982) presented the first coherent model of industrial dynamics and growth in evolutionary economics. Their model builds on interacting dynamic processes that govern the way that an economy or an industry evolves. Most prominent among those are the mechanisms ensuring variation in product space, selection (market competition), and knowledge transmission over time (routines). Routines

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[4] For a detailed account of the weaknesses in the theory building of endogenous growth models, see Braunerhjelm (2011). See also Antonelli (2007) on the "economics of complexity."

[5] The neo-Schumpeterian models define entrepreneurs either in a very rudimentary way or in a way in which they have a highly specific role, e.g., discovering the next pharmaceutical blockbuster (Aghion and Howitt 1992; Segerstrom 1991; Grossman and Helpman 1991).

[6] See Aghion et al. (2013) for a survey.

are shown to be cost efficient, but they may change over time, i.e., a routine is characterized as a "pattern of behavior that is followed repeatedly, but is subject to change if conditions change" (Winter 1964, p. 263).[7] The evolutionary approach emphasizes the central role of a continuous selection of firms and products appearing in the market.

Moreover, scholars in this field have stressed the differences in routines between incumbents investing in R&D and firms adopting an "entrepreneurial routine" that exploits strategies other than R&D investments to achieve competitiveness. The chosen routine depends on technological differences across sectors (Dosi 1982; Nelson and Winter 1982; Malerba and Orsenigo 2000). In concentrated sectors characterized by considerable fixed costs, large incumbents drive R&D-based innovations. Moreover, appropriability conditions are important. Simultaneously, different routines work in sectors characterized by other technological opportunities that are more conducive to entrepreneurial endeavors (Winter 1984; Malerba and Orsenigo 1996).

The evolutionary economics approach includes many properties that characterize real-world economies, such as path dependence, adaptivity, feedback mechanisms, and varying firm age and size. Still, the models are vague regarding policy conclusions, and they are more concerned with determining how industries and technologies evolve over time than with identifying policies that promote growth and social welfare.

4.2.3 The Systems of Innovation Approach

A parallel literature—the SI literature—has had a considerable impact, although it is disconnected from the growth literature.[8] The SI approach emphasizes the necessary building blocks for innovation, the interaction between them, and the key players in the innovation system. Therefore, the organizational structure and composition of systems are emphasized, where government organizations or semipublic bodies often are the centerpieces.

A major weakness is that the SI literature rarely considers the market mechanism and the importance of the incentive structure. Instead, the innovation process is analyzed, often with an emphasis on the importance of interactive learning among key agents. The profit-driven firms or entrepreneurs that are the vehicles for transforming knowledge into innovation and welfare-enhancing goods and services are basically absent. The policy focus is on interventionist technology measures, predominantly with a national perspective, despite the increasingly global character of knowledge. Competition is viewed with skepticism.[9]

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[7] See Orsenigo (2009) for a survey.

[8] The seminal studies are Freeman (1987) and Lundvall (1992). The concept originates in List's (1841) "national production systems."

[9] In his survey of the extensive research on SI, Carlsson (2007) shows that the overwhelming majority of studies address invention rather than innovation, and no more than 2–3 % of the studies

The solutions proposed within the SI approach are often referred to as institutions by its proponents. Still, the term "institutions" is almost always used as a synonym for the organizations constituting the system rather than "the rules of the game in society" (North 1990). Edquist (2011) argues that the institutions in the latter sense should be included. He claims that (p. 1739) "…it is important to ascertain that existing institutions are appropriate for promoting innovation and to ask the same question of how institutions should be changed or engineered to induce innovations of certain kinds." However, Edquist provides no indication regarding how pertinent institutions should be designed to promote innovation.

Edquist (2011) also asserts that the performance of an innovation system should be measured, but according to him (p. 1741), "output is—simply—*innovations*." As empirical proxies, he suggests the share of firms that have introduced a process or product innovation in the last three years (new to either the firm or the market) and the share of total turnover attributable to new or significantly improved products. The difficulties in measuring innovation are well known, and subjective evaluations by incumbent firms can be questioned for numerous reasons.[10] Thus, the extent to which these innovations translate into economic activity through entrepreneurship is ignored; individual agency is ignored.[11] Neither is the feedback from the rate of return on innovation leveraged by entrepreneurship back to new innovation (Holcombe 2003) discussed.

Yet, we share the conclusion drawn from the SI approach that investment in R&D alone is insufficient to boost innovation, and the lack of a positive correlation between aggregate measures (as measured by the EU Innovation Index) of innovation and growth (Fig. 4.1) at the macrolevel supports the insufficiency of such a strategy.

Acs et al. (2014a, p. 479) instead propose a "National System of Entrepreneurship" approach:

> A National System of Entrepreneurship is the dynamic, institutionally embedded interaction between entrepreneurial attitudes, activities, and aspirations, by individuals, which drives the allocation of resources through the creation and operation of new ventures.

This approach is a considerable improvement over the SI approach, but in our view, it is insufficient. The institutional variables that are used, such as technology absorption, gender equality, R&D spending, and depth of capital markets, are not institutional variables; they are outcomes resulting from the evolution of the economic system in a given institutional setup. Although Acs et al. focus on key components of the system, a more explicit analysis of key institutions governing the incentives of the individuals and organizations involved in the innovation and subsequent entrepreneurial exploitation is necessary.

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surveyed discuss entrepreneurship. Less than 3 % of the SI studies address output criteria such as the effect on productivity, rate of growth, rate of innovation, and patenting.

[10] See Gault (2013), Hall (2011), and OECD (2010) for reviews of the literature. Hall's preferred measure of innovation is TFP growth.

[11] Hung and Whittington (2011) are a partial exception, although their point is somewhat different. Hung and Whittington indicate that SI can become self-reproducing "systems of inertia," which can sometimes be escaped through institutional entrepreneurship.

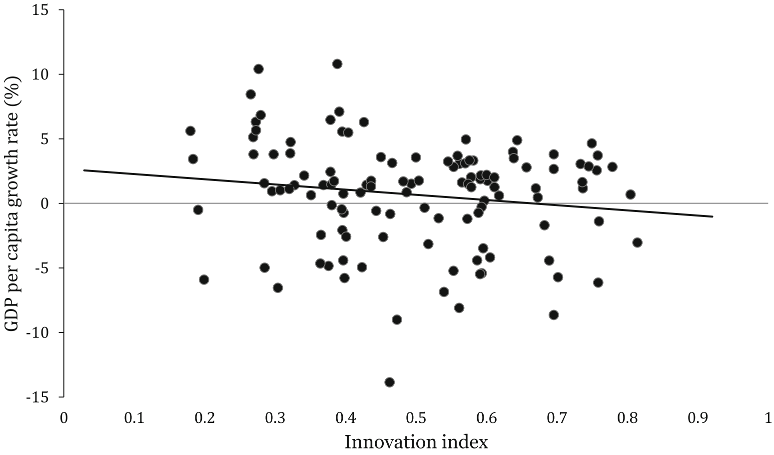

Fig. 4.1 Economic growth and the rate of innovation in EU countries, 2006–2010. *Source*: Braunerhjelm (2012)

4.3 Linking Growth to Institutions

Where does this brief account of the major theoretical contributions leave us concerning implications for policy and institutional design? The theories differ in their policy priorities, each focusing on a limited number of growth-stimulating measures. However, the policy conclusions are derived from a highly stylized setting whose definition requires both strong assumptions and the exclusion of pertinent aspects. Innovation requires a broader perspective than policy aimed at knowledge investment, encompassing the entire spectrum of processes and activities involved—from basic schooling to research, innovation, entrepreneurial venturing, and large-scale industrial production and distribution.

The decisive role of institutions protecting ownership and providing a "rule of law" for society has been convincingly demonstrated (North 1990; de Soto 2000; Baumol 2002; Rodrik et al. 2004; Acemoglu and Johnson 2012). Our analysis pertains to high-income countries where the rule of law applies, where private property rights are reasonably secure, and where financial markets are deregulated. Therefore, we will not address these factors further. Rather, we will focus on the determinants for how new discoveries—and new combinations of old discoveries—are transformed into innovations and subsequently are converted to new and growing firms. To obtain the full social benefits of knowledge, we identify the institutions that are required to attain a general level of knowledge necessary to be globally competitive and to diffuse this knowledge in the form of innovative entrepreneurship and high-growth firms (HGFs).

The subsequent analysis will clarify that, for example, even if financial markets are fully deregulated, other institutions, such as the tax system or rules governing pension savings schemes, may influence how well financial markets can fulfill their role in financing innovative entrepreneurship. A general conclusion is that multiple institutions interact in complex ways, either reinforcing or abating the total effect.

Generally, we agree with, among others, Baumol (2010), Lazear (2005), and Carree and Thurik (2010) that entrepreneurship or the entrepreneurial function can effectively be considered a distinct factor of production. In line with Wennekers and Thurik (1999, pp. 46–47), we define entrepreneurship as the ability and willingness of individuals, on their own or in teams, inside and outside existing organizations to:

- Perceive and create new economic opportunities (new products, new production methods, new organizational schemes, and new product market combinations).
- Introduce their ideas in the market, in the face of uncertainty and other obstacles, by making decisions regarding location, form, and the use of resources and institutions.

In addition, we postulate that entrepreneurs should have ambition to grow the resulting venture.

The entrepreneur often "creates" the capital of the firm by investing in tangible and non-tangible assets that, in time, create a return, such as developing a product and building firm structures. This capital requires a continued commitment on the part of the entrepreneur. The entrepreneur is rewarded for exerting effort and for postponing the consumption of firm equity into an uncertain future. Successful entrepreneurial firms require several components that are difficult or nearly impossible to purchase externally, such as product or business ideas, sufficient managerial skills to implement innovations, and commitment to exert time and effort to realize an uncertain outcome.

The challenge is to provide an institutional framework that connects knowledge and entrepreneurial effort in promoting growth. To facilitate such a connection, the Schumpeterian entrepreneur must be given a central role in the growth process. Uncertainty, search, and experimentation are crucial aspects of the innovative process, and the outcome of this process is determined by a combination of the individual's cognitive and noncognitive abilities and the given opportunity space, the latter of which is shaped by the institutional system. Disregarding these aspects indicates that substantial knowledge creation concerning innovation and economic growth is neglected.

4.4 Key Agents in Turning Knowledge into Entrepreneurial Venturing and Large-Scale Production

To create a large knowledge base that translates into significant knowledge-based commercial activity, many crucial steps are involved. Fundamentally, the right incentives must be in place at all levels for individuals to invest in valuable human capital. We will return to the incentive structure in detail in Sect. 4.5. In this section, we will discuss the individual's choice, the key actors, and the importance of matching the right competence provider with the firm's needs in different phases of the entrepreneurial process.

4.4.1 From Educational Choice to Knowledge-Based Entrepreneurship

Successful entrepreneurs in the USA tend to have a far more advanced education than average, and they must be able to recruit highly competent people to grow their firms.[12] Potential entrepreneurs face several educational and career choices, especially early in life. If the incentives to seek advanced education are weak or erroneous, individuals risk making choices at many junctures that render acquiring the type of knowledge that is valuable to entrepreneurial firms more difficult.

The first strategic choice facing an individual occurs in high school when the individual decides whether to enter the labor market or to proceed to university. If the individual enrolls in a university, he or she faces a choice between science- and technology-based disciplines (or STEM fields—science, technology, engineering, and math)[13] and other areas. At graduation, the natural science graduate can again choose between employment and graduate studies with the objective of obtaining a Ph.D. After receiving a Ph.D., the individual faces yet another choice between a university career and other employment.[14]

Successful entrepreneurial ventures are often highly dependent on academically trained and motivated individuals. Several other sources are important for recruiting people to knowledge-based entrepreneurship, such as the pool of individuals with either a graduate or an undergraduate degree, individuals with such an educational background working at other firms, and, in some cases, even university faculty.

Figure 4.2 shows that many links must function efficiently for knowledge-based entrepreneurship to flourish. First, incentives to invest in human capital at the university level must be present (1a, 1b, 1c). Second, incentives to become involved in knowledge-based entrepreneurial ventures must exist (2a, 2b, 2c, 2d, 2e). Third, incentives in the university system must be present to adjust the lines of study to demand in the private sector and to facilitate the transfer of knowledge from academia to the entrepreneurial sector. This third factor can be expected to have complex repercussions throughout the entire decision tree depicted in Fig. 4.2. The incentives in the university system will directly influence the propensity of faculty to become involved in entrepreneurial ventures (2a), but it will also affect students' educational choices (1b, 1c, 3).

Thus, it must be beneficial to acquire productive knowledge that is subsequently used intensely. Income taxes, wage differentials, a well-designed social insurance system, and an efficient service sector facilitating specialization are important components that we will address below.

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[12] See Henrekson and Sanandaji (2014) and the references in Sanandaji (2011).

[13] Recent research has documented that worker knowledge in the STEM fields is particularly important for economic growth. This result also holds for workers without a college degree. See Rothwell (2013) for an overview.

[14] The evidence suggests that, in most cases, it is not advisable for faculty to become entrepreneurs. There are few cases where faculty have transitioned to an entrepreneurial career with great success (Åstebro et al. 2013). Instead, it is often preferable for former students to start firms and for faculty members to assume advisory positions in these firms.

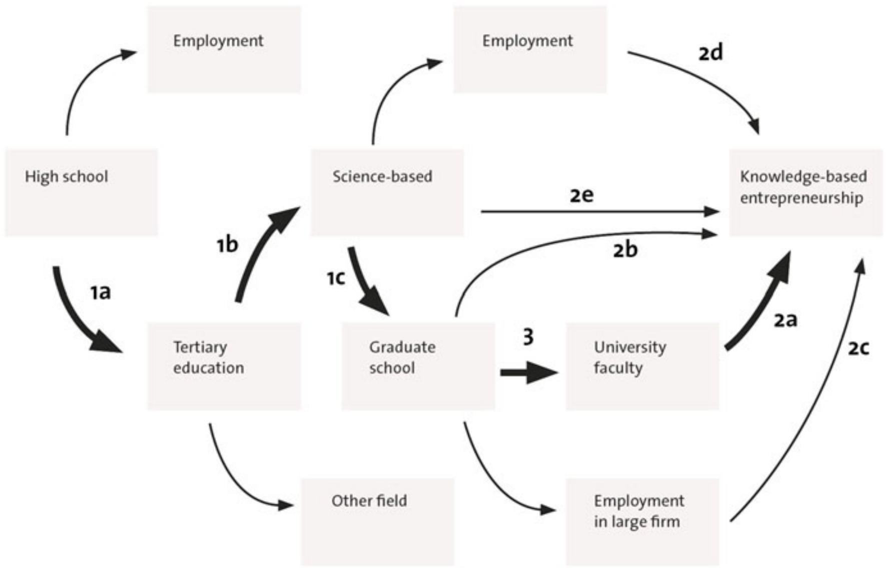

Fig. 4.2 From educational choice to knowledge-based entrepreneurship. *Source*: Adapted from Henrekson and Rosenberg (2001)

4.4.2 From Innovation to Large-Scale Production: The Crucial Agents

The development of a successful firm requires the combination of many complementary agents—a competence structure—each contributing key competencies. Entrepreneurship is vital,[15] but other agents, including early stage financiers (business angels and venture capitalists), industrialists, inventors, innovators, skilled labor, competent customers, actors on secondary markets (notably buyout firms, portfolio investors, and management buy-ins), and other support agencies, are also important (see Fig. 4.3). Successful venturing that generates rapid growth is a function of how well the different agents acquire, update, and jointly use their respective competencies. The opportunities and incentives for success are largely determined by the institutional structure.

The first phase of commercialization (introduction and early growth of firms) involves entrepreneurs, whereas skilled workers often are involved only to a small extent. Industrialists are active in the phase of industrialization and rapid growth, which requires a significant amount of skilled labor. Business angels and venture capitalists are important financiers in the earlier phases. In later phases when the firm is larger, agents in secondary markets also play the role of financier. Figure 4.3 is a simplification. For example, industrialists and secondary-market agents may

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[15] The introduction of new ideas to and the (possible) subsequent development of the original innovations in large-scale businesses generally require two separate competencies (Baumol 2004).

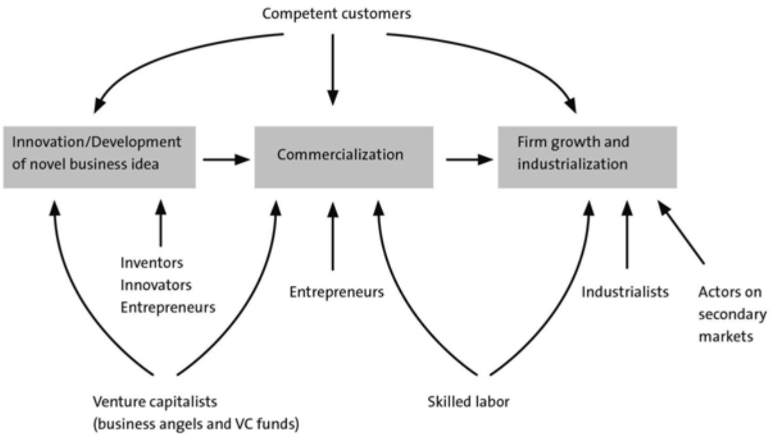

Fig. 4.3 The roles and interaction of different agents in the commercialization process. *Source*: Henrekson and Johansson (2009)

also be involved in an earlier stage, and one person can fill several functions. Competent customers are typically involved in all phases, and they ultimately (with other customers) determine the demand for goods.

The development of a successful firm thus requires many key actors with complementary competencies who interact to generate, identify, select, expand, and exploit new ideas to satisfy consumer preferences more efficiently.[16] When the competence structure is complete, the complementary competencies of these actors will produce a dynamic process of creative destruction—channeled through firm entry, expansion, contraction, and exit—which causes structural transformation in the perennial struggle between new and old structures.

Successful entrepreneurship and firm growth are a function of how well these actors, with their different skills and competencies, acquire and use their competencies in ways that render reaping the benefits of the complementarities possible. To exploit complementarities, appropriate institutions that *harmonize* the incentives of the different types of actors are necessary. Hence, different skills and expertise with an institutional structure conducive to risk taking and experimentation are required.

Figure 4.4 outlines the central phases in the evolution of an entrepreneurial firm in the typical case when the founder-entrepreneur does not have sufficient funds of his own to finance the development of the firm until it can be sold to outside parties.

A new firm based on a unique idea is typically started by one or several founders who are carriers/owners of the innovation and the concomitant tacit knowledge necessary to launch the firm. If a firm is in a high-tech sector or if the firm is based on a truly novel idea, the risk associated with engaging in a new venture is extremely

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[16] To our knowledge, the idea concerning the importance of complementary competencies to generate growth was first recognized by Gunnar Eliasson (e.g., Eliasson 1996). Henrekson and Johansson (2009) explicitly use this framework to analyze the effects of a wide array of policies on high-growth firms (HGFs).

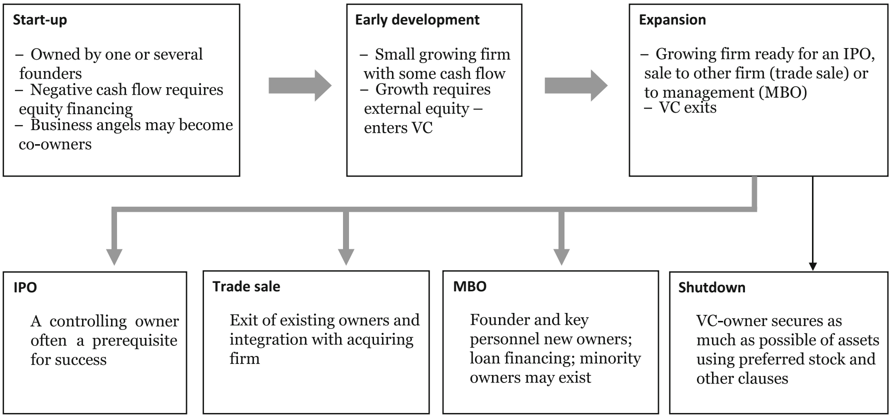

Fig. 4.4 Central phases in the evolution of an entrepreneurial firm. *Source*: Henrekson and Sanandaji (2016)

high.[17] Even when the firm is eventually a success, it usually takes a long time before the finished product is introduced to the market and longer still before the cash flow becomes positive. In each phase, typical problems must be managed.[18] The risks involving innovative entrepreneurship are rarely calculable by either the founder or external investors (Knight 1921). This situation contrasts with portfolio investments in public firms where historical data offer a basis for calculating the expected risk-return relationship.

A production factor that is used in a certain highly specialized activity is relation specific, i.e., it can rarely be reallocated to another activity without incurring substantial costs (Caballero 2007). Thus, the value of such a production factor is contingent on its continued use in precisely its specialized activity, i.e., where it has developed and honed its unique competencies.

For our purposes, the most relevant example of relation-specific assets arises when an entrepreneur/founder starts financing his firm by raising equity from external investors. Because of the founder's superior information, specialist knowledge, and de facto control of the company, the investors' investment becomes non-fungible. The value of the external investors' equity would decrease significantly if they ousted the founder. Moreover, the founder must recruit key personnel who will make highly relation-specific human capital investments.

The high degree of uncertainty and asset specificity in innovative entrepreneurial ventures render formulating explicit contracts that provide all parties the right incentives to build relation-specific assets virtually impossible. It becomes especially important to protect oneself against opportunistic behavior by other parties,

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[17] Three-fourths of all American entrepreneurs receiving VC funding ultimately get a zero rate of return (Hall and Woodward 2010).

[18] Much has been written about the challenges and vagaries facing entrepreneurial firms and the high risks involved. See Gompers and Lerner (2001) for an easily accessible text.

e.g., the risk that the founder or other key personnel are outmaneuvered by the external owners and forced to leave the firm prematurely.[19]

Therefore, contractual devices that make ownership and control contingent on (unpredictable) future outcomes are decisive for orchestrating entrepreneurial success. The high transaction costs and non-calculable risks often necessitate equity financing.[20] Further, very few founders have the financial means to finance the venture until the point at which the cash flow turns positive or the degree of uncertainty has fallen sufficiently to make the firm creditworthy. One way to compensate for these problems is soft loans from public bodies. However, scientific evaluations of such schemes are seldom encouraging.[21] One reason for the weak scientific support for these schemes is that politicians are often tempted to establish such programs to solve other pressing problems, such as helping an ailing industry or an impoverished region.

As will be discussed more fully below, appropriately designed stock options are a powerful instrument to build firms and attract and retain key personnel. However, the use of stock options presupposes appropriate tax rules.

4.5 Key Institutions in Linking Knowledge to Innovative Entrepreneurship and Growth[22]

Wealthy countries have factors that are customarily identified to be crucial for development, such as the right to education, the rule of law, reasonably secure private property rights, and well-functioning financial markets.[23] Thus, further discussing these factors is unlikely to substantively advance our understanding of the effects of institutions on entrepreneurship and innovation-based firm growth.

We emphasize a selected number of institutional areas that we define as particularly important for promoting innovation, entrepreneurship, and, ultimately, growth. In selecting these areas, we start out from our two building blocks of growth: knowledge and the diffusion of knowledge. This approach leads us to examine skills and human capital (education and research, i.e., the knowledge base), the labor market (diffusion and allocation of knowledge), other regulations (diffusion of knowledge and entry barriers), taxes (incentives to invest in education and enterprising), financing (diffusion of knowledge and entry barriers), and agglomeration (diffusion of knowledge).

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[19] For an in-depth analysis of the effects of incomplete contracts, see Bolton and Dewatripont (2005, Ch. 11).

[20] Debt financing is problematic in this case, since firms have neither assets that can be used as collateral nor a positive cash flow. Asymmetric information and the tendency among entrepreneurs to overestimate the future prospects of their start-ups also contribute to the difficulties of obtaining bank financing.

[21] See Lerner (2009) and Sandström et al. (2014) for a survey of the literature.

[22] Research on the welfare effects of regulations or institutions originated in Pigou's (1938) work on "public interest theory." The basic idea is that unregulated markets will give rise to market failures that require the imposition of regulations. Subsequent research has questioned these insights (Coase 1960). In particular, public choice theory has emphasized the negative effects of vested interests, rent seeking, and regulatory capture (Tullock 1969; Stigler 1971; Peltzman 1976).

[23] See Rodrik et al. (2004) and Levine (2005).

Below, we discuss the most relevant policies and institutions in detail. Throughout this discussion, we try to remain concrete and to connect the discussion to the analysis of different models and approaches above.

4.5.1 Incentives in the Educational System[24]

Policies intended to facilitate technology transfer exist in the larger context of their respective university systems. In contrast to the university systems in most European countries, the American university system is decentralized and intensely competitive. American universities retain a high degree of autonomy; thus, they can pursue opportunities to solve their own problems and to build on their own unique strengths and aspirations. Competition occurs along several dimensions: (1) competition among universities for students and, at the graduate level, among professors for the best students; (2) competition among universities for the best professors in a cultural and economic context where mobility is high; and (3) competition among professors for research support, which provides time away from teaching and access to complementary resources.

The US university system thus seems more responsive to the economic needs of society than the university systems in most European countries. To justify high tuition fees, students expect a high degree of relevance of the offered curricula. Likewise, professors who are dependent on research are more likely to adjust their research to fields that have high economic value (Rosenberg 2000).

Decentralization and competition in the American system result in greater salary dispersion, where salary differences likely reflect the economic relevance of the professor’s field and his/her achievements in research and teaching. Entirely new fields and major breakthroughs in established fields have been rapidly introduced to the curricula of leading US universities over the years.

By contrast, most European university systems are highly centralized. Universities tend to be government owned, and entry of private universities is disallowed or highly restricted. The government typically grants charters to universities and determines the rules of admission and the size of universities (through budgetary allocations), as well as the size of specific fields of study. Such control permits less flexibility for individual institutions to allow remuneration to track an individual professor’s research and teaching performances more closely and to vary the level of remuneration according to the economic value of the professor’s field. Greater centralization also renders adjusting the allocation of research budgets across fields in response to changing demand outside the university more difficult for individual universities.[25]

With respect to the specific role of universities as suppliers of trained personnel in appropriate fields of study, timing is crucial. In competitive world markets, large economic rents are commonly available to those firms (and those countries) that can quickly respond to economic opportunities that are created by new technologies or

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[24] This section draws on Henrekson and Rosenberg (2001, section 1).

[25] For an example, see Jacobsson et al. (2001) who document the slow response of the Swedish university system to the sharp increase in demand for training in electrical/electronic engineering and computer science in the 1970s and 1980s.

new disciplines. Late arrivals are likely to find that the large financial rewards have already been acquired because competitive forces have driven down prices.

In European countries, university degree requirements are typically formulated as a fixed program rather than a flexible accumulation of requirements and credits, as in the USA. In the European system, making changes is therefore more difficult.

4.5.2 The Tax System

The extent and design of the tax system affects the net return to entrepreneurship both directly and indirectly. The tax system determines a potential entrepreneur's risk-reward profile and, consequently, his or her incentives for undertaking entrepreneurial activities. Even if nonpecuniary rewards that are unaffected by taxes (such as autonomy and individual flexibility) also matter, the financial effects of taxation cannot be neglected. Extensive research has analyzed the theoretical and empirical effects of the tax system; however, its effects are often complex and sometimes counterintuitive.

From a theoretical point of view, the tax system affects entrepreneurial activity through a variety of mechanisms. The theoretical literature identifies four main effects: (1) an *absolute effect* influencing the supply and effort of potential entrepreneurs in the economy; (2) a *relative effect* influencing an individual's choice of occupation and organizational form; (3) an *evasion effect* influencing the willingness to become an entrepreneur to exploit opportunities to decrease the tax burden; and (4) an *insurance effect* influencing the amount of risk that people are willing to assume and, therefore, the likelihood that people undertake entrepreneurial activities.

The absolute effect renders starting or expanding a business more expensive; an absolute increase in the taxation of entrepreneurs lowers the (expected) after-tax reward. Increased taxation also makes expansion financed by retained earnings more difficult and negatively affects the liquidity position of entrepreneurs. Lower after-tax returns and higher expansion costs discourage entrepreneurial activities and impede the emergence of new start-ups and the expansion of firms.[26]

Taxation may also alter the relative return of different activities if it favors one form of employment over another. Thus, a higher tax rate may encourage income shifting and may positively influence (some form of) entrepreneurship in the economy.

The evasion effect arises if evading taxes on entrepreneurial income either illegally or legally is easier than paying them. Evading taxes is often easier for self-employed entrepreneurs;[27] self-employed entrepreneurs may be able to underreport income by neglecting to register cash sales, overstate costs by recording private expenses as business costs, or use informal agreements that are difficult for the tax authority to verify.[28] Higher taxes may therefore encourage self-employment. When a business expands above a certain level, it becomes more difficult to exploit tax avoidance opportunities.

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[26] See, e.g., the discussion in OECD (1998).

[27] See, e.g., Long (1982) and Pestieau and Possen (1991) for a discussion of tax evasion and choice of occupation. Robson and Wren (1999) conclude that the average tax rate affects evasion behavior.

[28] A Swedish study estimates that the self-employed underreport their income by 30 % (Engström and Holmlund 2009).

