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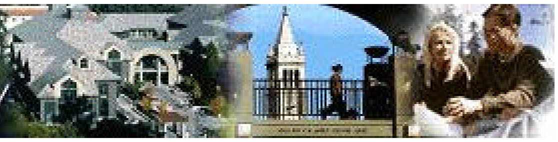

A comparative analysis of R&D in public and private organizations and the effects of recent public policy activity in U.S.

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Abstract:

The goal of this paper is to analyze and highlight the nature of R&D and the fundamental analogies and differences surrounding the organization of R&D in different institutions such as Universities, National Labs and corporate Laboratories. Based on this analysis we evaluate the matching between desired objectives and empirical effects of the most important public policies aimed to improve U.S. industry competitiveness. The analysis is performed within the framework of dynamic capabilities. Finally, we highlight the major findings and we address the problem of better policy design.

1. INTRODUCTION

Research and Development (R&D) is the preliminary step towards the commercialization of basically any technology-based product or service, therefore its effectiveness and efficiency are the basis to create wealth for the society. As a consequence, industrialized nations have tried to devise institutions and public policies to improve this process and the global competitiveness over other nations. The goal of this paper is to analyze the nature of R&D, how it is performed, which are the institutional players who perform R&D, how public policy activity is addressing R&D and its effects in the United States. In particular, in the second section we characterize the nature of R&D and its different facets. In the third section, we study the three major institutional players, i.e. the university, the government laboratories and the corporate laboratories, and their role in R&D using the framework of dynamic capabilities developed by Teece. In the fourth section we present the public policy activity of the last two decades aimed to improve technology transfer process from R&D to commercialization. We also summarize the major findings and observations of the consequences of these policies. Finally, in the last section we summarize the major flows of current public policy and address the issues for better policy design.

2. R&D

It is widely accepted that a strong and articulated Research and Development (R&D) system is a necessary condition for innovation and wealth creation in the society. Nonetheless, the optimal structure for such a system is still source of great debate and of paramount relevance from a public policy point of view.

In particular, in the United States, it is possible to distinguish three major entities within this system: the universities, the government laboratories and the industrial laboratories.

Each of these entities participates in R&D, but their objectives and organizations are different. Before studying them in detail, it is appropriate to spend few words to define what we mean for R&D. R&D is a very broad term that includes basic scientific research, applied research and development of technologies possibly into marketable products.
Basic scientific research[1] may be defined as the human activity directed toward the advancement of knowledge, where knowledge comprises observed data of repeatable experiments and theories which aim to predict observed data. Basic scientific research is strongly believed to be the starting base for *applied research*, where applied research is defined as a reasonably systematic activity directed toward the creation of new and improved practical processes and products. Applied research is often associated with *inventions*. Finally, once a product is proved to be technologically feasible, *development* includes all the technological activities and processes (mainly, but not only, manufacturing) necessary to bring into the market this product. The boundaries between these three activities are often blurred, but it is fair to say that the public sector, *i.e.* universities and government labs, dedicates most of its resources into basic scientific research, while the public sector into the development (see Figure 1).

A natural question arises at this point, i.e. what are the goal and the value of R&D? This may sounds like a trivial question, but it is at the core for understanding the presence institutions as diverse as universities, national labs and industrial labs in R&D. From an economic point of view, the social value of R&D can be defined as the "flow of benefits (properly discounted), from a given expenditure, that would not have been created had none of our resources been directed by R&D". If R&D was a perfect market, private profit opportunities would naturally draw into technological research activities as great amount of resources as socially desirable. Unfortunately, this is not the case because of the "public" nature of R&D and knowledge which are intangible assets, therefore difficult to create, transfer and protect[2]. Since private entities allocate resources that maximize profits, they allocate resources only when the value captured from the flow of benefits is expected to exceed the investment costs. In basic research, the uncertainty of

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[1] Some of definitions in this section are liberally adapted from Nelson (1959)

[2] A more comprehensive description of these issues can be found in Chapter 1 in Teece (2000)

success is high and the appropriability regime[3] for new discoveries is weak, therefore there is little incentive for the private sector to invest in it. The private sector prefers to invest in applied research and development where costs, time-to-market, and product roadmaps are more linear, and where the appropriability regime is stronger[4]. Therefore, since basic research does generate value for the whole community, the public sector must actively support it through specific structures, such as universities and government labs, or by subsidizing the private sector. Universities are mainly devised for educational purposes and for expanding public human knowledge in a broad sense, not only related to science. Government labs, instead, have been created and sustained to respond to nation priorities in national defense and energy security, which necessitate expensive infrastructures, lengthy investments and high level of secrecy. Although both these entities generate knew knowledge and innovation, they are not suited for exploiting their discoveries in marketable products, where the private sector is more effective and efficient thanks to competition.

Much of the recent public policy debate and action has been directed in promoting the interaction between these different research institutions in order to accelerate the transfer of technology and research into products and services, and to bias the basic and applied research towards market and society needs. This approach, meant to improve U.S. industrial competitiveness, is bidirectional, since from one side it is ought to exploit existing technology to create new marketable products, and from the other it is ought to bias basic research towards markets needs. This approach arises several questions. Which are the best policies to achieve this goal? How do we quantitatively quantify the effectiveness of these policies? Which are the long term consequences of these policies on the U.S. R&D system? Section 4 will address these issues.

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[3] Physical laws, methodologies, algorithms cannot be patented and their diffusion is proportional to their value to the community.

[4] Legal protection such as patents, copyrights, trade secrets are easier to enforce when product scopes are narrower. Also the tacit nature of knowledge in this stage, in particular in processes, reinforces the appropriability regime.

