The returns to R&D: Division of Policy Research and Analysis at the National Science Foundation

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Abstract:

The US National Science Foundation's (NSF's) Division of Policy Research and Analysis (PRA) supported academic research related to, among many other things, measurement of the returns to private and public R&D, during the early 1980s. The findings from this body of research became a foundation for a number of technology and innovation policies promulgated in the aftermath of the US productivity slowdown in the 1970s, and, as we suggest in this paper, a foundation for many contemporary technology and innovation policy initiatives. We argue that there are lessons to be learned from PRA's successes from its sponsorship of research in this area, and we suggest one possible area of future emphasis for NSF's ongoing Science of Science and Innovation Policy program.

Keywords: Division of Policy Research and Analysis | National Science Foundation | returns to R&D | technology | innovation | science of science and innovation policy

Article:

1. Introduction

The National Science Foundation's (NSF's) Division of Policy Research and Analysis (PRA) was established on 9 February 1976 within the Scientific, Technological, and International Affairs (STIA) Directorate. Alden Bean was made Director of PRA in September 1977, having been preceded by Acting Directors John V. Granger and Thomas Ubois. Bean was followed, in August 1981, by two Acting Directors Robert Trumble and Peter Wilkniss. In 1983, Peter House was hired as Director of PRA. PRA remained in the STIA Directorate until October 1991, when it was moved administratively into the newly established Office of Planning and Assessment

(OPA).[1] House remained as Director of PRA until December 1994. OPA, and thus PRA, was disestablished on 7 January 1995. PRA was replaced by the Office of Policy Support.[2]

Among PRA's many areas of concern and responsibility, it was frequently asked to respond to requests from the White House about the social returns to research, especially academic basic science.[3] As Greenberg (2001: 113–4) noted:

> Starting with Lyndon Johnson's presidency [in 1963], the White House periodically demanded to know what the taxpayers were getting from their continuously rising, though never sufficient, spending on research, particularly in the strange grantland of academic basic science, and why they weren't getting more … PRA looked for answers, through its own research and in studies that it financed in universities.

2. PRA's support of research on the returns to R&D

Arguably, one of the more important contributions that PRA made to US technology and innovation policy came from the research that it funded on the returns to private and public R&D.[4] This research was motivated in part by the above-noted ongoing requests from the White House to learn more about the consequences of funded research, and in part by PRA's foresight to investigate culprits associated with the productivity slowdown—often quantified as the slowdown in aggregate total factor productivity—that began in the early 1970s and that was exacerbated in the late 1970s. PRA quickly anticipated questions about the contribution of R&D to economic growth, and it also anticipated that answers to such questions would soon influence the direction of any responsive technology and innovation policies.[5]

The academic model underlying this thread of research was based on a generalizable production function applicable to the *i*th firm, *i*th industry, *i*th sector, or the *i*th country, that was written as:

$$Q_i = A_i \mathrm{F}(K_i, L_i, T_i) \tag{1}$$

where Q represents the output. In Equation (1), A is a neutral disembodied shift factor. The stock of physical capital and labor are K and L, respectively. The stock of technical capital available to the unit of observation, i, hereafter referred to as the firm for simplicity, is represented as T.

In the early studies funded by PRA, T was written in terms of the *i*th firm's internal or self-financed previous R&D expenditures, RD, as:

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[1] With the move of PRA into OPA, PRA became a division of an office rather than a division of a directorate.

[2] This background information on PRA was graciously researched and provided by Marc Rothenberg, NSF's historian.

[3] Such requests came to NSF before PRA was established, and they have continued beyond PRA's existence.

[4] This area of research was a subset of the research that the PRA funded. Its portfolio included research on patent policy, trade policy, energy policy, innovation processes, academic science and engineering facilities, personnel tax policy, and more.

[5] The case could also be made that the PRA's support of the 1981 National Bureau of Economic Research conference, from which the papers in Griliches (1984) came, engendered a new generation of young scholars who would devote their research careers to the study of the economics of R&D, technology, and innovation, especially as related to public policy.

$$T_i = \Sigma a_{i,j} RD_{i,t-j} \tag{2}$$

where the ith firm's accumulation weights, a_j, reflect the influence of a j-period distributed lag and obsolescence rate of R&D.

Most of the early empirical studies of the technology–productivity growth relationship were based on a simplified Cobb–Douglas production function:

$$Q = A_0 \mathrm{e}^{\lambda t} K^{\alpha} L^{\beta} T^{\gamma} \tag{3}$$

where A_0 is a constant, λ is a disembodied rate of growth parameter and α, β, and γ are output elasticities. Constant returns to scale were assumed.

