Organization of Markets for Science and Technology

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Abstract

The traditional concentration of basic research activities in academic settings, as opposed to applied research more prevalent in industrial settings, represents a fundamental structural distinction of science and technology markets. This structure arises from a unique combination of product characteristics, in particular, the inherent uncertainty and incomplete appropriability associated with research efforts. The conduct of research organizations and individual researchers is critically dependent on these structural conditions. Incentives associated with the contractual relationships and internal policy choices of research organizations provide a number of important influences on the conduct of research as well.

This paper proposes a conceptual framework within which the workings of research markets can be understood and policy implications drawn. We combine ongoing theoretical advances in the economics of internal organization with the familiar structure-conduct-performance paradigm of industrial organization. A selective review is provided to show how separate elements of the emerging literature on the research process fit together. Responses to recent policy initiatives encouraging collaborative research efforts are best understood in the context of this comprehensive framework, including both external and internal determinants of conduct. It is hoped that the proposed framework will also provide a basis for additional research on the process of research.

Organization of Markets for Science & Technology

"Research is formalized curiosity. It is poking and prying with a purpose."

Zora Neale Hurston, *Dust Tracks on a Road*, 1942

INTRODUCTION

The allocation of society's resources toward research efforts represents an investment in one of the fundamental sources of economic growth. And yet, the social benefits of research investment are not fully reflected in private incentives to research producing organizations and individuals. This has given rise to a distinctive market structure, in which university/academic research plays an essential role, and a combination of public policy interventions. Understanding the process of research is important for public policy makers, institutional leadership and the community of research performers. The environment in which research is conducted and the incentives for research productivity are determined by the choices of all of these market participants.

An extensive literature has emerged on the economics of science and technology as reviewed by Stephan (1996) and Audretsch et al (2002). Notable contributions to this literature address the nature and measurement of research output, various perspectives on patents, the productivity and compensation of research personnel, industrial productivity spillovers, and responses to recent policy initiatives. These separate topics represent important elements of the research process; however, there has been far less attention paid to the development of a comprehensive framework within which the behavior of research organizations can be studied and policy conclusions drawn.

In this paper we propose a formal framework in which one can see the influences and implications of the behavior of research organizations and individuals. The familiar paradigm of industrial organization (Scherer and Ross (1990)) relates market structure to the conduct of market participants which, in turn, determines market performance. These conceptual linkages as applicable to research markets are presented in Figure 1. We offer a selective literature review in this context.

A unique combination of product characteristics, particularly in the case of basic research, gives rise to the market structure of science and technology markets. The fundamental distinction between academic and nonacademic sectors is presented as a crucial structural determinant of the conduct and performance of research markets. Although this distinction has been recognized in the literature, we highlight the need for additional study into the far-reaching implications of concentrating basic research in academic settings. Further, this distinction provides useful insights into the workings of research markets and for the evaluation of public policies related to research.

Incentives associated with the contractual relationships and internal policy choices of research organizations also provide a number of important influences on the conduct of research. These issues are represented under the heading of "internal organization" in Figure 1 and in a corresponding section of our discussion. Ongoing theoretical advances here offer practical contributions toward the development of optimal research environments. These insights should be of particular interest to institutional leadership at universities and research laboratories.

The proposed framework should also be useful in evaluating the impact of policy choices. While the ultimate goals of research policy involve performance, all roads lead through conduct.

We consider several policy instruments that propose to influence the conduct of research organizations and individuals directly, through market structure, and through internal organization. Particular attention is devoted to technology transfer policies encouraging increased university-industry collaborative research. We turn next to a detailed discussion of the different linkages shown in Figure 1.

STRUCTURE OF SCIENCE AND TECHNOLOGY MARKETS

Research output characteristics

The structure of science and technology markets arises from a unique combination of product characteristics. Salient features of research include inherent uncertainty in the discovery process, negligible social value of repeated discovery, and incomplete appropriation of benefits by the discoverer. The successful outcome of research efforts, codified knowledge, is subject to nonexclusive use (Dasgupta and David (1987)). This gives rise to a "tragedy of the commons" problem somewhat analogous to that faced by other public goods. It could be argued that the problem is more severe in this case because the value of knowledge is enhanced by its use.