Finally, regarding the insurance effect, taxation (with full loss offset) functions as insurance that stimulates risk taking (Domar and Musgrave 1944). With respect to entrepreneurship, increased tax on the net return with full loss offset will reduce the after-tax variance of profits and therefore the risk associated with the business. If potential entrepreneurs are risk averse, this risk reduction may stimulate entrepreneurship.[29] The insurance effect also assumes a proportional tax rate with full loss offset. Given that entrepreneurial income is more variable than salaried income, the average tax will be higher for entrepreneurs in a progressive tax system. A progressive tax system with imperfect loss offset therefore deters entrepreneurial business entry (Gentry and Hubbard 2000).

Many studies in this field often analyze the effect of a specific tax, such as the tax on earned income. One should analyze taxes on entrepreneurial income, however. Yet, no specific tax on income from entrepreneurial effort exists in practice. From a tax perspective, entrepreneurial income can be taxed in many different forms, including labor income, business income, current capital income (dividends and interest), or capital gains. These taxes may affect entrepreneurial activities differently. A thorough analysis of the effects of taxation on entrepreneurship must disentangle these effects.

Moreover, much of the entrepreneurial function is conducted by employees without an ownership stake in the firm, for whom the earned income tax schedule is applicable. For these categories, a high tax on earned income may have negative incentive effects on entrepreneurship.

Regarding capital and corporate taxation, a high tax rate on business profits discourages equity financing and encourages debt financing (Desai et al. 2003; Huizinga et al. 2008). To the extent that debt financing is less costly and more available to larger firms, high corporate tax rates coupled with tax-deductible interest payments disadvantage smaller firms and potential entrepreneurs (Davis and Henrekson 1999). Taxing corporate profits also reduces the amount of retained earnings that can be used to expand the existing venture. Further, taxing profits in small firms often leads to lower growth rates (Michaelas et al. 1999). A high tax rate on dividends encourages the reliance on retained earnings for financing expansion. Such a tax rate punishes new ventures, locks in retained earnings, and traps capital in incumbent firms. Therefore, a high tax rate on dividends obstructs the flow of capital to the most promising projects because it favors incumbent ventures (Chetty and Saez 2005).

Most of the economic return from successful high-impact entrepreneurial firms materializes as steeply increased market value rather than dividends or large interest payments to the owners. Thus, the taxation of capital gains on stock holdings greatly affects the incentives for potential high-impact entrepreneurs (Cumming 2005; Da Rin et al. 2006). Successful entrepreneurs are also highly sensitive to wealth, property, and inheritance taxes.[30]

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[29] A recent discussion of this effect is provided by Cullen and Gordon (2007). In practice, no tax system has full loss offset.

[30] Certain assets are exempted from taxation in many countries, such as corporate wealth or pension savings, and the imputed value used as the basis for assessments is often based on arbitrary accounting rules. These rules may encourage (such as the corporate wealth exemption) or discourage (such as the pension savings exemption) investments in entrepreneurial activities. See Rosen (2005) for an overview.

Stock options can be used to encourage and reward individuals who supply key competencies to a firm. In ideal circumstances, stock options provide incentives that closely mimic direct ownership. The efficiency of stock options greatly depends on the tax code. If gains on stock options are taxed as wage income, some of the incentive effect is lost—particularly if the gains are subject to (uncapped) social security contributions and if the marginal tax rate on wage income is high.

The situation changes dramatically if an employee with stock options can defer the tax liability until the stocks are eventually sold. The effectiveness is further reinforced if the employee suffers no tax consequences on the granting or the exercise of the option and if the employee is taxed at a low capital gains rate when the acquired stock is sold (Gilson and Schizer 2003).

The tax systems of many countries evolved before complicated ownership structures involving private equity (venture capital [VC] and buyout firms) financing existed. Private equity (PE) ownership involves layers of ownership: private ownership stakes by founders and key personnel, an ownership share by the PE firm, an ownership stake by PE partners (often indirect), an investor stake in the PE fund, and final beneficiaries of institutions investing in PE funds. Sophisticated mechanisms were initially needed to provide high-powered incentives for many actors in addition to the final equity holders. In fact, the modern VC industry in the USA could not evolve until the tax system was changed in key respects. Sharp reductions in the capital gains tax and stock option legislation in 1981 allowed the tax liability to be deferred to the point when stocks were sold rather than when the options were exercised. In addition, new legislation in 1979 allowed pension funds to invest in high-risk securities that were issued by small or new companies and VC funds (Misher 1984; Fenn et al. 1995).

To calculate the total effect of taxation, one must consider the specific rules for depreciation and valuation in corporate taxation and the taxation of interest income, dividends, capital gains, and wealth. The effective total tax rates also depend on the ownership category.[31] In many developed countries, business ownership positions that are directly held by individuals and families have been taxed more heavily than other ownership positions. The wave of tax reforms that swept the OECD in the 1980s resolved many of these differences.[32] The differences that still persist, however, provoke an endogenous response in the ownership structure of the business sector to the tax-favored owner categories.[33] If individual stock holdings are disfavored relative to institutional holdings and if institutions are less willing to invest in small and new entrepreneurial projects, entrepreneurial activity would be discouraged.[34]

Table 4.1 summarizes our analysis of the tax system and outlines a tax system design that promotes innovative entrepreneurship.

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[31] These types of highly complicated estimates have been made for many countries using the methodology developed by King and Fullerton (1984).

[32] Jorgenson and Landau (1993).

[33] Rydqvist et al. (2014).

[34] Henrekson and Johansson (2009).

Table 4.1 Key characteristics of a tax system favoring innovative entrepreneurship

Type of tax
Low personal tax on capital income
Low personal tax on long-term capital gains
Low tax on stock option gains not due until eventual exit
Tax neutrality across owner categories
Tax neutrality across sources of finance
No wealth taxation of asset holdings or exemption for equity holdings
Effective corporate tax rate neutral across types of firms and industries
Symmetric tax treatment of profit and losses

4.5.3 *The Organization of Labor Markets*

The way that labor markets are organized and regulated affects labor mobility. This effect on labor mobility may have repercussions for unemployment, workforce participation, and aggregate demand, which in turn may affect growth. Moreover, labor mobility may affect productivity and innovation. Caballero and Hammour (2000) stress that "constrained contractual capabilities" in labor markets (and in the financial system) may inhibit the process of creative destruction.[35]

Mobility increases productivity at the firm level (Nicoletti and Scarpetta 2003; Bassanini et al. 2009; Andersson and Thulin 2008). The proposed reasons for this increased productivity are a better match between firms' needs and the skills of labor (Bessen and Maskin 2009), the spillover of knowledge embodied in labor, and extended externalities related to network spillovers (Powell et al. 1996; Zucker et al. 1998; Song et al. 2003; Hoti et al. 2006). As new knowledge, embodied in labor, enters the firm, established processes and methods are challenged. New knowledge provides new insights, increases efficiency and productivity, and leads to potential new business opportunities.

A recent empirical strand in the literature specifically examines how innovation performance (defined as patent applications) is affected by labor mobility. Kaiser et al. (2011) and Braunerhjelm et al. (2014), implementing similar employer-employee datasets for Denmark and Sweden, conclude that firms' innovative performance is considerably improved as labor mobility increases. Overall, research in this field, although limited, suggests that labor mobility has a positive effect on invention and innovative behavior.[36]

Scarpetta and Tressel (2004) present evidence suggesting that labor market regulations negatively influence the incentives to engage in innovation and technology,

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[35] See also Djankov et al. (2002), Desai et al. (2003), and Shleifer et al. (2008).

[36] One exception is Cassiman et al. (2011) who show that participation in joint ventures is more conducive to innovation than labor mobility.

which can be expected to have a negative effect primarily on innovation in smaller firms. Micco and Pagés (2006), Autor et al. (2007), and Kugler and Pica (2008) all report a slower restructuring of the economy and a negative impact on entry when labor markets are more regulated. Similarly, studies on the determinants of foreign direct investments find a negative effect of regulated labor markets (Javorcik et al. 2006; Gross and Ryan 2008).

Entrepreneurs establish new firms to commercialize new combinations. If successful, these firms expand, while others will stagnate or exit. Similarly, existing firms are continuously challenged by—and challenge—new and existing competitors. If successful, these firms expand, if not they contract and eventually exit. This dynamic process of creative destruction—channeled through firm entry, expansion, contraction, and exit—causes structural transformation. A successful economy ultimately exhibits disproportionate growth of high-productivity firms relative to other firms.

Extensive churning is a pervasive trait of all OECD economies (Martin and Scarpetta 2012). Remarkably, 80 % or more of the reallocation of workers occurs in narrowly defined sectors of the economy in developed countries (Caballero 2007). There are two basic drivers for this reallocation: (1) adjustment among firms with different technologies and (2) experimentation with improved products, management, and so forth. Moreover, excess job reallocation rates are higher for newer firms because of greater uncertainty, more experimentation, and higher variance in the quality of the goods produced.

The empirical findings regarding churning and restructuring provide evidence that strict employment security provisions and other regulations that restrict contracting flexibility are more harmful to enterprises that would like to grow rapidly than to mature firms and firms without growth aspirations. Both the rate at which workers separate from jobs and the rate at which employers eliminate job positions decline with the size, age, and capital intensity of the employer (Bartelsman et al. 2004). Hence, a low level of labor market regulations increases the flexibility of high-risk entrepreneurial companies, rendering the evolution of new companies to HGFs more likely. Figure 4.5 illustrates this tradeoff by depicting the relationship between the strictness of employment protection and the rate of high-growth expectation, early stage entrepreneurship. The figure clearly shows that stricter employment protection is associated with a lower share of early stage entrepreneurship.

Generous, far-reaching employment protection legislation increases employees' opportunity cost of changing employers or leaving a secure salaried job to become an entrepreneur. Given that initiatives resulting in HGFs often require a change of workplace, far-reaching employment protection legislation should be avoided.

Additionally, very small firms may be able to avoid unionization and the signing of collective agreements, and they therefore benefit from greater freedom of contracting. Such freedom is likely lost once the firm size exceeds a certain threshold. Therefore, these evasive measures do not help HGFs and are not instrumental in promoting welfare-enhancing structural transformation.

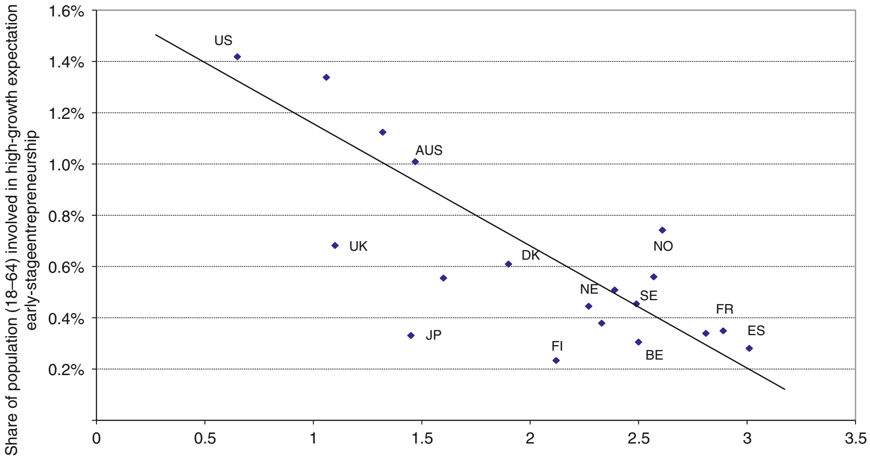

Fig. 4.5 Strictness of employment protection and high-growth expectation, early stage entrepreneurship. *Note*: Employment protection refers to the 2004 OECD index (version 2), and high-growth expectation, early stage entrepreneurship is the average over the 2004–2009 period according to the Global Entrepreneurship Monitor (GEM). $R^2=0.57$. *Source*: Bosma and Levie (2010)

Wage-setting institutions may affect the scope of cooperation among key actors with complementary competencies, the conditions for (potential) HGFs, and structural transformation through several channels. In particular, the wage compression associated with centralized wage bargaining is likely to disadvantage potential HGFs. An artificially compressed wage structure impedes profitable firms with high productivity from using salaries as an incentive to recruit new productive employees, making expansion more difficult. Minimum wages set above the market equilibrium level, on the other hand, force low-profit firms with low productivity out of business. Indeed, Halabisky et al. (2006) demonstrate that HGFs are low-salary companies at the beginning of their life cycle and that large firms in slowly growing industries are high-salary companies. When young potential HGFs realize their growth potential and begin to grow rapidly, salaries start to grow quickly. This finding suggests that a compressed wage structure that maintains minimum wages above the market equilibrium level tends to choke potential HGFs in their infancy. Potential HGFs have difficulties bearing high wage costs early in their life cycle when they are still developing their product and are in the early phase of commercialization.

Given the large intra-firm differences in productivity, especially in young and rapidly expanding industries and firms (Caballero 2007), the cooperation among the key actors needed for HGFs is impaired if wages are set in negotiations far from the individual workplace and if the above issues are therefore not properly considered.

4.5.4 Institutions Providing Insurance and Governing the Channeling of Savings

Sinn (1996) formally demonstrates that by providing insurance for unfavorable outcomes, an extensive and generous public social insurance system can theoretically encourage individuals to pursue entrepreneurial endeavors, but to our knowledge, this hypothesis has yet to be tested empirically. A generous welfare system would seemingly make it less costly to bear uncertainty as an entrepreneur or to move to a risky job in an entrepreneurial firm. In labor markets where job security is closely linked to job tenure, the effect of a generous welfare system may no longer hold. What matters is the opportunity cost, i.e., how much income security an employee must surrender if she transfers to self-employment or a risky job in an entrepreneurial firm. For a tenured employee with a low-risk employer, the opportunity cost rises considerably in many OECD countries.

In many countries, important benefits are connected to employment, such as health insurance in the USA. Many workers and potential entrepreneurs become "trapped" in large companies that provide generous health insurance for the employee and his/her family. Decoupling health insurance from employment would increase labor flexibility and reduce fears of losing adequate health insurance and other important benefits that may be attached to employment. In Denmark, generous welfare systems are combined with weak job security mandates, sometimes called "flexicurity" (Andersen and Svarer 2007). This situation can be contrasted with the situation in Sweden, where somebody who voluntarily gives up a tenured position for self-employment may not have any more security than that provided by (means-tested) social welfare. Public income insurance systems combined with employment protection legislation tend to penalize individuals who assume entrepreneurial risk. Hence, the opportunity cost of resigning a tenured position is substantially lower in Denmark than in Sweden.

Furthermore, the way that savings are channeled to various investment activities influences the type of business organization that can obtain credit. Pension funds are less likely than business angels or VC firms to channel funds to entrepreneurs. Therefore, the composition of national savings is not neutral in its impact on entrepreneurship and business development. If the government forces individuals to keep a large part of their savings in a national pension fund, the availability of small business financing will suffer relative to that provided by an alternative policy and institutional arrangements that allow individuals more choice regarding their savings and investments.

A final point concerns the design of a supplementary pension system. Supplementary pension plans that are not fully actuarial and individualized contain elements of redistribution and risk sharing across individuals in a group, such as white-collar workers in a certain industry. The pension benefit level may be disproportionately connected to the wage level achieved at the end of a professional career. Moreover, transferring the accumulated pension assets in the case of a change in employer and/or industry may be difficult. To the extent that transferring the accumulated pension assets is difficult, the mobility of (older) workers across firms and the hiring of unemployed elderly individuals are significantly discouraged.

4.5.5 Product Market Regulations, Entry, and Competition Policy

Excessive product market regulation deters entry, reduces growth at the firm level, and impedes growth and productivity at the aggregate level.[37] Institutions matter, as shown by, for example, Gordon (2004) and Bosma and Harding (2007), who claim that the growth differences between Europe and the USA are explained by differences in the quality of regulations. Additionally, in Europe, considerable differences can be discerned. Shleifer et al. (2008) argue that a French legal origin (civil law) tends to weaken the incentives for innovation and the effect of innovation on growth compared with an Anglo-American common law legal origin. Therefore, regulations have a decisive impact on entry, innovation, and growth.

More precisely, compliance with regulation implies that costs are incurred, which particularly damages new and smaller firms (Glaeser and Kerr 2009). The most detrimental effects are attributed to high start-up costs (Fonseca et al. 2001, 2007). In addition, regulations not only imply higher direct costs of entering a market but also lead to potentially substantial indirect effects that deter entry. As shown by Ciccone and Papaioannou (2006), Ardagna and Lusardi (2009), and Klapper and Love (2011), the positive effect associated with skills (education) diminishes considerably in more regulated countries, particularly for opportunity-based entrepreneurship. Regulations also significantly reduce the propensity for marginalized groups to start new firms. Similarly, the positive effects of knowing people who are entrepreneurs, i.e., the spillover effects associated with networks and entrepreneurial culture, become restricted.[38] These effects prevail primarily with respect to opportunity- and innovation-based entrepreneurship.

Another stream of literature builds on the industrial organization tradition (Bain 1956) that centers on not only entry but also on the effects pertaining to preemption and strategic interaction (Gilbert and Newbery 1982; Laffont and Tirole 1993; Nickell 1996; Berry and Pakes 2003; Aghion et al. 2006). These models are comprehensive, incorporating the effects of competition and innovation of incumbents and new firms in the analysis. For example, Aghion et al. (2006) show that entry—or entry threats—has positive effects on the innovative behavior of incumbents near

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[37] See Evans and Leighton (1989), Geroski (1989), Blundell et al. (1999), Nickell (1996), Hurst and Lusardi (2004), Djankov et al. (2007), Fiori et al. (2007), Gentry and Hubbard (2000), Nicoletti and Scarpetta (2003), Arnold et al. (2008), Ciccone and Papaioannou (2006), and Ardagna and Lusardi (2010).

[38] These effects are quantified by Ardagna and Lusardi (2009). For example, the positive network effects are reduced by more than two-thirds.

the technological frontier, whereas no similar effects are found for technological laggards. Aghion et al. call these effects the "escape-entry" effect and the "discouragement effect," and the policy implications of these effects depend on the type of industry (Aghion and Griffith 2005).

Product market regulations thus stifle competition and entry, thereby reducing growth. Even if new entrants do not display high productivity, they trigger incumbents to improve their performance (Inklaar et al. 2008; Andersson et al. 2012). Maintaining low entry barriers becomes strategically important (Howitt 2007).

Regulations may also affect the diffusion of new findings. As Poschke (2010) argues, a more favorable regulatory system facilitates faster adoption of new technology in the USA, thus giving US producers a competitive edge over European producers, particularly in the service sectors. This result is partly attributed to weaker competition in Europe, which has less innovation and weaker incentives to adopt new technology. As shown in Fig. 4.6, although all OECD countries have deregulated since the 1990s, there are still large cross-country variations.

Similarly, if competitive forces are weakened, lower allocative efficiency in factor markets can be expected. More productive firms and sectors may not attract the production factors that are required for expansion, which will result in lower growth. These negative effects need not be linear, but they can generate disruptive and sudden effects (Arnold et al. 2011).

All in all previous research emphasizes the importance of competition and entry. Regulations that create disincentives for firms and individuals to engage in experimental and innovative activities can be expected to impede growth. Combined with rapid technological change, where competition should be understood in a dynamic rather than a static sense, conditions can change quickly and could render regulations obsolete.

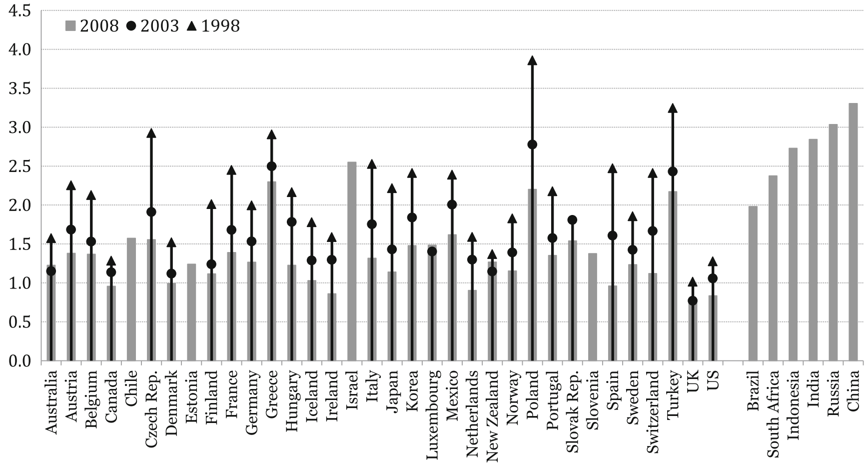

Fig. 4.6 Product market regulations in a number of countries (Index: 0 to 6). *Source*: Arnold et al. (2011)

4.5.6 Agglomeration Economies, Housing Markets, and Infrastructure

Spatial concentration of people, firms, and human capital enhances productivity according to the agglomeration literature (Rosenthal and Strange 2008). The advantages of proximity arise through several means, such as the facilitation of knowledge diffusion, the creation of communications externalities, the generation of specialization, and the reduction of transport costs.

Evidence indicates that knowledge spillovers are particularly important for more technologically sophisticated production and for contexts in which knowledge is still in a more fluid and early stage. This evidence corresponds with findings demonstrating that proximity to specific knowledge nodes, such as universities, tends to increase innovativeness.[39]

The mechanisms causing knowledge diffusion and innovations (compare Sect. 4.5.3) are frequent job changes and close interactions among employees. These repeated encounters drive dynamic processes, generating vertical and horizontal connections that appear in productivity effects regarding the transmission of knowledge/information (Saxenian 1994; Porter 1998; Glaeser and Gottlieb 2009). Indeed, evidence also shows that firms are likely to patent more in regions characterized by higher labor mobility (Kim and Marschke 2005) and greater population density (Lööf and Nabavi 2012).

Regarding entrepreneurship and firm location, a large literature supports a positive effect of a geographically concentrated environment. Similarly, better access to finance and services, greater flows of ideas, larger markets, less swings in demand, and lower entry costs are among the most commonly cited advantages that induce agglomeration.[40] Geographical proximity seems to be critical to knowledge transmission, a process that is further intensified because density also encourages fierce competition.

Thus, innovation processes and entrepreneurial activity are largely localized processes, and innovation capabilities originate from the interplay between generic knowledge and learning processes that are embedded in the knowledge and market environment of regions.[41] A critical mass seems to be required for dynamic and innovative processes to emerge. Empirical findings also suggest that innovative processes are more concentrated than inventive or production activities, enhancing the incentives for firms to locate in dense, knowledge-intensive areas (Feldman 1994; Feldman and Audretsch 1999; Paci and Usai 1999; Ejermo 2009).

Furthermore, dense environments are characterized by distinct wage and productivity premiums (Puga 2010). Glaeser and Maré (2001), for example, report a wage premium in the USA of 33 % between the largest metropolitan areas and non-urban locations. Therefore, strong centripetal forces attract both individuals and firms to dense environments.

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[39] See, e.g., Zucker et al. (1998) and Andersson et al. (2004).

[40] See, e.g., Fujita et al. (1999) and Henderson and Thisse (2004).

[41] See, e.g., Martin and Ottaviano (2001) and Agrawal et al. (2008).

Delgado et al. (2014) show that industries belonging to strong clusters have higher employment and wage growth as well as higher growth in the number of establishments and patenting. Growth at the level of the industry or cluster also increases with the strength of related clusters in the region and with the strength of similar clusters in adjacent regions. Moreover, the study provides evidence that new regional industries emerge when a strong cluster environment exists. This evidence suggests that the existence of strong clusters in a region enhances growth opportunities in other industries and clusters.

Innovation policy must therefore include a strategy for cluster development and urbanization. Well-functioning markets where prices are allowed to reflect scarcity and preferences are necessary conditions for continued growth in dense areas—particularly in the housing market. Housing must be supported by adequate infrastructure that allows smooth transportation and commuting. If these prerequisites are absent, inherently centripetal forces may become centrifugal and may result in dispersion—or few of the potential agglomeration effects may be realized. By contrast, when different policies complement and reinforce one another, region-specific connections and institutions evolve and adapt over time in a complex interaction that often becomes a key component of a region's competitive advantage (Gertler 2004; Wolfe and Gertler 2006).

4.6 Concluding Remarks

In the aftermath of the IT crash and the precipitous loss of market capitalization in the "new economy," entrepreneurship was no longer heralded in policy discussion, at least in Europe. After several years, a new buzz word appeared: innovation. The USA launched its national innovation strategy in 2009, and the goals were lofty: "President Obama's *Strategy for American Innovation* seeks to harness the ingenuity of the American people to ensure economic growth that is rapid, broad based, and sustained. This economic growth will bring greater income, higher quality jobs, and improved quality of life to all Americans."[42] In the following year, the OECD presented its innovation strategy (OECD 2010). Moreover, in the European Union, the "Innovation Union" was launched as a key component in the EU 2020 strategy. For the European Union, the tone is urgent, verging on desperation: "We need to do much better at turning our research into new and better services and products if we are to remain competitive in the global marketplace and improve the quality of life in Europe. We are facing a situation of '*innovation emergency*'."[43]

Innovation has understandably become a favorite concept among policy makers. In addition to avoiding the burden of previous overuse, innovation connotes novelty,

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[42] Cited from www.whitehouse.gov/issues/economy/innovation (accessed November 1, 2014).

[43] Cited from http://ec.europa.eu/research/innovation-union/index_en.cfm?pg=why (accessed November 1, 2014).

modernity, and dynamism. The question concerns how to design a long-term institutional structure that is conducive to innovation and growth.

Cross-country differences in long-term economic performance are ultimately caused by differences in the rules of the game in society or the institutional system, broadly construed. Factors of production are only proximate causes of growth, whereas the ultimate causes reside in the incentive structure that encourages individual effort, entrepreneurship, and investment in physical and human capital as well as in new technology.

In reality, the interaction between various dimensions of an institutional system and entrepreneurial activity and the relationship between this interaction and innovation is highly complex and difficult to disentangle. Each country has its own bundle of formal and informal institutions that have evolved over time. The efficiency of an institutional setup depends on the *complementarity* of its various constitutive elements (Freeman et al. 1997; Schmidt and Spindler 2002). Moreover, entrepreneurs are not the only agents who are important for economic progress. Successful entrepreneurs who identify and exploit new ideas—thereby creating and expanding businesses—depend on many complementary agents, such as innovators, skilled workers, industrialists, venture capitalists, agents in secondary markets, and competent customers. High-impact entrepreneurship becomes impossible without these complementary competencies and inputs. Focusing solely on entrepreneurship has never been a credible political strategy. Still, entrepreneurship is crucial, as a lack of entrepreneurs cannot be fully offset by an ample supply of skilled labor or an extensive capital market.

Because of the strong complementarity of the elements constituting an institutional setup, a major weakness in one element cannot easily be compensated by improvements in other elements. For example, excessive taxation of gains on stock options effectively bars the development of a vibrant VC industry.[44] Thus, great benefits can be gained by identifying and eliminating institutional bottlenecks (Acs et al. 2014b).

We, however, anticipate a significant risk that future innovation policies will become fragmented and overly focused on R&D subsidies and other support programs for high-tech firms. A suboptimal policy mix with regard to the conditions for knowledge diffusion, in contrast to knowledge accumulation, could impede countries and regions from reaching their potential growth trajectories.

Based on an evolutionary Schumpeterian view of the functioning of the economy, we instead recommend a more comprehensive approach. Our objective is to create institutional conditions that will render the national economy, as a whole, more innovative and growth oriented in the long term. The development of such institutional conditions requires tax and regulatory systems that stimulate the creation, diffusion, and productive use of knowledge in *all* sectors of the economy. For this purpose, we suggest several measures that collectively constitute a framework for innovation and entrepreneurship policy. This framework should focus on complementary institutions that combine to achieve two objectives:

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[44] See Henrekson and Sanandaji (2016).

- *The accumulation, investment, and upgrading of knowledge*. The policy areas involved in this objective relate to institutions that are needed to encourage high-quality education at all levels, to develop internationally leading universities and university research, to establish connections between academia and the commercial sectors, and to fund universities.
- *The implementation of mechanisms that enable knowledge to be exploited such that growth and societal prosperity is increased*. This objective involves a completely different set of institutions, such as tax policies, the regulatory burden, competition policy, and enabling policies that facilitate cluster formation. These policies create environments and strong incentives for innovation, entrepreneurial venturing, and the subsequent expansion of the most viable ventures.

We cannot define the exact components of policies that are likely to accomplish both knowledge upgrading/accumulation and knowledge diffusion, as the effect of institutions on innovation and entrepreneurship depends on a coherent design over different national and regional policy areas. But we can identify the most important institutional areas to achieve the abovementioned objectives. We assert that the following policy areas are key to promoting long-term, sustainable growth.

First, a critically important and necessary condition is a high-quality education system at all levels. Such a system implies continuous evaluation of school performance and student skills and sizeable sanctions if schools underperform. Competition and diversity among schools should be encouraged but monitored and audited. Academic research must be world class in at least some areas, and the incentives for cutting-edge research must be sufficiently strong to attain this objective. Research policy should have a time perspective of a decade or more to reassure the involved agents that the government has a long-term commitment. In addition to auditing by government agencies, the instrument to achieve these goals is benchmarking with other leading nations.

