The "Swing of the Pendulum" from Public to Market Support for Science and Technology: Is the US Leading the Way?

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ABSTRACT

The structure and financing of science and technology activities are undergoing a slow, but profound, change. This change can be briefly characterized as a shift from relying and supporting public science to a stronger emphasis on "market-based" incentives for science and technology. In this paper we analyze this shift in a historical perspective, discussing both the theoretical explanations and the empirical trends of the ongoing change. While we do not claim to provide a comprehensive and exhaustive identification of the causes of this shift, we argue that it is largely driven by the perception of a shift of the US policy towards market-based, rather than publicly support, incentives for science and technology. This, in turn – given the strong economic performance of the US over the 1990s – has influenced policies in most OECD countries, and especially in Europe.

We conclude by analyzing the evolution of research in US higher education and find two major trends: an increasing diversity in the number of institutions of different types other than universities and a steady and continuous public funding of the leading US universities. This has allowed the construction of an infrastructure now used largely by the private sector, but it also noted that the US has not compromised public support for core areas or in those fields in which there is a clear perception that market incentives are not sufficient for meeting the strategic targets of the US policy. The implication is that there is a considerable "policy diversity" in the US practice and that all aspects of this diversity should be considered when using the US as a reference.

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1- Introduction

Today most of the financing for research and development (R&D) in the most advanced (technologically and economically) countries comes from private sources, rather than from public ones. Consequently, the great majority of R&D is performed in firms. Consider the data in Figure 1. With the exception of the less developed OECD countries, business expenditure on R&D accounts for the majority of total expenditure, and has an overwhelming share in the most developed countries[1].

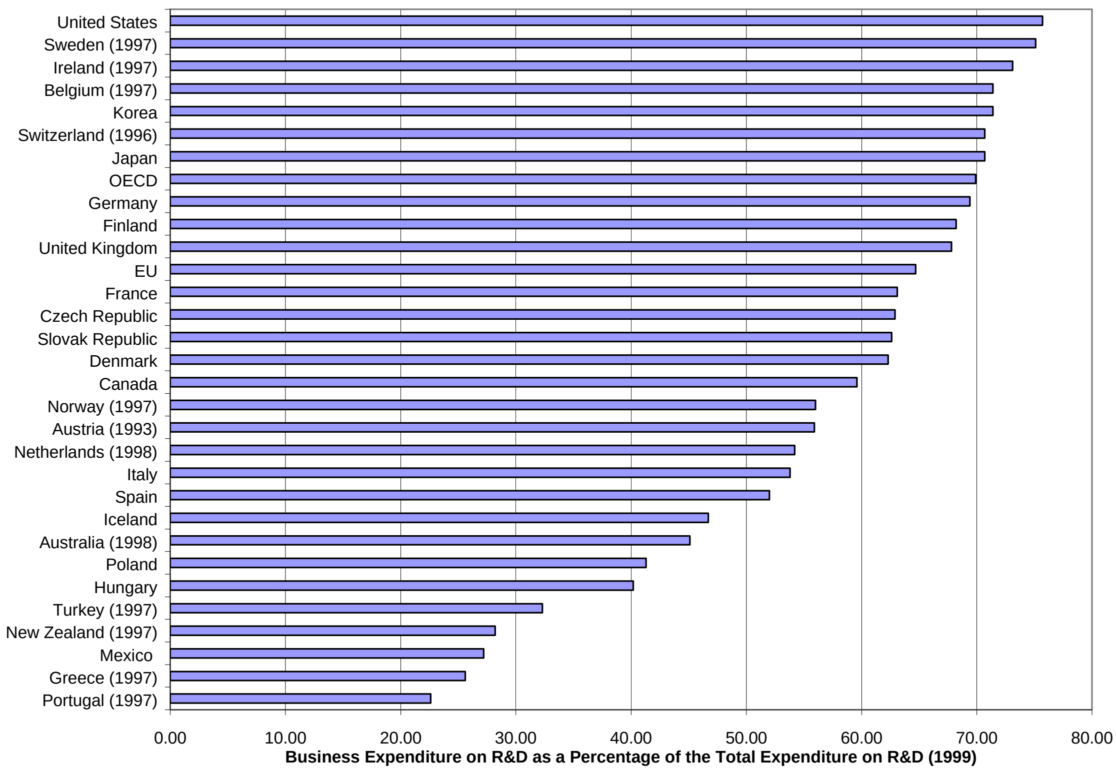

Figure 1- Business Expenditure on R&D as a Percentage of the Total Expenditure on R&D (1999). Source: US NSB, 2000, [1].

[1] For some countries (Sweden, Ireland), the business expenditure is driven in large part by foreign affiliates, which account for about 90% of the total business expenditure, rather than domestic firms. In the US domestic firms are dominant.

This fact is certainly not surprising. We hear ever more frequently that we live in knowledge-based economies[2]. A growing, and large, proportion of the world's GDP is now "weightless"[3]. Progress in science and technology, ranging from agriculture to medicine, from telecommunications to transportation, have increased standards of living and have brought the world closer together. Fuelling this process with new ideas has become increasingly important for improving economic performance and well-being. Economic incentives are increasingly aligned to reward skills, creativity and innovation, with high valued-added activities being linked with producing "ideas" rather than with producing "things" [2,3]

Firms, therefore, align their strategies to enhance the generation of new ideas. An important element, or perhaps manifestation, of these strategies is the allocation of firm private resources towards R&D. In fact, Baumol [9] has suggested that competition in advanced, market-based, democratic countries is principally based on the ability to generate ideas. Rather than price competition, there is an "arms-race" to innovate, whereby firms invest in R&D and innovation because they fear that failure to do so will allow a competitor to overtake them with a new product or process. This dynamic can explain, for example, Moore's Law on the seemingly unstoppable improvements in performance of semiconductors [10].

While this dynamics characterizes most of the advanced economies, there is a generalized perception that it is particularly strong in the US, a point made by Baumol [9]. Further

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[2] Statements to this effect abound and here we provide a recent example [2], "The ability to create, distribute and exploit knowledge is increasingly central to competitive advantage, wealth creation and better standards of living." The concept in Europe has been particularly studied, as in references [3,4], and recent OECD statements emphasize the role of science and technology for wealth creation [5].

[3] This results both from the increasing share of weightless services in employment and output, and the intangible value embedded in material objects (the software that exists in automobiles today, for example. Alan Greenspan [6] famously remarked that, in terms of physical weight, the US GDP at the end of the 1990s was the same as in the beginning of the century. More recently, Baily [7] estimates show that the value of US GDP per pound rose from $3.64 in 1977 to $7.96 in 2000. Quah [8] gives examples for other countries.

evidence that the US relies heavily on private incentives can be understood to be a distinguishing characteristic of the US innovation-promotion system and not just its high reliance on private firms to fund R&D. In fact, as we saw in Figure 1, other advanced countries share this characteristic. Venture capital investments are higher in the US than in any other country and are particularly concentrated on high-technology sectors (Figure).

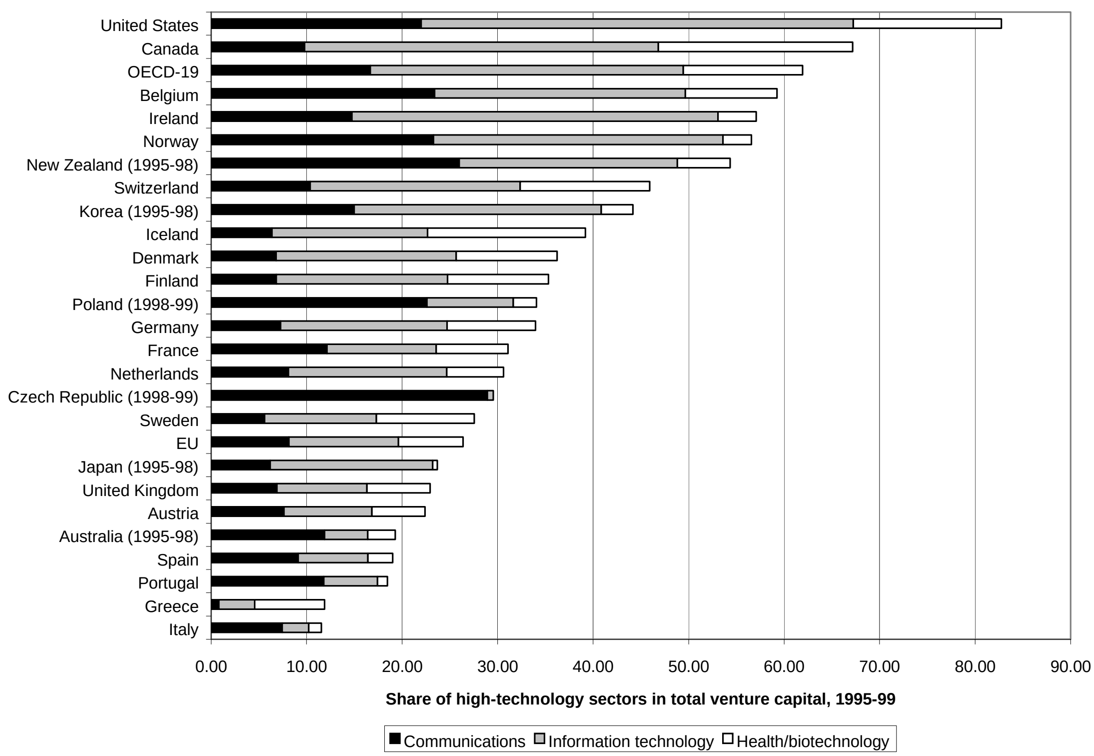

Figure 2- Share of venture capital devoted to high-technology ventures. Source: US NSB, 2000, [1].