Basic research, or science, has been variously described as research efforts not directed toward a specific goal or problem and often yielding answers to unposed questions. Scientific inquiry may be particularly susceptible to uncertainties of successful discovery. An additional source of uncertainty here is the need for external acceptance of the new idea, for example, publication by an academic journal. To the extent that basic research outcomes serve as a broad and accessible knowledge base for subsequent discovery, the problem of incomplete appropriation of research benefits is clearly a significant issue as well.

In contrast, applied research is tied to solving a more clearly defined problem, such as refining a specific process or creating a distinctive new product. Specific objectives are likely to reduce the uncertainty of discovery. However, Kamien and Schwartz (1982) argue that applied research is more directly affected by demand uncertainty associated with ultimate diffusion of innovations. The specific and definable nature of applied research outcomes may be useful in resolving the dilemma of incomplete appropriation. Protection of intellectual property rights may be feasible for clearly definable innovations. Firms may also be able to appropriate private returns to applied research investments effectively through immediate application with adequate lead time over rivals (Harabi (1995)).

Academic versus nonacademic sectors

The observed concentration of basic research activities in academic settings, as opposed to applied research more prevalent in industrial settings, reflects a market structure response to these attributes. This traditional distinction between academic organizations (primarily universities) engaged in basic research and nonacademic organizations (primarily industrial firms) conducting applied research is a fundamental structural distinction in science and technology markets.

Academic organizations are mostly not-for-profit enterprises with revenues from a combination of public subsidies, voluntary contributions and tuition. Private firms constitute a dominant share of nonacademic research performers (Audretsch et al (2002)). They anticipate cost savings from process innovations, enhanced revenues from product market innovations, or direct revenues from sale or licensing of successful innovations. These conditions influence choice of research projects and contractual arrangements with researchers. Profit-seeking firms tend to engage in applied research, to which identifiable outcomes and appropriable returns are more likely to be attached. Basic research faces greater uncertainty of discovery and a more intractable public goods problem. In the absence of well-defined commercial product or process outcomes, basic research efforts are more likely to occur in academic organizations (Rosenberg and Nelson (1994), Powell and Owen-Smith (1998)). This difference in research outcomes across research organizations has important implications for the appropriability of research benefits, which are at the heart of incentives for conducting research.

Competition in research markets

Applied research outcomes play a fundamental role in the dynamics of competitive markets. Firms engage in applied research to discover product or process innovations before rivals. Successful innovators (and perhaps the most efficient) are rewarded with transitory monopoly status, a Schumpeterian day in the sun (Schumpeter (1942)). This represents an essential incentive for investment in innovative activities under various non-cooperative market forms (Goel (1999)).

With respect to basic research, however, Nelson (1959) argues that there is a direct contradiction between appropriability conditions and competitive markets. Market failure arguments of this type are often invoked as consistent with the traditional association of basic research with academic settings and public funding of research in universities (Rosenberg and Nelson (1994), Powell and Owen-Smith (1998)). About three-fourths of all U.S. academic research effort in recent years has been devoted to basic research (National Science Board, 2000, p. A-310).

It should be noted that the implicit assumption that universities and academic research personnel are removed from market competition has not gone unchallenged (Del Rey (2001), De Fraja and Iossa (2001)). Nonetheless, the structural distinction between academic and nonacademic sectors provides valuable insights regarding conduct and performance in science and technology markets. Moreover, our discussion below introduces internal organization practices, public policy alternatives and professional institutions with direct bearing on the appropriability of basic research.

CONDUCT

The familiar paradigm of industrial organization relates market structure influences to the conduct of market participants (Scherer and Ross (1990)). The distinction between academic and nonacademic sectors, described in the preceding discussion, plays a critical role. Various aspects of conduct such as the nature of research output, redundant research efforts, and collaboration between research organizations are examined.

Research productivity

The explicit incentives facing research efforts are best understood in the context of research output measurement and evaluation. Ideas are the output of basic research; however, journal articles are the primary measure. The continuing emphasis of academic organizations on basic research is evident from the aggregate data. Over seventy percent of scientific and technical articles published in the United States every year during 1989-1997 were produced in academia. The corresponding figure for articles generated by industry was about eight percent (National Science Board, 2000, p. A-394).