3. UNIVERSITY, NATIONAL LABORATORY AND INDUSTRY R&D ANALYSIS THROUGH THE 3P

In this section we compare the organization of R&D in universities, national labs and corporate labs within the framework of dynamic capabilities, and specifically using the 3P model: Positions, Processes and Path[5]. Positions refer to the tangible and intangible assets that an organization holds at present. These assets are the inputs necessary to create a product of service. Processes are the routines that orchestrate the positions to generate products or services. They are in practice the repository of knowledge and the result of experience of an organization. The path is the history of the organization and is strongly correlated to the learning process that has shaped the organization. This approach will be very useful in the next section when studying policies, which will be regarded as "meta-routines", i.e. routines that in the long term reshape processes to adapt to ever changing external environments. In this framework, a product could be the result of an R&D project; regardless this is something tangible and physically quantifiable.

University:

Positions:

- *Funding:* Although public and private universities have different sources of financial support for R&D they can be divided into three main categories: internal funding, industrial funding and public funding through federal institutions such as National Science Foundation (NSF), Defense Advanced Research Projects Agency (DARPA), HHS , Department of Energy (DOE), NASA (see Figure 2). While internal funding could be substantial in private universities, in general faculty in scientific disciplines proactively search for additional external funding by competing for existing grants or by creating collaborations with the industry. Projects are funded for a period of time of average 1-6 years, often with annual

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[5] Although this model has been originally developed to analyze the position of a single firm within an industry, we think it can be extended to analyze the three different organizations above within the R&D innovation process. See Teece (2002) and class notes of "Managing Innovation and Change" class (2002) for description of the model.

reviews, which means that projects funds can be cut if proposed milestones are not delivered.

- *Faculty:* U.S. Universities compete among them and against industry in hiring the most talented researchers in order to increase their prestige and to attract more and better students. Faculty main drivers are probably public recognition, research freedom and the gratification of creating innovations that will shape future. Salary is definitely an important factor but probably not as much as in industry.
- *Students:* Graduate students and researchers, together with faculty, are the main responsible of R&D. Graduate students are admitted through a selection process that is meant to fairly evaluate every individual in the interest of the school itself. They are strongly motivated individuals who work for 1-6 years on one or few projects. The final outcome of the project or the research is determinant when pursuing an academic career or a job in the industry at the end of the graduate program, therefore students have strong incentives to make the project succeed.
- *Technology:* Often universities develop their own technology, but laboratory equipment and necessary infrastructure is built incrementally through university and industry donations and collaborations.
- *Reputation:* Long traditions of fundamental and steady contributions to research and innovation have created a strong reputation in the US university system, in particular for some prestigious schools. Students, researchers and faculty are attracted from all over the world. Moreover, industry and government often consult with schools and faculty about the future direction of scientific research and technology.

Processes:

- *Student admission process and supporting:* The university system is a very competitive one, best students and faculty try to get admitted and hired into best schools, best schools try to attract best students and faculty. Although there is no official institution appointed at determining school ranking, different independent sources periodically publish such ranking based on different criteria. Several kinds of scholarships are available to graduate students, either through teaching assistantships or research.

- *Faculty Hiring process:* Faculty are hired not only based on their ability of performing relevant research, but also on their ability in creating collaborations with other faculty members and with other schools, in proactively establishing collaborations with industry, and in writing effective research proposals for fundraising.
- *Projects design and evaluation:* Most of the projects developed deal with basic or applied research. Even product development is in general related to research in creating better manufacturing or design methodologies with no intent to actually make a product ready for the market. In general, faculty is interested in exploration of new research directions and proof-of-concept products. The actual development of a marketable product is left to the private sector, sometimes with the direct contribution of the faculty and students (start-ups, consultancy). Projects are evaluated in terms of results achieved. They can be substantial different from those initially proposed, therefore every project is opportunistically evaluated on a regular base in order to reduce, increase, extend funding and students working on it. This system is very flexible but at the same time quite efficient in an environment where discoveries and innovations follow a discontinuous path along often unpredicted directions. U.S. universities have a very open and public R&D system. Scientific research and projects are evaluated according to qualitative criteria rather than quantitative metrics. Success rate, performance, cost, etc. are sometimes misleading metrics in an environment where innovation follows nonlinear paths. Different indirect criteria are more meaningful such as original contribution, based on the number of papers published in prestigious journal conferences and conferences; such as diffusion of ideas in the scientific community, based on the number of collaborations and people who share the same vision; such as the number of national and international awards won. Both faculty and students are motivated to diffuse their research, ideas and results through the scientific community, which in the end benefit as a whole. Besides, this approach requires modest investments in

equipment and technology since products are not produced for market needs and quantities[6].

- *Faculty Salary:* Some schools offer only a limited amount of financial resources for research to faculty that must proactively search additional contributions in the industry or through federal grants. Moreover in some schools, like in Engineering at UC Berkeley, the salary to faculty is limited to the teaching activity, therefore during summer, income is guaranteed only if personal grants are available. This is an additional stimulus for faculty in searching external funding sources for research.

Paths

- *History:* The university system has of long tradition of scientific contribution and innovation for society. In particular, many universities emerged as leaders in specific area of research, and created a self sustaining local environment of industry, such as Silicon Valley for semiconductors, San Diego for biotechnology.

Federal Laboratories:

Positions:

- *Funding:* Funding for government labs comes directly from federal budget. Allocation of resources is mainly a top-down process, based on the political decisions of the US Congress. The budget distribution among all national laboratories is a rather rigid process with little flexibility for reallocation and for grants competition among different labs. As a consequence, superficial assessment of specific scientific competencies of different labs is performed and little incentive is given to labs for competing for financial support on a scientific and technological basis.
- *Management:* Top management is involved in a substantial administrative and political discussion and negotiations with technocrats with are not always aware of the scientific and technological issues. This process slows down scientific research, hampers the reallocation of resources to more promising projects, and

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[6] A recent article claims that a dollar worth of academic invention or discovery requires upwards of $10.000 of private capital to bring to market, and that companies that license ideas from universities wind up paying 99% of the innovation's final cost. See Economists (December 14, 2002).

creates a substantial frustration in the lower level of management and in the scientists.