Assuming K, L, and T are all functions of time, t, and letting $X' = \mathrm{d}X/\mathrm{d}t$, the growth rate of output is:

$$Q'/Q = \lambda + \alpha K'/K + \beta L'/L + \gamma T'/T \tag{4}$$

The residually measured total factor productivity growth ($TFPG$) is defined as:

$$TFPG = Q'/Q - \alpha K'/K - \beta L'/L = \lambda + \gamma T'/T \tag{5}$$

In Equation (5) the output elasticities α and β are estimated, respectively, by the shares of physical capital and labor in output.

The parameter, γ, in Equation (3) is the output elasticity of technical capital:

$$\gamma = (\partial T/\partial T)(T/Q) \tag{6}$$

Substituting the right-hand-side of Equation (6) into Equation (5), and rearranging terms, yields:

$$TFPG = \lambda + \rho(T'/Q) \tag{7}$$

where $\rho = (\partial Q/\partial T)$. From Equation (7), ρ is the marginal product of technical capital and T' is the firm's net private investment in the stock of technical capital.

If it is assumed that the stock of R&D-based technical capital does not depreciate, or if it does depreciate it does so very slowly, then T' is reasonably approximated by the flow of self-financed R&D expenditures in a given period of time, RD:

$$TFPG = \lambda + \rho(RD/Q) \tag{8}$$

Empirical estimates of ρ from Equation (8) have been interpreted as an estimate of the marginal rate of return to investments in R&D.

Among the many empirical studies that PRA funded, selected ones that are directly related to a measure of the returns to private R&D, and later as data became available to estimate the returns to public R&D, are briefly described in Table 1. These studies, funded in the early 1980s in the aftermath of the productivity slowdown, were based on variants of Equations (1) and (8), where *RD* was measured in terms of total R&D expenditures and also in terms of the composition of total R&D expenditures by character of use and, selectively, by source of funding.[6]

Table 1. Selected PRA-funded studies on returns to US R&D

Author(s)	Generalizable findings
Griliches (1980)	Positive returns to total industry R&D
Link (1980)	Positive returns to total firm R&D in the US chemicals industry. The returns increase with firm size
Mansfield (1980)	Positive returns to industry and firm basic research and applied research, with the returns to basic research being larger
Link (1981)	Positive returns to firm-funded basic research and firm-funded applied research plus development, with the returns to basic research being larger; positive returns to government-funded firm-performed basic research
Link (1982a)	Positive returns to total firm R&D, and positive yet different returns when total R&D is disaggregated to process R&D and product R&D
Link (1982b)	Positive returns to total industry R&D, but the policy-induced portion of R&D devoted to environmental regulations had a negative impact on measured productivity growth
Link (1983)	Positive returns to total firm R&D, and positive returns to the disaggregated portion of R&D allocated to purchased technologies
Terleckyj (1982)	Positive returns to total industry R&D, and positive yet different returns when total R&D is disaggregated to process R&D and product R&D
Clark and Griliches (1984)	Positive returns to total firm R&D
Griliches and Mairesse (1984)	Positive returns to total firm R&D
Mansfield (1984)	Positive returns to total firm R&D, and when disaggregated to domestic and overseas R&D
Griliches (1986)	Positive returns to total firm R&D, with privately-funded R&D having a larger contribution than government-funded R&D, and positive returns to basic research

Depending on the study, the time period, and if R&D is considered in total or by disaggregated character of use, the returns to R&D range from about 15% to nearly 100%

We argue that the PRA-funded foundational research on the returns to private and public R&D listed in Table 1 has had an important and lasting impact on technology and innovation policy. That impact was most visible in public policies promulgated in the early 1980s that provided incentives for firms to conduct more R&D (e.g. the R&E Tax Credit of 1981 and its continuous renewal, the Small Business Innovation Development Act of 1982, and the National Cooperative Research Act of 1984).[7] Arguments were made that firms were underinvesting in the socially desirable level of R&D.

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[6] See Hall et al. (2012) for a comprehensive review of the returns to R&D literature.

[7] The research and experimental (R&E) tax credit was part of the Economic Recovery Tax Act of 1981. For a discussion of its continued renewal see Atkinson (2007) and Tassey (2007a).