Second, the quality of regulations is decisive for creating an attractive environment for innovators, entrepreneurs, and incumbent firms. Excessive red tape distorts the functioning of markets and encourages regulatory capture and rent seeking. Proposals for new regulation should be automatically dismissed unless backed by a cost-benefit analysis. Because government agencies often have considerable freedom to impose new legislation or regulations, we suggest that an independent "Regulation Committee" should have the mandate to order cost-benefit analyses from the agencies concerned. This mandate will avoid the introduction of onerous regulation, unless the benefits are convincingly shown to exceed the costs. Such authorities exist, e.g., in Canada. The mandate could also be extended to include a more general advisory function whereby interactions among regulations are analyzed. For example, strong intellectual property rights may not yield the expected results unless they are supported by adequate competition policies.

Third, a relevant incentive structure must be in place. Such an incentive structure refers to a tax system that encourages investment in education and valuable skills, entrepreneurial experimentation, and the exploitation of scale economies. The most successful entrepreneurs are highly educated. In addition, incumbents' performance depends on a well-educated labor force. Innovation and productivity relate to matching and attracting relevant skills. High taxes discourage these dynamics. Appropriately designed stock options are a powerful instrument to build firms by attracting and retaining key personnel. Capital taxes are essential to the pay-offs of entrepreneurial risk taking. Again, in an increasingly globalized market, benchmarking with other countries may constitute a straightforward method to attain a competitive and well-functioning tax system. The tax system should be considered from both sides, namely, the costs to individuals and firms and the benefits to societal services. The societal services that a tax system provides are also part of the attractiveness of an economy.

The normative conclusions may seem trivial and easily construed. It is also tempting to look for a country that is perceived to do well on a particular aspect and to argue that a certain institutional element, which allegedly causes this fortunate outcome, should be imported. However, matters become more complicated, as each country has its own bundle of formal and informal institutions that have evolved over time. The efficiency of an institutional setup depends on the complementarity of various elements, and an isolated and ill-conceived change in one element can cause inconsistencies, rendering the entire system less efficient. Therefore, caution and humility are necessary. Still, there is no other way but to learn from the best *and* to be aware of the difficulties involved in importing particular policies and institutions from other countries. Although it is naïve to believe that one country can imitate and import ready-made institutions from other countries, there is room for learning, adoption, and adaptation.

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Chapter 5
Radical and Incremental Innovation and the Role of University Scientist

Aileen Richardson, David B. Audretsch, Taylor Aldridge, and Venkata K. Nadella

5.1 Introduction

Innovation has emerged as a source of economic growth, employment creation, and global competitiveness in the United States. On February 2011, President Barack Obama released his vision and plan for *A Strategy for American Innovation: Securing Our Economic Growth and Prosperity.*[1] Similarly, in his 2011 State of the Union Address to the United States Congress, President Obama emphasized, "America's economic growth and competitiveness depend on its people's capacity to innovate. We can create the jobs and the industries of the future by doing what America does best—investing in the creativity and imagination of our people. To win the future, the U.S. must out-innovate,

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This chapter is largely founded on the report "University Science Faculty Ventures into Entrepreneurship," Audrestsch, D., Aldridge, T., and Nadella, V. Prepared for the United States Small Business Administration Office of Advocacy, under Contract #SBAHQ-11-M-0212, April 2013.

[1] "A Strategy for American Innovation: Securing Our Economic Growth and Prosperity," National Economic Council, Council of Economic Advisers, and Office of Science and Technology Policy, Washington, D.C.: The White House, February 2011, http://www.whitehouse.gov/sites/default/files/uploads/InnovationStrategy.pdf/

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D.B. Audretsch, A.N. Link (eds.), *Essays in Public Sector Entrepreneurship*,
International Studies in Entrepreneurship 34, DOI 10.1007/978-3-319-26677-0_5

out-educate, and out-build the rest of the world. We have to make America the best place on earth to do business."[2]

The strategy of promoting innovative activity as an engine of economic growth is not new. In fact, the era of stagflation, or the twin burdens of inflation combined with high unemployment triggered by the 1973 OPEC oil embargo, ushered in a host of new policies focused on innovation as a source of reinvigorating economic growth. The early 1980s witnessed a series of new legislation enacted by the United States Congress to spur American innovative activity including the Small Business Innovation Research (SBIR) program in 1982, which was explicitly tasked to reinvigorate jobs and economic growth through enhancing the innovative performance of the United States, and the Bayh-Dole Act.[3] The SBIR program had the explicit mandate to promote technological innovation, enhance the commercialization of new ideas emanating from scientific research, increase the role of small business in meeting the needs of federal research and development, and expand the involvement of minority and disadvantaged persons in innovative activity.

Similarly, the *Bayh-Dole Act* in 1980 was an effort to increase the amount of knowledge spilling over from the universities for commercialized innovative activity.[4] The explicit goal of the Bayh-Dole Act was to foster the commercialization of university science (Kenney and Patton 2009). Thus, both scholars and public policy makers have viewed investment in university research as a key component to generating innovative activity. Capitalizing upon the investment in university research and transforming it into innovative activity involve not just increasing the magnitude of scientific research but also fostering its commercialization.

Studies focusing on commercialization of university research have generally been mixed, and at best many have been critical about the paucity of innovative activity emanating from universities. In fact, the number of patents applied for and granted to universities has exploded since the Bayh-Dole Act was passed. Between 2000 and 2008 there were 83,988 new patent applications filed by universities in the United States.[5] In addition, universities entered into and signed 41,598 license and option agreements. Studies find that only a handful of universities have generated large flows of licensing revenue (Phan and Siegal 2006). Similarly, studies suggest that the number of officially sponsored start-ups spawned by universities has been remarkably low (Phan and Siegal 2006), leading many to conclude that the transfer of technology from universities to the private sector has not been particularly effective. As *Businessweek* reports, "Bayh-Dole critics postulate that universities and technology transfer offices are inefficient obstacles to the formation of startup companies."[6]

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[2] "Obama's Innovation Agenda," *Forbes*, January 25, 2011, http://www.forbes.com/sites/brianwingfield/2011/01/25/obamas-innovation-agenda/

[3] Testimony of David B. Audretsch to the House of Representatives, Committee of Small Business, March 16, 2011, http://smallbusiness.house.gov/uploadfiles/david_audretsch_sbir_testimony.pdf

[4] Public Law 98-620.

[5] "Defending the University Tech Transfer System," *Businessweek,* February 19, 2010, http://www.businessweek.com/smallbiz/content/feb2010/sb20100219_307735.htm

[6] "Defending the University Tech Transfer System," *Businessweek,* February 19, 2010, http://www.businessweek.com/smallbiz/content/feb2010/sb20100219_307735.htm

However, Aldridge and Audretsch (2010, 2011) point out that much of the assessment of the extent and impact of the commercialization of university research is influenced by asking the universities about their activities, rather than the principle agents, the scientists. In their 2010 and 2011 studies, Aldridge and Audretsch found that entrepreneurial activity, in the form of starting a new business, was considerably more prevalent based on a database of scientist commercialization activity rather than on data reported by the universities. Perhaps the most striking result of the study is that one in four scientists reported starting a business.

However, a severe limitation of the Aldridge and Audretsch (2010, 2011) studies was that their database consisted of scientist entrepreneurial activity solely from one main scientific field—cancer research. Additionally, the scientists included in their database rank among the very top performers in the field. These limitations beg the question whether the strong propensity for scientists to become entrepreneurs identified in the Aldridge and Audretsch (2010, 2011) studies was limited to the particular sample of high-performing scientists engaged in cancer research or whether it also extends to other scientific fields.

The purpose of this study is to examine university scientist entrepreneurship across a broader spectrum of scientific fields. In particular, this study seeks to identify the prevalence of university scientists in a number of scientific fields. In addition, this study seeks to identify the extent to which the determinants of such university entrepreneurship is not only homogenous across the different scientific fields but also mirrors that for what has already been found to drive entrepreneurial activity for the more general population.

In the following section, the role of knowledge spillovers from universities and the exact reasons for analyzing the entrepreneurial activities of individual scientists rather than that for the universities are explained. The methods used to compile a new and unique database measuring scientists' entrepreneurship across a broad spectrum of scientific fields are explained in the third section. In the fourth section, the main determinants for scientific entrepreneurship are introduced and developed. The empirical results are presented in the fifth section. In section six the scientist entrepreneur's incremental and radical innovation material is presented. Finally, in the last section, a summary and conclusion are presented. In particular, this paper provides compelling evidence that scientists' entrepreneurial activity, in the form of starting a new business, is considerably more prevalent and robust than is commonly thought. For the entire sample of university scientists, this paper finds that nearly 13 % have started a new firm. In addition, the propensity for a scientist to engage in entrepreneurial activity is not homogenous but rather varies systematically across scientific fields. For example, in certain scientific fields, such as computer and network systems, the prevalence of entrepreneurship is 23.8 %. Similarly, in civil, mechanical, and manufacturing innovation, just over one in five scientists has started a new firm. By contrast, in environmental biology, the prevalence rate of entrepreneurship is 4.6 %, and in particle and nuclear astrophysics, it is 6.2 %.

Similarly, the determinants of university scientific entrepreneurship are apparently heterogeneous and depend crucially upon the nature of a particular scientific field. In addition, the entrepreneurial activities in certain scientific fields are more conducive to radical innovation, while in others they tend to be more closely associated with incremental innovation.

5.2 Knowledge Spillovers from Universities: Scientist Versus University Entrepreneurship

5.2.1 The Managed Economy

The following section explains the role of knowledge spillovers from universities in what has been termed as the "managed economy" or an economy where investments in the physical capital provide the engine of growth. The managed economy characterizes a historical era when economic growth, employment creation, and competitiveness were shaped by investments in physical capital such as factories, machinery, and plants. According to the Nobel Prize winner, Robert Solow (1956), the driving forces underlying economic growth consist of two key factors of production—physical capital and (unskilled) labor. Solow did point out that most of economic growth remained unaccounted for in his model. In fact, Solow attributed to the unobserved factor of technical change, which was characterized to "fall like manna from heaven."

The neoclassical growth model was econometrically verified in a vast number of studies linking measures of economic growth to the factors of physical capital and labor. According to Nelson (1981, p. 1032), "Since the mid-1950s, considerable research has proceeded closely guided by the neoclassical formulation. Some of this work has been theoretical. Various forms of the production function have been invented. Models have been developed which assume that technological advance must be embodied in new capital… Much of the work has been empirical and guided by the growth accounting framework implicit in the neoclassical model."

There did not seem to be much of an economic contribution that a university could make in a capital-driven economy. The major activities and focus of universities—research and education—did not seem to be relevant in either generating physical capital or increasing the availability of unskilled labor for industry.

Rather, it was in the social and political realms that the university could contribute during the era of the managed economy. The university was an institution preparing young people to think freely and independently and where the fundamental values of Western civilization and culture were passed down from generation to generation.

American universities had evolved from being an extension of religious institutions to effective independent institutions of higher learning by the twentieth century. The earliest colleges founded in the United States, such as Harvard College, were burdened with explicit ties to the church. In fact, the church played a fundamental role in creating and sustaining institutions of higher education during the early years of the country. The sponsorship and support of universities by the church were more the norm than the exception and had been established as the norm for higher education in Europe.

Alexander von Humboldt disrupted the historical and institutional linkage between the church and the university in the 1800s in Berlin. In particular, Humboldt triggered a new tradition for universities centering on freedom of thought, learning, intellectual exchange, research, and scholarship as the salient features of the university. As the Humboldt model for the university diffused first through Europe and subsequently to the other side of the Atlantic, universities became free from parochial constraints, leading instead to the non-secular university committed to independence of thinking, learning, and research.

Thus, the Humboldt tradition for the university was reinforced during the managed economy, with the emphasis on physical capital and unskilled labor as the twin factors shaping economic performance. Despite the preeminent contributions to social and political values, the economic contribution of universities was modest.

5.2.2 The Knowledge Economy

The stagflation characterized by the twin problems of inflation and unemployment starting in the 1970s ushered in the demise of the managed economy. Both scholars and policy makers began to turn toward a new source of economic growth, employment creation, and competitiveness—knowledge. The primary of knowledge and innovation became the salient feature of the endogenous growth models (Romer 1986, 1994; Lucas 1988). The main advancement of the endogenous growth models was that the factor of knowledge became explicit in the growth model. While knowledge, or technical change, entered the Solow model only as an undetermined residual in the endogenous growth models, knowledge was not only a key factor driving economic growth, but it was also explicitly included in the model. Not only did knowledge drive economic growth, it is particularly potent because of its inherent propensity to spillover from the firm or university creating that knowledge for other firms and individuals who could apply that knowledge.

In fact, the deviation from the traditional role afforded by the Humboldt model of the university that came about from the Second World War was supported by an even older tradition which oriented the land-grant colleges and universities toward commercialization established by passage and implementation of the Morrill Act. The Morrill Act, which was more commonly known as the Land-Grant Act, was signed into law by Abraham Lincoln in 1862 and granted land to each state that was to be used in perpetuity to fund agriculture and mechanical colleges benefiting the state. As they evolved, the land-grant universities developed an effective set of institutional mechanisms that enabled the commercialization of science and technology from the land-grant universities that contributed to agriculture in the United States becoming the most productive in the world (Audretsch 2007).

As the knowledge economy replaced the managed economy, or as the factor of knowledge became more important in comparison to physical capital, the role of universities in the economy shifted from being tangential and marginal to playing a central role as a source of knowledge. Universities in the United States became viewed as institutions that promote social and cultural values but also as key engines driving the growth of the economy. In the Solow economy, where economic growth was achieved by combining unskilled labor with physical capital, the economic contribution of universities was marginal. As the knowledge economy replaced the Solow economy, a new role for the university emerged, as an important source of economic knowledge (Audretsch 2014).

5.2.3 The Entrepreneurial Economy

The implicit assumption in the endogenous growth models that investments in new knowledge, either by firms or universities, would automatically spill over for commercialization resulting in innovative activity and ultimately economic growth has not proven to be universally valid. In fact, new knowledge investments must penetrate what has been termed “the knowledge filter” in order to contribute to innovation, competitiveness, and ultimately economic growth (Audretsch et al. 2006; Acs et al. 2010). The knowledge filter is defined as the barrier or gap between the investment in new knowledge and its commercialization. The knowledge filter poses a barrier that impedes or preempts the commercialization of investments in research and knowledge. While he did not use the phrase “knowledge filter,” Senator Birch Bayh was essentially concerned about the magnitude of the knowledge filter when he admonished his colleagues in Congress to beware, “A wealth of scientific talent at American colleges and universities—talent responsible for the development of numerous innovative scientific breakthroughs each year—is going to waste as a result of bureaucratic red tape and illogical government regulation.”[7]

The knowledge filter can be viewed as posing a barrier or impediment between investments in new knowledge and their commercialization, which leads to innovative activity and growth of the economy. The existence of formidable knowledge filter can actually render investments in research and science impotent in terms of their spillovers for commercialization and innovative activity. As Senator Bayh wondered, “What sense does it make to spend billions of dollars each year on government-supported research and then prevent new developments from benefiting the American people because of dumb bureaucratic red tape?”[8]

The existence of the knowledge filter suggests that investments alone in research at universities will not suffice in facilitating the spillovers that are requisite to generating innovative activity and economic growth. In order to take advantage of the massive investments in research and education, additional entrepreneurial activity was required by the universities. In particular, the universities needed to become more entrepreneurial in that they proactively developed mechanisms and incentives and even change their culture from that of the Humboldt University, of knowledge for its own sake, to a university that facilitates knowledge spillovers for commercialization out of the universities.

In order to spur innovative activity to spur American economic growth, employment creation, and competitiveness, the United States Congress enacted the Bayh-Dole Act in 1980. The Bayh-Dole Act represented an explicit policy attempt to facilitate knowledge spillovers from universities for commercialization, which would lead to economic growth and activity (Kenney and Patton 2009; Link and Siegel 2005; Link et al. 2007).

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[7] Introductory statement of Birch Bayh, September 13, 1978, cited from the Association of University Technology Managers Report (AUTM) (2004, p. 5).

[8] Statement by Birch Bayh, April 13, 1980, on the approval of S. 414 (Bayh-Dole) by the US Senate on a 91-4 vote, cited from AUTM (2004, p. 16).

Part of the response to creating the entrepreneurial university was the development of academic fields and areas of research that were not just focused on "knowledge for its own sake," which is the gold standard of scholarly inquiry under the model of the Humboldt University, but rather oriented toward knowledge for the sake of solving specific and compelling problems and challenges confronting society. Thus, relevance and applicability emerged as the key guiding values in these new, external oriented fields and areas of research, such as biochemistry, informatics, and bioengineering.

In his highly influential book on higher education in the United States, *A Larger Sense of Purpose: Higher Education and Society* (2005), the former Princeton University president Harold Shapiro laments that American universities do not actually seem to possess a larger sense of purpose. Shapiro's concern echoes a recent assessment condemning what is characterized as the selling out of American universities in the *New York Times*, which chides higher education in the United States because "colleges prostitute themselves to improve their U.S. News & World Report ranking and keep up a healthy supply of tuition-paying students, while wrapping their craven commercialism in high-minded sounding academic blather…I would keep coming up with what I thought were pretty outrageous burlesques of this stuff and then run them by one of my professor friends and he'd say 'Oh yea, we're doing that'."[9]

Similarly, Steve Lohr of the *New York Times* warns "the entrepreneurial zeal of academics also raises concerns, like whether the direction of research is being overly influenced by the marketplace."[10] The eminent sociologist Toby E. Stuart wonders whether "basic scientific questions are being neglected because there isn't a quick path to commercialization? No one really knows the answer to that question."[11]

5.2.4 University Entrepreneurship versus Scientist Entrepreneurship

There has been wide acclaim for the impact of the Bayh-Dole Act on innovative performance of universities. According to *The Economist*, "Possibly the most inspired piece of legislation to be enacted in America over the past half-century was the Bayh-Dole Act of 1980. Together with amendments in 1984 and augmentation in 1986, this unlocked all the inventions and discoveries that had been patented in laboratories through the United States with the help of taxpayers' money. More than anything, this single policy measure helped to reverse America's precipitous slide into industrial irrelevance. Before Bayh-Dole, the fruits of research supported by government agencies had gone strictly to the federal government. Nobody could

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[9] Stephen Budiansky, "Brand U.," *New York Times,* April 26, 2006, p. A23.

[10] Steve Lohr, "U.S. Research Funds Often Lead to the Start-Ups, Study Says" *New York Times,* April 10, 2006.

[11] Quoted from Steve Lohr, "U.S. Research Funds Often Lead to Start-Ups, Study Says," *New York times,* April 10, 2006.

exploit such research without tedious negotiations with a federal agency concerned. Worse, companies found it nearly impossible to acquire exclusive rights to a government owned patent. And without that, few firms were willing to invest millions more of their own money to turn a basic research idea into a marketable product."[12]

Similarly, *Businessweek* concludes that "Since 1980 the Bayh-Dole Act has effectively leveraged the tremendous value of academic research to create American jobs, economic growth, and public benefit. The Act has resulted in a powerful system of knowledge transfer unrivaled in the world. One would think that the combination of public benefit and the productive, job-creating effects of the Bayh-Dole Act would be a winner in every sense."[13]

The mechanism or instrument attributed to facilitating the spillover of knowledge from university scientist research to commercialization and innovative activity is the university Technology Transfer Office (TTO). The TTO was not explicitly created or mandated by the Bayh-Dole Act, but as consequence of the Act in 1980, most universities created a TTO dedicated to commercializing their university-based research. Virtually, every research university has a TTO or similar office today.

The TTO not only oversees and directs the commercialization efforts of a university. In addition, the TTO is charged with the painstaking collection of the intellectual property disclosed by scientists to the university along with the commercialization activities achieved by the TTO. A national association of Offices of Technology Transfer, the Association of University Technology Managers (AUTM), collects and reports a number of measures reflecting the intellectual property and commercialization of its member universities.

The databases collected and assembled by AUTM have been subjected to considerable empirical scrutiny, resulting in the emergence of a large and growing body of research. These studies have been largely concerned with analyzing the impact of the Bayh-Dole Act in general and the TTOs on generating innovative activity from the research and scientific activities at universities (Lockett et al. 2003, 2005; O'Shea et al. 2008; Pham et al. 2005; Siegel et al. 2007; Siegel et al.2007). It is important to recognize that the bulk of these studies analyze and reach conclusions about the inputs and outputs of the TTOs at universities (Mustar et al. 2006; Mosey and Wright 2007; Shane 2004; Powers and McDougall 2005; Phan and Siegal 2006; Di Gregorio and Shane 2003; Mowery et al. 2004). As Phan and Siegal (2006) point out, most of this literature concludes that the commercialization efforts of the TTOs have been strikingly positive.

However, most of these studies (Phan and Siegal 2006) analyze the outputs of the TTO in terms of patents and/or licensed technology. While the conclusions based on these studies are generally remarkably positive, considerably less attention has been given to start-ups emanating from universities.

In fact, scientist entrepreneurship, as measured by new firms started by university scientists, is seemingly remarkably modest. The data reported by university TTOs and collected by AUTM suggests a paucity of commercialization spilling over from universities in the form of scientist entrepreneurship. For example, the

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[12] Innovation's Golden Goose," *The Economist,* 12 December, 2002.

[13] "Defending the University Tech Transfer System," *Businessweek*, 19 February 2010.

number of university-based start-ups in the United States reported by AUTM (2004) averaged 426 per year for the entire country from 1998 to 2004. When compared to the amount of research conducted at universities and the dollar amount invested in scientific research at universities, this amount of university entrepreneurship does not seem to be particularly encouraging or in any sense an endorsement of a robust system of knowledge spillovers from universities.

Similarly, an examination of entrepreneurial performance of particular universities also points to a paucity of university entrepreneurship. For example, one study found that TTO of the Massachusetts Institute of Technology (MIT) generated only 29 start-ups in 2001 (O'Shea et al. 2008). At the same time, there were only six start-ups facilitated by and registered at the TTO at Stanford University. Thus, however successful universities have been at generating patents and licenses, entrepreneurial activity seems to be considerably more meager and modest, leading, perhaps, at least some to infer that based on the TTO data measuring scientist entrepreneurship at universities compiled by AUTM, universities have not been particularly successful in commercializing research and science.

Aldridge and Audretsch (2010, 2011) point out that there may be inherent limitations in the inferences made about university entrepreneurship and knowledge spillovers based solely upon data collected by the TTOs. In particular, using data generated and compiled by the TTOs, and collected and made available by AUTM, could lead to underestimating the extent to which entrepreneurial activity is being generated by universities. Aldridge and Audretsch (2010, 2011) point out that the main task of the TTO is not to measure and document all of the intellectual property created by university research along with the subsequent commercialization. While the TTO does measure and document the creation and commercialization of intellectual property, its commercialization activities are typically a subset of the broader and more pervasive intellectual property being generated by university research and its commercialization. In fact, as Thursby and Thursby (2002, 2005) and Mosey and Wright (2007) point out, there are considerably more commercialization activities undertaken at universities which may not interface or fall within the TTO's activities. Similarly, Shane (2004, p. 4) finds that, "Sometimes patents, copyrights and other legal mechanisms are used to protect the intellectual property that leads to spinoffs, while at other times the intellectual property that leads to a spinoff company formation takes the form of know how or trade secrets. Moreover, sometimes entrepreneurs create university spinoffs by licensing university inventions, while at other times the spinoffs are created without the intellectual property being formally licensed from the institution in which it was created. These distinctions are important for two reasons. First, it is harder for researchers to measure the formation of spinoff companies created to exploit intellectual property that is not protected by legal mechanisms or that has not been disclosed by inventors to university administrators. As a result, this book likely underestimates the spin-off activity that occurs to exploit inventions that are neither patented nor protected by copyrights. This book also underestimates the spin-off activity that occurs 'through the back door,' that is companies founded to exploit technologies that investors fail to disclose to university administrators."

Shane's (2004) concern that relying upon data collected by the TTO could result in a systematic underestimation of the entrepreneurial activity emanating from universities has been echoed by other scholars (Thursby et al. 2009; Aldridge and Audretsch 2010, 2011). Placing an undervalued estimate on the extent to which university research and science is commercialized may also lead to underestimating the extent to which knowledge spills over for commercialization and innovative activity from universities.

The economic performance of the United States depends crucially upon the capacity to generate knowledge spillovers from universities. Such knowledge spillovers are essential for generating economic growth, creation of jobs, and competitiveness in global markets. Underestimating the extent to which knowledge actually spills over from the universities, and the impact of university science and research, can lead policy makers to undervalue the economic and social impact of investments in research and science.

In order to mitigate such policy distortions, Aldridge and Audretsch (2010, 2011) proposed an alternative method for measuring and analyzing scientist entrepreneurship. Rather than asking universities what they do in terms of commercialization activities, Aldridge and Audretsch (2010, 2011) instead went directly to university scientists and asked the scientists what they do in terms of commercialization.

Aldridge and Audretsch (2010, 2011) surveyed university scientists who had been awarded the largest grants from the National Institute of Cancer at the National Institutes of Health. Thus, their database consisted of commercialization activities identified by the scientists themselves rather than the standard method prevalent throughout the literature of turning to the TTOs and the commercialization activities they report, which are ultimately compiled and made public by AUTM. In particular, Aldridge and Audretsch (2010, 2011) developed alternative measures of scientist entrepreneurship and other commercialization activities on the basis of the scientists reporting their own commercialization and entrepreneurial efforts.

The Aldridge and Audretsch (2010, 2011) studies enabled them to create a measure of scientist commercialization of university research and identify which factors are conducive to scientist entrepreneurship and which factors inhibit scientist entrepreneurship. A key finding of the Aldridge and Audretsch (2010, 2011) studies was that of the patenting scientist. Around one in four had started a new firm to commercialize their research. A second key finding of the studies emerged from subjecting their new university scientist-based data set to empirical scrutiny to ascertain which factors influence the propensity for scientists to become an entrepreneur. This enabled a comparison of the factors conducive to scientist entrepreneurship to what has already been solidly established in the literature for the more general population. In fact, the empirical results suggested that scientist entrepreneurship does not simply mirror what has been found in the more general entrepreneurship literature (Aldrich and Martinez 2010), for the entrepreneurial activities of the general population. By comparison, the likelihood of becoming an entrepreneur was found to be less influenced by certain personal characteristics, such as age, gender, and experience, as well as by human capital. Social capital seems to play a particularly important role in influencing which scientist becomes an entrepreneur and which scientist abstains from entrepreneurial activities.

However, there are a number of important qualifications and limitations involved in the Aldridge and Audretsch (2010, 2011) studies. The first is the highly selective and special nature of the scientists included in the database. In fact, only exceptionally highly performing scientists within a very narrow scientific field, cancer research, were included in the database. A second restriction was that only scientists who had been granted intellectual property protection by a patent were included in the database. The entrepreneurial activities of scientists in all of the other scientific fields were not considered, just as the entrepreneurial activities of scientists not awarded a patent were not considered.

5.3 Developing a Database

5.3.1 Introduction

This section summarizes the salient findings from the scientist entrepreneurship database created using the 1899 scientist responses from an online survey administered among 9150 scientists (response rate of 20.75 %). The survey captures the number and frequency of start-ups, among scientists that received funding from the National Science Foundation (NSF) between 2005 and 2012, in one or more of the six broad fields of research. The survey measures various modes of start-up commercialization, such as patents, innovative products, and consulting, and measures the success or failure of scientist firms during this period.

Section 5.3.3.1 summarizes findings on scientist start-ups. Results indicate that, on average, one in eight scientists has commercialized their research by starting up a legally recognized company. There was also considerable degree of variation in scientist start-ups across various modes of start-up commercialization and fields of research. Possible causal mechanisms and practical implications are discussed.

Section 5.3.3.2 describes scientist characteristics across gender, age, country of origin, and fields of research. It is observed that gender, age, and country of origin are strong determinants of scientist start-up commercialization across and within fields of research. Practical significance of these demographic characteristics is discussed.

Section 5.3.3.3 describes the effect of availability and access to various sources of financial and human resources on scientist start-up commercialization across the six fields of research. It is observed that financial and human resources have a strong positive effect on the scientist's likelihood to commercialize research through start-ups. The practical significance and analytical power of financial and human resources on the scientist commercialization decision are discussed.

Section 5.3.3.4 explains the relationships between scientist human capital—constructed as scientist's tenure status and experience (years of experience in tenured status)—and scientist start-up commercialization decision. It is observed that there is a strong positive relationship between determinants of scientist human capital and scientist commercialization through start-ups.

Section 5.3.3.5 explains the relationships between scientist social capital—observed as scientist's status as a board member—and scientist start-up commercialization. It is observed that there is a strong positive relationship between determinants of scientist social capital and scientist commercialization through start-ups.

Section 5.3.3.6 explores the relationship between the locational and institutional factors on the scientist's start-up commercialization decision. Locational factors are captured as the effect of scientist's location and field of research, and institutional factors are captured as the department head's entrepreneurial orientation and department's overt encouragement toward research commercialization, characteristics of the Technology Transfer Office (TTO).