The message emerging from this data seems unmistakable. S&T and innovation are, it seems, pushed forward by private financing. In fact, there has been a persistent and long decreasing trend in the ratio of public vs. public expenditure in the US (Figure).

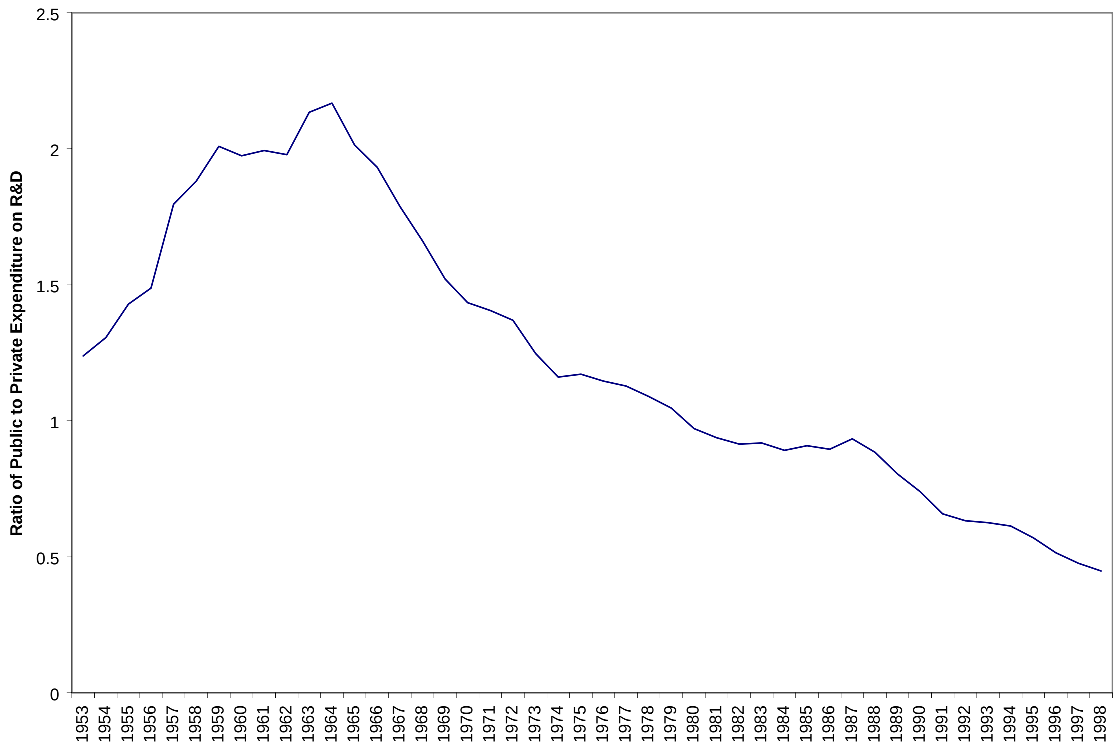

Figure 3- Evolution of the ratio of Public vs. Public expenditure on R&D in the US. Source: US NSB, 2000, [1].

Additionally, there has been an increasing reliance on market-based mechanisms to promote innovation. Changes in policy in the US have favored and resulted in the more intense use of private mechanisms for the promotion of innovation. Although there is a long tradition of supporting intellectual property rights in the US (it is part of the US Constitution), since the 1980s there has been an increasing intensification and strengthening of private incentives for innovation, namely by enlarging the scope and depth for patent protection. These policy changes have included, among other, the following:

- The creation of a federal court focusing on patent litigation
- The Bayh-Dole act, which has permitted outcomes of federal-funded (publicly funded) research to be patented
- The increase breadth of patent claims allowed by the US Patent Office

- Widening of national patent and intellectual property rights to the global level (namely through the WTO Trade-Related Aspects of Intellectual Property Rights, or TRIPS, agreements)

While there is a wide controversy over the effect of these policy changes on patents, most scholars now accept that these changes have influenced decisively the number of patent applications[4]. Hall [12], in particular, has argued persuasively that there has been a "structural break" in the historical pattern of patents in the mid-1980s :

> As several authors have demonstrated, the creation of a centralized court of appeals specializing in patent cases in 1982, together with a few well-publicized infringement cases in the mid-1980s, have led to an increased focus on patenting by firms in industries where patents have not traditionally been important, such as computers and electronics.

Figure (also from Hall) shows graphically the dramatic explosion in US patents associated with in the electric machinery, electronics, and instrument industries.

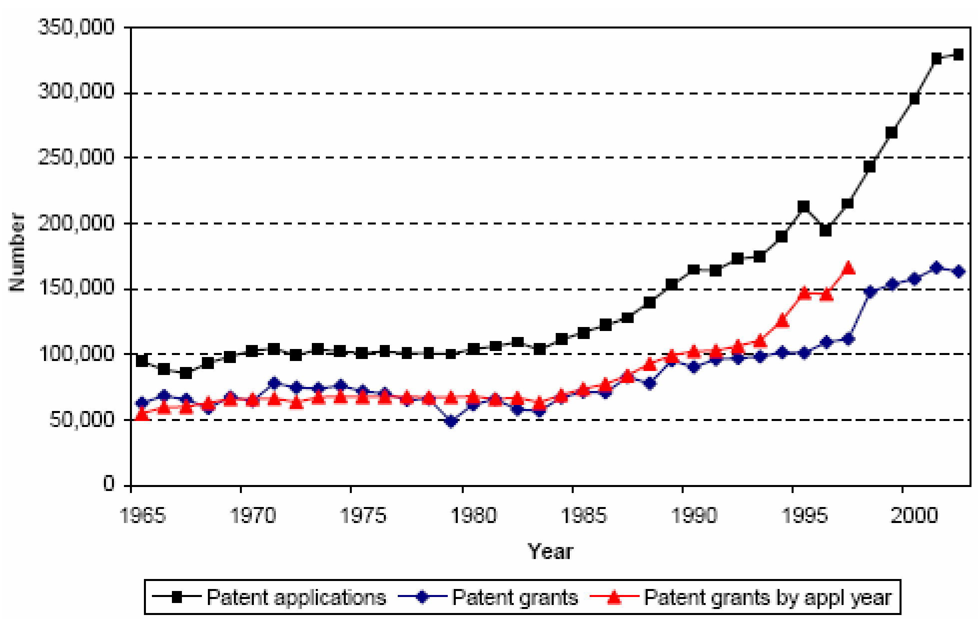

Figure 4- Evolution of US Patent Office Utility Patents. Adapted from Hall [12]

[4] The alternative hypothesis, that there has really been an acceleration in technological innovation that has required more patenting, has been defended in Kortum and Lerner [11].

As is well known, patents are a crude and imperfect measure of innovation. In fact, with the exception of the chemical sector and the pharmaceutical industries, patents are only partially – and often tenuously - related with efforts to appropriate innovations, and are more related with gaining advantages in financing (entry or expansion) or as a defensive strategy to be used to dissuade patent infringement filings by competitors (notable in the computer, electronics and, more specifically, semiconductor industries). Still, for our purposes, it is enough to note the explosion in patenting as a result of the policy changes that center on providing private incentives to innovate. It is the effect, rather than the interpretation of the rationales or even the effectiveness of patents, that interests us here.

The strong economic performance of the US economy over the 1990s outlined above, have contributed to a general and widespread shift towards market-based, rather than publicly-supported, incentives for science and technology in most OECD countries, and, especially, in Europe [3,4]. In fact, the conclusions of the European Union intergovernmental summit held in Lisbon in 2000 (i.e., the so-called “Lisbon Council”) can be interpreted as a call for Europe to enact policies that, in part, seek to replicate and improve upon the innovation-based economic performance that has characterized US economic growth [13,14].