Similarly, patents are commonly treated as the observable measure of applied research production (see Scherer (1983)). A number of recent studies have documented an upward trend in academic participation in applied research as measured by university patenting (Henderson et al (1998), Mowery et al (2001)). Nonetheless, publishing rates far outstrip patenting rates among university faculty (Agrawal and Henderson (2001)) and academic institutions received only 3,151 of the 147,520 patents granted in the United States in 1998 (National Science Board, 2000, pp. A-476, A-536).

This is not to say that publications and patents are solely the respective outputs of the academic and nonacademic sectors but they serve as a relevant reference point (Rosenberg and Nelson (1994), Rosenberg (1990)). For example, if the primary value of basic research is as a knowledge base for subsequent discovery then citations would provide a more appropriate measure than publications alone (Hamermesh et al (1982), Diamond (1986), Moore et al (2001)). Ideas, solutions and knowledge are all principally intangible, and yet, these are the products of research effort. Observable proxies are a matter of necessity, not only for external quantitative study, but also as a focal point for internal incentives.

Measurement shortcomings are well documented in the case of patents (see Comanor and Scherer (1969), Pavitt (1985), *Research*...(1986), Acs and Audretsch (1989), Griliches (1990)). Quality variation is a primary concern with a tremendous range of inventions counting equally and inconsistent standards across countries and over time. In a case study of computer tomography scanners, Trajtenberg (1990) finds support for patent citations as a measure of the value of an innovation. Assigning patent statistics to the appropriate industry (originating source, intermediate producer or end use beneficiaries) presents a challenge for empirical research.

In addition, the absence of a patent may reflect strategic choice to not patent as opposed to the absence of a successful applied research outcome. Harabi (1995) and Cohen et al (2000) provide evidence of firms relying on lead time or secrecy to appropriate research benefits. Unpatented innovations and unpublished scientific outcomes are difficult to document both in terms of quantity and quality (Diamond (1986)). If the respective research outputs of the two sectors are measured in publications and patents then the productivity of the two sectors may well be misrepresented.

Multiples and redundant research effort

Merton (1973) and Mansfield et al (1981) discuss "multiples," the case of independent and simultaneous discovery by researchers. Such redundancy is socially wasteful as only one success in invention is sufficient from the society's perspective. Redundant research efforts have been explored at length in the context of patent races (Merton (1973), Kamien and Schwartz (1982), Hartwick (1991)). The relatively specific objectives of patent-oriented applied research do not appear to eliminate the social cost of redundant efforts. An interesting question that has yet to be addressed is whether the academic sector or nonacademic sector is characterized by more duplicative research effort.

Collaboration in research

Complementary inputs are more productive when employed in a coordinated fashion than when working independently. In the presence of complementary research resources there may be substantial gains to collaborative research efforts. Research Joint Ventures (RJVs) involving firms that are also competitors convey potentially conflicting implications with regard to conduct. On the one hand, the coordination of research efforts will tend to capitalize on complementary resources. Extensive industry participation would also provide for pooling of inherent risks and improve conditions for appropriation of benefits. On the other hand, collaborative interaction in the production of research may facilitate collusive conduct in the product market.

Somewhat different considerations are associated with collaborative research efforts that reach across the academic-nonacademic divide (Mansfield (1995)). Productivity gains in this case arise from the complementarity between basic and applied research activities. Recent policy initiatives open the door to nontraditional forms of university-industry collaboration based on the prospect of improving the appropriability of basic research outcomes (Henderson et al (1998), Powell and Owen-Smith (1998), Mowery et al (2001)). Uncertainty of discovery may be reduced, in this case, by introducing specific research questions into academic settings. On the other hand, increased incentives to focus academic efforts on industry-generated research questions raises concern regarding substitution away from basic research.