- *Employees:* Employees are mainly represented by experienced researchers, technical and scientific support. In large national labs this work force spans several scientific fields, from life science to material science, from nuclear physics to engineering, from biotechnology to environment conservation. The background diversity among employees is a major and unique asset of national labs, which is rarely present in university R&D or corporate labs.
- *Technology:* The laboratory mission has changed over time, as the early focus on basic research in physics and nuclear weapons development has for sometime been supplemented by research in energy, environmental, and other technologies. Most of the technology necessary for R&D projects has been developed internally, thus creating almost self-sustaining entities whose activities ranged from basic research, to applied research to development. This process has created an incredible asset in term of technology and experience. This is a rather unique feature of national labs with respect to university and corporate labs which focus only a specific field of R&D.

<u>Processes:</u>

- *Projects evaluations:* Being national defense and energy security the priorities of most of the research activities, projects were evaluated based on performance, quality and reliability rather that cost and development time. Besides, the secrecy required by most of these projects has created over the years a close system where in-house development was preferred to collaborations.
- *Employee evaluation:* It is mainly based on peer reviews and project success.
- *Hiring process:* Major incentives for people looking into job opportunities in the federal labs are the diverse and unique technology and human assets and resources that are neither available to universities nor large corporate labs, in particular in fields like basic and high energy sciences, supercomputing and nuclear physics.

<u>Paths:</u>

- *History:* As mentioned already mission has changed over the years, from basic research in physics and nuclear weapons development towards more “social” technologies. This transformation is far from being smooth, since “social” technologies require processes and expertise that can be quite different from the competencies currently in place in national labs. Indeed, this troubled transformation has raised the question weather this transformation is feasible at all. Next section discusses this issue.

Corporate Laboratories:

Positions:

- *Funding:* Funding for corporate R&D comes directly from the firm financial resources, but recent public policies have allowed the private sector to access federal funds under specific circumstances. Large enterprises have large portfolios of projects and resources allocations are directed to the answer market needs within the strategic plans of the company. Very often R&D projects are created, maintained or terminated regardless the social value or scientific success, unless they match market needs and company strategic position. As a consequence, even the most visionary firms rarely invest in projects longer than 1-5 years.
- *Technology:* The extent of technology assets that each firm owns greatly depends on the size of the firm and the market of interest. Small companies have technology specifically designed for the current or short-future products, while diversified large corporate labs have large technological assets built over the years possibly in a large range of products. However, even in the former case, technology is always local to the current competencies of the firm.
- *Employees:* The range of experience and expertise is very wide and heterogeneous. Employees range from newly graduated to many years experienced professionals, from engineers and scientists to marketing and financial personal. This is a consequence of a more direct contact or at least concern with market, customer needs and company resource constraints.

Processes:

- *Projects evaluations:* Project evaluation is very complex since R&D projects have a very high failure rate and at the same time they need to be addressing the company customers' needs. Differently from university and national laboratory projects, technical success is just one of the possible dimensions to evaluate a project. Others like cost, time-to-market, customer needs satisfaction, strategic positioning of the company, just to name few, are sometimes far more important. When the company is a large company, portfolio management of technologies becomes another important factor when dealing with resource allocations and projects evaluations
- *Employee evaluation:* mainly based on the results of on-budget requirements and on-time project deadlines. High failure rate makes difficult to fairly evaluate the quality of employee effort. This remains a problem for most companies and it is still an area of debate.

Paths:

- *History:* R&D organization in the industry has changed considerably in the past fifty years. While after II World War large corporate R&D labs such as the Bells Labs, IBM Labs, Xerox Labs, were the norm, over the years a different model of smaller flexible labs were most of the basic R&D is outsourced and assembled into products and services[7]. As a consequence, absence of internal capabilities and skills is compensated via alliances, collaborations and acquisitions. This transformation has increased flexibility and accelerated product-cycle in the industry, but at the same time has created very shallow and highly specialized firms that can hardly adapt to sudden change in the marketplace.

4. PUBLIC POLICY AS META-ROUTINE

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[7] See Chapter 3 in Teece (2000)

R&D collaboration between universities, national labs and private sector is believed to have contributed to the resurgence of competitiveness of U.S. economy in the past two decades[8]. The public policy activity and debate in the past two decades have been directed to unleash the technological discoveries dormant within universities and national labs into commercial products to increase U.S. industry competitiveness and wealth. This activity covers a diverse array of programs, projects, and institutional actors, and although it can yield positive payoff, it is not without risks. The framework of dynamic capabilities developed in the previous sections is meant to provide the necessary tools to evaluate the long term consequences of the public policies. These policies are regarded as meta-routines, i.e. routines that bias the current processes of one of three entities described above to achieve their objectives.

Promotion of Industry-led consortia[9]. In the past two decades many legal antitrust impediments to officially create collaborations and consortia in the industry, have been removed. Moreover, these consortia were given the possibility to receive public funds if they were meant to pursue long term R&D. The most celebrated example is the SEMATECH, a consortium devoted to the development of performance standard for new semiconductor manufacturing equipment. The main objectives for these actions were the creation of incentives for long term research; the capture of “knowledge spillovers” by all participating firms; the reduction of duplication of R&D investments; the lowering of barrier of entry in R&D for small companies; the acceleration of commercialization of new technologies. In practice, it has been observed that:

1. Most industry-led consortia support R&D with a short time horizon of three to five years.
2. They focus more on activities that resemble technology and standards adoptions rather then new technology creation. This is particularly risky in consortia where large firms have strong hold on complementary assets, since it promotes the maintenance of the status-quo rather than innovation.

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[8] see Mowery (1998)

[9] This subsection in mainly based on Mowery (1995) and Grindley (1994)

3. Substantial financial and human investments were required for “in-ward” transfer of the technology developed in the consortia, thus reducing the hypothetical benefits for smaller companies.
4. Management of resources of these consortia is often very complex and lengthy, therefore flexibility in agenda-setting and adaptation may be difficult to achieve, especially when additional requirements of public oversight and evaluation of publicly funded programs are present. As a consequence, consortia can indeed lead to suboptimal use of resources and longer time-to-market.