More recently, for example, consider the influence that the findings from these have had on the following contemporary policy statements (cited in the References): *U.S. Technology Policy; Mastering a New Role: Shaping Technology Policy for National Economic Performance; Innovate America; Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future; A Strategy for American Innovation: Securing Our Economic Growth and Prosperity* ; and *The Competitiveness and Innovative Capacity of the United States*. As summarized in Table 2, many of the premises underlying each of these policy statements—and this is only a partial list of relevant policy statements—can be traced directly to the findings from the PRA-funded studies in Table 1, especially those studies related to the returns to basic or fundamental research. Similarly, the premises underlying a number of contemporary technology and innovation policy initiatives can also be similarly traced. As shown in Table 3, this is the case for the Biomass R&D Act of 2000, the 21st Century Nanotechnology Research and Development Act, the America COMPETES Act of 2007, and the America COMPETES Reauthorization Act of 2010.

Table 2. Influence of PRA-funded studies on returns to R&D on contemporary technology and innovation policy statements

Policy statement	**Explicit reference to positive returns to R&D**	**Explicit acknowledgement of importance of basic or fundamental research**	**Implicit reference to high returns to R&D and to basic research**	**Statements of support for basic or fundamental research**
U.S. Technology Policy (Executive Office of the President 1990)	No	Yes	Yes	p. 5: 'Increase Federal investment in support of basic research. Private industry does not invest heavily in basic research because the payoffs are so unpredictable and diffuse that individual firms cannot be confident of fully recovering their investments. However, the long-term potential benefits of this research are so large that society cannot afford not to make the investment, especially in university research which, in addition to new knowledge, also produces trained scientists of the future.'
Mastering a New Role: Shaping Technology Policy for National Economic Performance (Committee on Technology Policy Options in a Global Economy, 1993)	No	Yes	Yes	p. 62: 'the U.S. basic research enterprise has the potential to continue to provide the country with unique advantages in both the creation and the assimilation of new scientific and technological knowledge.'
Innovate America (Council on Competitiveness 2005)	No	Yes	Yes	p. 57: '… publicly funded research has been steadily moving away from the frontiers of knowledge and closer to application and development. The federal research investment has grown conservative—increasingly driven by consensus, precedent and incremental approaches. At this time of global opportunity and challenge, what is

Policy statement	Explicit reference to positive returns to R&D	Explicit acknowledgement of importance of basic or fundamental research	Implicit reference to high returns to R&D and to basic research	Statements of support for basic or fundamental research
				needed is a return to the basics—a forward-looking vision that drives the nation's research investment across uncertain terrain toward new knowledge and breakthrough innovation.'
Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future (Committee on Science, Engineering, and Public Policy 2007)	Yes	Yes	Yes	p. 7: 'Recommendation B: Sustain and strengthen the nation's traditional commitment to long-term basic research that has the potential to be transformational to maintain the flow of new ideas that fuel the economy, provide security, and enhance the quality of life.'
A Strategy for American Innovation: Securing Our Economic Growth and Prosperity (Executive Office of the President 2011)	No	Yes	Yes	p. 3: 'The commercial innovations that drive economic progress often depend on breakthroughs in fundamental science. … These sustained science investments will lay the foundation for new discoveries and new technologies that will improve our lives and create the jobs and industries of the future.'
The Competitiveness and Innovative Capacity of the United States (US Department of Commerce 2012)	Yes	Yes	Yes	p. vi: 'The need for Federal government to play an important role in the first pillar—research, particularly basic research—derives from the fact that there is a divergence between the private and social returns of research activities which leads to less innovative activity in the private sector than is what is best for our country. However, government support of basic research can remedy this problem.'

Table 3. Influence of PRA-funded studies on returns to R&D on contemporary technology and innovation policy initiatives

Legislation	Explicit reference to positive returns to R&D	Explicit acknowledgement of importance of basic or fundamental research	Implicit reference to high returns to R&D and to basic research	Statements of support for basic or fundamental research
Biomass R&D Act of 2000 (Public Law 106-224)	No	No	Yes	Sec. 302 (12) (A): '… because of the relatively short-term time horizon characteristic of private sector investments, and because many benefits of biomass processing are in the national interest, it is appropriate for the Federal Government to provide

Legislation	Explicit reference to positive returns to R&D	Explicit acknowledgement of importance of basic or fundamental research	Implicit reference to high returns to R&D and to basic research	Statements of support for basic or fundamental research
				precommercial investment in fundamental research and research-driven innovation in the biomass processing area; …'.
21st Century Nanotechnology Research and Development Act (Public Law 108-153)	No	No	Yes	Sec 2.b: 'The activities of the Program shall include— 1) developing a fundamental understanding of matter that enables control and manipulation at the nanoscale; …'
America COMPETES Act of 2007 (Public Law 110-69)	Yes	Yes	Yes	Sec 1008.a: 'It is the sense of Congress that each Federal research agency should strive to support and promote innovation in the United States through high-risk, high-reward basic research projects that — 1) meet fundamental technological or scientific challenges; 2) involve multidisciplinary work; and 3) involve a high degree of novelty.'
America COMPETES Reauthorization Act of 2010 (Public Law 111-358)	No	Yes	Yes	Sec 519 (a) (4): '… reauthorization of the America COMPETES Act should continue a robust investment in basic research and education and preserve the essence of the original Act by increasing the investment focus on science, technology, engineering, and mathematics basic research and education as a national priority.'