The structural distinction between academic and nonacademic settings has implications for the conduct of collaborative research at an individual level. Complementary skills of individual researchers offer the potential for mutual gains to collaboration; however, individual incentives to shirk in team production may jeopardize these gains.[1] The degree to which intellectual and physical capital is individual-specific varies across disciplines. Individual collaboration within nonacademic research organizations tends to be a matter of assignment, either to a particular division of the organization or through managerial formation of project teams. Thus nonacademic researchers have less say in whether to participate in research teams. Nonacademic research managers face a challenge in designing incentive-compatible contracts for

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[1] There are conflicting findings on coauthorship of journal articles in economics. Sauer (1988) finds individual returns from coauthorship with n authors are ($1/n$) times the returns to single-authored papers. Moore et al (2001) find no coauthorship discount in individual returns to publication.

collaborative assignments (Holmstrom (1982)). Collaborative relationships that develop in the relative autonomy of academic settings are characterized by self-selection and are not restricted by organizational boundaries. These traditional features would tend to enhance the relative productivity of collaborative efforts in basic research.[2]

PERFORMANCE

Conduct of market participants, in turn, determines market performance. From society's perspective, performance can be evaluated on the basis of economic welfare and efficiency. We address social benefits from productivity spillovers, overall allocative efficiency of science and technology markets as well as efficiency in the production of research.

Productivity spillovers

The benefits of both academic and nonacademic research are imperfectly appropriable to individual researchers. External social benefits, or productivity spillovers, are present across and within the two sectors (Griliches (1992)). Intellectual property rights are more difficult to establish or maintain for basic research than for applied research. However, Mansfield et al (1981) have shown that even patented innovations are copied.[3] Cross-discipline spillovers tend to flow mainly from universities as industries develop applications based on basic research conducted at universities (Jaffe (1989), von Hippel (1988)).[4] Greater spillovers of basic research

2 The increased co-authorship in academic journals has indeed been noted in the literature (Hudson (1996)).

3 From an imitator=s point of view, the monetary rewards to imitating applied research might even be greater due to its greater commercial viability (compared to basic research).

4 In the case of research collaboration between the two sectors, it might be quite difficult to separate the relative contribution of each.

imply that there would be diminished incentives for conducting such research and, from a social perspective, a more severe problem of underinvestment of resources.

The effect of research on productivity growth has long interested policymakers and researchers (Dasgupta (1988), Feller (1990), Griliches (1992, 1994)). An empirical study of direct productivity spillovers at the industry level is provided by Lichtenberg and Siegel (1991) who document the impact of R&D investment on productivity within specific industries. The indirect impact of academic research on downstream industrial productivity would seem more difficult to ascertain; however, Adams (1990) and Grossman et al (2001) both find significant spillovers of this variety, albeit with substantial lags (up to 30 years for basic scientific research outcomes).

The geographic concentration of research facilities also makes a difference to the extent there are opportunities for formal and informal collaborations. Jaffe (1989) notes that geographic proximity is especially significant when knowledge is transferred through informal channels and finds a significant spillover impact of local factors. Examples of this route to external social benefit can be seen in the geographic concentration of academic institutions in the Boston area, information technology firms adjacent to the San Francisco Bay area and nonacademic institutions in North Carolina's Research Triangle.

Economic growth and social welfare

The relationship between research activities, productivity spillovers and economic growth remains a recurring theme in the economic literature. Romer (1986), Dasgupta (1988), Aghion and Howitt (1992) and others argue that the pace of endogenous growth is substantively influenced by the characteristics of research output and the structure of research markets. Goel and Ram (1994) find empirical support for the link between R&D spending and growth with cross-country panel data.

To the extent that these far-reaching social benefits exceed appropriable private returns there will be underinvestment in research efforts (Dasgupta and David (1987)). Due to a variety of issues arising from the inherent characteristics of research, markets for basic science are more likely to be plagued by chronic problems of allocative efficiency than are markets for applied technology.

A longstanding public policy response to this market failure is to establish intellectual property rights while restricting the degree of market competition. However, less competitive environments also lead to underinvestment. Private firms with market power restrict output of the good, in this case socially beneficial innovation (Goel (1999)). If we hope to incorporate marginal social benefits in the incentives facing research organizations (and individuals) then it would seem essential to account for productivity spillovers, especially those arising from academic-basic research. Of course, measurement of social benefits to basic research will be hampered by the same imprecise definition of goals and outcomes that give rise to market failure in the first place. Consequently the design of resource allocation policies for the academic sector cannot be the same as in the nonacademic sector.