This paper argues that “replicating” the US policy changes in different national and economic contexts can be not only misguided, but even ineffective and possibly harmful. To make this point, the paper examines, in section 2, the impacts of incentives to promote science and technology. In fact, it seems that in designing policies to stimulate innovation, the analytical and conceptual insights that have been made over the last 50 years are forgotten or dismissed. Then, in section 3, the paper takes a more detailed look at the actual US policies. This empirical analysis shows that, despite the perceptions and what one might be inclined to conclude from the discussion above, the actual US policies to promote innovation and to support science and technology are more complex than a mere shifting of the pendulum from public to private incentives. Section 4 briefly presents our main conclusions.

2- Analytical Perspectives on Promoting Technological Innovation and Scientific Progress

The promotion of technological innovation and of scientific progress depends on the generation of knowledge. Knowledge has very specific characteristics that make it different from most kinds of goods. To be precise, we are considering only *codified* knowledge, thus excluding from our analysis *tacit* knowledge. Polanyi's [15,16] definition of tacit knowledge is helpful. Polanyi defined as "tacit" knowledge that knowledge which people have but unaware that they have. Cowan, David and Foray [17] argue that not all types of non-codified knowledge are tacit in the original Polanyi's sense, and that the term "tacit" is used abusively. These aspects, however, will matter little to our discussion centered on codified knowledge. Virtual all conceptual analyses of knowledge depart from (or replicate) the work of Nelson [18] and of Arrow [19] on the economics of information. Their key insight was to articulate the fact that knowledge is inherently a public good. Codified knowledge is "non-rival" in consumption: it can be possessed and used jointly by as many as care to do so. The nonrivalry of codified knowledge has also been defined as "infinite expansibility", namely by Dasgupta and David [20], who favor a more descriptive term for this property. Additionally, knowledge is also typically non-excludable, in the sense that is difficult (costly) to retain exclusive possession of codified knowledge while this knowledge is being put to use.

The public good nature of knowledge implies that, as Arrow [19] indicated, it will be undersupplied in decentralized markets. The reason for undersupply in competitive markets is simple: the costs of production are decoupled from the benefits of consumption. Consider Pythagoras's theorem: the cost of producing this specific instance of codified knowledge was born entirely by Pythagoras himself millennia ago, but the benefits have been accrued freely by generations, and will continue to be so in the future. This is true also for knowledge embodied in tangible goods. Or consider a vaccine or a drug. These are examples of combinations of intangible codified knowledge (the formulation of a vaccine or of a drug) with tangible embodiments (the physical mechanism for the delivery of the drug or the vaccine). Both the codified knowledge and the tangible embodiments are costly to the producer, but only the tangible part is costly to the consumer or to a rival[5].

It is important to note that the lack of incentives for knowledge production in competitive markets does not mean that it cannot be privately supplied nor does it imply that it must necessarily be produced by the state. Rather, it entails that some type of incentive structure must be adopted that rewards the efforts of creation. It is not our analytical argument that in the absence of these needed incentive structures *no* knowledge would be produced. Disinterested individuals or magnanimous firms would likely emerge to invest in the generation of *some* knowledge even without any reward. However, certainly the level of knowledge supplied would not be as abundant as when institutionalized incentive mechanisms were in place to compensate creative efforts in the production of codified knowledge.

So what have been the solutions to these knowledge provision problems that have emerged over time? We start with a brief historical overview. Two main incentive structures (intellectual property rights – IPRs – and public support) emerged to stimulate the production of knowledge, [22]. These incentive structures have had a different historical evolution. Each incentive structure has also radically different implications in the way in which knowledge is made available and diffused. We discuss the evolution and characteristics of each in turn and move, in a second step, to summarize the way they are currently understood and implemented.

2.1 The Emergence of IPRs

Historically, the incentive mechanism that has successfully stimulated the generation of knowledge is also the most natural one: let the discoverer profit at will from the knowledge that he/she has produced. To profit, however, the knowledge discovered would have to be kept from others through secrecy. Following David [23], in the

[5] The discussion of the combination of intangible codified knowledge with tangible embodiments draws from Gallini and Scotchmer [21].

medieval and Renaissance traditions of alchemy the objective was to discover some formulae that would bring power over material things. These formulae would be kept secret and used only for the benefit of the discoverer. Geographical knowledge of trade routes and accurate maps would be kept from the public domain and used only by the merchants or rulers for military or mercantile gains. Craftsmen kept close watch over the technologies used in their trade, even when no formal guild restrictions applied.

Secrecy continues to be used today as a means to protect knowledge but the same principle of attributing to the discoverer the power to exclude others from access to new knowledge has been institutionalized in the incentive structure of IPRs. Secrecy is rather limited as a means to restricting others from using knowledge, since it may possible to understand the underlying knowledge embodied in a product or associated with a certain process of production. With IPRs knowledge is made excludable, since the creator has the right to exclude others from access to the creation. If this is the case, private market incentives work: the creator provides access to knowledge only to those who are willing to pay compensation for access and/or usage.

IPRs are an extension of the traditional incentives for knowledge generation associated with the secrecy of the medieval era and Renaissance. IPRs constitute powerful incentives for knowledge generation, and, as Kahn and Sokoloff [24] note, were included in the first article of the US Constitution precisely with the intention of providing a stimulus for the "progress of science and of the useful arts". Kahn and Sokoloff trace the development of patenting and of patent institutions throughout the 19th century in the US, showing the parallel growth in patents and the development of institutional arrangements to protect and to market (exchange through intermediaries) new knowledge. A key feature of patents is that they are driven by demand (or the expectation of demand), as Kanh and Sokoloff [24] note, describing the evolution of patenting in the US throughout the 19th century: "[the] close relationship between access to markets and patenting is certainly consistent with the view that inventive activity was responsive to material incentives, as well as to the availability and security of property rights in technology."

2.2 The Emergence of Open Science and Public Support to the Production of Knowledge

At the same time that IPRs were taking hold in the US, in Europe a second means to institutionalize incentives for knowledge generation was emerging. This second institutional structure was based on dramatically different incentives with very distinct, even opposite, effects on the dissemination of knowledge. In post-Renaissance Europe a system of aristocratic patronage by rulers and nobles (both lay and ecclesiastical), concerned with the "ornamental" benefits of the discoveries of the philosophers and savants they sponsored, planted the seeds for a research culture of open science [23].

Rather than keeping the discoveries private, the incentives were oriented towards the rapid and wide dissemination of the new achievements, to enhance the prestige and power of the patron. Those sponsored by others in turn scrutinized these discoveries, to make sure that the claims to grandeur were legitimate. The philosophers that consistently showed ability to produce important discoveries gained reputation, a reputation that was based on the wide dissemination and scrutiny of their discoveries.

Today the rules of engagement of the scientific community are based on this second incentive structure. Robert Merton [25] described these rules, in which incentives for discovery are associated with reputation building, which, in turn, is based on rapid, wide and comprehensive disclosure of the new knowledge. This openness entails that the public good nature of knowledge is preserved, which is compatible with a reward structure based on accepted claims to priority within a college of peers. Stephan [26], following on the seminal sociological work of Merton, described the functioning of the scientific community as being based on a "winner-takes-all contest" set of rules. This means that creativity is most highly prized: the first scientist to achieve a result receives the credit, and all similar ensuing results from other scientists are ignored. This type of work ethic yields the necessary private (individual) benefits for production [24].

2.3 Private and Public Incentives for the Production of Knowledge: the Reality Today

The two basic institutional mechanisms that have just been briefly described in a historical perspective (IPRs and public support) exist today as the main incentive structures to address the lack of an economic incentive for the production of knowledge in decentralized markets. It is important to stress that these two incentive structures exist, simultaneously, as a matter of empirical fact. They result from a long and complex process of institutional evolution, [27].

These two incentive mechanisms separate knowledge into two categories. Individuals and firms are willing to pay for knowledge for which substantial private benefits are expected. These private benefits create market demand for knowledge, making it lucrative to produce knowledge that can be sold after IPRs have been awarded to the innovator. For other category of knowledge, the benefits are so widespread, uncertain or long-term that no individual or firm will fund the effort to produce it. Thus, the two institutional mechanisms tend to create knowledge of two types: one that remains in the public domain (funded by the public, or sometimes, voluntarily provided) and one that is private (protected by IPRs or by secret). This dichotomy can be applied, in a very crude way, to the distinction between "science" and "technology" [20, 27].