Results suggest that locational and institutional factors have varying effects depending on the scientist's field of research. Roughly, 25 % of the scientists described the TTO as incompetent in understanding their area of research, and 15 % of the scientists described TTOs as unsuccessful in commercializing research. However, the majority of the scientist responses indicated that the TTOs are of significant help in assisting scientists in overcoming the knowledge filter. Practical significance and hypothesis for future empirical research are discussed.

5.3.2 Survey

This section describes the scientist entrepreneurship database, which was created using survey responses from an online adaptive survey administered among scientists that received funding from the National Science Foundation (NSF), conducting research in six different fields of research, between 2005 and 2012-Q2. The scientific fields of research discussed in this report are civil, mechanical, and manufacturing innovation, environmental biology, computer and network systems, physical oceanography, particle and nuclear astrophysics, and biological infrastructure.

The purpose of this section is to discuss the aggregate and annual characteristics of National Science Foundation (NSF) awards by scientific fields of research between 2005 and 2012-Q2. A total of 13,777 NSF awards were granted to 9361 scientists, across six different fields of research.

This section also describes the survey instruments used in the online survey, the survey response rates, and robustness of the scientist entrepreneurship database. The online survey was administered on a sample of 9150 scientists, from six different fields of research, with 1899 scientist responses, a survey response rate of 20.75 %.

This section discusses the aggregate and annual characteristics of National Science Foundation (NSF) awards by scientific fields of research between 2005 and 2012-Q2. In the 90 months between 2005 and 2012-Q2, a total of 13,777 NSF awards were granted to scientists in six broad scientific fields of research—civil, mechanical, and manufacturing innovation, computer and network systems, biological infrastructure, environmental biology, physical oceanography, and particle and nuclear astrophysics.

Table 5.1 Summary of NSF awards by award instrument

Award instrument	Number of awards
Standard Grant	9402
Continuing grant	4062
Fellowship	169
Cooperative Agreement	90
Interagency Agreement	45
Personnel Agreement	6
Contract Interagency Agreement	2
Contract	1
Grand Total	13,777

Source: Web of Knowledge

5.3.2.1 Award Instrument

The 13,777 NSF awards were made through multiple award instruments—Standard Grant, Continuing grant, Contract, Contract Interagency Agreement, Cooperative Agreement, Fellowship, Interagency Agreement, and Personnel Agreement. Table 5.1 summarizes the 13,777 awards by the type of award instrument.

These figures indicate that 9402 (65.6 %) of the awards are standard grants, and 4062 (29.5 %) of the awards are continuing grants issued to scientists in six different fields of research. Furthermore, these results indicate that about one in three awards is tranche (or block) payments of awards which were awarded in previous years. Since we are primarily interested in identifying scientist that received funding from the NSF across the six fields of research, these awards represent the entire population of scientists who have funding from the NSF as of 2012-Q2.

5.3.2.2 Number of Awards

Figure 5.1 shows the distribution of the 13,777 NSF awards by scientific field of research, between 2005 and 2012-Q2. Roughly 45 % (6211) of the awards were granted to the fields of environmental biology, physical oceanography, and biological infrastructure. These figures signify that the broader interdisciplinary academic fields of biological and environmental sciences receive the dominant share of NSF awards. Furthermore, roughly 42.5 % (5842) of the awards were granted to the civil, mechanical, and manufacturing innovation and computer and network systems fields of research. These figures signify that the broader academic disciplines of engineering and computer science received the second largest share of NSF awards. About 12.5 % (1724) of the awards were granted in the particle and nuclear astrophysics field of research.

It is important to note that one in three awards is continuing grants, and hence, there is a many to one relationship between NSF awards and scientist research. Since we are primarily interested in analyzing scientist research, we shifted the unit

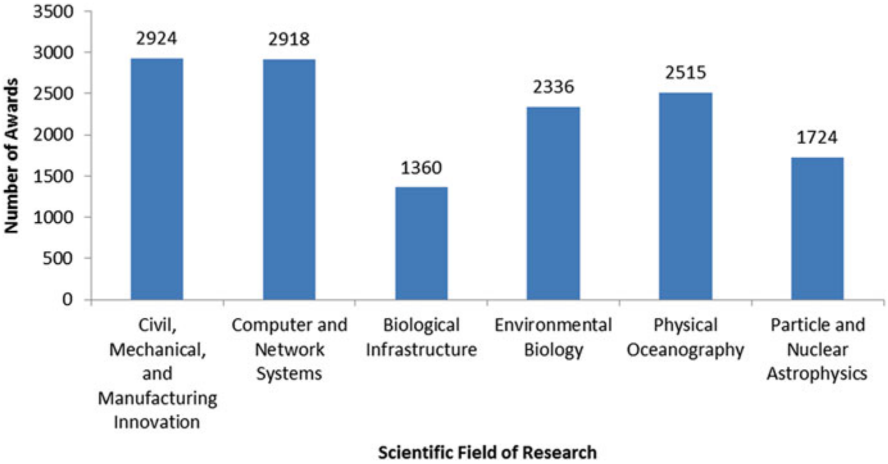

Fig. 5.1 Awards by scientific field of research, 2005–2012-Q2. *Source*: Web of Knowledge

of analysis from awards to scientists. The 13,777 awards were grouped to obtain a total of 9361 unique scientists as defined by the NSF awards' principal investigator (PI) and the PI's organization/university affiliation.

5.3.2.3 NSF Funding Amount

The award amounts for the 9361 unique scientists were combined to obtain the total NSF funding available to the scientist between 2005 and 2012-Q2. These 13,777 NSF awards, to 9361 scientists, aggregated to a total of 6,897,223,522 USD, averaging 4,703,719 USD per scientist.

Table 5.2 shows the aggregate and average NSF funding amounts to scientists by their scientific field of research. The average amount awarded varies considerably between the scientific fields of research. Civil, mechanical, and manufacturing innovation has the least average award amount of 413,053 USD, and physical oceanography has the highest award amount of 1,317,341 USD. It is also interesting to note that the awards in the field of particle and nuclear astrophysics have an average grant amount of 1,270,744 USD, signifying a considerable degree of heterogeneity among awards aimed at theoretical and application-based research.

It is interesting to compare the average award amounts between the applied fields of civil, mechanical, and manufacturing innovation (413,053 USD), environmental biology (478,126 USD), and computer and network systems (622,759 USD). We would expect that the award amounts for civil, mechanical, and manufacturing innovation and environmental biology would be higher, due to the human resource-intensive projects typical to these fields; however, the average grant amounts for these fields are lower than that of computer and network systems. These comparisons suggest that scientific research output in these fields is not as capital intensive as one would normally expect.

Table 5.2 Aggregate and average award amount by scientific field of research

	Number of awards	Total award amount	Average award amount
Civil, mechanical, and manufacturing innovation	2073	856,259,169	413,053
Environmental biology	1657	792,254,675	478,126
Computer and network systems	1811	1,127,815,651	622,759
Physical oceanography	1463	1,927,269,264	1,317,341
Particle and nuclear astrophysics	1159	1,472,792,525	1,270,744
Biological infrastructure	1198	720,832,238	601,696
Total	9361	6,897,223,522	4,703,719

Source: Web of Knowledge

5.3.2.4 Construction of Sample

This section describes the construction of sample of scientists, survey instruments used in the online survey, and the survey response rates of the independent variable and measures for key determinants of scientist entrepreneurship.

The web of knowledge database contained email addresses of 9361 scientists that received NSF funding between 2005 and 2012-Q2. The online survey questionnaire was directed to the entire population of 9361 scientists in the first round of survey administration—we detected that 30 scientists were on sabbatical, 9 scientists were inactive, and email addresses of 172 scientists were returned since they were incorrect/incomplete. Hence, we ended up with a survey sample of 9150 scientists (97.75 % of the population).

5.3.2.5 Survey Administration

The online survey was administered on a sample of 9150 scientists, from six different fields of research, with 1899 scientist responses, a survey response rate of 20.75 %. The survey was administered in three rounds—the initial round of survey questionnaire was administered on the entire population of 9361 scientists in the first three weeks of May 2012, with responses from about 1600 scientists (84 % of total responses). The second round of questionnaire was administered on the remainder of the sample, after truncating the population to a sample of 9150 scientists in the last week of May 2012, with responses from 220 scientists (11.5 % of total responses). The final round of questionnaire was administered on the remainder of the sample in the second week of June 2012, gathering roughly 80 responses (8.5 % of the sample).

5.3.2.6 Survey Questionnaire

The survey questionnaire was designed to capture scientist entrepreneurship through start-ups (our key dependent variable). The survey also captures the use of patents, innovative products, and consulting in scientist start-ups, for scientists who indicated that they founded a legally recognized company.

Furthermore, the survey included measures for key determinants of scientist entrepreneurship like availability of financial resources from other sources of funding, availability of human resources, scientist human capital, scientist social capital, scientist locational and institutional contexts, and scientist demographic information. The response rates of the dependent variable and measures for key determinants of scientist entrepreneurship are provided in Appendix A.

The survey instrument used to measure the key dependent variable, scientist start-ups, is the first question of the online survey—"Have you started a legally recognized company?" The survey respondents could either respond yes or no to the question. This survey instrument is used to construct the key dependent variable, scientist start-ups, which had a survey response rate of 99.5 %.

The survey instrument used to measure the use of patents in scientist start-ups—"What sort of start-up have you founded?"—was administered on scientists who responded "yes" to the question of scientist start-ups. This survey instrument had a survey response rate of 91.7 %.

The survey instrument used to measure the use of innovation in scientist start-ups—"Does your business currently or intend to sell an innovative product?"—was administered on scientists who responded "yes" to the question of scientist start-ups. This survey instrument had a survey response rate of 77.6 %.

The survey instrument used to measure the provision of consulting services in scientist start-ups—"Does your business do a majority of consulting service with industry or government?"—was administered on scientists who responded "yes" to the question of scientist start-ups. This survey instrument had a survey response rate of 76.3 %.

All key determinants of scientist entrepreneurship had a survey response rate of over 80 %, except the survey instrument measuring tenure experience of the scientist—"In what year did you attain 'tenure' status?" This survey instrument had a response rate of 45 %.

The Appendix A presents the response rates of all the determinants of scientist entrepreneurship. Also, please refer to Appendix B for the online survey questionnaire administered on the sample of 9150 scientists.

5.3.3 Salient Findings

5.3.3.1 Scientist Start-Ups

This section describes the likelihood of scientist commercialization through start-ups and compares the likelihood of various modes of start-up commercialization—patents, innovative products, and consulting—across six different fields of research:

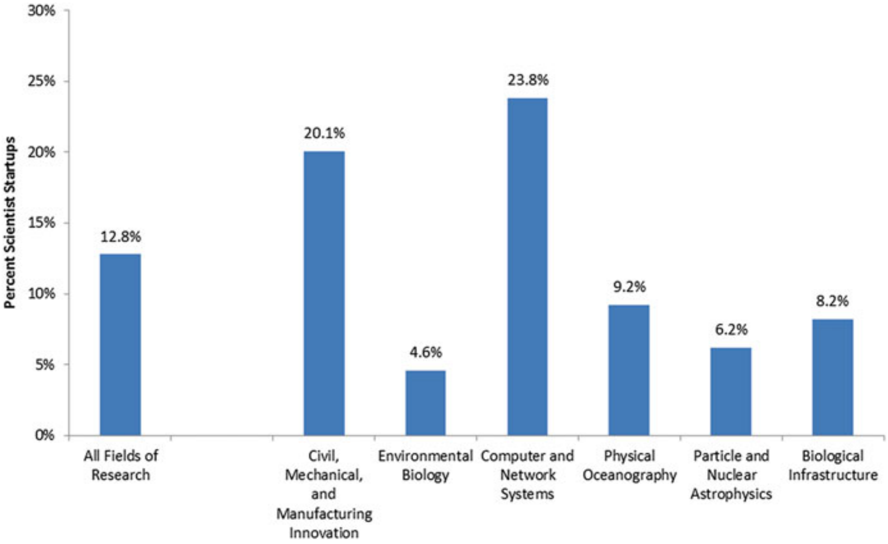

Fig. 5.2 Scientist start-up by field of research

civil, mechanical, and manufacturing innovation (CMMI), environmental biology (DEB), computer and network systems (CNS), physical oceanography (OCE), particle and nuclear astrophysics (PHY), and biological infrastructure (DBI).

5.3.3.1.1 Scientist Start-Ups

Figure 5.2 compares the likelihood of scientist commercialization through start-ups across the six fields of research. Of the 1889 scientist respondents, an average of 12.8 % across six fields of research, 241 indicated that they have commercialized their research by starting up a legally recognized company. Furthermore, there is considerable variation in the likelihood of scientist commercialization through start-ups, ranging from 4.6 % in environmental biology to 23.8 % in computer and network systems.

The figure also explains the nature of research, and the likelihood of commercialization through start-ups, across the fields of research. There is sufficient evidence to indicate that scientists in the fields of computer and network systems (23.8 %, 86 out of 361 scientists) and civil, mechanical, and manufacturing innovation (20.1 %, 73 out of 364 scientists) are more likely to commercialize and have historically been more successful in commercializing their research over time.

On the other hand, scientists in the fields of physical oceanography (9.2 %, 25 out of 271 scientists), biological infrastructure (8.2 %, 26 out of 317 scientists), particle and nuclear astrophysics (6.2 %, 13 out of 209 scientists), and environmental biology (4.6 %, 19 out of 415 scientists) are less likely to commercialize their research through start-ups.

The variation in commercialization through start-ups can be explained in numerous ways. First, it is likely that scientists in the fields of biological, physical, and environmental sciences need greater human capital (access to large number of prior patents, collaboration from a large number of field experts) in order to commercialize their research.

Second, due to the interdisciplinary and basic nature of research, it is likely that scientists in these fields need greater access to financial (funding from sources other than the government) and institutional (location of industry, networks of suppliers and buyers) resources to commercialize their research.

Third, and most importantly, it is likely that the Technology Transfer Offices in their universities are not competent in understanding their area of research and hence are unsuccessful in surpassing the knowledge filter in commercializing their research through start-ups.

Finally as Aldridge and Audretsch (2010, 2011) suggest, it is likely that scientists in these fields prefer to commercialize their research through other modes of commercialization like patents and licensing commitments, without founding a legally recognized company. These reasons for variation in scientist commercialization across fields of research are further explored in the empirical findings section of the report.

5.3.3.1.2 Patents

Figure 5.3 compares the likelihood of scientist start-up commercialization through the use of patents across the six fields of research. Seventy of the 221 scientist start-ups, an average of 31.7 % across six fields of research, have indicated that their start-ups own patents of one or more founding members. This indicates that, in three out of ten scientist start-ups, patents have played a significant role in commercializing scientist research through starting up a legally founded company.

Furthermore, there is variation in the significance of scientist start-up commercialization across the six fields of research, ranging from 5.6 % (1 out of 18 start-ups) in environmental biology to 40 % (29 out of 79 start-ups) in computer and network systems. These figures indicate that patents play a significant role in commercializing one in four start-ups in the fields of civil, mechanical, and manufacturing innovation, computer and network systems, particle and nuclear astrophysics, and biological infrastructure. The lack of significance of patents in start-up commercialization in the fields of environmental biology and physical oceanography can be explained in part by the basic and exploratory nature of research and in part by the patent hoarding by large corporations in these sectors. Hence, Aldridge and Audretsch (2010, 2011) suggest it is likely that scientists in these fields prefer to license or sell their patents in the marketplace than commercialize them through start-ups.

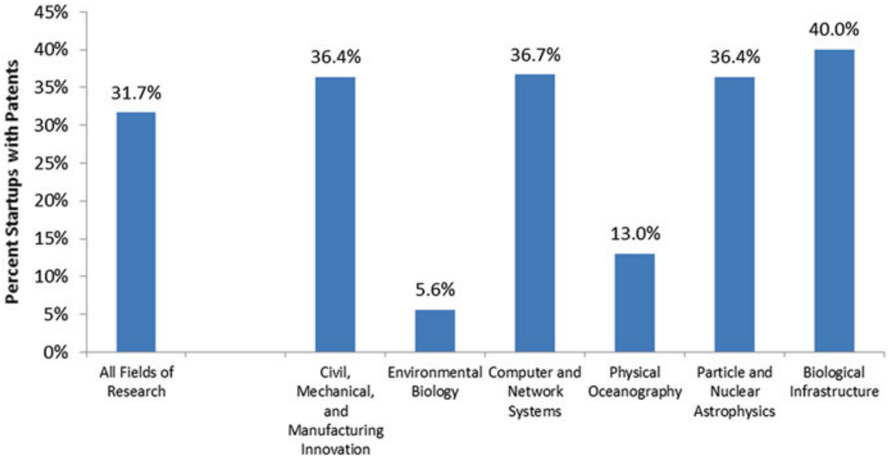

Fig. 5.3 Scientist start-ups with patents, by field of research

5.3.3.1.3 Innovative Products

Figure 5.4 compares the likelihood of scientist start-up commercialization through innovative product offering across the six fields of research. One hundred three of the 187 scientist start-ups, an average of 55.1 % across six fields of research, have indicated that their start-ups commercialize research by offering innovative products and services. This indicates the extreme significance of innovative products in scientist start-up commercialization. Furthermore, these figures provide evidence for the enormous potential, and demand, for innovative products through the scientist start-up commercialization route, and the substantial role Technology Transfer Offices can play in realizing this potential.

It is interesting to note that more than half of scientist start-ups across all fields of research, except environmental biology, use innovative products in commercializing their research. This indicates that there is tremendous potential for product innovations from scientist research, irrespective of the field of research. The significance of patents in developing innovative products for scientist start-up commercialization is explored in Fig. 5.4.

Figure 5.5 explains the significance of patents in determining the likelihood of scientist start-up commercialization through the use of innovative products across the six fields of research. Forty-nine of the 63 scientist start-ups, an average of 78 % across six fields of research, have indicated that patents were used in developing innovative products for scientist start-up commercialization. This further underscores the significance of patents, in designing innovative products and facilitating scientist research commercialization through start-ups.

It is important to note that in most fields of research, except environmental biology and particle and nuclear astrophysics, patents play an important role in deter-

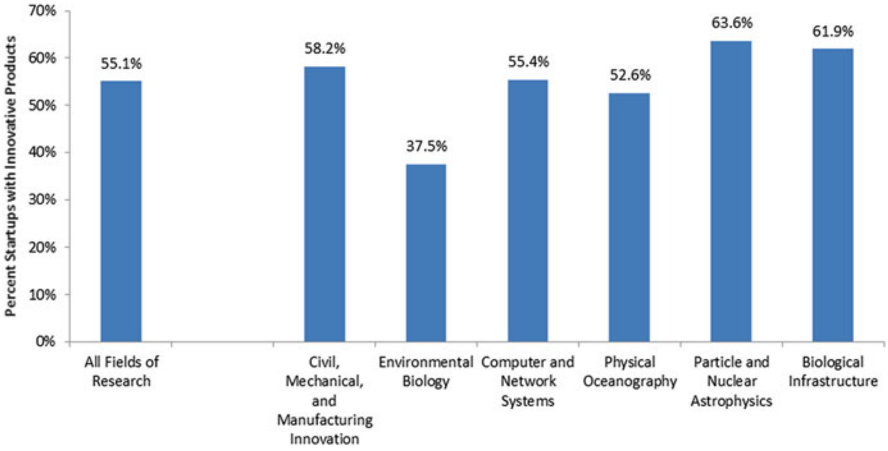

Fig. 5.4 Scientist start-ups with innovative products

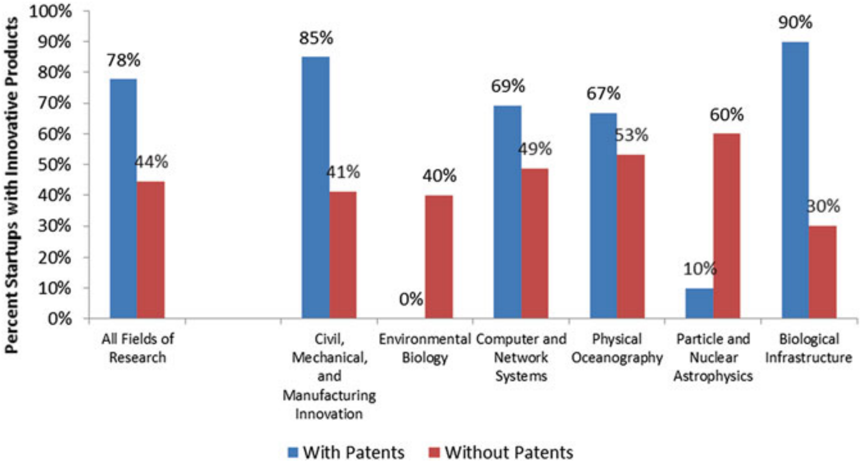

Fig. 5.5 Scientist start-ups with innovative products and patents

mining the use of innovative products in scientist start-up commercialization, most likely by increasing the firm’s competitiveness and chances of success.

5.3.3.1.4 Consulting Services

Figure 5.6 compares the likelihood of scientist start-up commercialization through consulting services across the six fields of research. Sixty-three of the 184 scientist start-ups, an average of 47.6 % across six fields of research, have indicated that their start-ups commercialize research through consulting services.

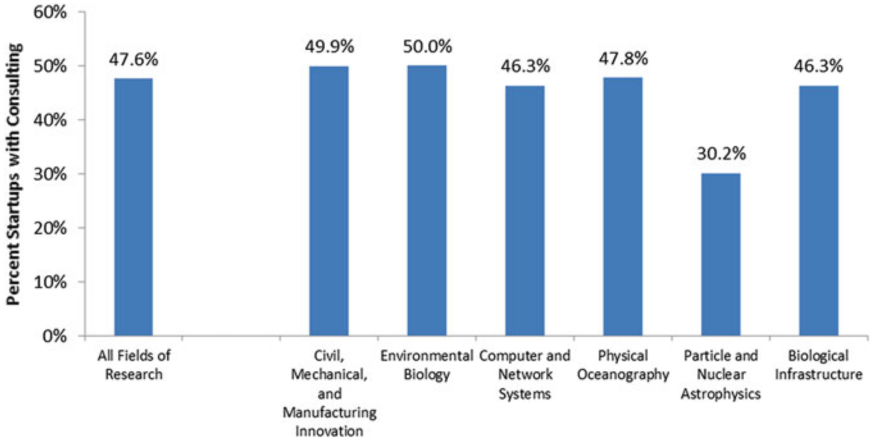

Fig. 5.6 Scientist start-ups with consulting service

This indicates that one in every two scientist start-ups offers consulting services, which provides evidence of commercial value of scientist research to the industry on the one end and the multidimensionality of modes of commercialization among scientist start-ups.

In summary, these results suggest that one in eight scientists commercializes their research through start-ups, with one in three start-ups using scientist patents and one in two start-ups offering innovative products and consulting services in commercializing their research through start-ups. These figures provide evidence that scientist start-ups rely on more than one revenue source in commercializing their research, hence increasing the likelihood of scientist start-up success. Table 5.3 summarizes the scientist start-up success rate by their mode of start-up commercialization.

5.3.3.1.5 Firm Success

Table 5.3 compares the likelihood of scientist start-up success between those with innovative products and those with only patents across the six fields of research. One hundred thirty-five of the 185 scientist start-ups, an average of 73 % across six fields of research, have indicated that their start-ups are currently active. This indicates that three out of four scientist start-ups have been successful in commercializing their research across six fields of research, using various modes of start-up commercialization. There is an exceptionally high rate of scientist firm success in the field of physical oceanography (89 %) and civil, mechanical, and manufacturing innovation (78 %). The relatively low rate of success in the field of computer and network systems (though at a significant 68 %) can be attributed, in part, to the rapid rate of innovation, and competition in scientist research, from industry.

It is important to note that across all fields of research, scientist firms' likelihood of success is significantly enhanced when the mode of start-up commercialization is

Table 5.3 Scientist firm success, by innovative products and patents

	Number of firms	% Firm success	With innovative product	With patent
All fields of research	185	73.0 %	91.1 %	74.2 %
Civil, mechanical, and manufacturing innovation	54	77.8 %	93.5 %	84.2 %
Environmental biology	17	70.6 %	100.0 %	0.0 %
Computer and network systems	65	67.7 %	91.4 %	61.5 %
Physical oceanography	18	88.9 %	100.0 %	100.0 %
Particle and nuclear astrophysics	10	70.0 %	71.4 %	75.0 %
Biological infrastructure	21	71.4 %	84.6 %	90.0 %

through the use of innovative products and patents. The results indicate that nine out of ten scientist start-ups with an innovative product offering, and three out of four start-ups with a patent, are likely to succeed across the six different fields of research. Also, there is a wide range of variation in the significance of patents in determining scientist firm success in the fields of environmental biology and computer and network systems, possibly due to the competition from large innovative firms in the respective sectors.

5.3.3.2 Scientist Characteristics

This section compares the characteristics of scientists that commercialized their research through start-ups with scientists that did not, across the six fields of research.

The scientist life cycle model suggests that the scientist's decision to commercialize scientific knowledge depends on the scientist's life cycle and career trajectory (Levin and Stephan 1991). Scientist's life cycle explains how scientists make investments in human capital toward production of new economic knowledge in order to build scientific reputation. Scientist career trajectory explains how scientists, under different institutional contexts, establish career-specific priorities in seeking rewards to new scientific knowledge and reputation. Audretsch and Stephan (2000) show that due to differential incentive structures, scientists in the university context primarily seek to advance their careers through publications in scientific journals, whereas scientists working in industry tend to commercialize their research in the market.

The scientist life cycle and career trajectory are expected to be influenced by the scientist's age, gender, country of origin, and their field of research. The age of the scientist captures how the scientist life cycle and their career trajectory influence their commercialization decision, by serving as a proxy for the level of scientist human capital and their scientific reputation. The entrepreneurship literature has consistently found gender to be a strong determinant of an individual's decision to become an entrepreneur (Minniti and Nardone 2007), and as Aldridge and Audretsch (2010, 2011) suggest, gender also plays a critical role through numerous other mechanisms including scientist's propensity to patent and their access to financial resources. The scientist's country of origin, measured as the continent in which the scientist completed his/her undergraduate education, is expected to impact the scientist's career trajectory by serving as a proxy for how scientists, from different ethnic backgrounds, prioritize their career-specific decisions and appropriate economic value to new knowledge.

Furthermore, scientist life cycle and career trajectory, and their decision to commercialize scientific research, are heavily influenced on the access to resources, their human and social capital, and importantly the institutional context in which they conduct their research. The significance and influence of these concepts on the scientist's decision to commercialize their research are discussed, and empirically tested, in future sections of this report.

5.3.3.2.1 Gender

Figure 5.7 compares the likelihood of scientist start-up commercialization by gender, across the six fields of research. Findings indicate that male scientists are two and a half times more likely, across six fields of research, to commercialize their research through start-ups than female scientists. On average, 13 out of 100 male scientists, and one in five female scientists, reported that they commercialized their research by founding a legally recognized company.

It is interesting to note that in all fields of research, except particle and nuclear astrophysics, male scientists are more likely to commercialize their research through start-ups than female scientists. Also, in the fields of civil, mechanical, and manufacturing innovation (CMMI) and computer and network systems (CNS), the gender gap appears to be very dominant—approximately one in five—and one in four male scientists reported commercializing their research through start-ups, whereas

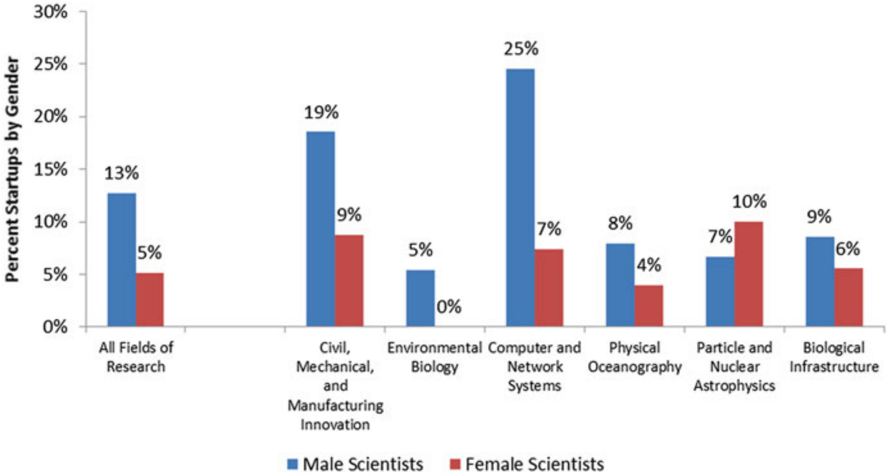

Fig. 5.7 Scientist start-ups and gender

only one in ten and 1 in 14 female scientists reported commercializing their research through start-ups in the fields of CMMI and CNS, respectively. This variation can be explained by the predominant gender gap in the fields of engineering and computer science, both in the industry and the academia.

5.3.3.2.2 Age

Figure 5.8 compares the average age of scientists that commercialized their research through start-ups, across the six fields of research. It is observed that the average age of a scientist when they commercialized their research through start-ups was 43.8 years. It is interesting to note that, like the life cycle model suggests, the scientist entrepreneur's age is significantly higher than what is usually observed among entrepreneurs in the entire population—scientists that commercialize their research through start-ups do so at significantly later stages of their careers.