Efficiency in research

Efficiency in the production of basic and applied research suffers from the social costs of duplicate research efforts. While an individual researcher (or organization) is rewarded for being the first to establish priority of discovery or obtain a patent, society is unconcerned with the identity of the researcher and there is little social benefit from repeat (second or subsequent) discoveries (Dasgupta (1989)). Under these circumstances, redundant research efforts reduce society's gains from a given allocation of resources.

How substantial are the social costs of duplicative research across academic and nonacademic settings? How responsive are duplicate research efforts to collaborative research arrangements? While patent races have received attention in the economic literature, there has been virtually no empirical evaluation of redundant efforts in basic research.

INTERNAL ORGANIZATION

It is not uncommon to portray the household or the firm as a unified entity. Recent advances in "organizational economics" highlight the importance of incentives associated with the contractual relationships and internal policies of firms (Gibbons (1998)). Much of the theoretical literature relating to markets for science and technology assumes that research effort, decisions regarding the research process, ownership of resources, and even end use are all embodied in the same economic agent (Dasgupta and Maskin (1987)). Frequent departures from these conditions play a critical role in the conduct of research organizations and personnel.

Vertical integration and research contracts

The fundamental distinction between basic and applied research is not simply a matter of differentiated goods produced by firms in different sectors of the same industry. Basic research outcomes are often a crucial input to applied research. Thus, the academic and nonacademic sectors participate in sequential stages along a vertical chain of research production. What is the nature of transactions between these two sectors? Under what conditions would vertical integration in research markets be optimal?

A theoretical literature is beginning to emerge to directly address these concerns. For example, Aghion and Tirole (1994) explore alternative ownership and contractual arrangements between the "customers" and "suppliers" of innovation. Vertical integration is found to be less likely under a number of conditions, including the case where intellectual inputs are substantial relative to capital inputs. Other recent efforts demonstrate how the conduct of a research producing organization is affected by contractual relationships with research producing partners, downstream application developers, or funding sources. Jensen and Thursby (2001) derive contract conditions to address the moral hazard associated with inventor involvement in subsequent commercialization. They conclude that contracts for basic research that provide an equity stake in application profits are more effective than contracts for sponsored research effort or output-based royalty payments. Additional study along these lines could illuminate aspects of the traditional segmentation of basic research into academic entities, as well as emerging public-university-industry contractual arrangements.

Agency concerns and individual rewards

What are the determinants of productive conduct by individual researchers? Agency theory, in which individual objectives are not assumed to be naturally aligned with research organization (or funding source) goals, offers an appropriate framework for developing practical insights. Holmstrom (1989) relates the inherent uncertainty and cumulative nature of basic research outcomes to shortcomings in standard incentive pay arrangements. Agency theory also offers an ideal framework for evaluating questions of complementarity, substitution and multitask incentives. Cockburn et al (1999) demonstrate that pharmaceutical firms with strong promotion-based incentives for basic research also provide greater intensity of incentives in applied research. Notable differences between academic and nonacademic sectors, such as the degree of self-selection in team production or output observability, would seem good candidates for further inquiry.

Priority-based rewards are a fundamental distinction regarding the incentives facing individuals working within research organizations (Merton (1973), Stephan (1996)). One of the incentives to establish priority of discovery in basic research is a significant relationship between compensation and measures of publication success.[5] These include the number of publications, quality of outlets, and subsequent citations (Hamermesh et al (1982), Moore et al (2001)). A substantial portion of pay that is independent of publication success would be consistent, in the context of agency theory, with the inherent uncertainty of publication success.

The role of reputation in the academic research community serves as further evidence of priority-based rewards. Incentives to establish priority include individual recognition, research grant income, enhanced access to university-based resources, prestigious prizes, and even having one's name permanently attached to the discovery (Merton (1973). As a result of these rewards to reputation, increasing inequality over time characterizes career patterns of research productivity and pay among scientists in several different disciplines (Levin and Stephan (1991)).