Bayh-Dole Act and industry-university collaborations:[10] The Bayh-Dole Act in 1980 and subsequent amendments rationalized and simplify federal policy toward patenting and licensing by non-profit institutions of the results of publicly funded research. In particular, it provides blanket permission for recipients of federally funded research to file for patents on the result for such research and to grant licenses for these patents, including exclusive licenses, to other parties. The Bayh-Dole Act stemmed from the idea that stronger protection for the results of publicly funded R&D would accelerate their commercialization and increase economic returns for U.S. taxpayers. Also it was meant to create additional incentives for long term R&D investments to the private parties involved in these projects. This set of policies has been sponsored as one of the major responsible of resurgence of U.S. economy in the late 80s’ and in the 90s’. Surprisingly enough recent empirical studies have unveiled a more complex scenario and cleared some misbelieves.

1. The patenting activities did increase during the 80s’ and 90s’. The share of U.S. patent accounted for by grew from less than 1% in 1975 to almost 2.5% in 1990. The university ratio of patents to R&D spending doubled during 1975-1990, while overall U.S. ratio was declining[11].
2. The characteristic of invention disclosures from faculty seems it had little effect. Mowery[12] found that patenting activity started growing considerably even before the Bayh-Dole Act in schools with long patenting tradition like University of

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[10] This subsection in mainly based on Mowery (1995) and Mowery (1999)

[11] Mowery (1999)

[12] Mowery (1999)

California and Stanford. Many universities entered into patenting and licensing activity for the first time, in particular related to biomedical and biotechnological inventions thanks to a major increase in federal budget in these areas (see Figure 3).

3. Patents are only one of the steps towards technology transfer. The ratio of patents issued and licenses granted in far from being close to unity[13], especially for universities that entered the patenting activity recently with a naïve attitude. This is particularly harmful for two reasons. The first reason it simply increases university costs and paperwork, without generating returns. The second reason is that it can slow down research in complementary technologies that may infringe the patent. Patents to be valuable only in assembled into bundles that can be used to address a market need. The portfolio assembling, the marketing research and the license negotiation processes require specialized and experienced transfer technology offices can perform[14].
4. Revenues from patent licensing increased steadily in universities. As an example, at the University of California system of nine campuses and three national labs the licensing income increased forty times from 1981 to 2000, from around $2M to about $80M (see Table 1). However, net returns from technology have become flat and such trend seems to be likely to continue (see Table 2) and it is a small percentage of the total R&D spending in University. Therefore, the argument of using revenues earned out of technology transfer activities can be used internally to cross-subsidize basic research is mainly a hypothetical benefit.
5. Little evidence is available about university-industry collaborations aimed to support long-term research, which rather tended to focus on relatively near-term research problems and issues faced by the industry[15].
6. Industry funding to university R&D research has grown steadily over the past two decades but it has never exceeded 10% of the total funding to university R&D, which is supported for 60-70% by federal funds. Indeed, this ratio has remained

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[13] Granieri (2002) and UC Technology Transfer Annual Report (2001)

[14] Granieri (2002)

[15] Mowery (1998)

constant in the past few years (see Figure 4); therefore it is unlikely that industry will support most of basic research.

7. Most of the revenues from licensing in university come from a very limited number of licenses. Again, a representative case is the University of California, where out of a total portfolio of more than two thousand patents in Y01 the top five inventions accounted for 58% of total royalty and fee income, and the top twenty-five inventions for 77% (see Table 3). Similar findings have been observed in other universities[16]. Moreover, these top inventions stemmed out from biomedical research, area in which individual patents have considerably strength (see Table 1). In different industries such as semiconductors and chemical engineering, patents are less valuable since they are more difficult to defend.
8. Considerable inward transfer and absorption of R&D costs and efforts remain necessary[17].

<u>CRADA and industry-federal laboratories collaborations[18]:</u> In the mid 80s' a new policy called Cooperative Research and Development Agreement (CRADA) created a mechanism for R&D collaboration between industrial firms and federal laboratories. Under the terms of a CRADA, federal labs are empowered to cooperate in R&D with private firms and may assign private firms the rights to any intellectual property resulting from the joint work. This action was an answer to the budgetary pressures emerged after the end of the Cold War on federal R&D support to the federal laboratory system, based on the belief that national labs were the repository of a treasure of technologies that just needed to be commercialized. Since then, hundreds of CRADAs have been signed, between the 1989 and 1995, the DOE alone signed more than 1,000 CRADAs[19]. However, after the initial excitement the number of CRADAs between labs and companies has dropped by a factor of four over the past five years[20]. Technology transfer is waning due to a variety of factors that have not been addressed by federal

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[16] Mowery (1999)
[17] Mowery (1998)
[18] This subsection is mainly based on Mowery (1998), Ham (1995) and Ham (1998) and ManufacturingNews (September 16, 2002)
[19] Mowery (1999)
[20] ManufacturingNews, September 16, 2002

policymakers, according to those participating in a recent roundtable on the topic and observed also in empirical studies by Mowery:

