Bigger Science: Implications for Innovation
Research Proposal
Paula Stephan
Georgia State University and NBER

**Abstract:** Big science certainly existed when Vannevar Bush authored *The Endless Frontier*. Caltech was in the process of designing and building a 200-inch reflecting telescope and cyclotrons had been up and running at several locations for ten years or more. But by today's standards, even these activities were relatively "small." The Hale telescope, as the 200-inch scope was named upon completion, cost somewhere in the neighborhood of $6 million dollars, or approximately $79 million in today's prices. [1] By way of contrast, the projected cost of the 30-Meter Telescope (TMT) that is now in a $77 million design-development phase, is $1 billion.[2] The first model of Lawrence's cyclotron was built with wire and sealing wax for approximately $25.[3] No one could have imagined that 50 years later a consortium of countries would construct the $8 billion Large Hadron Collider and that just under 6,000 scientists would be working at the four associated detectors. In many fields small science was the norm at the time that Bush wrote his work. University labs had minimal equipment and, with the exception of some specialized apparati, the equipment in labs was arguably more of the garden variety order.

In the past 60 years, research has become considerably more capital intensive, requiring not only outlays for specialized equipment but considerable expenditures for consumables to run the equipment. Moreover, as equipment has become more important to research, needs for research space and trained individuals to run and work with the equipment have grown. The demand for graduate students and postdocs has increased.

Concomitantly, and arguably not unrelated, scientists working in the public sector began to be expected to garner grants to help fund their research. The U.S. government, in fits and starts, encouraged this trend by making resources increasingly available for university research. Universities began to adopt the practice of supporting newly hired scientists for three years with start-up packages and then cutting the cord on support. Nowhere have the changes been more striking than in the biomedical sciences ,which went from "miniscule" to medium-sized science in a period of no more than 40 years. Today a relatively small lab in the biomedical sciences at a public university, composed of eight researchers—a faculty principal investigator, three postdoctoral fellows, and four graduate students, plus an administrator, has annual personnel costs of just over $400,00 after fringe benefits but before indirect costs. Add in 500 mice (a small number by today's standards) and $18,000 a year in supplies for each researcher, and lab costs come to about $550,000 a year before one has even opened the equipment catalogue, which could easily set the lab back another $50,000 to $100,000, not including funds the lab contributes for core equipment.

The increased capital intensity of science and the associated increase in the scale and cost of science have arguably changed the innovation process in several key ways. First, scientists now spend a considerable portion of their time on administrative details (a recent survey puts it at 42 percent).[4] Second, with the growth of peer review as a mechanism for distributing research resources, scientists spend considerable time serving as reviewers. Third, increased capital intensity makes discoveries from

"outsiders" increasingly unlikely—be the outsider young or working in a field or area that does not provide access to specialized equipment or resources that are key to discovery. Fourth, the need for resources to support their research has arguably led scientists to be more risk averse in the research they propose when seeking funding. (Forty to fifty years ago a scientist could often do research without access to substantial resources. This possibility still exists in certain fields of math, for example, but it has become increasingly less likely in most other fields.) Fifth, the need to raise research funds encourages entrepreneurship among scientists. Getting money from a venture capitalist is not that different from getting money from a funding agency—both require making a strong pitch. Some of these changes have led to increased innovation—for example, the increased ability to "sell" one's science, while others, such as a predisposition towards risk aversion, detract from innovation.

**Data and current state of the research:** The proposed paper, which is in nascent form, explores these trends, providing historic context for the trends discussed above. I have only begun to look for data to support the narrative. However, promising sources include, but are not limited to, the following:

1. Data from NIH concerning budgets for extramural research, success rates, and the number of PIs funded (data request has been submitted; the earliest relevant data are available is for the 1950s).
2. Similar data from NSF. Request to be submitted.
3. Data on number of PhD programs by field over time for certain fields (American Institute of Physics, for example, keeps excellent records). Data can also be inferred from the number of programs included in the Cartter ratings of PhD programs in 1966, the number included in Roose and Anderson's ratings that followed four years later, followed by the 1982 study of PhD program quality by Jones, Lindzey and Coggeshall, the 1993 NRC study of PhD programs and finally the most recent 2010 study.
4. Number of PhDs granted by field by year: data exist and are readily available from the SED for 1958 onward but administrative data were collected before this and the author has access to this data.
5. Possible case studies of lab size in several fields at several universities over time. It is too early for me to know the feasibility of collecting such data.
6. Equipment catalogs
7. Budgets for research projects submitted to NSF (I have yet to investigate the feasibility of getting such data).
8. Examination of changes in the biomedical research and development price index for the period 1950 to the present (data available on line).[5]

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[1] Cost comes from http://en.wikipedia.org/wiki/Hale_telescope (received funding of $6 million in 1928. CPI data comes from ftp://ftp.bls.gov/pub/special.requests/cpi/cpiai.txt.
[2] Page 97, *How Economics Shapes Science,* Paula Stephan.
[3] http://inventors.about.com/library/inventors/bllawrence.htm
[4] Page 65, *How Economics Shapes Science,* Paula Stephan
[5] http://officeofbudget.od.nih.gov/xls/fy2012/BRDPI%20Table%20of%20Annual%20Values_01_20_2012.xlsx