3. Lessons to be learned from PRA

It might be argued that a PRA-like emphasis on research related to technology and innovation was not seen again at NSF until John Marburger, President George W. Bush's science advisor, emphasized publicly the importance of understanding the science of science policy.[8] He wrote:

> How much should a nation spend on science? What kind of science? How much from private versus public sector? Does demand for funding by potential science performers imply a shortage of funding or a surfeit of performers? These and related science policy questions tend to be asked and answered today in a highly visible advocacy context that makes assumptions that are deserving of closer scrutiny. A new 'science of science

[8] For additional information about John Marburger's tenure as science advisor to President Bush, see Pielke and Klein (2010).

> policy' is emerging, and it may offer more compelling guidance for policy decisions and for more credible advocacy. (Marburger 2005: 1087)

Kaye Husbands Fealing developed NSF's Science of Science and Innovation Policy (SciSIP) program in 2005. Since that time, the program has filled a conspicuous void for the funding of academic research related to technology and innovation policy. There is no reason to believe that it will not continue to do the same in the future. That said, there are possibly lessons to be learned from the influential success of PRA. Among the lessons that might be learned from the history and legacy of PRA, as presented in this paper, by SciSIP and other divisions are to look forward, to encourage explicitly, and to support appropriately research that might provide a foundation for future technology and innovation policy.

As one example, consider infrastructure technology, or infratechnology as referred to by Tassey (2005b: 92–3):[9]

> Infratechnologies are a diverse set of technical tools that are necessary to efficiently conduct all phases of R&D, to control production processes, and to execute marketplace transactions for complex technology-based goods. These tools are called infratechnologies because they provide a complex but essential technical infrastructure. Many infratechnologies are adopted as industry standards, emphasizing their public good content. Without the availability of this technical infrastructure, especially codified as standards [and test methods], transaction costs for all three major stages of economic activity—R&D, production, and marketing—would be much higher thereby significantly slowing the evolution of technology lifecycles.

Infrastructure technology has only recently—perhaps not longer than within the past decade—begun to be acknowledged as an important element of production that influences technological change at all levels of aggregation.[10] Yet, little is still known about the role of infrastructure technology much less about the level of investment in its stock by the public sector.

If Equation (1) is rewritten to include infrastructure technology (*IT*) as an explicit production input, then:

$$Q_i = A_i F_i(K_i, L_i, T_i, IT_i) \tag{9}$$

Following the derivations above:

$$TFPG = \lambda + \rho(RD/Q) + \psi(STM/Q) \tag{10}$$

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[9] See also, Tassey (2007b). See Link and Scott (2012) for examples of the economic impact of infrastructure technology.

[10] Infrastructure technology is not the only quasi-public good element of industrial technology, but it is used here to make the case that technology and innovation policy should be more broadly focused than private R&D. See Tassey (2005a) for a comprehensive model that included technology platforms as well as infrastructure technology. See Scott and Scott (2013) for a more recent empirical analysis of the impact of infrastructure technology.

As in Equation (8), *RD* represents R&D expenditures in a given period of time. In Equation (10), *STM* represents publicly financed standards and test methods research expenditures in a given period of time under the assumption that these expenditures build the stock of infrastructure technology, *IT*.

From an econometric perspective, taking account of the studies in Table 1, if the variables (*RD*/*Q*) and (*STM/Q*) are uncorrelated, then an estimate of ρ, the marginal return to investments in R&D from Equation (8), will equal an estimate of ρ from Equation (10). However, if (*RD*/*Q*) and (*STM/Q*) are positively correlated, then previous estimates of the return to R&D from specifications like that in Equation (8) have overstated the true return to R&D, or to elements of the composition of R&D. Of course, if (*RD*/*Q*) and (*STM/Q*) are negatively correlated, the previous estimates of the returns to R&D have been too low. In either case, because of our lack of understanding of infrastructure technology, for example, biased information will have informed technology and innovation policy. [11]

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References

Atkinson, R. D. (2007) 'Expanding the R&E tax credit to drive innovation, competitiveness and prosperity', Journal of Technology Transfer, 32: 617–28.