There is variation in the average age of scientists across fields of research—on average, scientists in the fields of civil, mechanical, and manufacturing innovation and computer and network systems are younger than scientists in other fields when they decide to commercialize scientific research through start-ups. This variation can be explained, in part, by the career trajectory of scientists in the fields of engineering and computer sciences (on average scientists in these fields complete their doctoral education and start their academic careers a few years earlier that other fields) and in part by the greater degree of industry-academia collaboration in these sectors (hence, scientists have a better understanding on how to market scientific knowledge to industry).

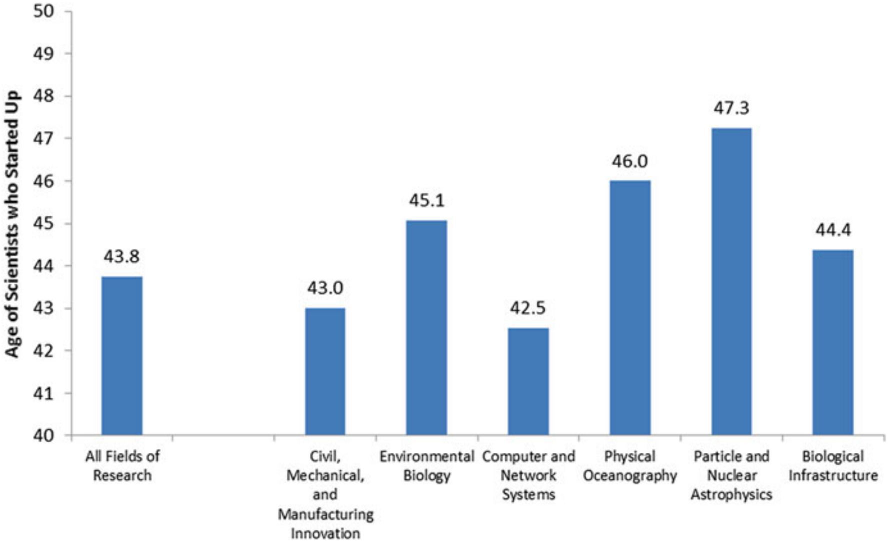

Fig. 5.8 Scientist age and start-up commercialization

Table 5.4 Scientist start-ups by continent of origin

Continent of origin	Number of scientists in the sample	Number of scientist who started up	Percent scientist start-ups
North America	1195	137	11.46 %
South America	30	2	6.67 %
Europe	184	21	11.41 %
Africa	15	–	–
Asia	148	15	10.14 %
Australia/Oceania	4	–	–
Total	1576	175	

5.3.3.2.3 Country of Origin

Table 5.4 compares scientists that commercialized their research through start-ups by country of origin, across the six fields of research. Out of 1899 scientists, 1576 indicated their continent of origin, measured as the continent in which the scientist completed his/her undergraduate education. From North America, predominantly the United States, 11.46 % (137 out of 1195 scientists), 11.42 % (21 out of 184 scientists) from Europe, 10.14 % (15 out of 148 scientists) from Asia, and 6.67 % (2 out of 30 scientists) from South America have commercialized their research through start-ups.

It appears that the effect of scientist career trajectory on scientist's decision to commercialize research, across the six fields of research, is very similar for scientists from North America, Europe, and Asia. However, the effect of career trajectory for scientists from South America, Africa, and Australia seems to vary considerably based on field of research (see Appendix C for a comprehensive summary of start-ups by scientist country of origin across the six fields of research). This provides preliminary evidence of the effect of scientist's ethnicity on his/her decision to commercialize research through start-ups.

5.3.3.3 Resources

This section compares the likelihood of scientist commercialization through start-ups by the amount of financial and human resources available to scientists, across the six fields of research. The basic hypothesis is that the scientist's likelihood to commercialize scientific research through start-ups increases with greater access to resources.

In the entrepreneurship and innovation literature, resources have often been found to have a strong positive effect on firm's innovative activity and aggregate innovative output. In his model of knowledge production function, Griliches (1979) recommended that investments in knowledge generating inputs have the greatest effect on innovative outputs. Though much of the literature focuses on the innovative activity of firms, as Aldridge and Audretsch (2010, 2011) suggest, the unit of analyses can be extended to the individual scientist, both as an agent utilizing available resources for knowledge creation and as an agent transforming scientific knowledge into innovative outputs. To this end, the scientist entrepreneurship database captures the amount of financial and human resources available to the scientists.

Financial resources are measured as the amount of funding available to the scientist to conduct scientific research from the National Science Foundation (NSF) and the availability of financial resources from other sources of funding such as nonprofits, university, government, international governmental organizations, industry, and other sources. The amount and availability of financial resources are expected to positively influence the factors in the knowledge production function of the scientist, both in knowledge creation and in transforming scientific knowledge into innovative outputs.

Human resources are measured as the number of student collaborators that worked closely with the scientist during the duration of research (students as factors in the process of knowledge creation) and as the number of student collaborators that was later hired by the scientist's start-up subsequent to commercializing research through founding a legally recognized company (students as human capital factors in transforming scientific knowledge into innovative outputs).

5.3.3.3.1 Financial Resources

This section describes the likelihood of scientist start-up commercialization by their availability and access to funding resources, across the six fields of research. The scientist entrepreneurship database measures financial resources in two different ways—NSF funding amount and availability of significant sources of funding (>750K) from other sources (nonprofits, university, government, international governmental organizations, industry, and other sources).

5.3.3.3.2 NSF Funding

Figure 5.9 compares the average amount of NSF funding received by scientists that commercialized their innovation through start-ups with scientists that did not. On average and across all fields of research, except in the fields of environmental biology and particle and nuclear physics, scientists that commercialized research through start-ups received greater amounts of funding than scientists that did not.

The impact of funding appears to be the largest in the field of physical oceanography, possibly due to the high amount of capital required in creating incremental innovations which possess commercial potential in the industry.

5.3.3.3.3 Other Sources of Funding

Figure 5.10 shows the likelihood of scientist's to commercialize their research through start-ups by comparing the proportion of scientists that received other significant sources of funding with scientists that did not, across the six fields of research. On average and across all fields of research, scientists that receive funding

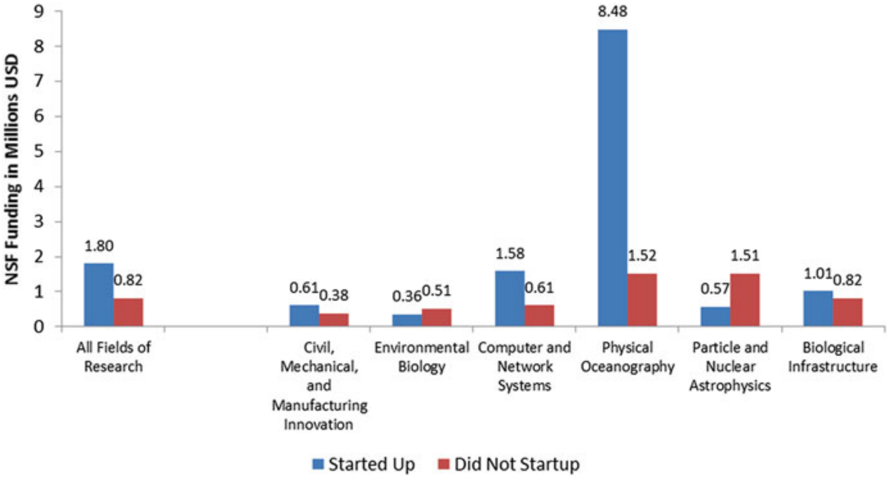

Fig. 5.9 NSF funding and scientist start-ups commercialization

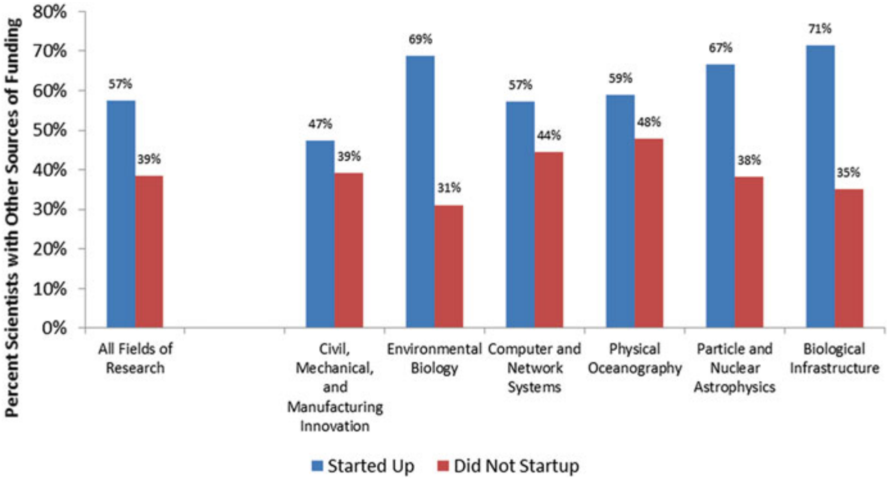

Fig. 5.10 Other sources of funding and scientist start-ups

from other sources are more likely to commercialize their research through start-ups than scientists that do not.

It is interesting to note that the impact of other sources of funding is the largest in the fields of environmental biology, particle and nuclear physics, and biological infrastructure possibly due to the capital-intensive nature in commercializing innovations in these fields. Also, it is possible that these fields probably are in greatest need of funding and collaborations from the industry, nonprofits, and the government due to the radical nature of innovations attempted through research. In general, these findings suggest that financial resources have a strong positive impact on the scientist's likelihood to commercialize research through start-ups. For a detailed discussion of the impact of funding from various sources by field of research, see Appendix D.

5.3.3.3.4 Human Resources

This section describes the likelihood of scientist start-up commercialization by their access to human resources, across the six fields of research. The scientist entrepreneurship database measures human resources in two different ways—the number of student collaborators that was closely associated with the scientist's research and the number of student collaborators that was subsequently employed the scientist's start-up.

5.3.3.3.5 Number of Student Collaborators

Figure 5.11 shows the likelihood of scientists to commercialize their research through start-ups by comparing the average number of student collaborators available to the scientists that started up with scientists that did not start up. On average and across all fields of research except physical oceanography, scientists with more student collaborators are more likely to commercialize their research through . For further discussion of student collaborators' employment decisions subsequent to their collaboration with the scientists, see Appendix E.

These results provide preliminary evidence that scientists with greater availability and access to financial and human resources are more likely to commercialize research through start-ups.

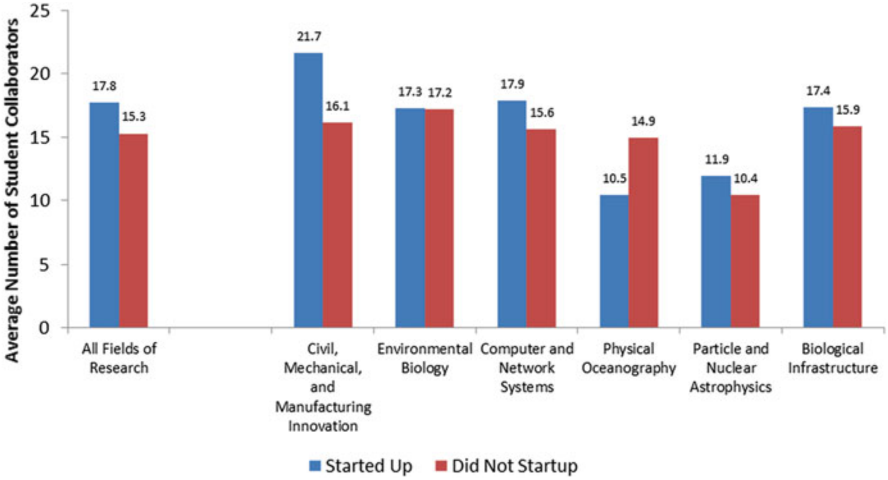

Fig. 5.11 Scientist start-ups and number of student collaborators

5.3.3.4 Scientist Human Capital

This section discusses and compares the likelihood of scientist commercialization through start-ups by the level of scientist human capital, across the six fields of research.

The entrepreneurship literature has extensively examined the link between human capital and entrepreneurship (Bates 1995; Evans and Leighton 1989; Gimeno et al. 1997; Davidsson and Honig 2003). The general finding is that, for the general population, higher levels of human capital increase the ability of individuals to recognize entrepreneurial opportunities and their propensity to seize those opportunities. There is no reason to believe that the same relationship will hold for the population of scientists, in general. Though higher levels of human capital (measured as scientific reputation) may increase entrepreneurial opportunities, it is important to note that the mechanisms through which human capital affects entrepreneurial decision of scientists may be different from that of the general population, due to the unique institutional contexts in which scientists operate.

As discussed earlier, the knowledge production function and the scientist life cycle and career trajectory provide valuable structure in understanding and modeling the commercialization decision of scientists. However, since the scientists represent an exceptionally high achieving section of the general population, it is challenging to find an appropriate measure of their human capital. As the discussion on the effect of scientist life cycle and career trajectory on entrepreneurship decision (refer to Sect. 5.3.2) suggests, the most appropriate measure of scientist human capital is a measure of their reputation.

The scientist entrepreneurship database measures the tenure status and the experience (years in tenure) of the scientist. Though the scientist entrepreneurship database has obtained the common measure for scientific reputation as evidenced through citations or number of citations per publication (Audretsch and Stephan 2000; Aldridge and Audretsch 2011), it is argued that the tenure status and experience level of the scientist serve as a strong proxy for their relative levels of human capital.

5.3.3.4.1 Tenure Status

Table 5.5 compares the tenure status of scientists and their likelihood to commercialize scientific research through start-ups, across the six fields of research. It is observed that 10.9 % of nontenured scientists and 11 % of tenured scientists commercialized scientific research through start-ups. These results are not surprising given that nontenured scientists may also include scientists with varying degrees of scientific reputation from the industry, along with young nontenured professors in the academic setting. However, it is important to note that a majority of the scientists that obtained NSF funding are conducting scientific research in a university setting.

Table 5.5 Scientist characteristics, tenure status

	Total sample	Number of start-ups	Started up (%)
Nontenured scientists	*156*	*17*	*10.9*
Tenure scientists	*1486*	*163*	*11.0*
Assistant professor	150	4	2.7
Associate professor	442	34	7.7
Full professor	716	90	12.6
Endowed professor	146	33	22.6
Emeritus professor	32	2	6.3
Total	1642	180	

The likelihood of commercializing scientific research increases in a linear fashion by the tenure status of the scientist with 2.7 % of assistant professors, 7.7 % of associate professors, 12.6 % of full professors, 22.6 % of endowed professors, and 6.3 % of emeritus professors commercializing scientific research through start-ups. These results are not surprising since the tenure status of the scientists also represents their scientific reputation, and as explained by the scientist life cycle model, scientists with higher levels of human capital (i.e., scientific reputation) are more likely to commercialize their research. Another way to measure scientist reputation and human capital is the level of experience, i.e., years in tenured status.

5.3.3.4.2 Experience: Years in Tenured Status

Table 5.6 compares the likelihood of scientists to commercialize scientific research through start-ups by their level of experience measured as the number of years in tenured status, across the six fields of research. It appears that there is a strong linear relationship between scientist's experience and their likelihood to commercialize scientific research through start-ups. However, the nature of relationship between scientist experience and their likelihood of start-up commercialization appears to be weaker than their tenure status. This anomaly can be explained in one of two ways—first, only 855 of the 1486 tenured scientists revealed their year of tenureship; hence, it is likely that the nature of missing values is distributed across experience levels in a nonrandom fashion. Second, experience of scientists in the academic context is influenced by the extent of their linkages with the industry, which may be very specific to the field of research. For example, scientists in computer and network systems are probably more likely to seek tenure status in the academic setting after they have pursued research in the industry for a few years, which may not be the case with scientists in particle and nuclear astrophysics.

Overall, these findings provide evidence of a strong positive relationship between scientist human capital and their likelihood to commercialize scientific research through start-ups.

Table 5.6 Scientist characteristics, years in tenured status

	Total sample		Started up (%)
Nontenured scientists	*156*	*17*	*10.9*
Tenure scientists			
0–5 years	67	6	9.0
6–10 years	200	31	15.5
11–15 years	184	20	10.9
16–20 years	170	33	19.4
21–25 years	101	13	12.9
26–30 years	59	6	10.2
31–35 years	42	7	16.7
More than 35 years	32	2	6.3
Total	1011	135	

5.3.3.5 Scientist Social Capital

This section compares the likelihood of scientist commercialization through start-ups by the amount of scientist social capital, across the six different fields of research. Scientist social capital refers to the scientist's potential to derive tangible and intangible benefits from interactions and cooperative activities with other individuals and groups.

The macroeconomic growth literature typically lays emphasis on the importance of physical capital and human capital (Solow 1956) and knowledge capital through the process of accumulation (Romer 1986, 1994; Lucas 1988). However, the concept of social capital (Putnam 2000) can be considered as an extension to the usual factors of production in the endogenous growth models as it explains the social dimension in the factors of production.

Numerous recent studies testing the effect of social capital on entrepreneurship have concluded that entrepreneurial activity of general population is enhanced with greater investments in social capital (Mosey and Wright 2007; Aldrich and Martinez 2010; Shane and Stuart 2002; Davidsson and Honig 2003).

Furthermore, the entrepreneurship literature proposes numerous causal mechanisms through which social capital enhances the likelihood of entrepreneurial activity. First, interactions and linkages among scientists working in different institutional contexts, such as working with scientists in the industry, function as conduits of knowledge spillovers and flow of information about the process and modes of commercializing scientific research (Thursby and Thursby 2002; Aldridge and Audretsch 2011). Second, interactions and linkages with industry, such as being part of the scientific board of firms in the industry, facilitate flow of knowledge and information about the latent potential and rate of success in commercializing scientific research. Third, interactions with scientists in the same institutional context such as the entrepreneurial orientation of the head of the department can be posited to facilitate exchange of information and knowledge about the practice of commercializing scientific research among scientists (discussed under regional and institutional contexts).

The scientist entrepreneurship database collects information about the board membership of the scientist. It is suggested that the board membership of the scientist serves as a perfect proxy for his/her social capital with regards to the scientist's linkages and interactions with the industry.

5.3.3.5.1 Board Membership

Figure 5.12 compares the likelihood of scientists to commercialize research through start-ups by their membership on the board of directors of firms in the industry, across the six fields of research.

These findings indicate that scientists that are on the board of directors of other firms in the industry are significantly more likely to start a firm of their own, than scientists that do not possess such interactions and linkages with other firms in the industry, across all fields of research. It is most interesting to note that this significance is most striking in the field of particle and nuclear astrophysics, where the nature of research is expected to have the most significant barrier in the knowledge filter.

On average, scientists with interactions and linkages to the industry through board membership in these six fields of research are two to three times more likely to commercialize their research through start-ups. These results shed light on the significance of this instrument in influencing the scientist's decision and mode of commercializing scientific research. These results provide evidence of a strong relationship between social capital and the scientist comm ercialization.

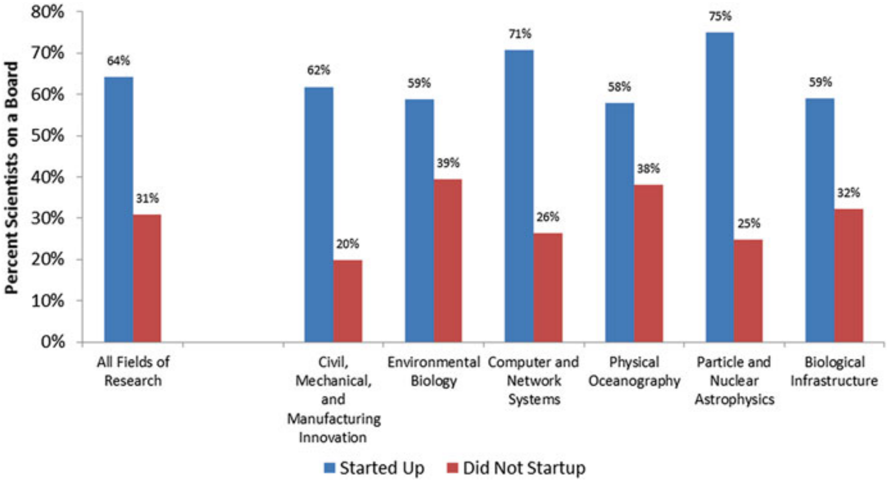

Fig. 5.12 Scientist on board of directors other firms

5.3.3.6 Locational and Institutional Contexts

This section compares and discusses the influence of locational and institutional contexts on the likelihood of scientist commercialization through start-ups across the six fields of research.

In addition to individual characteristics, access to financial and human resources, and factors of production in the knowledge production function, several locational and institutional factors influence the decision of a scientist to become an entrepreneur. First, knowledge tends to spill over within geographically bounded regions (Jaffe (1989), Audretsch and Feldman (1996), Jaffe et al. (1993), and Glaeser et al. (1992)). This means that location matters in determining the level of investments in new knowledge, in accessing technological knowledge, in facilitating knowledge spillovers, and in shaping the institutional and scientist behavioral norms and attitudes toward commercialization (Louis et al. 1989).

Second, certain institutional features may encourage or act as an impediment to scientist entrepreneurship depending on the institutional contexts in which the entrepreneurial decision is made (Henrekson and Stenkula 2010; Karlsson and Karlsson 2002). Two distinct features of the institutional context play a role in influencing the scientist's decision to commercialize his/her research through start-ups—support from the department and characteristics of the Technology Transfer Office. First, the department's conscious efforts in encouraging commercialization of scientific knowledge and the department head's entrepreneurial orientation may act as substitutes in encouraging the scientist to commercialize his/her research. Second, the characteristics of the Technology Transfer Office (TTO) determine the level of assistance in scientist commercialization depending on their resource availability (Mowery 2005) and their influence on the scientist's mode of commercialization depending on their organizational priorities (Markman et al. 2005; O'Shea et al. 2005; Lockett et al. 2005).

The scientist entrepreneurship database collects information on the locational (region) and institutional (the entrepreneurial orientation of the scientist's department head, TTO characteristics) contexts of the scientist. Though the actual frequency and significance of the scientist's interactions with his/her department head and the TTO's organizational priorities are not measured, it is argued that the department head's entrepreneurial orientation and scientist's perception of the TTO serve as strong proxies for the scientist's institutional context.

This section compares and discusses the factors through which locational contexts influence the scientist's likelihood to commercialize research through start-ups, across the six fields of research. Specifically, the influence of regions in the United States—classified as Northeast, West, South, and Midwest—is discussed. Please refer to Appendix F for a discussion on how the classifications have been made. Though the analysis does not include an extensive discussion of knowledge spillovers at the university level, the subsequent section on institutional contexts discusses the effect of department- and university-level factors on the scientist's start-up commercialization decision.

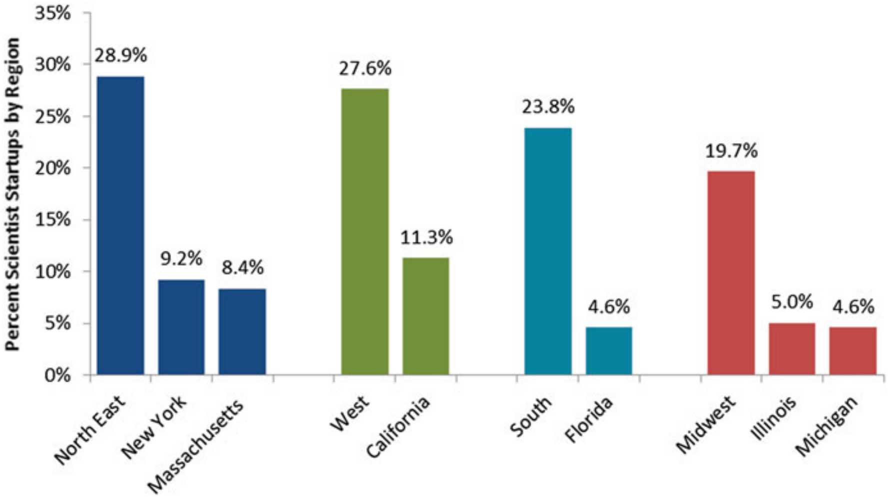

Fig. 5.13 Share of scientist start-ups by region

5.3.3.6.1 Region

Figure 5.13 compares the share of scientist start-ups by location of scientist across all six fields of research.

Results indicate that 29 % of scientist start-ups across the six fields of research are from the Northeast region, with 9.2 % and 8.4 % of scientist start-ups from New York and Massachusetts, respectively. Furthermore, 27.6 % of scientist start-ups are from the West region of the United States, with 11.3 % from the state of California—the highest from any one state in the United States. The South and Midwest regions contribute 23.8 % and 19.7 % of the start-ups, respectively. These results provide evidence for the influence of two distinct locational factors. First, there is significant amount of variation in the number of scientist start-ups by region—this can be attributed in part to the variation in the level of investment in new knowledge creation and in part to the access to technological knowledge in facilitating knowledge spillovers. Second, with a dominant proportion of start-ups from one or two states, this can be attributed to the institutional and scientist behavioral norms and attitudes toward commercialization in those states and to the state-specific investments, especially in public universities, in different fields of research.

5.3.3.6.2 Fields of Research

Table 5.7 compares the proportion of scientists that commercialize their research through start-ups, by their location and fields of research. Findings indicate that roughly 15 %, one in seven, of scientists in the Northeast region, 13.17 % of

Table 5.7 Scientist start-ups by region, across fields of research

	Northeast (%)	Midwest (%)	South (%)	West (%)
All fields of research	14.97	12.21	10.69	13.17
Civil, mechanical, and manufacturing innovation	19.48	27.47	19.49	12.82
Environmental biology	5.38	0.00	3.31	9.43
Computer and network systems	30.21	23.08	15.00	27.00
Physical oceanography	12.66	0.00	5.88	10.68
Particle and nuclear astrophysics	5.08	5.66	10.00	2.70
Biological infrastructure	11.94	5.41	6.98	8.89

scientists in the West region, 12.21 % of scientists in the Midwest region, and 10.69 % of scientists in the South region commercialize their research through start-ups. These findings are not surprising since we know that the technological knowledge in facilitating knowledge spillovers is greater in the Northeast and West regions, especially in California, New York, and Massachusetts.

Furthermore, results also indicate the location-specific effects on fields of research. We find that the proportion of scientists that are in the field of civil, mechanical, and manufacturing innovation based in the Midwest region are most likely to commercialize their research through start-ups. These findings are not surprising given the competitiveness of the manufacturing sector in the Midwest states. In the field of environmental biology, scientists from the West region are most likely to commercialize their research through start-ups—this maybe largely due to the vibrant biotechnology sector and heavy investments in research and development from the industry in California and Washington. In the fields of physical oceanography and biological infrastructure, scientists from the Northeast region are most likely to commercialize their research through start-ups—this is possibly due to large industry research and development investments in environment and biological sciences in New York, Massachusetts, and Pennsylvania.

The fields of computer and network systems and particle and nuclear astrophysics are the most peculiar with regards to the effect of locational factors on the scientist's likelihood of commercializing research through start-ups due to the nature of innovative activity in these fields.

First, scientists in the field of computer and network systems seek incremental innovations, in that they tend to accumulate knowledge by building upon existing knowledge and resources and hence are faced with lesser barriers in facilitating knowledge spillovers between and from the industry, whereas scientists in the field of particle and nuclear astrophysics seek radical innovations, in that they tend to produce innovations that require completely new knowledge and/or resources in commercializing their research and hence are faced with greater barriers in facilitating knowledge spillovers between and from the industry.

Second, scientists in the field of computer and network systems tend to have more industry interactions and linkages and more favorable institutional factors in commercializing their research than scientists in the field of particle and nuclear astrophysics due to the applied and incremental nature of their research and more favorable scientist-community norms toward commercialization and firm failure. Hence, we observe that a larger proportion of scientists in the field of computer and network systems are able to commercialize their research through start-ups than scientist in the field of particle and nuclear astrophysics.

Overall, we observe that locational factors strongly influence scientist start-up commercialization decision depending on the nature of technological knowledge in facilitating knowledge spillovers and the field of research.

This section compares and discusses the factors through which institutional contexts influence the scientist's likelihood to commercialize research through start-ups, across the six fields of research. Specifically, we discuss the effect of department- and university-/industry-level institutional factors on the scientist's start-up commercialization decision.

5.3.3.6.3 Management Inclination

Figure 5.14 compares the likelihood of scientist commercialization through start-ups depending on the head of department's entrepreneurial orientation, across the six fields of research. Though the actual frequency of scientist's interactions with his/her department head is not measured, it is argued that the department head's entrepreneurial orientation serves as strong proxies for the scientist's departmental context.