IPRs and public support have been used by countries as strategic policies to support the development of science and technology of national concern: improving domestic industry's competitiveness, strengthening national defense, and addressing country-specific social problems. The central strategic role of science and technology emerged during, and in the aftermath, of World War II, [28]. Advances in science and technology, having been crucial to the outcome of the war, became even more strongly linked to the state during the Cold War. This was the period under which national resources devoted to R&D and to technological development increased substantially, at the same time that new professions associated with science and technology became institutionalized.

Salomon [29], who provides a detailed historical account of the emergence on national science and technology policy on which much of the last paragraph of this article is based, notes that in 1939 the entire US Federal R&D budget was of US$ 1 billion. The Manhattan Project alone, which developed the three first atomic bombs, expended US$ 2 billion during three years in the early 1940s[6]. The Apollo Program to put a man on the man cost US$ 5 billion per year over ten years during the 1960s.

During this period science and technology became increasingly interdependent, representing a break with the historical pattern [28]. Many of the technological advances of the Industrial Revolution were not based on science – having resulted, rather, from the work of craftsmen and engineers. Individual inventors, such as Edison and Bell in the US or Solvay in Belgium, were able to turn inventions largely developed by individual persons into major technological advances, which created entire new industries. The "Second" Industrial Revolution was already more dependent on science, but the relationship was still remote. Landes [30], for example, provides a detailed description of the increasing importance of institutionalized science for technological development over the transition from the first to the second Industrial Revolutions, and beyond. As science and technology converged, the public/private distinction in incentives for knowledge production became blurred. Some companies engaged in basic research and the government supported technological development.

Thus, the last half of the twentieth century is characterized by the emergence of explicit national science and technology policies[7]. These national policies include not only the deployment of large public resources to the promotion of R&D, [34], but also the design of a framework that encourages private involvement in science and technology development. First developed and then developing countries designed and implemented national science and technology policies. The enthusiasm for the development of national science policies from the 1950s onwards was shared by developing countries. Latin American countries, which had already a strong intellectual and cultural life, established considerable scientific and intellectual infrastructures, namely in Argentina, Brazil and Chile. In Africa, several countries invested in science and technology as a strategy of

[6] Values in current dollars

[7] Although with changing rationales and shifting focuses, often associated with country-specific economic and political evolution [31]. See, for example, Kim and Nelson [32] and Nelson [33]. We abstain from

national affirmation (Kenya, Egypt, Ghana), often in the aftermath of newly acquired independence, [35]. India and Pakistan, in Asia, also invested since independence on building a strong national scientific and technological capability[8].

2.4. Should we rely on Private or Public Support to Innovation and Science?

Knowledge generation depends on both the level and balance between public support and IPRs. Both are needed and interdependent. Would problems emerge if one were exclusively dependent on privatization (or reliance on IPRs for the production) of knowledge? Would an improper "institutional mix" between private and public incentives be harmful? The insights from analytical work on this area indicate that departing from a healthy mix would be harmful for two reasons. First, it would have implications on the diffusion of knowledge and innovation. Second, and due in part this effect on the diffusion of knowledge, the overall rate of knowledge generation is likely to be suboptimal. This section elaborates on these points.

The way in which knowledge is diffused depends on the incentive structure under which it was generated, [22]. The two institutional mechanisms for the production of knowledge provide oppositing incentives for diffusion. While IPRs' incentives for knowledge generation rest precisely on the ability to restrict the diffusion of knowledge, the value of public support is in the fact that knowledge is widely diffused. The challenge to the design of IPRs is striking the right balance on the restrictions to knowledge diffusion. [27].

Why is the diffusion of knowledge important? There are two reasons. First, the higher the level of diffusion, the greater the number of people that have access and can use codified knowledge, a concern associated with static efficiency. Second, knowledge is cumulative: today's discoveries build on what was known yesterday. Therefore, the higher the

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commenting on these specificities and focus, rather, on the main point, which is the existence of *national* science and technology policies.

[8] See [36, 37] for a fuller account of the emergence of national science and technology policies in developing countries.

diffusion of knowledge, the greater the probability of even more breakthroughs.. Diffusion of knowledge is itself important for knowledge production, and thus diffusion of knowledge is important in terms of dynamic efficiency over the long run.

Designing IPRs so that the level of restriction to knowledge diffusion is not excessive to harm dynamic and static efficiency is important. But, as David [23] argues, it is equally important to strike a right balance between IPRs and public support as the two main incentive structures supporting knowledge generation. The need for balancing the IPRs with public support is important because it is a way to achieve a balance between static and dynamic efficiency, not through the details of the way in which IPRs are designed, but through a "division of labor" between IPRs (which tend to restrict diffusion) and public support (which encourage diffusion).

This balance between IPRs and public support should not be confused with other issues associated with the interaction of the public and private in the production of knowledge. For example, we are not necessarily arguing at this stage that private R&D is socially under-optimal and that public incentives are needed. This may be the case [38, 39], but our argument here is more fundamental. Neither are not saying that public support must be provided by the state. Clearly, resources need to be mobilized from agents that are willing to have knowledge remain largely in the public sector, but this can be achieved through public-private partnerships. We are not even saying that without public support no basic science would ever be produced. Rather than a question of "whether", the issue is "how much".

One consequence of an over reliance on private incentives is that we may be privileging innovation at the expense of diffusion, which can slow the overall rate of technological change, or knowledge diffusion and adoption. To illustrate this possibility, Romer and Nelson [40] ask what would have happened if the concept behind a worksheet, first introduced by Lotus, would have been given exclusive rights: the competition between Lotus, Microsoft, and Borland (with their products Lotus 123, Excel, and QuattroPro), that entailed significant improvements in worksheets, might never have happened.

Stiglitz [41] provides an argument along the same lines, using as an example the patent issued to Selden of a horseless and self-propelled carriage. Henry Ford later successfully challenged this patent. This success opened the way for the development of the automobile industry.

Another risk from the over-reliance on the property mechanism is the possibility of an increasing fragmentation of the ownership of pieces of knowledge. This is a possible concern, given the cumulative nature of knowledge, based largely on a large stock of publicly available “software commons”. If much of the knowledge needed for further inventions becomes privatized by various entities, then the transaction costs associated with accessing and using all these fragments of knowledge may hinder the generation of new “software”. Heller and Eisenberg [42] analyzed this possibility, coining the term “tragedy of the anticommons” to describe it.

Public support to science and technology is often seen as just the provision of subsides. However, public support to science and technology can be conveyed through a variety of tools that meet different challenges and have different advantages and shortcomings. It is important to look into the “black box” of public incentives for innovation to appreciate the diversity of tools and variety of approaches available to policymakers to encourage the generation of knowledge.

Direct public support to science and technology can been deployed through three mechanisms: grants, procurement contracts and prizes [27]. Grants are typically given as a result of a competitive process of proposal submission. Proposals are judged based on their scientific merits. Funding is allocated with few strings attached as long as the scientific program of the proposal has been complied with. Procurement for a specific military technology or scientific solution for a national problem entails contracting with an R&D performer and possibly restricting the dissemination of knowledge generated in the end. Finally, prizes, corresponds to a practice common during the 18^{th} and 19^{th} century, and is a combination of the grant and the procurement approach. The government decides on which problem is wants to see addressed (as in procurement) but rather than a procurement contract, it commits to award a monetary prize to whoever solves the specific scientific or technological problem.

Indirect support to increase the overall level of R&D has also been provided through public support, often through incentives oriented towards the private sector. The rationale behind public support to privately executed R&D is associated with the large positive spillovers that are presumed to be associated with R&D. Although the evidence at the micro or industry level on the existence of spillovers is controversial [38], at the aggregate country level the existence of spillovers is well established [43]. Indirect support is provided through tax exemptions or tax credits on private expenditure on R&D.

The question, then, becomes, which is the best type of incentive, with public support, to stimulate knowledge generation. The answer is that there is no single mechanism superior in every circumstance to the others. Wright [44] shows that the identification of the best incentive depends on the market and technological conditions, and that each is preferable to others in different situations. We will next briefly compare each of these mechanisms.

Prizes

Prizes can be considered a “pull” type of mechanism, in the sense that it is the prospect of gains from discovery that entices the development of R&D. A “prize” incentive structure commits a certain amount of resources to reward the generation of new knowledge, but *only* if this knowledge is produced are the funds disbursed. Prizes are, therefore, similar conceptually to IPRs. However, the reward is now chosen not by *the market* but by *the public*. Thus, when there is a clear social and public need for knowledge and there is no market, prizes may be a good alternative when IPRs fail.

Procurement

In other cases procurement is the best solution, namely when both prizes and IPRs create incentives that generate an R&D race. This may lead to over investment on R&D. If it is possible to identify and control the capable R&D performers, it may be better to award a public contract [21][9]. Procurement is a “push” type of incentive, since public resources are disbursed as R&D is being executed, and have to be paid regardless of the success of the project.