1. Time delays in project approvals have been probably the main complain from the private sector. Virtually all public-private R&D collaboration face the dilemma between the need of flexibility in project organization and expenditures in complex, uncertain undertakings, and the requirement of democratic system for oversight, which can produce inflexible list of goals and priorities. Unfortunately this dilemma has been particularly evident in CRADAs. The administrative process for approval could be as long as a year, and this delay is extremely detrimental for small-medium companies for which even few months delay is mortal.
2. CRADAs are mainly concentrated around short term projects, not only because of natural tendency of firm to focus on technology development, but also because of the uncertainty associated with the changing political environment, since is the Congress directing the areas into which the money is flowing and into which the federal labs are going to be putting their efforts. The most illustrative example is the Partnership for a New Generation of Vehicles (PNGV), which was initially celebrated as a new model of technology transfer, but then died due in part to the burden of paperwork.
3. Not all industrial partners in CRADAs were interested in obtaining intellectual property (IP) rights for the jointly developed results. Some of the projects were rotating around transfer of "knowledge" rather then bare technology, i.e. the learning, training and consulting benefits of the collaboration. Therefore, in many cases, the lengthy and over-detailed negotiation of IP rights process associated with CRADAs just reduces the attractiveness of collaborations to industrial partners.
4. Cultural differences also contributed to create the discontent between the private sector and the national labs. As explained in the previous section, national labs projects were more concerned with quality and performance rather then cycle-time, cost and diverse customer base needs. The difference between these objectives creates friction between the laboratory and the firm engineers who

have different approaches to the problem, and consequent loss in effectiveness of the whole project.

5. Commitment and support from high-level management of national laboratories are often insufficient. The participants in these collaborations are often frustrated trying to obtain timely access of resources and decision making, due to absence of dedicated structures and personal for CRADAs.
6. Inward transfer of technology is still very expensive and critical in particular during the transition from product development to product commercialization. Lack of post-project support can undermine the success of the commercialization of the product, even in the case when the collaboration itself was successful.

5. CONCLUSIONS

Although the intent to improve the effectiveness of technology transfer from the public sector to the private sector, and to increase of collaborations in R&D among university, national labs and industry three, are a "good thing" in and on itself, the actual implementations of these policies is of paramount relevance for them to succeed. The nature of R&D, as described in the second section, and the individual positions, processes and paths of three institutional actors, as described in the third section, are the basis to understand the effectiveness, risks and benefits of policies. The majors finding can be summarized in following few points:

1. The very same nature of basic scientific research which is public, and the necessity for a private firm to capture "proprietary" returns from investments, determine the nature of public-private collaborations and industry-led ventures. The private sector is naturally biased towards short-term development or applied research projects. In particular, small companies do not have the luxury to invest in R&D projects with a lifespan longer than few years. Even when long term research ventures and collaborations are engaged, the main goal of the (strongest) participants is to promote the adoption of standards rather than the development of radically new technologies. This is a concrete

concern when the large corporations that participate in these projects, hold substantial complementary assets necessary for the success of the technology being developed[21]. Therefore, it is unlikely to foresee successful long-term basic research collaborations even with the financial support from the public sector. Basic and applied research must be sustained by public intervention for its majority.

2. Patents and, IP rights in general, are only one of the possible means to ensure a strong appropriability regime. These are particularly valuable in industries like biotechnology and medical equipments, but less valuable in others like semiconductors where trade secrets or simply the tacit nature of knowledge are more important. Most of the collaborations between the university or national laboratory and the industry partners necessarily require a long negotiation process to establish IP rights. Although for some projects the transfer of ownership of IP rights is central, in those for which IP rights are of secondary importance, time delays due to the approval process discourage industry partners to engage in collaborations in the first place. Therefore, more flexible and project-tailored instruments of collaborations must be designed.
3. Culture differences between researched at university, national labs and firm influence the outcome of the projects. Mowery observed that most successful collaborations in a weapon laboratory were dealing with products or services which were already familiar to the laboratory researchers, while the least successful collaborations were associated with problem arising from unfamiliarity of commercial priorities such as time-to-market and customer base interaction. Also, Mowery observed that all industrial partners were seeking the unique combination of equipment, technology and expertise rarely available elsewhere, especially is a single organization, and the ability to assemble multidisciplinary research teams. A better projects selection process that tries to match the unique competences (not only technology), of the public institutions with the industrial partners is therefore necessary.

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[21] An instructive exercise is to look at the joint ventures in which large firms such as Intel, Microsoft participate. Few of them regard core technologies for these two companies, while most of them are complementary (such as Bluetooth or Java, just two cite two of them).

4. Management of collaborations is key for their success. Empowering universities and national laboratories to establish collaborations without creating the necessary organizational structure to support them, is of little help for the effectiveness of technology transfer. This seems quite a trivial statement, but too often "the devil is in the details". This is probably the most severe problem currently hampering the success of CRADAs. High level of bureaucracy, uncertainty in the political environment, unclear decision making structure are the most common critics from industry and national laboratory personal to CRADAs current state. In universities, this problem is somehow reduced since faculty is responsible for seeking, establishing, managing and maintaining collaborations with industrial partners, therefore good matching with university unique competencies is likely, and the flexibility of resources management is higher. As a matter of fact, current debate is focusing on how to built a stable decision-making structure for CRADAs, and weather this structure is compatible with the mission of national laboratory system.
5. The legal tools granted to universities to protect the intellectual property resulting from collaborative ventures via patenting and licensing of inventions were aimed at accelerating technology transfer by creating incentives for both university and industry. Restrictive licensing promises larger revenues for universities and proprietary technology for industry firms[22]. Interestingly enough, the empirical information collected in this paper shows that net income form licensing is just a fraction of total R&D support from other sources, such as federal and state funding, even for experienced universities such as University of California and Stanford. Besides, patents seem valuable and effective only in research areas such as biomedicine, and not all firms are interested in patenting results from collaboration. This raises the question of weather restrictive licensing terms have indeed a chilling effect on other channels of technology transfer. We described above how the effectiveness of university R&D is based on a reinforcing set of incentives for all players, students, faculty, and university, stemming from the publicity of research.