Findings suggest that in all fields of research, except particle and nuclear astrophysics, the head of department's entrepreneurial orientation, i.e., if the department head commercialized scientific research through starting up a legally founded com-

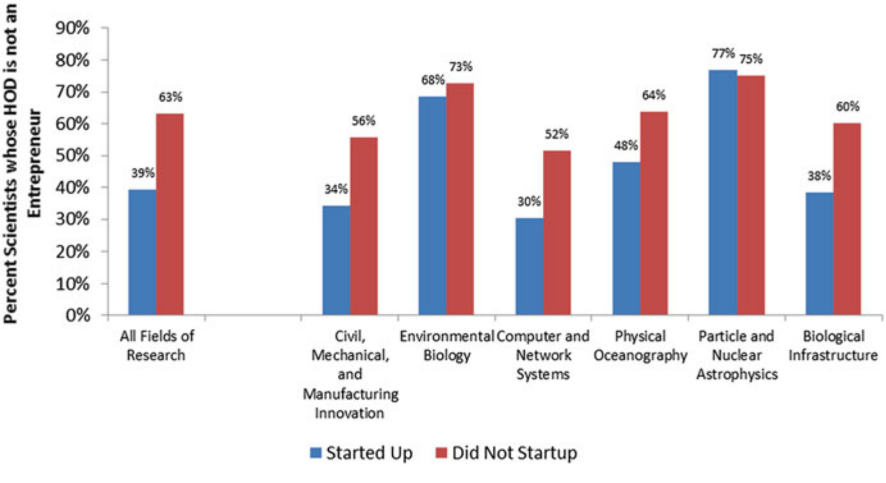

Fig. 5.14 Scientist start-ups and department HOD entrepreneurial inclination

pany, is positively related to the scientist's likelihood of commercializing research through start-ups. As discussed earlier, the insignificance of department head's entrepreneurial orientation in the field of particle and nuclear astrophysics is possibly due to the radical nature of innovations typical to the field.

5.3.3.6.4 Technology Transfer Office

This section discusses the effect of the Technology Transfer Office (TTO) characteristics on the likelihood of scientist to commercialize research through start-ups. Roughly, 25 % of the scientists described the TTOs as incompetent in understanding their area of research, and 15 % of the scientists described TTOs as unsuccessful in commercializing research. However, the majority of the scientist responses indicated that the TTOs are of significant help in assisting scientists in overcoming the knowledge filter. Practical significance and hypothesis for future empirical research are discussed.

Figure 5.15 shows the difference in scientist's perception of the Technology Transfer Office (TTO) characteristics between scientists' that commercialized their research through start-ups and scientists that did not.

The scientist entrepreneurship database captures scientist's perception of TTO characteristics in two ways—competence of the TTO in understanding the scientist's area of research and success of the TTO in commercializing scientist's research. Results indicate that, on average, scientists that started up have found the TTO to be relatively less competent in understanding the scientist's area of research and unsuccessful in commercializing scientist's research. These results are not surprising given that scientists that either are unsuccessful in seeking help from the TTO or

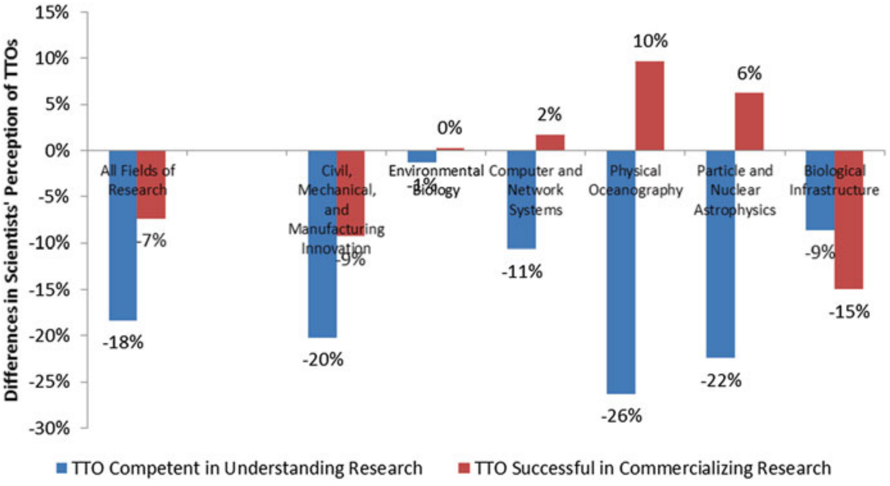

Fig. 5.15 Difference in scientist's perception of TTO institutional factors

choose not to use the services offered by the TTO tend to commercialize their research through start-ups (Aldridge and Audretsch 2011).

Furthermore, it appears that scientists in the fields of computer and network systems, physical oceanography, and particle and nuclear astrophysics that started up felt that their TTO was successful in commercializing their research. However, on average, it can be said that scientists that started up seem to be less appreciative of the TTO than scientists that did not.

These results are not surprising given that most scientists that did not start up found the TTO to be more helpful either since they did not seek a very specific area of expertise from the TTO or because they found the TTO to be more knowledgeable about the mechanisms of knowledge spillovers in their field of research than themselves (due to their own limited interactions and linkages with the industry).

5.4 Determinants of Scientist Entrepreneurship

While very little literature has been devoted to understanding and analyzing scientist entrepreneurship, a much broader research has generated a plethora of studies focusing on entrepreneurship in a more general context (Acs and Audretsch 2010). At the heart of this literature is the question of what exactly distinguishes those people who choose to become an entrepreneur from those who choose not to become an entrepreneur. The entrepreneurship literature has been developed at both theoretical and empirical levels (Acs and Audretsch 2010).

In his exhaustive survey of the entrepreneurship, Parker (2010) finds that the basic theoretical building block is the conceptual framework or model of entrepreneurial choice. The following section explains the model of entrepreneurial choice. The subsequent sections apply the model of entrepreneurial choice to the context of the university scientist. The scientist context of entrepreneurial choice involves five distinct types of factors or influences that shape the decision of a scientist to become an entrepreneur. These five factors involve first characteristics specific to the individual. The second factor involves human capital. The third factor involves social capital. The fourth factor involves the institutional context. Finally, the fifth factor involves access to resources in general and financial capital in particular.

5.4.1 The Model of Entrepreneurial Choice

According to the model of entrepreneurial choice, an individual weighs the benefits of becoming an entrepreneur against those benefits that could be obtained through employment in an existing firm. The greater the gap between the benefits accruing from entrepreneurship and those earned from being an employee is, the more likely that person is to become an entrepreneur (Parker 2010).

The model of entrepreneurial choice has been empirically tested in a number of contexts but almost never for the context of university scientists. In fact, a large body of literature has been developed that relates individual characteristics to the decision to become or not to become an entrepreneur (McClelland 1961; Roberts 1991; Brandsetter 1997; Gartner 1990; Blanchflower and Oswald 1998). One of the pioneering studies was by McClelland (1961). More recently, Zhao and Seibert (2006) link the personality characteristics of entrepreneurs to the decision to start a new business. Similarly, Reynolds et al. (2004) use a large database, the Panel Study of Income Dynamics (PSID), to identify the role that personality characteristics play in the decision that an individual makes to start a new business.

The role of intentions to become an entrepreneur has played a particularly important role in the entrepreneurship (Wright et al. 2006; Shapero and Sokol 1982; Ajzen 1991; Gaglio and Katz 2001). While these studies find that entrepreneurial intentions are important in the entrepreneurial process, none of these studies focus on the context of university scientists. Thus, Aldridge and Audretsch (2011) suggest that it is not clear whether the consistent findings concerning entrepreneurship and entrepreneurial intentions for the more general population would also be expected to be valid for the context of university scientists.

5.4.2 Career Experience

Aldridge and Audretsch (2011) posit there are important reasons that the main influences underlying entrepreneurial intentions for university scientists may in fact not simply mirror that found for the more general population. The Levin and Stephan (1991) and Stephan and Levin (1992) studies both provided a compelling theoretical argument along with supportive empirical evidence, suggesting the existence of a life cycle model of scientist commercialization. According to the Levin and Stephan (1991) and Stephan and Levin (1992) studies, scientist life cycle model, the age of a scientist may impact the decision to become an entrepreneur differently than has been found for the more general population. A well-known finding in the overall literature of entrepreneurship is that younger people have a greater propensity to become an entrepreneur, while older people are less likely to become an entrepreneur. However, Levin and Stephan (1991) and Stephan and Levin (1992) found that a positive relationship between the age of a scientist and the likelihood that they start a business. Levin and Stephan (1991) and Stephan and Levin (1992) interpret their results using the lens of a life cycle framework. According to their life cycle model, when a scientist is in the early career stages, scientist productivity and output tend to be the greatest. During the early life cycle stages, the scientist therefore has the greatest incentives to invest in creating knowledge which is public in nature, through publication of their scientific findings in scholarly journals, which has the impact of enhancing the scientist's scientific reputation. As the scientist matures and has carved out a reputation of scientific prominence, diminishing returns set in to both the scientific productivity and the reputation of the scientist. The incentive to the scientist shifts toward investing not so much in public knowledge but rather scientific research which can be commercialized. Thus, as the scientist matures over the life cycle, the incentives to become an entrepreneur also increase.

The predictions of Levin and Stephan (1991) and the Stephan and Levin (1992) model of scientist commercialization over the life cycle of the scientist is consistent with the few studies that have focused on the commercialization and entrepreneurial activities of scientists. For example, Wright et al. (2006), Shapero and Sokol (1982), Gaglio and Katz (2001) and Ajzen (1991) all have found that entrepreneurial intentions and the propensity to be sensitive to entrepreneurial opportunities may increase as a scientist matures and garners more career experience.

However, while there are compelling reasons to predict that age is positively related to the decision of a scientist to enter into entrepreneurship, Aldridge and Audretsch (2011) did not find any empirical evidence, suggesting that age or experience influences the propensity of a scientist to become an entrepreneur. Still, their findings highlight that the role of age in the entrepreneurial decision of university scientists does not simply mirror that of the more general population

5.4.3 Gender

A second important individual specific characteristic that has consistently been found to be important in shaping the decision to become an entrepreneur is gender (Minniti and Nardone 2007). Gender, of course, is independent of the life cycle of a scientist and thus is not applicable to the life cycle models of Levin and Stephan (1991) and Stephan and Levin (1992). Most of the literature has generated empirical evidence suggesting that females are less likely to become an entrepreneur (Allen et al. 2007). For example, the female self-employment rate in the United States is around half as great as the self-employment rate for males (Allen et al. 2007). While nearly 7 % of females participating in the labor force are classified as being self-employed, the self-employment rate of males is considerably greater, well over 12 %. The Global Entrepreneurship Monitor (GEM) finds that well over one in ten females in the United States owns' a business (Allen et al. 2007). By contrast, just under one in five males owns a business in the United States (Allen et al. 2007).

While not many studies have been undertaken examining the impact of gender on the decision to become an entrepreneur in high-technology and knowledge-based industries, several studies have presented evidence, suggesting that it is considerably lower for females than for males. For example, Elston and Audretsch (2010) find that females have a lower likelihood to be an entrepreneur in a study based on Small Business Innovation Research (SBIR) grants to start a firm, and, in particular, Elston and Audretsch (2010) provide evidence showing that the reliance on grants from the SBIR program as a primary source of start-up capital is considerably lower for females than for males. Elston and Audretsch (2010) find that the negative effect of being female on probability of receiving SBIR funding was robust and persistent even after controlling for personal characteristics such as age, race, education, and wealth.

In a different study analyzing firms receiving funding from the SBIR, Link and Scott (2009) find that, just under, one in five of the SBIR firms in their sample from the National Institutes of Health (NIH) SBIR program was owned by females. The remaining four-fifths of the SBIR firms receiving funding were owned by males. Thus, the empirical evidence from several studies implies that gender plays an even larger role in the decision to become an entrepreneur in knowledge-based and high-technology fields. While Aldridge and Audretsch (2011) used these studies as a basis for hypothesizing that the likelihood of becoming an entrepreneur is lower for female university scientists than for their male counterparts, their results in fact suggested that gender plays no role in influencing the entrepreneurial activities of scientists. This would suggest a sharp contrast to the findings for the overall population, where gender is one of the greatest determinants of who becomes an entrepreneur and who does not.

5.4.4 Human Capital

In the more general entrepreneurship literature, human capital plays a central role in the decision of individuals to become an entrepreneur (Acs and Audretsch 2010). A number of studies have explicitly focused on the relationship between the human capital of individuals and their propensity to become an entrepreneur or start a new business (Evans and Leighton 1989; Bates 1995; Gimeno et al. 1997; Davidsson and Honig 2003; Wright et al. 2007). The ability of an individual to recognize the existence of an entrepreneurial opportunity has been found by studies to be positively related to the level of human capital. Similarly, the willingness of and ability to actually implement and pursue those entrepreneurial opportunities has been found to be positively related to the level of human capital.

In terms of measurement, human capital is most frequently measured by the number of years in education or else, alternatively, the highest degree attained. The empirical literature has found, with very few exceptions, that human capital is positively related to the propensity to become an entrepreneur.

Aldridge and Audretsch (2011) suggest that the positive relationship between human capital and the likelihood of becoming an entrepreneur found for the general population would also be expected to hold for university scientists. In fact, their findings do not support the hypothesis that the human capital of the scientist is positively related to the propensity to become an entrepreneur. Rather, their study suggests that the level of human capital seems to have no statistically significant impact on the entrepreneurial decision of a university scientist. Aldridge and Audretsch (2011) interpret this nonsignificance of the human capital variable as reflecting a sample of university scientists with extremely high levels of human capital, so that the variance in human capital is not found to make any significant difference in the scientist decision to become an entrepreneur.

5.4.5 Social Capital

While human capital refers to the knowledge capabilities of the individual, the extent of social capital reflects the extent to which an individual can take advantage of linkages and connections to other people. Just as *physical capital* refers to the importance of factories and machines to generate economic value (Solow 1956), the endogenous growth theory (Romer 1986; Lucas 1988) shifted the emphasis to knowledge accumulation, so that *knowledge capital* takes on a key role in generating economic value.

By contrast, Putnam (1993) and Coleman (1988) introduced the concept of *social capital* to reflect the relationships, connections, and linkages to other people. Coleman (1988) explains that social capital involves "a variety of entities with two elements in common: they all consist of some aspect of social structure, and they facilitate certain actions of actors…within the structure." According to Putnam (2000, p. 19) social capital has a positive impact on innovation and growth, "Whereas physical capital refers to physical objects and human capital refers to the properties of individuals, social capital refers to connections among individuals—social networks. By analogy with notions of physical capital and human capital—tools and training that enhance individual productivity—social capital refers to features of social organization, such as networks that facilitate coordination and cooperation for mutual benefits."

The scholarly literature in entrepreneurship has found a positive and significant relationship between various measures of social capital and the propensity for an individual to become an entrepreneur (Mosey and Wright 2007; Aldrich and Martinez 2010; Shane and Stuart 2002; Davidsson and Honig 2003). Aldridge and Audretsch (2011) argue that social capital should play a key role in the decision of a university scientist to become an entrepreneur. In particular, they suggest that linkages, connections to and relationships with other scientists employed by industry, as well as connections to industrial firms, will facilitate the ability of the scientist to recognize entrepreneurial opportunities and to act on those opportunities through entrepreneurial activity. Aldridge and Audretsch (2011) do provide empirical evidence, suggesting that those university scientists with a greater extent of social capital have a greater propensity to become an entrepreneur.

5.4.6 Institutional Influences

The general literature on entrepreneurship (Acs and Audretsch 2010) has also identified the institutional context within which an individual confronts the decision to become an entrepreneur as influencing the outcome of that entrepreneurial decision (O'Shea et al. 2005; Mowery 2005). They suggest that certain aspects of the institutional context have been found to encourage individuals to become an entrepreneur, while other aspects have been found to deter or impede entrepreneurship, (Saxenian 1994; Karlsson and Karlsson 2002; Henrekson and Stenkula 2010).

Aldridge and Audretsch (2011) argue that, just as the literature has found for entrepreneurship within the general population, the institutional context may also play an important role in shaping the entrepreneurial decision for university scientists

(Thursby and Thursby 2002). For example, the Technology Transfer Office (TTO) can play an important role in either encouraging or alternatively impeding entrepreneurial activity among university scientists (Mustar et al. 2006; Chapple et al. 2005). In fact, meticulously undertaken studies have found indications that TTOs do not have the same impact on entrepreneurial and other scientist commercialization activities among different universities (Roberts and Malone 1996; Vohora et al. 2004; Siegel et al. 2007; Wright et al. 2007; Breznitz et al. 2008). The studies suggest that there is considerable heterogeneity in the organization and strategies of Technology Transfer Offices across different universities. For example, Offices of Technology Transfer differ considerably in terms of size, access to human resources, and access to financial resources (Mowery 2005). As Aldridge and Audretsch (2010) suggest, those Technology Transfer Offices which have better access to more resources may be better situated to assist university scientists commercialize their research in the form of entrepreneurial activity.

Markman et al. (2005) explain that considerable heterogeneity exists across Offices of Technology Transfer with respect to their strategies and orientation. In particular, Markman et al. (2005) show that some OTTs place a greater priority on licensing of intellectual property rather than on generating the start-up of new firms by scientists. Markman et al. (2005) examine the mission statements from the Office of Technology Transfer from 128 universities. They find that most university TTOs prioritize licensing intellectual property over encouraging the scientist to start a new business. Similar findings have been found by O'Shea et al. (2005) and Lockett et al. (2005). These studies find that while some Offices of Technology Transfer encourage university scientists to license their technology to existing companies, others are more encouraging to enable university scientists to start a new business. In their 2010 and 2011 studies, Aldridge and Audretsch find considerable evidence that the TTO has an impact on the commercialization and entrepreneurial activities of university scientists.

5.4.7 Financial and Other Resources

An important finding in the general entrepreneurship literature is that access to financial resources, as well as other types of related resources, can have a significant influence on the propensity for people to become an entrepreneur (Acs and Audretsch 2010; Parker 2010). For example, Kerr and Nanda (2009, p. 1) suggest that the availability of financial resources is one of the biggest issues confronting nascent entrepreneurs and influences their decision as to whether to actually start a new business, "Financing constraints are one of the biggest concerns impacting potential entrepreneurs around the world." In a different study, Gompers and Lerner (2010) suggest that the importance of overcoming financing constraints may be even more important for scientists, because the ideas upon which the entrepreneurial start-up is based are characterized by an even greater degree of uncertainty, asymmetries, and transactions costs. In fact, Aldridge and Audretsch (2010, 2011) find support for the hypothesis that financial resources facilitate the propensity for a university scientist to become an entrepreneur.

5.5 Regression Results

The purpose of this section is to identify factors that are conducive, and those that are an impediment, to scientist commercialization through start-ups across the six fields of research. This section outlines the descriptive statistics, means and standard deviations, and simple correlation matrix of key determinants of scientist entrepreneurship discussed in Sect. 5.3.3.

We first outline the descriptive statistics, means and standard deviations, and simple correlation matrix of key determinants of scientist entrepreneurship discussed in Sect. 5.3.3. Section 5.5.1 discusses the estimation model and the measures of key determinants of scientist entrepreneurship that are used to calculate the likelihood of scientist commercialization through start-ups. The next section discusses the probit regression results for estimating the likelihood of scientist entrepreneurship across all fields of research.

Section 5.5.3 discusses the probit regression results for estimating the likelihood of scientist entrepreneurship in civil, mechanical, and manufacturing innovation.

Section 5.5.4 examines results for estimating the likelihood of scientist entrepreneurship in environmental biology. Section 5.5.5 reviews the probit regression results for estimating the likelihood of scientist entrepreneurship in computer and network systems. The next session discusses the probit regression results for estimating the likelihood of scientist entrepreneurship in physical oceanography.

Section 5.5.7 discusses the probit regression results for estimating the likelihood of scientist entrepreneurship in particle and nuclear astrophysics. Section 5.5.8 examines the probit regression results for estimating the likelihood of scientist entrepreneurship in biological infrastructure. Section 5.5.9 summarizes the relationships between key determinants of scientist entrepreneurship discussed in Sects. 5.5.3–5.5.9 by the field of research.

The means and standard deviations presented in Appendix G indicate that, on average, 12.75 % of scientists have commercialized their research through start-ups. The average funding amount to the sample of scientists is 950,000 USD, which is higher than the average of the scientist population discussed in Sect. 5.3.1. About 41 % of scientists, across the six fields of research, received funding from other external sources.

The scientist sample is observed to have 16 years of tenured experience, with a mean age of 50.3 years. Furthermore, about 44 % of scientists have reported that they are full professors. This indicates that the scientist sample, on average, has a high degree of scientist reputation. Please refer to Appendix H for a complete summary of the means and standard deviations of key variables used in the estimation model.

The simple correlation matrix of all variables used in the probit model estimations presented in the Appendix H suggests that there is little correlation between most variables, except age and scientist tenure experience signifying the relative exogenous nature of the sample. Though the scientists self-selected to participate in the survey, it appears that the scientist entrepreneurship database is pretty robust in its representativeness of the scientist population.

5.5.1 Estimation Model

5.5.1.1 Dependent Variable

The dependent variable in our analyses is scientist commercialization through firm creation; the dependent variable assumes a value of 1 if scientist who responded to the survey answered yes to our question—"Have you started a legally recognized company?"—and 0 if the scientist answered no.

The scientist entrepreneurship database measures numerous key determinants of scientist entrepreneurship that are expected to affect the scientist's likelihood to commercialize scientific research through numerous mechanisms (as discussed in Sect. 5.3.3). The probit regression models presented in Tables 5.8, 5.9, 5.10, 5.11,

Table 5.8 Probit regression results estimating likelihood of scientist start-ups, all fields of research

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	0.01 (1.85)[a]	0.011 (2.07)[b]	0.011 (2.04)[b]	0.011 (2.13)[b]
Other funding (>750K)—*financial resources*	0.343 (2.69)[c]	0.282 (2.27)[b]	0.297 (2.36)[b]	0.316 (2.46)[b]
Number of students—*human resources*	−0.001 (−1.95)[a]	−0.001 (−1.88)[a]	−0.001 (−1.89)[a]	−0.001 (−2.03)[b]
Years in tenure—*human capital*	−0.017 (−1.46)	−0.011 (−1.45)	−0.01 (−1.32)	−0.009 (−1.27)
Full professor—*human capital*		−0.209 (−1.33)	−0.196 (−1.23)	−0.201 (−1.26)
Board membership—*social capital*	0.702 (5.30)[c]	0.66 (5.26)[c]	0.636 (5.06)[c]	0.662 (5.19)[c]
Department encourages commercialization	−0.167 (−4.14)[c]	−0.161 (−4.07)[c]	−0.17 (−4.24)[c]	−0.191 (−4.47)[c]
Department head entrepreneurial orientation	0.525 (4.02)[c]	0.512 (4.04)[c]	0.521 (4.04)[c]	0.523 (3.97)[c]
University TTO success				0.048 (1.15)
Male	0.445 (2.33)[b]	0.469 (2.51)[b]	0.458 (2.43)[b]	0.466 (2.46)[b]
Age of scientist	0.015 (1.2)			
Asia—*country of origin*			−0.122 (−0.59)	−0.115 (−0.54)
Midwest *region*	−0.194 (−1.03)	−0.034 (−0.19)	−0.037 (−0.20)	−0.026 (−0.14)
South *region*	0.048 (0.28)	0.054 (0.32)	0.05 (0.3)	0.057 (0.33)
West *region*	−0.064 (−0.37)	−0.019 (−0.11)	−0.043 (−0.25)	−0.027 (−0.16)
Constant	−1.476 (−2.38)[b]	−0.613 (−1.66)[a]	−0.57 (−1.53)	−0.753 (−1.84)[a]
Number of observations	758	786	777	758
Wald chi-square	76.32	76.1	74.86	78.2

Notes: Absolute *z* values in parenthesis

[a]Denotes significant at the 10 % level

[b]Significant at the 5 % level

[c]Significant at the 1 % level

Table 5.9 Probit regression results estimating likelihood of scientist start-ups, civil, mechanical, and manufacturing innovation

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	0.196 (0.75)	0.111 (0.72)	0.116 (0.67)	0.116 (0.63)
Other funding (>750K)—*financial resources*	0.064 (0.2)	0.038 (0.14)	−0.022 (−0.08)	−0.018 (−0.06)
Number of students—*human resources*	0 (−0.33)	0 (−0.42)	−0.001 (−0.76)	−0.001 (−0.89)
Years in tenure—*human capital*	−0.051 (−1.88)[a]	−0.035 (−2.07)[b]	−0.04 (−2.31)[b]	−0.042 (−2.37)[b]
Full professor—*human capital*		−0.051 (−0.16)	−0.088 (−0.28)	−0.125 (−0.38)
Board membership—*social capital*	1.238 (4.17)[c]	1.082 (4.08)[c]	1.057 (3.92)[c]	1.053 (3.92)[c]
Department encourages commercialization	−0.12 (−1.30)	−0.116 (−1.44)	−0.104 (−1.31)	−0.059 (−0.65)
Department head entrepreneurial orientation	0.415 (1.50)	0.45 (1.71)[a]	0.431 (1.60)	0.427 (1.57)
University TTO success				−0.094 (−0.88)
Male	0.493 (1.32)	0.549 (1.6)	0.52 (1.49)	0.468 (1.32)
Age of scientist	0.029 (0.97)			
Asia—*country of origin*			−0.587 (−1.56)	−0.633 (−1.75)[a]
Midwest *region*	0.693 (1.47)	0.815 (1.83)[a]	0.941 (2.13)[b]	0.93 (2.09)[b]
South *region*	0.763 (1.55)	0.72 (1.57)	0.812 (1.78)[a]	0.782 (1.70)[a]
West *region*	−0.332 (−0.59)	−0.026 (−0.05)	0.014 (0.03)	0.008 (0.01)
Constant	−2.577 (−1.72)[a]	−1.151 (−1.43)	−1.005 (−1.26)	−0.612 (−0.65)
Number of observations	147	158	156	155
Wald chi-square	33.15	35.73	37.57	37.69

Notes: Absolute z values in parenthesis
[a] Denotes significant at the 10 % level
[b] Significant at the 5 % level
[c] Significant at the 1 % level

5.12, 5.13, and 5.14 analyze the effect of scientist social capital, human capital, access and availability to financial and human resources, locational and institutional factors, and other demographic control variables on the scientist's likelihood to commercialize research through start-ups, across the six fields of research.

5.5.1.2 Independent Variables: Financial Resources

The scientist entrepreneurship database includes two measures of financial resources—NSF grant award amount and availability of funding from other sources. The grant award amounts are secondary information obtained from the Web of

Table 5.10 Probit regression results estimating likelihood of scientist start-ups, environmental biology

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	−0.26 (−0.81)	−0.508 (−1.32)	−0.549 (−1.30)	−0.538 (−1.32)
Other funding (>750K)—*financial resources*	0.419 (1.14)	0.539 (1.51)	0.611 (1.70)[a]	0.613 (1.69)[a]
Number of students—*human resources*	0 (−0.62)	0 (−0.86)	−0.001 (−1.04)	−0.001 (−1.04)
Years in tenure—*human capital*	−0.016 (−0.53)	0.016 (0.83)	0.02 (1.05)	0.02 (1.05)
Full professor—*human capital*		0.539 (0.93)	0.554 (0.97)	0.526 (0.91)
Board membership—*social capital*	−0.076 (−0.19)	0.115 (0.33)	0.18 (0.52)	0.178 (0.52)
Department encourages commercialization	0.014 (0.13)	0.03 (0.3)	0.038 (0.38)	0.02 (0.18)
Department head entrepreneurial orientation	−0.511 (−1.1)	−0.446 (−0.89)	−0.425 (−0.85)	−0.411 (−0.81)
University TTO Success				0.04 (0.26)
Male				
Age of scientist	0.039 (1.05)			
Asia—*country of origin*				
Midwest *region*				
South *region*	−0.173 (−0.34)	0.136 (0.3)	0.148 (0.32)	0.134 (0.29)
West *region*	0.715 (1.62)	0.674 (1.53)	0.748 (1.64)	0.744 (1.59)
Constant	−4.12 (−2.46)[b]	−2.98 (−3.29)[c]	−3.141 (−3.44)[c]	−3.236 (−2.91)[c]
Number of observations	115	116	113	110
Wald chi-square	12.58	16.7	18.79	18.31

Notes: Absolute *z* values in parenthesis
[a]Denotes significant at the 10 % level
[b]Significant at the 5 % level
[c]Significant at the 1 % level

Knowledge database, which were then matched to the survey responses of scientists in the scientist entrepreneurship database. We aggregated the grant award amounts by scientist research, during 2005–2012-Q2, in millions of dollars. The database gathered information about funding from other sources using the survey instrument—"Did you have any other major sources of funding directly relating to your research from 2005 to 2010 (totaling over $750,000)?" This variable was coded 1 if the scientist responded that their research was funded by other major sources of funding and 0 if the scientist answered no.