Hartwick (1991, p. 205) observes, "The whole process of scholarly research in science can be viewed as an R&D race. Many are called but few are chosen to make fundamental discoveries. Participants train by investing in education...Research is conducted by each trained person and some make minor discoveries while the majority do not. A combination of skill and the positive feedback from success results in a few researchers making a disproportionately large number of discoveries." These features are more commonly associated with basic research efforts, where positive feedback comes in the form of increased publication odds and greater success in obtaining grants. Merton (1973) has coined "the Matthew effect," whereby the most

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5 Another indirect reward to research is that prolific researchers are more mobile due to a greater variety of potential job offers available to them (Skeels and Fairbanks (1968)).

prolific researchers benefit disproportionately from their reputations.

Among the alternative interpretations of these observations, Stephan (1996) argues that incentive alignment mechanisms associated with agency theory are worth considering. In particular, rewards to reputation prevalent in academic research are reminiscent of the winner-take-all incentives found in "rank-order tournaments." While property rights are typically retained by firms in industry-based research, academic reputation tournaments allow individual scientists to appropriate a portion of the social gains to basic research (Stephan and Levin (1996)). Conditions favorable to tournaments include relatively high costs of monitoring effort, sources of risk that are relatively exogenous to the organization, and variation in individual abilities making positive self-selection desirable (Lazear and Rosen (1981)). These conditions would appear consistent with notable features of the research environment found in academic settings.

Intrinsic motivation

Intrinsic motivation provides an additional determinant of productive conduct by individual researchers. Individuals attracted to scientific careers gain satisfaction from puzzle-solving and other non-pecuniary aspects of the process of research (Cole and Cole (1967), Bonaccorsi and Piccaluga (1994)). Stephan and Levin (1996) describe academic scientists as entrepreneurs, allocating effort to projects and collaborative opportunities in the relative autonomy of academic settings based on individual assessment of risks and rewards. Agency concerns are ameliorated to the extent that the unmanaged choices of scientists correspond to the objectives of research organizations. Moreover, intrinsic motivation may be valuable from society's perspective if an accurate sense of relative social benefit influences individual choices regarding effort and which puzzles to solve.

PUBLIC POLICY AND INSTITUTIONS

The framework developed here serves as a tool for reconsidering policy alternatives and the role of institutions. The relationships between product characteristics, market structure and conduct are at the heart of any discussion of intellectual property rights and mechanisms for public funding. Internal organization concerns provide valuable insights regarding conduct responses to a combination of recent technology transfer policies as well as the role of professional societies.

Intellectual property rights

Enforcement of intellectual property rights provides a longstanding public policy response to the problem of incomplete appropriation of research benefits. The intended effect of the patent system on conduct and performance works through market structure. Anticipated gains from future monopoly rights serve as an incentive for current innovative effort (Kaufer (1989)). In the absence of a patent, antitrust exemption for monopoly obtained through innovation is motivated by similar intentions. The historical criticisms of these arrangements involve the unintended effect on conduct and performance when the patent holder (or innovative monopoly firm) exercises government-sanctioned market power and restricts output.

As an alternative to patents, Wright (1983) and Shavell and Ypersle (2001) consider a system of prizes paid by the government to successful innovators. In theory, this policy offers incentives for innovative effort without the deadweight loss associated with subsequent monopoly behavior. In practice, information asymmetries regarding the value of innovations tend to favor the market valuation afforded through patents over administrative discretion associated with prizes.

There are several concerns with respect to the administration of the patent system as well. Substantial lags often exist between research effort and the granting of patents (Hall et al (1986)). A corrupt, or simply inefficient, patenting authority imposes additional costs on research organizations. Patents may provide imperfect legal protection from the development of market substitutes (Harabi (1995)). All of these concerns reduce the intended incentives of the patent system toward innovative conduct. In the case of patenting, applied research organizations are at the mercy of the government authority that holds a monopoly in the grant of patents. With respect to basic research, on the other hand, there tend to be low entry barriers and extensive competition among academic journals in publishing markets. Hence, one might hope that corruption, inefficiency or substantial publication lags would be less likely to persist in academic markets.