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[22] Granieri (2002)

> Unbalanced policies, such as restrictions on publications, can probably favor the commercialization of some inventions, but can endanger the very same source that generates these inventions. Most of the analysis of these policies has focused on the top-down process of technology transfer, i.e. how to commercialize inventions developed inside universities. Surprisingly, little has been written about the bottom-up process, i.e. how market needs can translate into better applied research inside universities[23]. Looking at policies from this prospective, collaborations and licensing options should be evaluated differently. As long as the publicity of research is preserved, collaborations focusing on market needs can only improve quality of research. Some researches have argued that a strong involvement of universities into applied research and commercialization can divert them from their basic research agenda[24]. Nonetheless, there is preliminary evidence that basic research is positively influenced by interaction with the industry[25], but more thorough studies are needed.

Evaluating R&D and public policies is a very hard objective since their activities span several years and their effects are implicit and difficult to measure quantitatively. The goal of this paper was to highlight the nature of R&D and the institutions that perform it, and to evaluate the matching between public policy objectives and their effects within the framework of dynamic capabilities. We believe that the framework of dynamic capabilities facilitates the recognition of possible consequences of policies and can improve their design. An attempt to use this framework to analyze few of the major flows of current policies has been performed, but more empirical research is needed to evaluate in depth our discussion.

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[23] Granieri (2002)
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[25] Siegel (1999)

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Table 1: U.C. Revenues of Technology Transfer Office

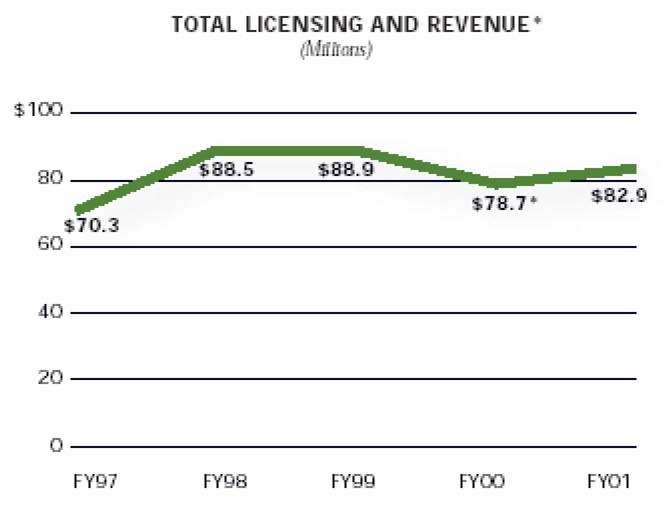


Table 2: U.C. Net Income of Technology Transfer Office

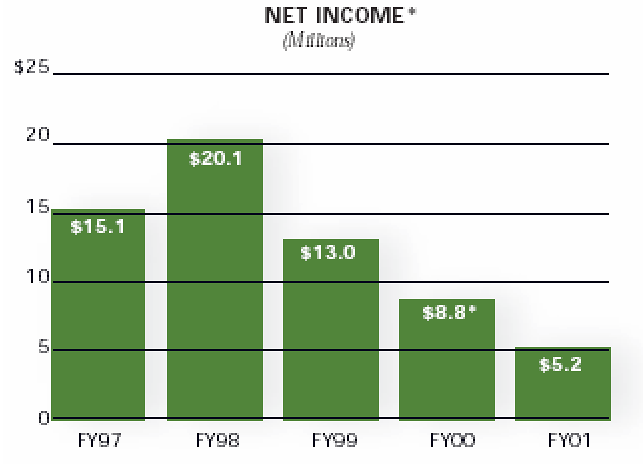
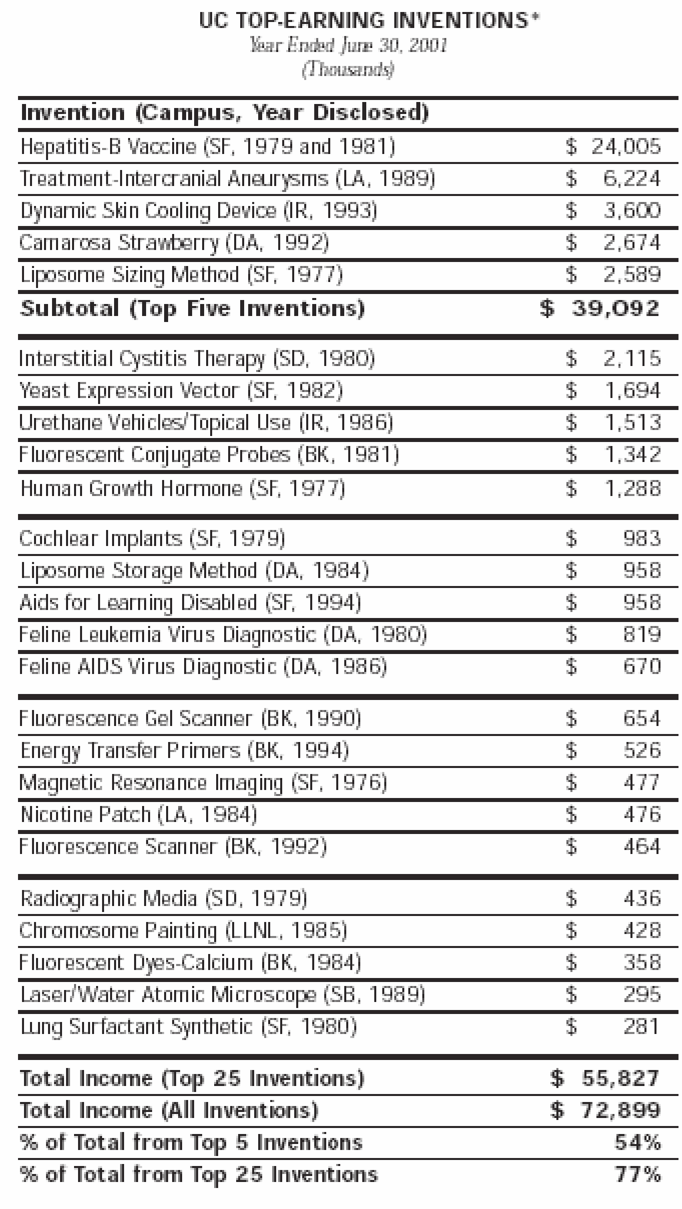