Table 5.11 Probit regression results estimating likelihood of scientist start-ups, computer and network systems

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	0.133 (1.08)	0.155 (1.05)	0.201 (1.29)	0.261 (1.50)
Other funding (>750K)—*financial resources*	–0.049 (–0.18)	–0.257 (–0.95)	–0.189 (–0.69)	–0.128 (–0.44)
Number of students—*human resources*	–0.001 (–1.34)	–0.001 (–0.98)	–0.001 (–1.15)	–0.001 (–1.26)
Years in tenure—*human capital*	0.001 (0.06)	0.017 (1.05)	0.018 (1.12)	0.013 (0.85)
Full professor—*human capital*		–0.181 (–0.41)	–0.197 (–0.44)	–0.205 (–0.45)
Board membership—*social capital*	0.894 (3.23)[c]	1.017 (3.71)[c]	0.927 (3.27)[c]	0.972 (3.34)[c]
*Department e*ncourages commercialization	–0.222 (–2.38)[b]	–0.238 (–2.54)[b]	–0.295 (–2.98)[c]	–0.311 (–2.94)[c]
Department head entrepreneurial orientation	0.531 (1.99)[b]	0.481 (1.85)[a]	0.575 (2.15)[b]	0.534 (1.96)[a]
University TTO success				0.039 (0.45)
Male	0.781 (1.61)	0.808 (1.81)[a]	0.828 (1.83)[a]	0.81 (1.75)[a]
Age of scientist	0.032 (1.4)			
Asia—*country of origin*			–0.397 (–1.19)	–0.405 (–1.18)
Midwest *region*	–0.216 (–0.54)	–0.168 (–0.40)	–0.222 (–0.49)	–0.212 (–0.46)
South *region*	–0.308 (–0.84)	–0.255 (–0.70)	–0.286 (–0.76)	–0.214 (–0.56)
West *region*	–0.207 (–0.68)	–0.086 (–0.29)	–0.188 (–0.62)	–0.074 (–0.24)
Constant	–2.337 (–1.87)[a]	–0.734 (–0.73)	–0.433 (–0.44)	–0.622 (–0.61)
Number of observations	135	143	140	135
Wald chi-square	28.68	36.58	36.16	38.53

Notes: Absolute z values in parenthesis

[a] Denotes significant at the 10 % level

[b] Significant at the 5 % level

[c] Significant at the 1 % level

5.5.1.3 Independent Variables: Human Resources

The scientist entrepreneurship database includes two measures of human resources—total number of human resources and the number of student collaborators. The total number of human resources available to the scientist was measured using the survey instrument—“Roughly what total number of undergraduate and graduate students have you worked with in your specific field of research from 2005 to 2010?”—and the number of student collaborators was measured using the survey instrument, “Roughly what number of undergraduate and graduate students have you worked closely with in your specific field of research from 2005 to 2010?” The estimation results include the number of student collaborators both as a measure of dedicated human resources as well as a measure

Table 5.12 Probit regression results estimating likelihood of scientist start-ups, physical oceanography

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	0.009 (1.18)	0.009 (1.32)	0.009 (1.32)	0.009 (1.63)
Other funding (>750K)—*financial resources*	0.466 (1.21)	0.495 (1.21)	0.479 (1.16)	0.85 (2.03)[b]
Number of students—*human resources*	−0.001 (−0.69)	−0.001 (−0.62)	−0.001 (−0.61)	−0.002 (−1.10)
Years in tenure—*human capital*	0.02 (0.56)	0.028 (1.42)	0.028 (1.39)	0.041 (1.76)[a]
Full professor—*human capital*		0.325 (0.5)	0.321 (0.49)	0.222 (0.34)
Board membership—*social capital*	−0.374 (−0.83)	−0.364 (−0.82)	−0.36 (−0.81)	−0.591 (−1.21)
Department encourages commercialization	−0.416 (−2.16)[b]	−0.424 (−2.21)[b]	−0.416 (−2.13)[b]	−0.492 (−2.54)[b]
Department head entrepreneurial orientation	−0.095 (−0.2)	0 (0)	−0.012 (−0.03)	−0.251 (−0.43)
University TTO success				0.556 (2.99)[c]
Male				
Age of scientist	0.008 (0.16)			
Asia—*country of origin*			.	.
Midwest *region*				
South *region*	−0.445 (−0.78)	−0.445 (−0.77)	−0.44 (−0.78)	−0.792 (−1.21)
West *region*	−0.888 (−1.99)[b]	−0.87 (−2.00)[b]	−0.87 (−2.02)[b]	−1.175 (−2.31)[b]
Constant	−0.205 (−0.08)	−0.127 (−0.09)	−0.13 (−0.09)	−3.03 (−2.09)[b]
Number of observations	90	90	87	87
Wald chi-square	16.55	16.26	15.81	30.66

Notes: Absolute *z* values in parenthesis

[a] Denotes significant at the 10 % level

[b] Significant at the 5 % level

[c] Significant at the 1 % level

for the source of ideas. This variable is an ordinal variable indicating the number of students closely associated with the research sponsored by the award.

5.5.1.4 Independent Variables: Human Capital

The scientist entrepreneurship database includes two measures of scientist human capital—scientist experience and scientist reputation. Scientist experience is measured as the number of years since they first obtained tenure; this ordinal variable was constructed using the year of tenure information provided by the scientists. Scientist reputation is measured as a dummy variable for full professorship. Hence,

Table 5.13 Probit regression results estimating likelihood of scientist start-ups, particle and nuclear astrophysics

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	−2.906 (−2.33)[b]	−1.144 (−2.53)[b]	−1.29 (−2.76)[c]	−1.276 (−2.84)[c]
Other funding (>750K)—*financial resources*	4.433 (2.97)[c]	0.826 (1.49)	0.773 (1.34)	0.676 (1.3)
Number of students—*human resources*	0.005 (0.97)	0.006 (1.05)	0.005 (0.99)	0.006 (1.08)
Years in tenure—*human capital*	−0.354 (−1.84)[a]	−0.099 (−2.46)[b]	−0.117 (−2.31)[b]	−0.126 (−2.30)[b]
Full professor—*human capital*		−2.18 (−3.03)[c]	−2.265 (−3.34)[c]	−2.024 (−3.22)[c]
Board membership—*social capital*		3.366 (3.40)[c]	3.869 (3.14)[c]	3.683 (3.10)[c]
Department encourages commercialization	−1.644 (−2.55)[b]	−0.165 (−1.15)	−0.151 (−0.97)	−0.053 (−0.36)
Department head entrepreneurial orientation	−0.612 (−0.59)	0.078 (0.11)	0.564 (0.79)	0.752 (1.14)
University TTO success				−0.209 (−1.13)
Male	5.372 (2.17)[b]	1.192 (1.84)[a]	1.68 (2.36)[b]	1.525 (1.65)[a]
Age of scientist	−0.103 (−1.06)			
Asia—*country of origin*				
Midwest *region*	3.868 (2.04)[b]	1.785 (2.24)[b]	2.209 (2.43)[b]	2.533 (2.62)[c]
South *region*	0.985 (0.96)	−0.199 (−0.32)	0.177 (0.25)	0.31 (0.48)
West *region*	−1.726 (−1.32)	−0.863 (−0.77)	−0.893 (−0.77)	−0.67 (−0.62)
Constant	10.166 (1.87)[a]	−1.316 (−1.38)	−1.528 (−1.57)	−0.679 (−0.55)
Number of observations	35	103	98	95
Wald chi-square	14.63	19.13	22.5	24.5

Notes: Absolute z values in parenthesis

[a] Denotes significant at the 10 % level

[b] Significant at the 5 % level

[c] Significant at the 1 % level

scientists who indicated their tenure status as full professorship are coded as 1, and all other scientists, including those scientists who indicated nontenured status, are coded as 0.

5.5.1.5 Independent Variables: Social Capital

The scientist entrepreneurship database includes a measure of scientist social capital, which was gathered using the survey instrument—"Do you sit (or have you sat) on a board of directors or scientific advisory board?" This variable is coded as 1 if

Table 5.14 Probit regression results estimating likelihood of scientist start-ups, biological infrastructure

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	0.082 (1.04)	0.144 (1.74)[a]	0.149 (1.83)[a]	0.147 (1.71)[a]
Other funding (>750K)—*financial resources*	0.828 (1.90)[a]	0.855 (2.20)[b]	0.886 (2.13)[b]	0.88 (2.07)[b]
Number of students—*human resources*	−0.003 (−2.22)[b]	−0.003 (−2.20)[b]	−0.004 (−2.26)[b]	−0.004 (−2.12)[b]
Years in tenure—*human capital*	0.004 (0.12)	−0.012 (−0.66)	−0.013 (−0.70)	−0.008 (−0.44)
Full professor—*human capital*		0.21 (0.45)	0.234 (0.5)	0.319 (0.76)
Board membership—*social capital*	1.079 (3.05)[c]	0.917 (2.82)[c]	0.934 (2.89)[c]	1.022 (3.06)[c]
Department encourages commercialization	−0.132 (−1.18)	−0.075 (−0.72)	−0.069 (−0.63)	−0.14 (−1.21)
Department head entrepreneurial orientation	0.407 (0.92)	0.573 (1.33)	0.58 (1.33)	0.597 (1.36)
University TTO success				0.157 (1.21)
Male	−0.004 (−0.01)	−0.141 (−0.32)	−0.132 (−0.30)	−0.074 (−0.17)
Age of scientist	−0.011 (−0.29)			
Asia—*country of origin*			−0.288 (−0.38)	−0.391 (−0.52)
Midwest *region*	−0.84 (−1.24)	−0.531 (−0.92)	−0.546 (−0.93)	−0.594 (−1.04)
South *region*	0.069 (0.13)	−0.083 (−0.18)	−0.076 (−0.16)	−0.164 (−0.36)
West *region*	0.501 (1.19)	0.19 (0.48)	0.203 (0.5)	0.125 (0.3)
Constant	−0.651 (−0.32)	−1.046 (−1.16)	−1.097 (−1.19)	−1.809 (−1.63)
Number of observations	102	107	106	103
Wald chi-square	25.27	24.95	25.9	25.2

Notes: Absolute *z* values in parenthesis
[a] Denotes significant at the 10 % level
[b] Significant at the 5 % level
[c] Significant at the 1 % level

the scientist responded that he/she is on the board of directors or a scientific advisory board of other firms and 0 if scientist responded no.

5.5.1.6 Independent Variables: Locational Context

The scientist entrepreneurship database includes secondary information of scientist's location of research obtained from the Web of Knowledge database. The secondary information on scientist's location includes their primary university affiliation and the state in which they are conducting their research. The probit estimation models include a control for scientist's location in one of four regions in the United States—Northeast, Midwest, South, and West.

5.5.1.7 Independent Variables: Institutional Context

The scientist entrepreneurship database includes two factors of the scientist's institutional context—departmental context and characteristics of the university Technology Transfer Office.

The scientist's departmental context is measured by the level of encouragement from department to commercialize their research and the entrepreneurial orientation of the department head. The level of encouragement from department to commercialize scientist research is measured using the survey instrument—"Please indicate on a scale from 1 to 7 to what extent you agree or disagree with the following statement…. My department encourages me to commercialize my research." This ordinal variable is coded with the value 7 being "strongly agree" with the statement and the value 1 being "strongly" disagree with the statement.

The entrepreneurial orientation of the department head is measured using the survey instrument—"The head/chair of your department at the time of your first NSF funding between 2005 and 2010, to the best of your knowledge, had which of the following: (1) do not know, (2) never, (3) before funding, and (4) after funding." This variable was coded as 0 if the chair of the department never started up and 1 if otherwise.

The characteristics of the university Technology Transfer Office are measured using the following survey instrument—"Please indicate on a scale from 1 to 7 to what extent you agree or disagree with the following statement…. My Technology Transfer Office is successful at commercializing my field of research." This ordinal variable is coded with the value 7 being "strongly agree" with the statement and the value 1 being "strongly disagree" with the statement. Though the TTO's organizational priorities and the actual frequency and significance of the scientist's interactions with the TTO are not measured, it is argued that the scientist's perception of the success of TTO in his/her field of research serves as a strong proxy for the degree of influence the university TTO has on the scientist's decision to commercialize.

5.5.1.8 Independent Variables: Scientist Demographic Controls

The scientist entrepreneurship database includes information about scientist's demographic characteristics. We control for scientist demographics like age, gender, and national origin in the probit estimation model.

5.5.2 Scientist Start-Ups: All Fields of Research

This section discusses the effect of, and the nature of relationship between, several key determinants of scientist entrepreneurship on the likelihood of scientist commercialization through start-ups across all the six fields of research—civil, mechanical, and manufacturing innovation, environmental biology, computer and network systems, physical oceanography, particle and nuclear astrophysics, and biological infrastructure—among scientists who received funding from the National Science Foundation (NSF) between 2005 and 2012-Q1.

Table 5.8 presents the probit regression results for estimating the likelihood of scientist start-up commercialization. In model 1, we observe that measures for financial resources and social capital of the scientist are positively associated with the probability of scientist entrepreneurship through start-ups, whereas the measures for human resource and institutional factors are negatively associated with the probability of scientist entrepreneurship through start-ups. Furthermore, we observe that, on average, male scientists are more likely to commercialize research through start-ups and that scientist's age and experience/reputation are not statistically significant at the 10 % level.

These results identify relationships between several important factors that are expected to affect scientist commercialization through start-ups and in determining the likelihood of scientist entrepreneurship. First, the amount of NSF funding and the scientist's likelihood of receiving significant amount of funding from other sources toward their research are strong determinants of, and conducive to, the scientist's decision and their potential in commercializing their research through start-ups.

Second, scientist's social capital measured as their membership on the board of directors/scientific advisory board of other firms increases the scientist's likelihood of commercializing their research through start-ups.

Third, the amount of human resources available to the scientist in conducting their research is negatively related to the scientist's likelihood to commercialize research through start-ups. However, the effect of this measure is practically insignificant (−0.001), compared to the effect of NSF funding amount (0.01) and availability of funding from other sources (0.343). The negative relationship can be interpreted as the excess allocation (redundancy) of human resources in scientific research, across the six fields of research.

Fourth, the institutional factors, department head's entrepreneurial orientation, and department's encouragement to commercialize scientific research seem to function as substitutes in the scientist's decision to commercialize research through start-ups. However, it is crucial to note that the head of department's entrepreneurial orientation has a larger positive effect (0.525) than the effect of department's encouragement in commercializing their research (−0.132). Overall, the effect of institutional factors on the scientist's likelihood to commercialize their research through start-ups is positive.

Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is from Asia), and the success of TTO in commercializing scientist research, respectively. Also, in models 2–4, we do not control for scientist age since the correlation factor between scientist age and their tenure experience is high (0.8).

Results from model 2 indicate that there is negative relationship between full professor's tenured status and their likelihood to commercialize research through start-ups, after controlling for their tenure experience. However, this relationship is not statistically significant effect at the 10 % level. The effects of other scientist entrepreneurship determinants are unchanged.

Results from model 3 indicate that there is a negative relationship between scientist's nativity (if the scientist is from Asia) and their likelihood to commercialize research through start-ups. However, this relationship is not statistically significant effect at the 10 % level. The effects of other scientist entrepreneurship determinants are unchanged.

Results from model 4 indicate that there is a positive relationship between the success of university TTO in commercializing the scientist's field of research and their likelihood to commercialize research through start-ups. However, this relationship is not statistically significant effect at the 10 % level. The effects of other scientist entrepreneurship determinants are unchanged.

Results in Tables 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, and 5.14 present probit regression estimates (using models 1 through 4 discussed in Table 5.1) of scientist entrepreneurship, by their field of research.

5.5.3 *Civil, Mechanical, and Manufacturing Innovation*

This section discusses the effect of, and nature of relationship between, several key determinants of scientist entrepreneurship on the likelihood of scientist commercialization through start-ups in the field of civil, mechanical, and manufacturing innovation (CMMI).

Table 5.9 presents the probit regression results for estimating the likelihood of scientist start-up commercialization in the field of civil, mechanical, and manufacturing innovation. In model 1, we observe that the measure for scientist social capital is positively associated with the likelihood of scientist entrepreneurship, whereas the measures of scientist human capital (scientist experience) are negatively associated with the probability of scientist entrepreneurship. Furthermore, we observe that, on average, scientist gender (male), age, and locational and institutional factors are significant determinants of scientist entrepreneurship and are not statistically significant at the 10 % level.

These results identify several important differences in the effect of scientist entrepreneurship determinants between CMMI scientists and scientists from other fields of research. First, it is observed that the amount of NSF funding and the scientist's likelihood of receiving significant amount of funding from other sources toward their research have a positive effect on the scientist's likelihood of commercializing their research through start-ups. However, the effect of financial resources is not statistically significant at the 10 % level, indicating that the CMMI scientist's decision to commercialize their research is not determined by the availability and access to financial resources.

Second, scientist's human capital (tenure experience) decreases the scientist's likelihood of commercializing their research through start-ups. Though the same effect was observed for the population of scientists across the six fields of research, this effect was not statistically significant in Table 5.1. This means that younger, less experienced, CMMI scientists are more likely to commercialize their scientific research through start-ups.

Third, the CMMI scientist's institutional factors and gender are not strong determinants of their likelihood to commercialize research through start-ups. Though the direction of effect from these factors is consistent with that of the aggregate scientist population, it is observed that the scientist's institutional factors and gender are not statistically significant.

Fourth, consistent with the findings for general population, CMMI scientist's social capital is found to be a strong determinant of their likelihood to commercialize research through start-ups.

Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is from Asia), and the success of TTO in commercializing scientist research, respectively. Also, in models 2–4, we do not control for scientist age since the correlation factor between scientist age and their tenure experience is high (0.79).

Results from model 2 indicate that there is a negative relationship between full professor's tenured status and their likelihood to commercialize research through start-ups, after controlling for their tenure experience. However, this relationship is not statistically significant effect at the 10 % level. The effects of other scientist entrepreneurship determinants are unchanged.

Results from model 3 indicate that there is a negative relationship between the scientist's nativity (if the scientist is from Asia) and their likelihood to commercialize research through start-ups. However, this relationship is not statistically significant effect at the 10 % level. The effects of other scientist entrepreneurship determinants are unchanged.

Results from model 4 indicate that there is a negative relationship between the success of university TTO office in commercializing the scientist's field of research and their likelihood to commercialize research through start-ups. This relationship is not statistically significant effect at the 10 % level. However, we observe a negative effect of CMMI scientist's nativity and their likelihood to commercialize research through start-ups.

In summary, these results indicate that younger, CMMI scientists, with less tenure experience and high social capital, are more likely to commercialize their research through start-ups. This likelihood is significantly enhanced among CMMI scientists who obtained their undergraduate education from non-Asian countries, predominantly the United States.

5.5.4 Environmental Biology

This section discusses the effect of, and nature of relationship between, several key determinants of scientist entrepreneurship on the likelihood of scientist commercialization through start-ups in the field of environmental biology (DEB).

Table 5.10 presents the probit regression results for estimating the likelihood of scientist start-up commercialization in the field of environmental biology. In model 1, we observe that none of the important determinants of scientist entrepreneurship are statistically significant (at the 10 % level). However, the nature of relationships between these factors and the likelihood of DEB scientist commercialization through start-ups are generally consistent with those observed for the aggregate scientist population.

These results identify some key differences between DEB scientists and scientists from other fields of research. First, it is observed that the amount of NSF funding and the scientist's likelihood of receiving significant amount of funding from other sources are not strong determinants of the scientist's likelihood of commercializing their research through start-ups. Furthermore, it is observed that the amount of NSF funding has a negative effect on DEB scientists' likelihood to commercialize research through start-ups.

Second, scientist's social capital has a negative relationship with the scientist's likelihood of commercializing their research through start-ups. This finding is very different from the statistically significant positive relationship observed among the aggregate scientist population.

Third, both institutional factors were found to hold an inverse relationship to the DEB scientist's likelihood of commercializing research through start-ups. This means that departments that encourage DEB scientists to commercialize their research, with department heads who are entrepreneurs, are less conducive to scientist entrepreneurship among DEB scientists. However, these relationships are not statistically significant at the 10 % level.

Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is from Asia), and the success of TTO in commercializing scientist research, respectively. Also, in models 2–4, we do not control for scientist age since the correlation factor between scientist age and their tenure experience is high (0.81).

Results from model 2 indicate that there is positive relationship between full professor's tenured status and their likelihood to commercialize research through start-ups, after controlling for their tenure experience. However, this relationship is not statistically significant effect at the 10 % level. The effects of other scientist entrepreneurship determinants are unchanged.

Results from models 3 and 4 indicate that there is a statistically significant positive relationship between the availability of significant amount of funding from other sources and the scientist's likelihood of commercializing their research through start-ups. This implies that DEB scientists whose research is supported by funding from other sources are more likely to commercialize their research through start-ups.

Results from model 4 indicate that there is a positive relationship between the success of TTO in commercializing scientist research and their likelihood to commercialize research through start-ups. However, this relationship is not statistically significant effect at the 10 % level.

In summary, these results indicate that DEB scientists whose research is supported by funding from other sources are more likely to commercialize their research through start-ups than DEB scientists that do not receive external funding.

5.5.5 Computer and Network Systems

This section discusses the effect of, and nature of relationship between, several key determinants of scientist entrepreneurship on the likelihood of scientist commercialization through start-ups in the field of computer and network systems (CNS).

Table 5.11 presents the probit regression results for estimating the likelihood of scientist start-up commercialization in the field of computer and network systems. In model 1, we observe that measure for social capital of the scientist and the institutional factors are positively associated with the probability of scientist entrepreneurship through start-ups.

These results identify a few key differences in the effect of scientist entrepreneurship determinants between CNS scientists and scientists in other fields of research. First, it is observed that the financial resources have a positive effect. However, these results do not have a statistically significant effect on the CNS scientists' likelihood of commercializing their research through start-ups.

Second, the scientist's institutional factors are strong determinants of CNS scientist entrepreneurship. The nature and magnitude of the relationship between institutional factors and the CNS scientists' likelihood to commercialize their research were found to be consistent with that of the aggregate scientist population.

Third, consistent with the findings for general population, the CNS scientist's social capital is found to be a strong determinant of their likelihood to commercialize research through start-ups.

Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is from Asia), and the success of TTO in commercializing scientist research, respectively. Also, in models 2–4, we do not control for scientist age since the correlation factor between scientist age and their tenure experience is high (0.66).

Results from model 2 indicate that there is negative relationship between full professor's tenured status and their likelihood to commercialize research through start-ups, after controlling for their tenure experience. However, this relationship is not statistically significant effect at the 10 % level. The effects of other scientist entrepreneurship determinants are unchanged.

Results from model 3 indicate that there is a negative relationship between the scientist's nativity (if the scientist is from Asia) and their likelihood to commercialize research through start-ups. However, this relationship is not statistically significant effect at the 10 % level.

Results from model 4 indicate that there is a positive relationship between the success of TTO in commercializing scientist research and their likelihood to commercialize research through start-ups. However, this relationship is not statistically significant effect at the 10 % level.

In models 2 through 4, we observe that, on average, male CNS scientists are more likely to commercialize research than female CNS scientists.

In summary, these results indicate that CNS scientists with high social capital, and more conducive departmental conditions, are more likely to commercialize their research through start-ups. This likelihood is found to be significantly higher among male CNS scientists than female CNS scientists.

5.5.6 Physical Oceanography

This section discusses the effect of, and nature of relationship between, several key determinants of scientist entrepreneurship on the likelihood of scientist commercialization through start-ups in the field of physical oceanography (OCE).

Table 5.12 presents the probit regression results for estimating the likelihood of scientist start-up commercialization in the field of physical oceanography. In model 1, we observe that scientist social capital and institutional factors are negatively related to determinants of scientist entrepreneurship, which is contrary to the strong positive relationship observed in the aggregate scientist population across the six fields of research.

These results identify a few key differences in the effect of scientist entrepreneurship determinants between OCE scientists and scientists in other fields of research. First, it is observed that scientist social capital is negatively associated to OCE scientist entrepreneurship. However, this relationship is not statistically significant at the 10 % level. These results indicate that social capital does not play a significant role in determining the OCE scientist's likelihood in commercializing research through start-ups.

Second, departmental-institutional factors have a statistically significant negative association with OCE scientist entrepreneurship. These results indicate that departments that encourage OCE scientists to commercialize their research are significantly less conducive to OCE scientist entrepreneurship.

Third, locational factors (negative coefficient for west region) have a statistically significant association with OCE scientist entrepreneurship. This means that OCE scientists in the Northeast region, predominantly Massachusetts and New York, are more likely to commercialize their research than OCE scientists in California (West region). This relationship can be explained by more efficient knowledge spillovers between academia and industry in the Northeast region compared to the West region.

Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is from Asia), and the success of TTO in commercializing scientist research, respectively. Also, in models 2–4, we do not control for scientist age since the correlation factor between scientist age and their tenure experience is high (0.82).

Results from model 2 indicate that there is positive relationship between full professor's tenured status and their likelihood to commercialize research through start-ups, after controlling for their tenure experience. However, this relationship is not statistically significant effect at the 10 % level. The effects of other scientist entrepreneurship determinants are unchanged.

Results from model 3 and 4 indicate several important relationships for OCE scientist entrepreneurship. First, there is a statistically significant positive relationship between the success of TTO in commercializing scientist research and their likelihood to commercialize research through start-ups. Furthermore, the magnitude of effect from university TTO offsets the negative effect from non-conducive departmental contexts. This means that overall, institutional factors have a strong positive relationship, and are hence more conducive, to OCE scientist entrepreneurship.

Second, there is a statistically significant positive relationship between financial resources and OCE scientist's likelihood of commercializing research through start-ups.

Third, OCE scientist human capital (scientist experience) is a strong determinant of the scientist's commercialization decision.

In summary, these results indicate that experienced OCE scientists with funding from external sources, in a university setting with an effective TTO, are more likely to commercialize their research through start-ups. This likelihood is found to be significantly higher among OCE scientists in the Northeast region compared to scientists in the West region.

5.5.7 Particle and Nuclear Astrophysics

This section discusses the effect of, and nature of relationship between, several key determinants of scientist entrepreneurship on the likelihood of scientist commercialization through start-ups in the field of particle and nuclear astrophysics (PHY).

Table 5.13 presents the probit regression results for estimating the likelihood of scientist start-up commercialization in the field of particle and nuclear astrophysics. In model 1, we observe that NSF funding amount, scientist human capital (scientist experience), and departmental-institutional contexts are negatively associated with the likelihood of PHY scientist entrepreneurship. Furthermore, scientist gender (male) and locational context (Midwest region) has a statistically significant positive difference to the Northeast region.

These results identify a few key differences in the effect of scientist entrepreneurship determinants between PHY scientists and scientists in other fields of research. First, the NSF grant funding is negatively associated with (−2.9), whereas funding from other sources is positively associated with (4.4) the likelihood of PHY scientist entrepreneurship. This relationship can be explained by the heterogeneity in scientist research aimed at theoretical and application-based advancements. Overall, the effect of financial resources is positively associated with PHY scientist entrepreneurship.

Second, scientist human capital is negatively related to the likelihood of PHY scientist entrepreneurship. This indicates that there is a generational effect in PHY scientists, which young scientists more likely to commercialize their research through start-ups than more experienced scientists.

Third, we observe that male PHY scientists are more likely to commercialize their research than female PHY scientists.

Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is from Asia), and the success of TTO in commercializing scientist research, respectively. Also, in models 2–4, we do not control for scientist age since the correlation factor between scientist age and their tenure experience is high (0.85).

Results from model 2 indicate that there is statistically significant negative relationship between full professor's tenured status and their likelihood to commercialize research through start-ups, after controlling for their tenure experience. This provides further evidence to the conjecture that there is a generational effect in PHY scientists' likelihood to commercialize research through start-ups.

It is also interesting to note that the overall effect of financial resources in model 2 is negative, and hence is an impediment, to PHY scientist entrepreneurship. Furthermore, scientist social capital is found to be statistically significant at the 1 % level, indicating that PHY scientists with greater linkages and interactions with the industry are more likely to commercialize their research through start-ups than PHY scientists without those linkages.

Models 3 and 4 indicate that there is a negative relationship between the success of TTO in commercializing scientist research and PHY scientist entrepreneurship. However, these results are not statistically significant at the 10 % level.

In summary, we observe that younger PHY scientists, with high social capital, are more likely to commercialize their research through start-ups. Furthermore, the likelihood of PHY scientist entrepreneurship is greater among male scientists from the Midwest region.

5.5.8 Biological Infrastructure

This section discusses the effect of, and nature of relationship between, several key determinants of scientist entrepreneurship on the likelihood of scientist commercialization through start-ups in the field of biological infrastructure (DBI).

Table 5.14 presents the probit regression results for estimating the likelihood of scientist start-up commercialization in the field of biological infrastructure. In model 1, we observe that financial resources from external sources and social are positively associated with the likelihood of DBI scientist entrepreneurship. Furthermore, availability of human resources has a statistically significant negative association with DBI scientist entrepreneurship; however, the magnitude (–0.003) of this effect is practically insignificant.

These results identify a few key differences in the effect of scientist entrepreneurship determinants between DBI scientists and scientists in other fields of research. First, funding from other sources is positively associated with (0.8) the likelihood of DBI scientist entrepreneurship.

Second, we observe that availability of human resources is negatively associated with DBI scientist entrepreneurship. Third, we observe that scientist social capital is a strong determinant of DBI scientist entrepreneurship. Fourth, scientist human capital and gender are found to be insignificant determinants of PHY scientist entrepreneurship.

Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is from Asia), and the success of TTO in commercializing scientist research, respectively. Also, in models 2–4, we do not control for scientist age since the correlation factor between scientist age and their tenure experience is high (0.85).