Perhaps the most commonly cited concern associated with the patent system is duplication of research effort through patent races (Kamien and Schwartz (1982)). A more competitive environment is likely to encourage inefficient production of priority-based research outcomes. A series of recent policy initiatives in the U.S. propose to alter market structure and facilitate cooperation among research-producing firms. The National Cooperative Research Act (NCRA) of 1984 and National Cooperative Research and Production Act (NCRPA) of 1993 provide antitrust exemption and other incentives for collaborative research efforts between private firms (see Link et al (2002)).

Public funding mechanism

An alternative policy response is to subsidize or contract directly for research efforts. Laying aside the question of appropriate research subsidy level, there have been surprisingly few economic studies on the most effective mechanism for public support of research efforts

(Stephan (1996)). The institute system, prevalent in Europe and Asia, fosters long term commitment to projects and may cut down on redundant research efforts through enhanced coordination of resources; however, there will be less market guidance as to which projects should be funded. The grant system, prevalent mainly in the U.S., encourages competition among researchers within the existing academic-nonacademic structure. This increases the probability that the socially valuable projects are funded but also promotes redundant research effort at the grant writing stage.

Link and Scott (2001) describe a mechanism for public funding of research activities in private industry. The government forms an investment partnership with the private research-producing organization, agreeing to share costs in exchange for mutually agreed upon research effort. Wright (1983) demonstrates that such contracts for research effort become an effective alternative to patents or prizes as the probability of discovery and "elasticity of research supply" increase. The U.S. Advanced Technology Program (ATP), the Very Large Scale Integrated Circuit (VLSI) program in Japan, and the European Research Coordinating Agency (EUREKA) provide applications of this variation on the public subsidy theme.

Tax credits provide a simple alternative for public support of research and development activities. While private firm expenditures on R&D are responsive to marginal incentives, tax credits serve as a relatively blunt policy instrument, unable to distinguish between basic research, applied research and development (Audretsch et al (2002)). Tax incentives encourage the pre-existing mix of industrial R&D expenditures and are not applicable to nonprofit research organizations. Such a policy would not appear promising as a solution to basic research underinvestment.

Technology transfer policies

The policy environment surrounding university research, especially with respect to interaction with industry, has undergone substantial change in recent years. The Patent and Trademark Amendments (Bayh-Dole Act) of 1980 granted U.S. universities and nonprofit institutions license to retain intellectual property rights to inventions resulting from federally financed projects. This was followed by various measures making government policy more receptive to commercialization of university research. These include the Stevenson-Wydler Act of 1980, the National Competitiveness Technology Transfer Act of 1989, and increased National Science Foundation funding for Industry-University Cooperative Research Centers (Powell and Owen-Smith (1998)). The anticipated gains from this collection of policy initiatives are best understood in the context of internal organization of research institutions.

Academic settings are most conducive to basic research, while specific commercial applications are likely to be developed in industry settings. The resources involved in these activities are complementary in nature. Both university and industry may see the gains to cooperation; however, from a game-theoretic perspective, it is in neither party's individual interest to make cooperative choices. Absent a mechanism for appropriability of benefits, it is unlikely that university research efforts would be directed toward projects with the highest downstream commercial value. The Bayh-Dole Act addresses this concern directly by introducing university patenting (see Nelson (2001)).

The path from "embryonic stage" to commercial use constitutes a vertical chain of production in which adaptive decisions, coordination of knowledge transfers and relationship-specific investments may all be required. These are the conditions under which Aghion and Tirole (1994) argue that "the two parties cannot contract for delivery of a specific innovation." Consistent with this result, Poyago-Theotoky et al (2002) describe a variety of principal-agent contract arrangements that would be feasible. These arrangements specify shared investments, intellectual property rights, and sharing rules for profits from commercialization. The prospect of direct university patenting broadens the range of contractual instruments available. Furthermore, relational exchange is facilitated by policies that enhance the flexibility of implicit contracting by universities and increase public funds to university-industry collaborative research ventures.