Table 3



UC TOP-EARNING INVENTIONS*

Year Ended June 30, 2001

(Thousands)

Invention (Campus, Year Disclosed)	
Hepatitis-B Vaccine (SF, 1979 and 1981)	$ 24,005
Treatment-Intercranial Aneurysms (LA, 1989)	$ 6,224
Dynamic Skin Cooling Device (IR, 1993)	$ 3,600
Camarosa Strawberry (DA, 1992)	$ 2,674
Liposome Sizing Method (SF, 1977)	$ 2,589
Subtotal (Top Five Inventions)	**$ 39,092**
Interstitial Cystitis Therapy (SD, 1980)	$ 2,115
Yeast Expression Vector (SF, 1982)	$ 1,694
Urethane Vehicles/Topical Use (IR, 1986)	$ 1,513
Fluorescent Conjugate Probes (BK, 1981)	$ 1,342
Human Growth Hormone (SF, 1977)	$ 1,288
Cochlear Implants (SF, 1979)	$ 983
Liposome Storage Method (DA, 1984)	$ 958
Aids for Learning Disabled (SF, 1994)	$ 958
Feline Leukemia Virus Diagnostic (DA, 1980)	$ 819
Feline AIDS Virus Diagnostic (DA, 1986)	$ 670
Fluorescence Gel Scanner (BK, 1990)	$ 654
Energy Transfer Primers (BK, 1994)	$ 526
Magnetic Resonance Imaging (SF, 1976)	$ 477
Nicotine Patch (LA, 1984)	$ 476
Fluorescence Scanner (BK, 1992)	$ 464
Radiographic Media (SD, 1979)	$ 436
Chromosome Painting (LLNL, 1985)	$ 428
Fluorescent Dyes-Calcium (BK, 1984)	$ 358
Laser/Water Atomic Microscope (SB, 1989)	$ 295
Lung Surfactant Synthetic (SF, 1980)	$ 281
Total Income (Top 25 Inventions)	**$ 55,827**
Total Income (All Inventions)	**$ 72,899**
% of Total from Top 5 Inventions	**54%**
% of Total from Top 25 Inventions	**77%**

Figure 1: Qualitative representation of involvement in different areas of R&D

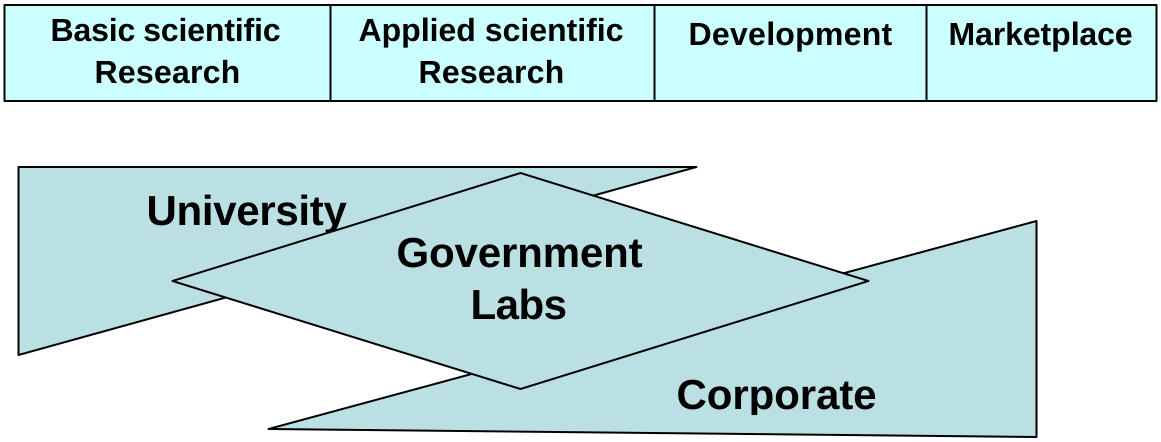
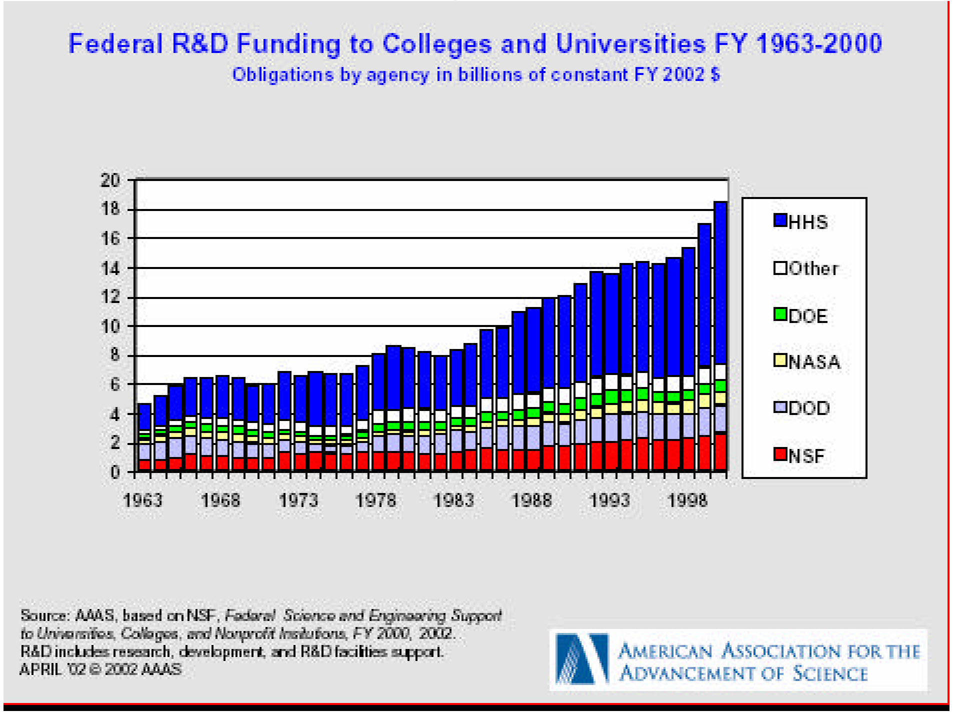