Results from model 2 indicate that there is negative relationship between full professor's tenured status and their likelihood to commercialize research through start-ups, after controlling for their tenure experience. However, this relationship is not significant at the 10 % level.

It is also interesting to note that the overall effect of financial resources in model 2 is positive, and hence is conducive, to DBI scientist entrepreneurship.

Results from model 3 indicate that there is negative relationship between DBI scientist's continent of origin and their likelihood to commercialize research through start-ups. However, this relationship is not significant at the 10 % level.

Results from model 4 indicate that there is a positive relationship between the success of TTO in commercializing scientist research and DBI scientist entrepreneurship. However, these results are not statistically significant at the 10 % level. The effects of other scientist entrepreneurship determinants are unchanged.

In summary, we observe that DBI scientists, with high social capital and greater access to financial resources, are more likely to commercialize their research through start-ups.

5.5.9 Summary of Scientist Entrepreneurship Determinants by Fields of Research

This section summarizes the relationships between key determinants of scientist entrepreneurship discussed in Sects. 5.5.3–5.5.9 by the field of research.

Table 5.15 provides a comprehensive summary of all statistically significant effects among key determinants of scientist entrepreneurship by the direction and nature of their propensities to include scientist commercialization through start-ups. These results are a synthesis of model 4 in Tables 5.8, 5.9, 5.10, 5.11, 5.12, 5.13, and 5.14. A positive relationship indicates that the factor is conducive to scientist entrepreneurship, and a negative relationship indicates that the factor is an impediment to scientist entrepreneurship.

Table 5.15 Summary of key determinants of scientist entrepreneurship by field of research

	All fields	CMMI	DEB	CNS	OCE	PHY	DBI
Financial resources	+		+		+	–	+
Grant amount	+					–	+
Other funding (>750K)	+		+		+		+
Human resources	–	–					–
Number of students	–	–					–
Human capital					+	–	
Years in tenure					+	–	
Full professor						–	
Social capital	+	+		+		+	+
Board membership	+	+		+		+	+
Institutional factors	+			+	+		
Department encourages commercialization	–			–	–		
Department head entrepreneurial orientation	+			+			
University TTO success					+		
Scientist demographics							
Male	+					+	
Asia—*country of origin*		–					
Midwest *region*		+				+	
South region		+					
West region					–		

Notes: CMMI is civil, mechanical, and manufacturing innovation; DEB is environmental biology; CNS is computer and network systems; OCE is physical oceanography; PHY is particle and nuclear astrophysics; and DBI is biological infrastructure

Table 5.15 highlights several important findings of this research. First, the availability and access to financial resources are found to have a positive effect on scientist entrepreneurship across all fields of research, except in the field of particle and nuclear astrophysics where there is heterogeneity in nature of theoretical and applied research. Also, financial resources do not have a significant effect in civil, mechanical, and manufacturing innovation.

Second, availability of human resources is generally found to have a negative effect on scientist entrepreneurship across all fields of research—however, this relationship is particularly significant in the fields of civil, mechanical, and manufacturing innovation and biological infrastructure. The magnitude of the effect of human resources was found to be practically insignificant, ranging from –0.001 to –0.003.

Third, scientist human capital is found to have a positive effect on scientist entrepreneurship in the field of physical oceanography and a negative effect on scientist entrepreneurship in the field of particle and nuclear astrophysics. However, we did not observe a strong relationship between human capital and likelihood of scientist entrepreneurship across other fields of research.

Fourth, scientist social capital is found to have a positive effect on scientist entrepreneurship across all fields of research, except environmental biology. This explains the significance of linkages and interactions in enhancing scientist entrepreneurship.

Fifth, institutional factors are found to have overall positive effect on scientist entrepreneurship, especially in the fields of computer and network systems and physical oceanography. However, it is important to note that the departmental-institutional factors are found to be driving the nature of this relationship, especially the department head's entrepreneurial orientation. Furthermore, the effect of university TTO was found to be positive only in the field of physical oceanography.

Sixth, on average, male scientists were found to be more entrepreneurial than female scientists. However, this relationship did not hold universally. In fact, the relationship was only statistically significant in the field of particle and nuclear astrophysics. This finding is contrary to findings in entrepreneurship literature for the entire population.

Finally, locational factors were found to have a significant effect in the fields of civil, mechanical, and manufacturing innovation and physical oceanography. Further research needs to be conducted to elaborate on the exact mechanisms of knowledge spillovers in these fields of research to draw general inferences.

5.6 Incremental and Radical Innovation by Scientist Entrepreneurs

This section discusses the effect of key determinants of scientist entrepreneurship on the likelihood of scientist start-ups by the nature of innovative activity (start-ups with patents, innovative products, and consulting services across the six fields of research). This section also includes a discussion of firm success comparing start-ups with patents, innovative products, and consulting services.

The central argument is that, by comparing scientist start-ups that use either patents or innovative products or both with scientist start-ups that don't use both patents and innovative products, we will be able to elaborate on the nature of mechanisms and success of scientist entrepreneurs in commercializing radical and incremental innovations. We abstract those scientist start-ups with patents as a scientist commercialization of radical innovations and those with innovative products as incremental innovation. There are exceptions to this construct of radical innovation, especially since we do not record the nature and extent of radicalness (popularly measured as the number of patent citations) of patents used in scientist start-ups. However, we argue that these estimates, particularly those of start-ups with both patent and innovative products, provide preliminary estimates for, and insights into, the nature of mechanisms through which radical and incremental innovations are realized through the scientist start-up route.

The purpose of this section is to (a) identify factors that are conducive, and those that are an impediment, to scientist start-ups by the nature of innovative activity, i.e., the use of patents, innovative products, and consulting services, and (b) identify the factors which increase the likelihood of firm success with the nature of innovative activity.

In Sect. 5.5 we were primarily interested in the question on why do some scientists commercialize their research through start-ups and why others don't. Hence, we explored the nature and significance of the effect of key determinants of scientist entrepreneurship on the likelihood of scientist's research commercialization through start-ups.

In this section, we are interested in the effect of those key determinants of scientist entrepreneurship on the likelihood that scientist start-ups use either one or more of the following—patents, innovative products, and consulting services. Essentially, we are exploring the nature and significance of the variation in key determinants of scientist entrepreneurship based on innovative activity of scientist entrepreneur. We argue that scientist start-ups providing consulting services are neither operationalizing incremental nor radical innovation.

Also, as discussed in Fig. 5.5 Sect. 5.3.3.1, the scientist firm's success is significantly enhanced when the mode of start-up commercialization is through the use of innovative products and patents. In order to explore the possible mechanisms through which the significant positive relationship between firm success and use of innovative products in scientist start-ups is obtained, we compare the success of scientist firms that use patents and innovative products with firms that do not operationalize either innovation.

5.6.1 Scientist Start-Ups with Patents

In this section we discuss the effect of key determinants of scientist entrepreneurship on the likelihood of scientist start-ups with patents across the six fields of research. We examine the nature of relationship between several key determinants of scientist entrepreneurship on the likelihood of scientist start-ups using patents. To this end, we compare scientist start-ups with a patent and scientist start-ups without the use of a patent using the probit estimation model discussed in Sect. 5.5.

Table 5.16 presents the probit regression results for estimating the likelihood of scientist start-ups with patents. In model 1, we observe that scientist social capital and institutional factors are positively related to the probability of scientist start-ups using patents, whereas the measures for human resource are negatively associated with the probability of scientist start-ups using patents. However, we observe that the statistically significant effect of departmental-institutional measures is negative on the measure which records the level of encouragement (toward commercialization) from the department.

It is interesting to note that the measure of social capital and departmental-institutional variables enhance the likelihood of scientist start-ups with patents. This implies that scientist's linkages and interactions with the industry and conducive

Table 5.16 Probit regression results estimating likelihood of scientist start-ups using patents

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	0.068 (1.03)	0.091 (1.41)	0.089 (1.37)	0.088 (1.35)
Other funding (>750K)—*financial resources*	0.448 (1.43)	0.309 (1.06)	0.292 (0.98)	0.288 (0.96)
Number of Students—*human resources*	–0.003 (–1.72)[a]	–0.003 (–1.93)[a]	–0.003 (–1.90)[a]	–0.003 (–1.81)[a]
Years in tenure—*human capital*	–0.015 (–0.54)	–0.015 (–0.77)	–0.016 (–0.80)	–0.016 (–0.79)
Full professor—*human capital*		0.334 (0.95)	0.29 (0.82)	0.293 (0.82)
Board membership—*social capital*	0.736 (2.20)[b]	0.949 (2.79)[c]	0.961 (2.80)[c]	0.954 (2.78)[c]
Department encourages commercialization	–0.136 (–1.84)[a]	–0.155 (–2.10)[b]	–0.139 (–1.83)[a]	–0.138 (–1.63)
Department head entrepreneurial orientation	0.18 (0.64)	0.175 (0.64)	0.18 (0.65)	0.181 (0.65)
University TTO success				–0.003 (–0.03)
Male	–0.478 (–0.92)	–0.535 (–1.14)	–0.501 (–1.06)	–0.5 (–1.06)
Age of scientist	–0.003 (–0.11)			
Asia—*country of origin*			0.133 (0.33)	0.133 (0.33)
Midwest *region*	–0.349 (–0.78)	–0.554 (–1.28)	–0.553 (–1.28)	-0.557 (-1.29)
South *region*	–0.089 (–0.23)	–0.094 (–0.24)	–0.068 (–0.18)	–0.071 (–0.19)
West *region*	–0.361 (–0.95)	–0.4 (–1.13)	–0.365 (–1.03)	–0.368 (–1.03)
Constant	0.641 (0.45)	0.275 (0.34)	0.23 (0.28)	0.24 (0.28)
Number of observations	102	109	107	106
Wald chi-square	24.67	29.03	28.46	27.28

Notes: Absolute *z* values in parenthesis
[a] Denotes significant at the 10 % level
[b] Significant at the 5 % level
[c] Significant at the 1 % level

institutional contexts significantly enhance the likelihood of scientist start-ups using patents.

Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is from Asia), and the success of TTO in commercializing scientist research, respectively. In these models we observe that the effects of social capital are unchanged. However, we notice that the departmental-institutional measure which records the level of encouragement (toward commercialization) from the department is no longer significantly negative. Furthermore, the availability of human resources reduces the likelihood of scientist start-ups using patents; however, these results are practically insignificant (–0.003). Hence, we conclude that scientist social capital is the most influential determinant of the use of patents in scientist start-ups.

5.6.2 Scientist Start-Ups with Innovative Products

In this section we discuss the effect of key determinants of scientist entrepreneurship on the likelihood of scientist start-ups with innovative products across the six fields of research. We examine the nature of relationship between several key determinants of scientist entrepreneurship on the likelihood of scientist start-ups using innovative products. To this end, we compare scientist start-ups with an innovative product and scientist start-ups without an innovative product using the probit estimation model discussed in Sect. 5.5.

Table 5.17 presents the probit regression results for estimating the likelihood of scientist start-ups with innovative products. Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is

Table 5.17 Probit regression results estimating likelihood of scientist start-ups with innovative products

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	−0.009 (−1.64)	−0.009 (−1.99)[b]	−0.009 (−1.94)[a]	−0.009 (−1.94)[a]
Other funding (>750K)—*financial resources*	0.325 (1.06)	0.359 (1.18)	0.324 (1.05)	0.298 (0.95)
Number of students—*human resources*	−0.001 (−1.01)	−0.001 (−1.21)	−0.001 (−1.11)	−0.001 (−0.72)
Years in tenure—*human capital*	0.02 (0.71)	−0.022 (−1.13)	−0.02 (−1.03)	−0.017 (−0.89)
Full professor—*human capital*		0.985 (2.69)[c]	0.982 (2.65)[c]	1.031 (2.79)[c]
Board Membership—*social capital*	0.263 (0.81)	0.775 (2.50)[b]	0.811 (2.57)[b]	0.867 (2.72)[c]
Department encourages commercialization	−0.111 (−1.50)	−0.13 (−1.74)[a]	−0.113 (−1.47)	−0.045 (−0.50)
Department head entrepreneurial orientation	−0.166 (−0.59)	−0.301 (−1.08)	−0.346 (−1.21)	−0.376 (−1.31)
University TTO success				−0.165 (−1.84)[a]
Male	0.666 (1.37)	0.661 (1.5)	0.676 (1.55)	0.628 (1.29)
Age of scientist	−0.078 (−2.38)[b]			
Asia—*country of origin*			0.692 (1.45)	0.642 (1.37)
Midwest *region*	−0.137 (−0.31)	−0.321 (−0.79)	−0.336 (−0.82)	−0.487 (−1.17)
South *region*	−0.347 (−0.90)	−0.353 (−0.84)	−0.326 (−0.77)	−0.412 (−0.96)
West *region*	−0.431 (−1.17)	−0.88 (−2.30)[b]	−0.828 (−2.13)[b]	−0.858 (−2.17)[b]
Constant	3.824 (2.58)[c]	−0.803 (−1.04)	−0.994 (−1.27)	−0.443 (−0.53)
Number of observations	104	111	109	108
Wald chi-square	30.24	28.68	33.54	42.91

Notes: Absolute *z* values in parenthesis
[a] Denotes significant at the 10 % level
[b] Significant at the 5 % level
[c] Significant at the 1 % level

from Asia), and the success of TTO in commercializing scientist research, respectively.

In model 2, we observe that scientist social capital and human capital are positively related to the probability of scientist start-ups using innovative products, whereas the measures for institutional factors are negatively associated with the probability of scientist start-ups using innovative products. Furthermore, we observe that the grant amount has a statistically significant negative effect on the likelihood of scientist start-ups with innovative products. This implies that scientists who commercialize their research through start-ups using an innovative product have significantly higher amounts of social and human capital, even in comparison to other scientist's that started up.

Models 3 and 4 demonstrate two key differences between scientist start-ups with innovative products and those without innovative products. First, the locational factors play an important role in determining the likelihood of scientist start-ups with an innovative product. Scientist start-ups in the Northeast region are more likely to have innovative products than scientist start-ups in the West region. Second, the university and departmental-institutional factors have a statistically significant negative relationship with the likelihood of scientist start-ups with innovative products. Hence, we conclude that scientist social capital, human capital, and institutional factors are highly influential in determining the likelihood of scientist start-ups with innovative products.

5.6.3 Scientist Start-Ups with Consulting Services

In this section we discuss the effect of key determinants of scientist entrepreneurship on the likelihood of scientist start-ups with consulting services, across the six fields of research. We examine the nature of relationship between several key determinants of scientist entrepreneurship on the likelihood of scientist start-ups providing consulting services to the industry or the government. To this end, we compare scientist start-ups offering consulting services and scientist start-ups that do not offer consulting services using the probit estimation model discussed in Sect. 5.5.

Table 5.18 presents the probit regression results for estimating the likelihood of scientist start-ups offering consulting services to the industry or to the government. In model 1, we observe a statistically significant positive effect from departmental-institutional factors. Furthermore, we observe a statistically significant negative effect with grant amount and a statistically significant positive effect with human resources.

Models 2 through 4 compare the effect of scientist's full professorship tenure status, country of origin (if the scientist is from Asia), and the success of TTO in commercializing scientist research, respectively. Models 3 and 4 demonstrate three key differences between scientist start-ups providing consulting services and those that do not provide consulting services. First, the locational factors play an important role in determining the likelihood of scientist start-ups with providing consulting services. Scientist start-ups in the South region are more likely to have innovative products than

Table 5.18 Probit regression results estimating likelihood of scientist start-ups with consulting services

Independent variables	(1)	(2)	(3)	(4)
Grant amount (in millions)—*financial resources*	−0.012 (−2.15)[b]	−0.01 (−1.86)[a]	−0.011 (−1.93)[a]	−0.01 (−1.99)[b]
Other funding (>750K)—*financial resources*	0.264 (0.82)	0.175 (0.61)	0.282 (0.96)	0.289 (0.93)
Number of students—*human resources*	0.003 (1.99)[b]	0.003 (2.09)[b]	0.002 (1.99)[b]	0.003 (1.90)[a]
Years in tenure—*human capital*	−0.063 (−2.55)[b]	−0.006 (−0.27)	−0.01 (−0.49)	−0.01 (−0.51)
Full professor—*human capital*		0.51 (1.29)	0.41 (1.02)	0.406 (1.01)
Board membership—*social capital*	−0.223 (−0.71)	−0.245 (−0.82)	−0.271 (−0.88)	−0.365 (−1.14)
Department encourages commercialization	0.198 (2.53)[b]	0.232 (3.02)[c]	0.228 (2.87)[c]	0.162 (1.75)[a]
Department head entrepreneurial orientation	0.106 (0.38)	0.249 (0.93)	0.4 (1.41)	0.499 (1.76)[a]
University TTO success				0.149 (1.53)
Male	0.036 (0.07)	−0.144 (−0.31)	−0.066 (−0.14)	0.014 (0.03)
Age of scientist	0.074 (2.32)[b]			
Asia—*country of origin*			−1.108 (−2.10)[b]	−1.106 (−2.04)[b]
Midwest *region*	0.184 (0.39)	0.137 (0.31)	0.154 (0.35)	0.186 (0.42)
South *region*	0.697 (1.81)[a]	0.809 (1.87)[a]	0.843 (1.94)[a]	0.844 (1.92)[a]
West *region*	0.225 (0.56)	0.323 (0.85)	0.281 (0.73)	0.192 (0.49)
Constant	−4.756 (2.58)[c]	−1.96 (−1.04)	−1.897 (−1.27)	−2.425 (−0.53)
Number of observations	102	109	107	106
Wald chi-square	23.97	21.08	28.91	30.69

Notes: Absolute z values in parenthesis
[a]Denotes significant at the 10 % level
[b]Significant at the 5 % level
[c]Significant at the 1 % level

scientist start-ups in the Northeast region. Second, the departmental-institutional factors have a statistically significant positive relationship with the likelihood of scientist start-ups with consulting services. Third, scientists' continent of origin is important in determining the likelihood of scientist start-ups providing consulting services; scientist entrepreneurs from Asia are less likely to provide consulting services than scientist entrepreneurs from North America, predominantly the United States.

Hence, we conclude that scientists' locational factors, departmental-institutional factors, and country of origin are highly influential in determining the likelihood of scientist start-ups with innovative products.

5.6.4 Summary of Key Determinants

This section summarizes the key determinants of scientist start-ups by nature of innovative activity—radical innovations (patents), incremental innovations (innovative product), and consulting services (knowledge spillover).

Table 5.19 highlights several important findings regarding the determinants of scientist start-ups by nature of innovative activity. First, both scientist start-ups with radical innovations (patents) and incremental innovations (innovative product) have a statistically significant positive relationship with scientist social capital. This means that scientist entrepreneurs who commercialized their research through radical and incremental innovations had a greater amount of social capital, on average, than scientist entrepreneurs that did not.

Second, both scientist start-ups with radical innovations (patents) and incremental innovations (innovative product) have a statistically significant negative relationship with departmental-institutional contexts. This means that scientist entrepreneurs who commercialized their research through radical and incremental

Table 5.19 Summary of key determinants of scientist start-ups using patents, innovative products, and consulting

	Scientist start-ups	With patents	With innovative product	With consulting services
Financial resources	+			
Grant amount	+		–	–
Other funding (>750K)	+			
Human resources	–	–	–	+
Number of students	–	–	–	+
Human capital			+	
Years in tenure			+	
Full professor				
Social capital	+	+	+	
Board membership	+	+	+	
Institutional factors	+	–	–	+
Department encourages commercialization	–	–		+
Department head entrepreneurial orientation	+			+
University TTO success			–	
Scientist demographics				
Male	+			
Asia—*country of origin*				–
Midwest *region*				
South region				+
West region			–	

Notes: CMMI is civil, mechanical, and manufacturing innovation; DEB is environmental biology; CNS is computer and network systems; OCE is physical oceanography; PHY is particle and nuclear astrophysics; and DBI is biological infrastructure innovations received little or no help from their department/TTO, on average, than scientist entrepreneurs that did not. Interestingly, scientist start-ups that provided consulting services had more encouraging departmental-institutional contexts compared to scientist start-ups that did not. These results suggest that departmental/university characteristics are powerful determinants of innovation activity of scientist start-ups.

Third, financial resources did not have a statistically significant impact on the nature of innovative activity in scientist start-ups.

In summary, these results provide preliminary evidence that the nature of radical and incremental innovations realized through the scientist start-up route are strongly determined by the scientist social capital and departmental/university institutional contexts, even among scientists with very high likelihood to commercialize their research.

5.6.5 Scientist Firm Success with Patents and Innovative Products

This section describes the likelihood of firm success based on key determinants of scientist entrepreneurship and innovation activity of scientist start-ups. The main dependent variable, firm success, is defined as 1 if the firm is active and 0 if the firm is inactive as of 2012-Q2.

Models 1 through 4, in Table 5.20, presents the results for probit model estimates for the likelihood of scientist firm success based on the type of innovation activity. In models 1 through 4, we observe a statistically significant positive effect from other sources of funding and a statistically significant negative effect with scientist human capital. This indicates that scientist firms founded by young scientists with a greater likelihood of funding from external sources are more likely to succeed than firms founded by highly experienced scientists without significant sources of funding from external sources, across all innovation activities.

Models 2 through 4 compare the effect of innovative activity on the likelihood of scientist firm's success across the following innovation activities (incremental innovation), patent (radical innovation), and innovative products and patents (higher radical innovation), respectively. In models 2 through 4, we observe similar effect of scientist human capital and other sources of funding. Furthermore, models 2 and 3 indicate that incremental innovation activities have a strong positive effect on the likelihood of scientist firm success, whereas radical innovation activities have a statistically insignificant negative effect on the likelihood of scientist firm success. These results suggest that scientist firms attempting radical innovations, on average, are less successful than those attempting incremental innovations.

Results in model 4 provide preliminary evidence that scientist firms attempting higher radical innovations—i.e., using both patents and innovative products—are more likely than scientist firms attempting incremental innovations. In summary, these results suggest that scientist firms founded by young scientists, who are more

Table 5.20 Firm success of scientist start-ups with patents and innovative products

Independent variables	Base model	Innovative product	Patents	Both patents and innovative product
Innovative product start-ups		1.558 (5.05)[c]		1.676 (3.57)[c]
Patent start-ups			−0.212 (-0.68)	−1.233 (−1.92)[a]
Innovative product and patent start-ups				0.559 (0.66)
Grant amount (in millions)—*financial resources*	−0.028 (−0.35)	−0.068 (−0.91)	−0.019 (−0.24)	−0.054 (−0.71)
Other funding (>750K)—*financial resources*	0.713 (2.27)[b]	0.757 (2.27)[b]	0.677 (2.12)[b]	0.726 (2.10)[b]
Number of students—*human resources*	0 (0.19)	0.001 (0.57)	0 (−0.08)	0 (−0.18)
Years in tenure—*human capital*	−0.047 (−2.21)[b]	−0.044 (−2.10)[b]	−0.049 (−2.31)[b]	−0.048 (−2.26)[b]
Full professor—*human capital*	0.532 (1.55)	0.105 (0.3)	0.546 (1.53)	0.164 (0.45)
Board membership—*social capital*	0.301 (0.9)	−0.171 (−0.51)	0.366 (1.04)	0.016 (0.04)
Department encourages commercialization	0.035 (0.41)	0.058 (0.62)	0.021 (0.23)	−0.023 (−0.22)
Department head entrepreneurial orientation	0.222 (0.77)	0.449 (1.53)	0.219 (0.76)	0.486 (1.58)
University TTO success	−0.048 (−0.57)	0.034	−0.044 (−0.52)	0.068
		−0.37		−0.7
Male	0.747 (1.68)[a]	0.627	0.698	0.527
		−1.44	−1.54	−1.18
Asia—*country of origin*	−0.052 (−0.10)	−0.481 (−0.83)	−0.031 (−0.06)	−0.48 (−0.91)
Constant	−0.308 (−0.42)	−0.893 (−1.14)	−0.149 (−0.19)	−0.526 (−0.59)
Number of observations	106	106	103	103
Wald chi-square	18.61	38.52	18.92	45

Notes: Absolute *z* values in parenthesis
[a] Denotes significant at the 10 % level
[b] Significant at the 5 % level
[c] Significant at the 1 % level

likely to receive funding from external sources and attempting to commercialize incremental innovations, are more likely to succeed.

The extent to which radical innovations decrease the likelihood of scientist firm success—i.e., the effect of radical significance/potential of patents measured as the number of patent citations—needs to be addressed by future research to provide insights into the mechanisms through which radical and incremental innovations affect scientist entrepreneurship.

5.7 Conclusions

Universities have evolved over time from being institutions that were largely peripheral to contributing to economic growth, employment creation, and global competitiveness to being at the heart of creating the types of resources and capabilities that have emerged as the driving engine or economic prosperity. Even as knowledge created by university research and science has emerged as a crucial input driving economic performance, investments in such knowledge do not at all guarantee that they will result in the desired growth, job creation and global competitiveness.

Rather, mechanisms are needed to facilitate the spillover of university research and science for commercialization and innovative activity. The Bayh-Dole Act along with the advent of the Offices of Technology Transfer was designed to facilitate knowledge spillovers from universities. An enormous scholarly literature has analyzed the impact of university technology transfer. These studies have invariably and almost exclusively relied upon data collected by the Offices of Technology Transfer and compiled by the AUTM to assess the impact of universities on innovation. While a number of important and invaluable insights have been gleamed from such studies, an important oversight is the entrepreneurial activities of individual university scientists that do not work explicitly or directly with the OTTs.

This paper has analyzed scientist entrepreneurship not by asking the university Technology Transfer Offices what they do in terms of entrepreneurial activities but rather university scientists directly what they do in terms of entrepreneurial activities. The results from this study are as startling and novel as they are revealing. While the Offices of Technology Transfer databases suggest that new firm start-ups by university scientists are an infrequent activity, this study finds exactly the opposite. Most strikingly, using a large database of scientists funded by grants from the US National Science Foundation, this study finds that around 13 % of the scientists have started a new firm. These findings would suggest that university scientist entrepreneurship is considerably more prevalent that would be indicated by the data collected by the Offices of Technology Transfer and compiled by AUTM.

In addition, the propensity for a university scientist to be engaged in entrepreneurial activity apparently varies considerably across scientific fields. In certain fields, such as computer and network systems, the prevalence of entrepreneurship is remarkably high, 23.8 %. Similarly, in civil, mechanical, and manufacturing innovation, over one in five of the university scientists reports starting a new business.

By contrast, in other scientific fields, the prevalence of entrepreneurship is considerably more subdued. For example, in environmental biology, only 4.6 % of the university scientists report having started a new business. Similarly, in particle and nuclear astrophysics, 6.2 % of the scientists have started a new firm, and in biological infrastructure, 8.2 % of the scientists have started a new firm.

There is also considerable evidence that university scientist entrepreneurship mirrors that for the more general population in certain important ways, while at the same time, in other ways scientist entrepreneurship clearly differs from more general entrepreneurial activity. In sharp contrast to what has been found in the entrepreneurship literature for the general population, certain personal characteristics of university scientists, such as age and experience, do not seem to influence the likelihood of a scientist becoming an entrepreneur. However, gender influences the entrepreneurial decision of university scientists in much the same way it does for the general population. Males have a greater likelihood of starting a new business, both for university scientists as well as for the more general population. Similarly, access to resources and high social capital, in the form of linkages to private companies, encourages entrepreneurial activity among university scientists, just as it does for the overall population.

However, the determinants of university scientist entrepreneurship apparently are not constant across scientific fields. Rather, what is important in influencing scientific entrepreneurship in some scientific fields is less important in other scientific fields. For example, the extent of social capital has no statistically significant impact on the entrepreneurial activity of university scientists in scientific fields such as environmental biology, while it has a positive and statistically significant impact on entrepreneurial activity in civil, mechanical, and manufacturing innovation, as well as in computer and network systems.

While the age of the university scientist generally does not play an important role, the empirical evidence does point to a negative relationship between age and entrepreneurial activity that is more radical and less innovative in nature. In particular, those university scientists starting a new business for products that are highly innovative tend to be younger.

Thus, the findings of this paper based on asking scientists about their entrepreneurial activities suggest that entrepreneurship is considerably more prevalent among a broad spectrum of university scientists than had been identified using databases reporting what Offices of Technology Transfer are doing in terms of entrepreneurship. These results would suggest that the spillover of knowledge from universities for commercialization, innovation, and ultimately economic growth, employment creation, and global competitiveness is substantially more robust than had been previously thought.

At the same time, the findings from this study caution against generalizations across heterogeneous fields of science. Just as the prevalence of entrepreneurship is found to vary substantially across scientific fields, so too do the determinants of entrepreneurial activity.

Future research needs to build upon and extend the findings of this paper by widening the spectrum of scientific and academic contexts analyzed for the commercialization of university science and research. Subsequent research would be well advised not just to consider the data reported by the Technology Transfer Offices to measure and analyze what universities contribute directly to commercialization and entrepreneurship but also to continue to uncover the actual commercialization and entrepreneurial activities of the scientists themselves.

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D.B. Audretsch, A.N. Link (eds.), *Essays in Public Sector Entrepreneurship*,
International Studies in Entrepreneurship 34, DOI 10.1007/978-3-319-26677-0