A number of recent studies document an upward trend in academic participation in applied research as measured by university patenting (Henderson et al (1998), Mowery et al (2001)). Rapid growth in the number of technology transfer offices, university-industry research centers and science parks in the U.S. and Europe is viewed as additional evidence of university response to these policy initiatives (Poyago-Theotoky et al (2002)). In a recent empirical study of university technology transfer offices, Siegel et al (forthcoming) conclude that internal organization elements, particularly faculty reward systems, influence relative productivity between research organizations.

Somewhat less attention has been paid to an essential concern regarding multitask substitution in academic settings (Lee (1996), Holmstrom and Milgrom (1991)). Do increased opportunities for university-industry collaboration and university-based patenting enhance or diminish basic research efforts? Hicks and Hamilton (1999) present evidence of an increase in university-industry coauthorship of publications in scientific journals with no reduction in quality, as measured by subsequent citations. Agrawal and Henderson (2001) offer assurance that publishing rates continue to far outstrip patenting rates among university faculty. Hall et al (forthcoming)) add that involvement of university partners in ATP projects appears to increase the basic research content of these projects.

Role of professional societies

Professional scientific and technical societies serve a valuable function in promoting information exchange between the academic research community, their counterparts in nonacademic research organizations, and a variety of industry participants. They publish journals, hold conferences and maintain communication networks. Nelson (1986) finds that scientific societies are particularly important to downstream firms that do not produce their own research.

To the extent that they participate in establishing the reputations of individuals, professional societies serve a unique role in the overall rewards structure. In many instances, these societies sponsor the most prestigious journals in a field and are thus gatekeepers to the advance of knowledge. With a degree of control over the quality and quantity of published research, professional societies are both an institutional solution to imperfect information concerns and a potential source of monopoly inefficiency. Performance of markets for science and technology are likely to be affected by conduct of the gatekeepers.

Nonetheless, Nelson (1986) observes that "few analyses by economists of the determinants of industrial R&D and technical change have explicitly considered universities or technical societies as part of the system generating these variables." It should be clear from our preceding review that there is notable ongoing progress with respect to universities. However, the role of professional scientific societies has remained, by comparison, unexplored.

CONCLUDING OBSERVATIONS

The importance of research, especially for economic growth, is well-known. However, there exits no comprehensive framework for the study of research markets. This paper attempts to plug this hole in the literature by proposing an overall framework within which the workings of research markets can be understood and policy recommendations drawn. Specifically, borrowing from the industrial organization literature, we argue that the structure of research markets affects their conduct, which in turn affects the overall performance of these markets. Previous literature has considered individual elements of the research process (see Stephan (1996), Audretsch et al (2002)). We provide a setup to show how these different elements fit and also provide a selective review of the literature.

It is argued that the primary structural difference in research markets exists between academic and nonacademic research organizations. The main research outputs of these two sectors are different and they face different competitive pressures. The conduct of research, including research productivity and collaboration in research, is critically dependent on the internal organization of research markets. Internal organization of research organizations deals with intra-market structure and the incentives of individual researchers to conduct research. Here, again, the research incentives vary across academic and nonacademic sectors. The performance of research markets deals with economy-wide issues related to economic growth and efficiency. Exogenous influences on the structure and conduct of research markets arise from government policies and institutions. Government policies deal with protecting intellectual property, technology transfer and funding research activity. Professional societies are important institutions that serve as gatekeepers to the advance of knowledge.

Besides providing a framework for study, our framework provides ground for policy formulation and evaluation. For instance, blanket technology policies, without noting the distinction between academic and nonacademic sectors, are likely to have undesirable effects. On the other hand, policies that note the academic-nonacademic divide but ignore the internal organization of research markets are likely to be equally unsuccessful.

The measurement issues plaguing research on science are well-known. These hamper efforts at empirically testing theories. For instance, the impacts of policies directed toward facilitating transfer of university research to the private sector need to be better understood, especially to the extent they crowd-out basic research at universities. Another unanswered question relates to the relative presence of redundancies in academic and nonacademic research efforts. On the theoretical front, however, there have some encouraging advances in modeling agency issues. It is hoped that the proposed framework will provide basis for additional research on this important topic and better our understanding of the research process.

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Figure 1: Organization of Markets for Science & Technology