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[9] The reason is that IPRs, awarding monopoly power are equivalent to a tax on a specific market, while public contracting if funded out of general tax revenues, which is less distortionary. This, again, assumes that information problems associated with identifying the capable performers are ignored or are inexistent.

Tax Incentives

Tax incentives for R&D are also "push" type of incentives. Tax incentives can be broad (so that they benefit any type of R&D) or they can be targeted (to benefit only specific types of R&D). In the first case, the incentive generates the production of any type of knowledge, while the second presumes that *the public* has, as with prizes and procurement, chosen a specific objective for knowledge creation. Tax incentives are transformed into a "pull" incentive when, instead of being awarded to the execution of R&D in a specific field, are associated with sales of the innovation that the R&D is expected to generate.

Grants

For prizes, procurement and target tax incentives, it is presumed that it is possible to identify a specific knowledge need. When there are specific needs for new knowledge and this knowledge has not yet been created, although it is clearly in reach given the current scientific and technological status, there is a "knowledge-gap" between need and incentive. However, often there is no means for articulating a specific and identifiable need. Some knowledge is too general or broad in the benefits to be circumscribed to a specific utilization. In this case, prizes, procurement or targeted tax incentives are not adequate incentives. Grants are the solution in these cases, and the outcome is likely to be contributions to basic scientific knowledge.

The Secret is in the Mix

Our main point here is, beyond the description of the different types of public incentives, to argue that there is not necessarily a single best solution to structure public support for knowledge generation. In line with the over-reliance on IPRs in comparison to public support of science, even when the need for public support is acknowledged, the preference tends to be the "pull" type of incentives. Our contention is that over-reliance "pull" type of incentive structures (prizes, tax credits on sales) *at the cost* of "push" (grants, tax credits on R&D) may be inefficient in the long run. IPRs, prizes and procurement may work well when a clear need, even a scientific puzzle, has been clearly identified. Additionally, "pull" mechanisms may not be sufficient to spur investments in knowledge when substantial opportunity costs exist. That is, if a firm facing the prospects of a prize sees an alternative market-induced investment that yields much higher returns may, in spite of the prize, decide not to perform research anyway. In other terms, establishing the value of the prize needed to induce research is quite problematic.

Over-reliance on IPRs is not just a problem of the lack of access. If the concern with access to existing knowledge is deep-seated, the public purchase of patents is a possible solution, as is compulsory licensing. The issue, rather, is that without “push” and, specifically, without grants, fundamental knowledge for the overall progress of science and technology may never be discovered, or take much longer to discover.

Increasing reliance on IPRs is a legitimate policy choice of any society. However, as we will see in the next section, one should be careful in using the US as a case of employing IPRs as the method for promoting innovation.

3- A Closer Look at the Historical Record and the Present Practice of Support to Innovation in the US

This section turns towards an empirical analysis of the historical and current policies to support innovation and science and technology in the US.

3.1. Historical Analysis

As we described in section 2, the large, systematic and sustained public support to science and technology is an “institutional invention” of the second half of the twentieth century. The ambition to establish a strong scientific and technological capability was shared by developed and developing countries alike. It was perhaps in the United States that this ambition followed with greatest enthusiasm and commitment. It is always enlightening to listen to Vannevar Bush’s eloquence, the main proponent in the US for the launching of a substantial public effort to support science and technology [45]:

> Science, by itself, provides no panacea for individual, social, and economic ills. It can be effective in the national welfare only as a member of a team, whether the conditions be peace or war. But without scientific progress no amount of achievement in other directions can insure our health, prosperity, and security as a nation in the modern world.

On whether the support to science should be the responsibility of the national government, Bush [45] wrote, still using some of the World War II rhetoric:

> […S]ince health, well-being, and security are proper concerns of Government, scientific progress is, and must be, of vital interest to Government. Without scientific progress the national health would deteriorate; without scientific progress we could not hope for improvement in our standard of living or for an increased number of jobs for our citizens; and without scientific progress we could not have maintained our liberties against tyranny.

The US established the National Science Foundation (NSF) in 1950, which has been the main US agency devoted to funding basic research. Results from NSF funded research include bar codes, computer aided design/computer aided manufacturing (CAD/CAM), fiber optics, the Internet and web browsers. In the environmental area, NSF funded research resulted in the understanding of the effects of acid rain and the identification of the Antarctic ozone hole[10].

The US public support to science and technology was extended with the creation of new agencies (such as NASA) and the support of research in areas of strategic national interest, such as health (through the National Institutes of Health) and energy (through the Department of Energy).

However, as Mowery [46] and David [23] show, there has been a clear tendency to reduce the public support to science and technology and to rely more heavily – and to give increasing importance – on IPRs as the incentive for knowledge generation. As an illustration of this trend, we showed in section 1 that the ratio of the public to the private funding in the United States has been steadily decreasing, after the build-up that followed the (Viet Nam) war, as the private sector takes an increasing share of overall funding for R&D. Figure complements this information, showing that private spending on R&D has

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[10] See: http://www.nsf.gov/od/lpa/nsf50/nsfoutreach/htm/n50_z2/pages_z3/text_list.htm.

been on an increasing trend, while public spending has decreased (in real terms) from the highs reached in 1987 and has remained stable at around $60 billion through the 1990s.

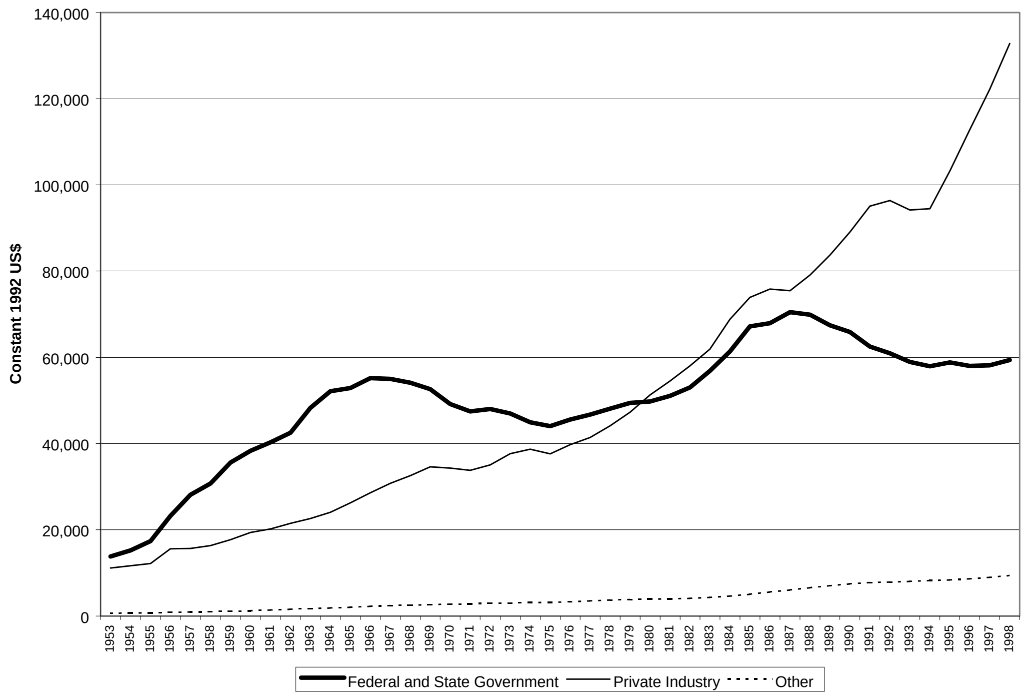

Figure 5- Private and Public Spending on R&D in the US. Source: US NSB, 2000, [1].

Thus, there has, indeed, been a relative withdrawal of the public in funding R&D, and, in addition, a "swing of the pendulum" towards property-based incentives and away from public-based incentives. This has been heightened by the rapid development of information and telecommunication technologies, which facilitate the rapid diffusion of codified knowledge and create opportunities for private R&D. The emergence of the Internet, in particular, has been a great reason for concern for music and print publishers. However, there may actually be gains to the producers of knowledge when sharing *does* occur.

This trend in the United States – itself an important fact given the sheer size and scientific strength of the US science system globally – can also be observed affecting and influencing most developed countries[11]. Indeed, the same can bee seen at the global level, as we witness great interest in bringing IPRs to the global scale. So why should not other countries follow the US strategy? The historical analysis demands that we consider two important dimensions of the US science and technology policy.