Clark, K. and Griliches, Z. (1984) 'Productivity growth and R&D at the business level: Results from the PIMS data base'. In: Griliches, Z. (ed.) R&D, Patents, and Productivity, pp. 393–416. Chicago, IL: University of Chicago Press.

Committee on Science, Engineering, and Public Policy. (2007) Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, DC: National Academies Press.

Committee on Technology Policy Options in a Global Economy. (1993) Mastering a New Role: Shaping Technology Policy for National Economic Performance. Washington, DC: National Academy of Engineering.

Council on Competitiveness. (2005) Innovate America. Washington, DC: Council on Competitiveness.

Executive Office of the President. (1990) U.S. Technology Policy. Washington, DC: Executive Office of the President.

[11] Hall et al. (2012) include in their production function model a variable called external knowledge. That variable may have played a similar role to that of infrastructure technology in our model.

—— (2011) A Strategy for American Innovation. Washington, DC: Executive Office of the President.

Greenberg, D. S. (2001) Science, Money, and Politics. Chicago. IL: University of Chicago Press.

Griliches, Z. (1980) ‘Returns to Research and Development Expenditures in the Private Sector’. In: Kendrick, J. W. and Vaccara, B. (eds) New Developments in Productivity Measurement, pp. 419–54. Chicago: University of Chicago Press.

—— (1984) R&D, Patents, and Productivity. Chicago, IL: University of Chicago Press.

—— (1986) ‘Productivity, R&D, and basic research at the firm level in the 1970s’, American Economic Review, 76: 141–54.

—— and Mairesse, J. (1984) ‘Productivity and R&D at the firm level’. In: Griliches, Z. (ed.) R&D, Patents, and Productivity, pp. 339–74. Chicago, IL: University of Chicago Press.

Hall, B., —— and Mohnen, P. (2012) ‘Measuring the returns to R&D’. In: Hall, B. H. and Rosenberg, N. (eds) Handbook of Economics of Innovation, pp. 1034–82. Amsterdam: North Holland.

Link, A. N. (1980) ‘Firm size and efficient entrepreneurial activity: A reformulation of the Schumpeter hypothesis’, Journal of Political Economy, 88: 771–82.

—— (1981) ‘Basic research and productivity increase in manufacturing: Additional evidence’, American Economic Review, 71: 1111–2.

—— (1982a) ‘A disaggregated analysis of industrial R&D: Product versus process innovation’. In: Sahal, D. (ed.) The Transfer and Utilization of Technical Knowledge, pp. 45–62. Lexington, MA: D.C. Heath.

—— (1982b) ‘Productivity growth, environmental regulations and the composition of R&D’, Bell Journal of Economics, 13: 548–54.

—— (1983) ‘Inter-firm technology flows and productivity growth’, Economics Letters, 11: 179–84.

—— and Scott, J. T. (2012) The Theory and Practice of Public-Sector R&D Economic Impact Analysis, Planning Report 11-1. Gaithersburg, MD: National Institute of Standards and Technology.

Mansfield, E. (1980) ‘Basic research and productivity increase in manufacturing’, American Economic Review, 70: 863–73.

—— (1984) ‘R&D and innovation: Some empirical findings’. In: Griliches, Z. (ed.) R&D, Patents, and Productivity, pp. 127–48. Chicago, IL: University of Chicago Press.

Marburger, J. H., III (2005) ‘Wanted: Better benchmarks’, Science, 308/5725: 1087.

Pielke, R., Jr and Klein, R. A. (2010) Presidential Science Advisors: Perspectives and Reflections on Science, Policy and Politics. New York: Springer.

Scott, T. J. and Scott, J. T. (2013) ‘Standards and the incentives for innovation’, Paper presented at Research Roundtable Conference on Technology Standards and Innovation, held 7–8 February 2013, Chicago, IL.

Tassey, G. (2005a) ‘The disaggregated technology production function: A new model of university and corporate research’, Research Policy, 34: 287–343.

—— (2005b) ‘Underinvestment in public good technologies’, Journal of Technology Transfer, 30: 89–113.

—— (2007a) ‘Tax incentives for innovation: Time to restructure the R&E tax credit’, Journal of Technology Transfer, 32: 605–15.

—— (2007b) The Technology Imperative. Northampton, MA: Edward Elgar.

Terleckyj, N. E. (1982) ‘R&D and U.S. industrial productivity in the 1970s’. In: Sahal, D. (ed.) The Transfer and Utilization of Technical Knowledge, pp. 63–99. Lexington, MA: D.C. Heath.

US Department of Commerce. (2012) The Competitiveness and Innovative Capacity of the United States. Washington, DC: US Department of Commerce.