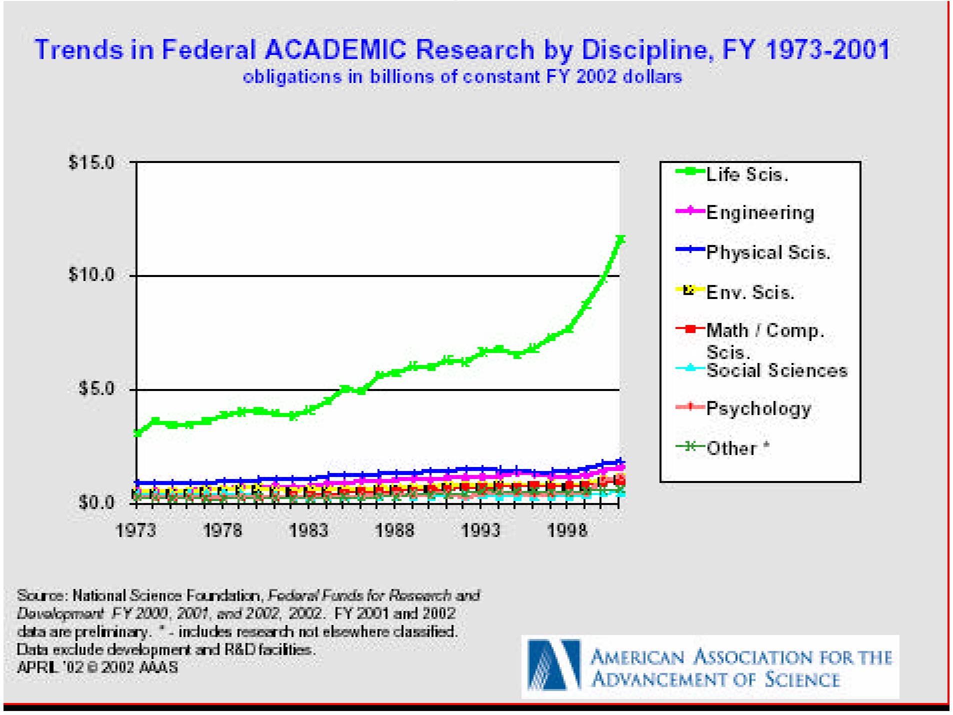
Figure 2


Federal R&D Funding to Colleges and Universities FY 1963-2000

Obligations by agency in billions of constant FY 2002 $

Source: AAAS, based on NSF, *Federal Science and Engineering Support to Universities, Colleges, and Nonprofit Institutions, FY 2000*, 2002.
R&D includes research, development, and R&D facilities support.
APRIL '02 © 2002 AAAS

Figure 3



Trends in Federal ACADEMIC Research by Discipline, FY 1973-2001

obligations in billions of constant FY 2002 dollars

Source: National Science Foundation, *Federal Funds for Research and Development FY 2000, 2001, and 2002*, 2002. FY 2001 and 2002 data are preliminary. * - includes research not elsewhere classified. Data exclude development and R&D facilities.
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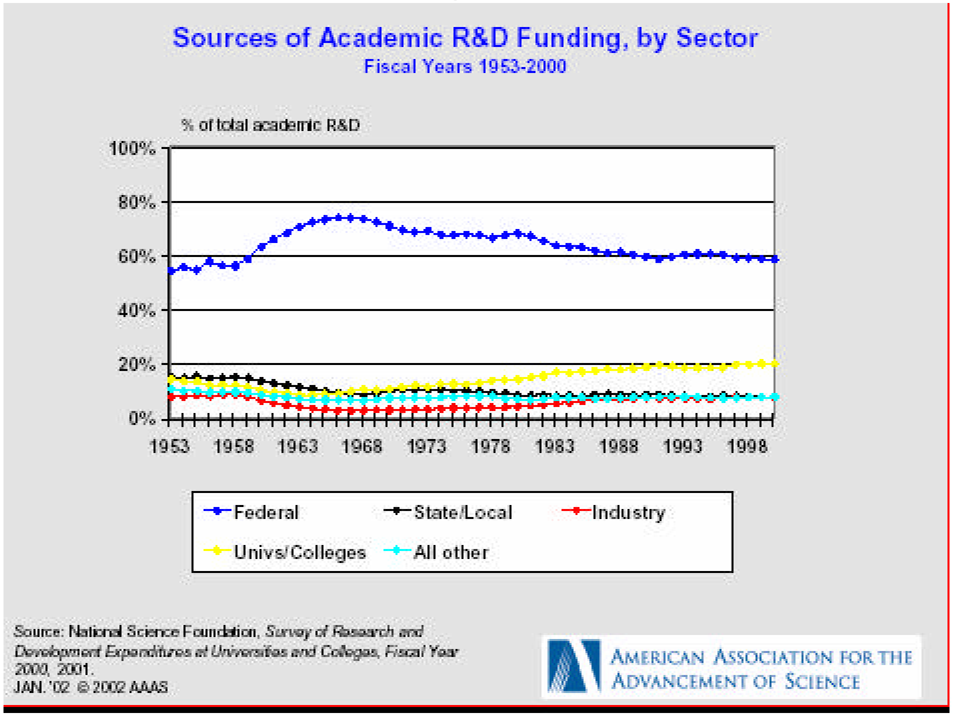
Figure 4



Sources of Academic R&D Funding, by Sector

Fiscal Years 1953-2000

Source: National Science Foundation, *Survey of Research and Development Expenditures at Universities and Colleges, Fiscal Year 2000*, 2001.
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