First, as indicated in section 1, although the increasing reliance on IPRs is associated with a surge in patenting in the US, this cannot unequivocally be interpreted as an upsurge in innovative activity. Rather, it seems that it is a direct response to policy changes associated with the protection of less relevant inventions in areas previously excluded from coverage. However, a rigorous assessment of the real effectiveness of changes in the patenting law in universities and small businesses that permit research results from federally funded projects to be patented by the researchers has yet to be conducted (the Bayh-Dole act). Intended to stimulate innovation, this change could also undermine even further the “division of labor” between basic science and applied technology, in part associated with, respectively, public support and IPRs [47].

Second, it is important to consider the cumulative effect of decades of sustained large scale public support to science and technology. In fact, in cumulative terms, only very recently has public support been surpassed by private support to R&D (Figure).

[11] See, for example, OCDE [2]

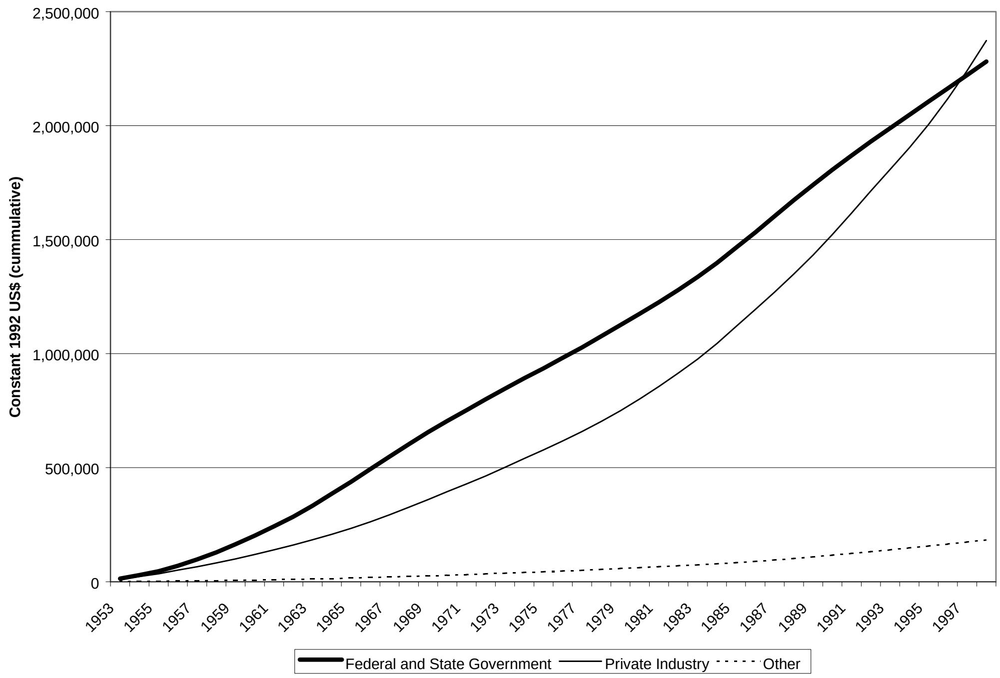

Figure 6- Cumulative Private and Public Support to R&D. Source: US NSB, 2000, [1].

Why is the cumulative "effect" important? Because it is a proxy for the effects associated with long-lasting investments in R&D. Knowledge is cumulative in nature. Innovations build upon basic science and previous innovations, which have had to been supported in the past. Similarly, the cumulative support is reflected in equipment and, much more importantly, institutions, such as the modern US research university, on which both private and public R&D and the training of people depends. Few, if any other, countries can lay claim to the sustained and large scale support – from the public sector – found in the US. Even if now the "pendulum" is swinging towards the private, the US, in a sense, can afford to do it. Others countries without the history of capacity building that is reflected in the cumulative public spending may be prodding creativity and innovation where no "raw materials" to do so exist.

But, as we will see next, the retreat of the public in the US is only partial.

3.2. Structural Analysis

The structural analysis presented here considers how expenditures are allocated across institutions and scientific areas. The main objective is to show that the "public has not pulled back" from core concerns of US policy, and that the pulling-back has been much less pronounced where, according to the analytical points made in section 2, the public has a clear and very distinctive role to play, that is often unique.

In fact, the "public" has not retreated from funding *basic* R&D. On the contrary, it can even be argued that public support to basic R&D is even inducing private spending on basic R&D (Figure 7). Perhaps more importantly, the "cumulative" investment in basic R&D continues to be led, by an overwhelming margin, by public expenditure. The US is investing in its long-term scientific future using mostly public, rather than private, incentives (Figure).

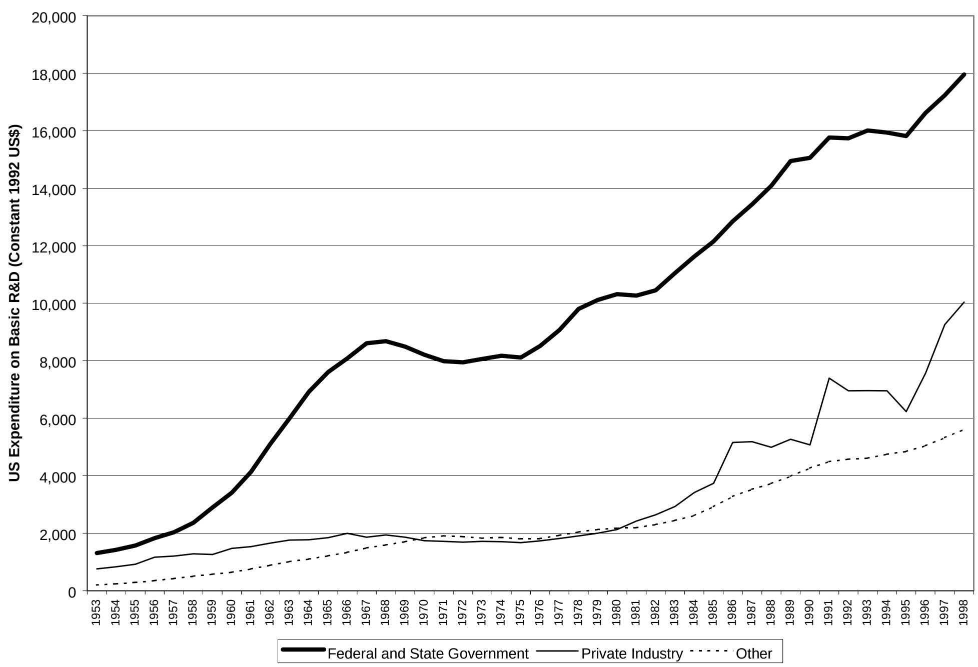

Figure 7-Public and Private Spending on Basic R&D. Source: US NSB, 2000, [1].

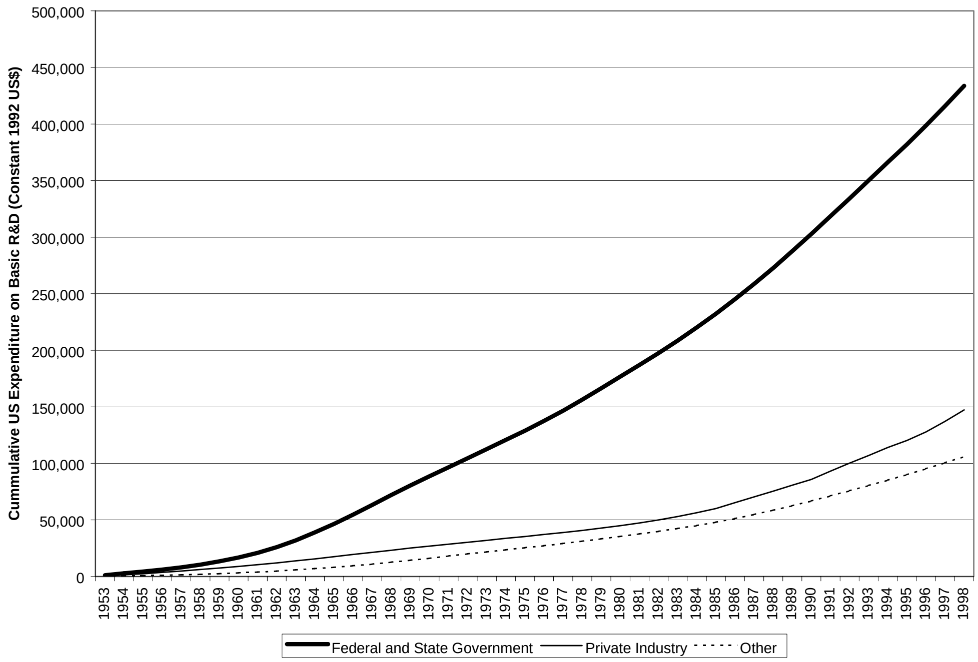

Figure 8- Cumulative Public and Private Spending on Basic R&D. Source: US NSB, 2000, [1].

Still, it is possible to discern an increasing relative importance of private funding. Figure compares the ratio of public vs. private expenditure of the total expenditure (vertical axis) and the ratio only for basic expenditure (horizontal axis). It is possible to identify three stages in Figure . First, the growth of total public funding overall through 1965, when public expenditure was two times that of private expenditure. Throughout this period, the ratio in basic expenditure remain relatively stable at around 2, increasing to 2.5 at the peak of total public/private expenditure. This is the “launch” period of the US S&T system. Then, from 1966 through 1987, the total public/private ratio decreased rapidly but, at the same time, the basic R&D public/private ratio *increased* rapidly. This is the “specialization” period, as the US public funding focuses more on basic R&D, as applied and research and development are left increasingly to the private sector. Finally, through the 1990s, the trend is that both ratios are decreasing, although the basic science one is still very high, around 3.

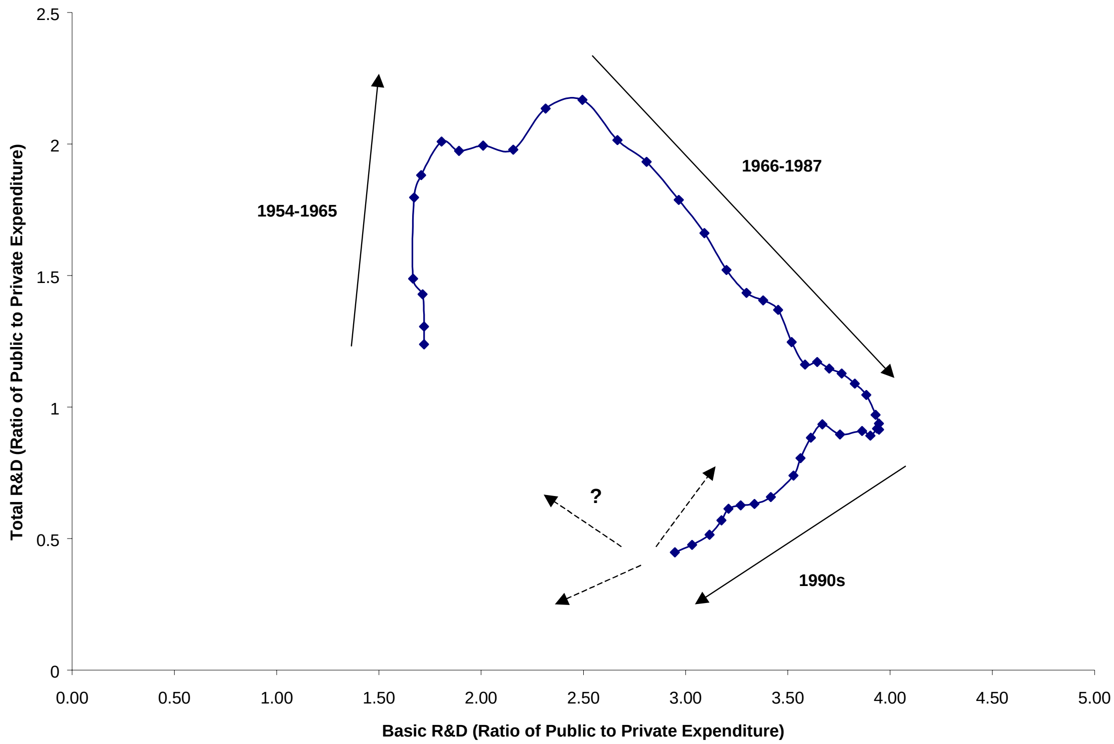

Figure 9- Ratio of Public vs. Private Expenditure for Total R&D and for Basic R&D.

Another important aspect that the "structural analysis" reveals is that much of the retreat in public funding in the US is related with the pulling back of financial support to defense-related R&D. In fact, for the first time since 1980, the non-defense related R&D public expenditure in the US is equal to the defense related expenditure (Figure). It is also important to note that the abrupt decrease in public expenditure of 1987 is related to the decrease of the defense-related expenditure. The non-defense public expenditure on R&D in the US is on an increasing trend for more than 20 years. So where the new public money is is going?[12]

[12] It should also be noted that, especially over the 1990s, there were pressures to reduce overall public spending, given the policy option to bring down the deficits of the US federal budget.

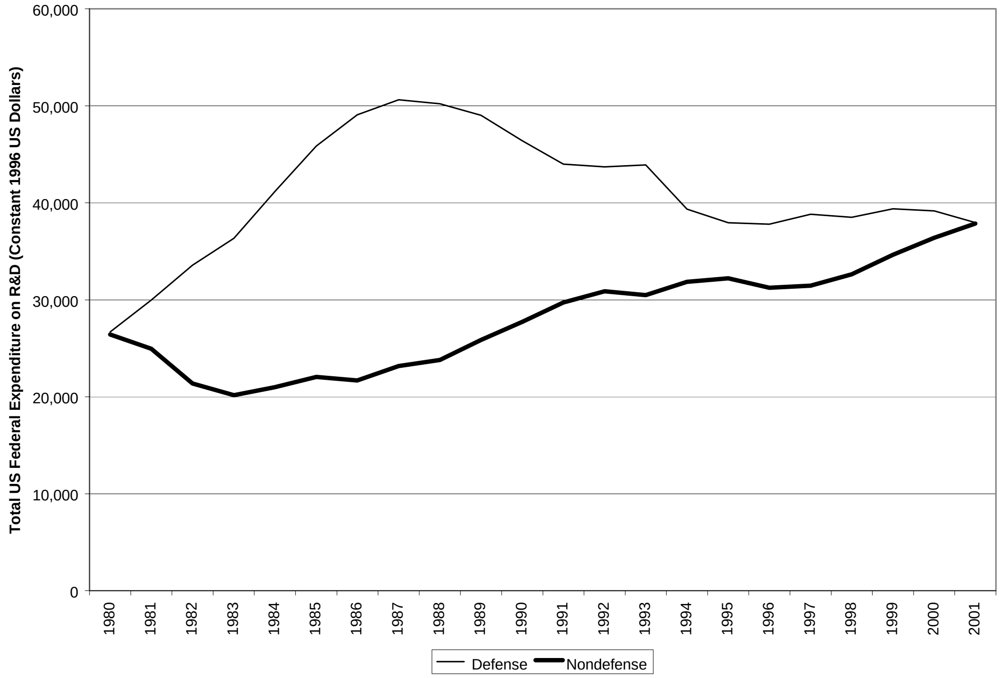

Figure 10- Spending on R&D for Defense and non-Defense related purposes. Source: US NSB, 2000, [1].

The growth in non-defense public R&D expenditure is principally in health and basic science (Figure). In 1999 the US Congress has committed itself to double the funding of the National Institutes of Health (which funds research in health-related areas) and of the National Science Foundation (which funds basic science). Preliminary budget requests of the Bush administration for 2003 comply with this commitment, putting the funding of the National Institutes of Health at close to US$ 30 billion.

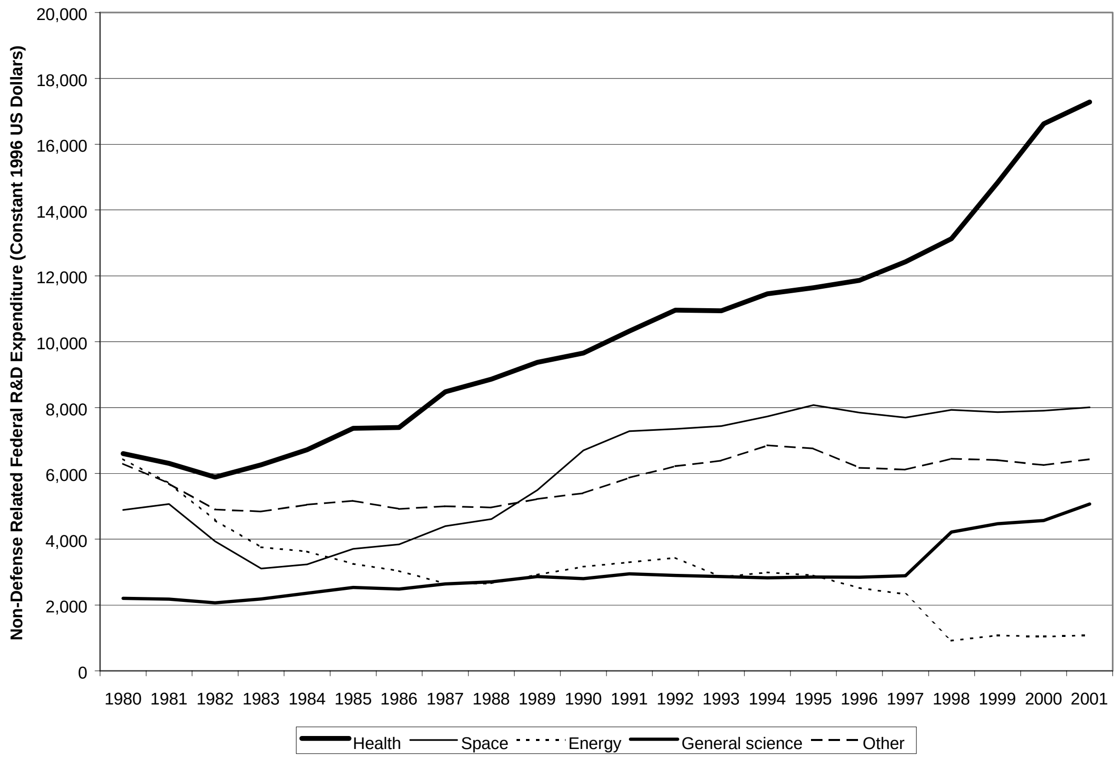

Figure 11- Evolution of Public R&D Non-Defense Expenditure. Source: US NSB, 2000, [1].

Finally, the public allocation of R&D resources to universities has exhibited a persistent increasing trend over the last half a century.

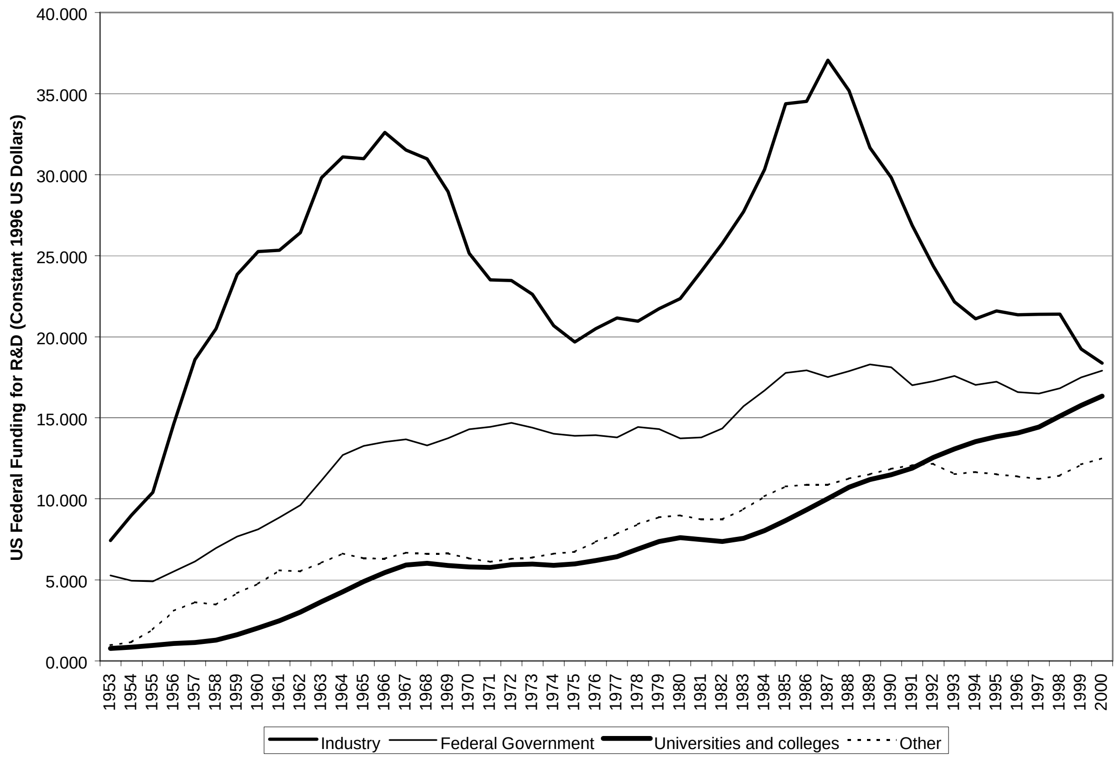

Figure 12- Evolution of the US Federal Public Allocation of R&D.

Figure shows that, while historically federal labs and private industry have received most of the federal funds (private industry with two great peaks by the mid 1960s and by the mid 1980s), if current trends continue universities will become the main receivers of public support to R&D in the US.

4. Conclusions

The analysis above describes the trajectory of the US incentives to science and technology and do find that, during the second half of the twentieth century, there has been a steady shift of support from the public to the private sector. Additionally, intellectual property rights and other market-based incentive structures have been extended and used more extensively. This trend has been identified, and shown to be reason for concern, by researchers in the field [48]. We share these concerns but we also find that there has been "core" science and technology activities in which the public intervention in the US had not declined. We find that this is particularly the case for US universities. Thus, we conclude by analyzing the evolution of research in US higher education and find two major trends: an increasing diversity in the number of institutions of different types other than universities and a steady and continuous public funding of the leading US universities.

The lessons we take from our analysis are the following. First, the US may be able to afford to "shift the pendulum" from public to private incentive structures because of its relatively long history of channeling substantial public funds for science and technology. This has allowed the construction of an infrastructure now used largely by the private sector. Attempting to "shift the pendulum" to the private sector without the infrastructure provided by a long history of public support may not only be misguided but ineffective. Second, we argue that the US has not compromised public support for core areas or in those fields in which there is a clear perception that market incentives are not sufficient for meeting the strategic targets of the US policy (see, for example, the doubling in the budget of the National Institutes of Health over the past five years). The implication is that there is a considerable "policy diversity" in the US practice and that all aspects of this diversity should be considered when using the US as a reference.

We have shown in section 1 of this paper that the structure and financing of science and technology activities in the US have clearly undergone the shift from relying and supporting public science to a stronger emphasis on "market-based" incentives for science, technology and innovation. Given the strong economic performance of the US over the 1990s, this shift has influenced policies in most OECD countries, and especially in Europe [3,4,13].

In section 2 we noted that, from an analytical perspective, the continuation of this shift to the point where only private incentives remain is not desirable. In fact, for many authors, the trend as it exists presently is already reason for concern, since rather than what theory prescribes – that there should be a mix of public and private incentives to science, technology and innovation – we may have reached a situation where incentives in the US favor too heavily the private side of the mix.

However, in section 3 we show that to say that the pendulum has swung too heavily from the public to the private set of incentives for R&D in the US is an oversimplification. Even though the shares of private versus public support have been moving towards making the private side more important, if one considers the cumulative investments over time (aggregation over time, that is, taking the integral to account for past investments) public and private expenditure on R&D in the US are on par. Additionally, public support has not been scarce for long term scientific endeavors (NSF, support to basic science), nor to those areas in which there is demand for R&D that the private sector alone is not tackling (health and NIH, NSF), nor to those institutions that depend on public support to maintain their institutional integrity (universities) so that they can persist in playing their unique and fundamental role. Exogenous policies not directly related with science and technology policy options (the retreat in defense investments, reductions in public spending in the US) may also account for some of the "retreat" of the public set of incentives in the US.

In fact, the US has historically pursued a wide range of approaches to encourage research and to build research infrastructure. New approaches have been adopted over time as the nature of the research/innovation endeavor evolved. The infrastructure is today quite diverse and robust with multiple performers. Similarly, the set of incentives to encourage research is diverse. Given the high uncertainty surrounding scientific research and innovation, this robust research infrastructure system minimizes the risk of poor targeting of research priorities, and the mix of public and private incentives strengthens this robustness. It is clear, in fact, that along with private incentives, public policy is needed to mobilize investment of social resources in new technologies and to insure the health of the overall enterprise. The expansion of research in health, the continued support to the NSF and basic science, and the recently announcement of increasing investments in space exploration, clearly reinforce the needed role of the public sector in mobilizing the research enterprise.

Our conclusion is that there is a considerable “policy diversity” in the US practice, and that all aspects of this diversity should be considered when taking into account the US as a reference. It is incorrect to conclude, prematurely, that, the US system is being driven by private incentives for S&T. “Blanket” recommendations to enhance property rights or to limit public resource allocation, based on the US experience, may be misguided. Even if there is a clear shift towards more private incentives in the US, there is a long history of past investments and a current division of labor or specialization that cannot be replicated in systems with a lower scale and complexity. The key elements of the US history are those of diversity of policies and increasing “institutional specialization” and of clarification of the unique roles of the private and public incentives to support S&T.

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