Remarks before the Senate Subcommittee on Commerce, Science, & Transportation[1]

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I. Introductory Remarks

Thank you very much for this invitation. It is an honor to testify before this Committee and I am grateful for the invitation. A common complaint about Washington is that there is gridlock in Congress. I, however, have the great pleasure of conducting research on Science and Innovation Policy, an issue for which there has been both wide-ranging, bi-partisan support for the majority of the past century and a tradition of national successes that demonstrate the contributions of the public sector, private sector, and interactions between the two.

I will begin with a brief introduction of my background and research. I am an Associate Professor of Strategy & Innovation at Boston University and a Research Associate at the National Bureau of Economic Research (NBER). I hold a Ph.D. from the Massachusetts Institute of Technology in Strategy & International Management. My official training is in management scholarship, although much of the work that I do is based in economics and contributes to research in that field.

My principal research interests have addressed three general questions:

(1) What are the historical drivers of national innovative output? Stated somewhat differently, this question asks, "Why are some countries more innovative than others and what have historically follower nations, like Israel and South Korea, done to close the gap in innovation between themselves and historical leader countries, like Germany, Japan, and the United States?[2]

(2) What is the role of location in the R&D productivity of science-based firms? For example, in this research line, I have investigated whether pharmaceutical companies' drug discovery efforts are,

[1] These comments heavily draw upon text the paper, "The America COMPETES Acts: The Future of U.S. Physical Science & Engineering Research?" forthcoming, forthcoming in, Josh Lerner & Scott Stern, ed, *Innovation Policy and the Economy* Vol 13, Chicago, IL: University of Chicago Press. The discussion of the America COMPETES legislation in that paper draws heavily on reports written by the Congressional Research Service.

[2] See, e.g., J.L. Furman (2011) "The Economics of Science and Technology Leadership," Leadership in Science and Technology: A Reference Handbook, William Sims Bainbridge, Editor, Sage Publications; J.L. Furman and R. Hayes (2004) "Catching up or standing still? National innovative productivity among 'follower' nations, 1978-1999," *Research Policy*; J.L. Furman, S. Stern, and M.E. Porter (2002), "The determinants of national innovative capacity," *Research Policy*; S. Stern, M.E. Porter, and J.L. Furman (2000) "Understanding the drivers of national innovative capacity – Implications for Central European economies," *Wirtschaftspolitische Blätter*; M.E. Porter, S. Stern, and J.L. Furman (2000) "Los Factores Impulsores de la Capacidad Innovadora Nacional: Implicaciones para España y America Latina" *Claves de la Economia Mundial*.

indeed, more productive when they are located in high-science areas, like Boston, Philadelphia, and San Diego.[3]

(3) How do particular institutions and public policies affect science and innovation output? For example, I have investigated (a) the impact of the U.S. human embryonic stem cell policy on national leadership in this research area; (b) the contribution of Biological Resource Centers, like the American Type Culture Collection in nearby Manassas, VA, to the rate of knowledge accumulation, and (c) the ability of the system of academic retractions to limit the negative impact of false publications. I should note that this last line of research has been supported by a grant from the National Science Foundation's Science of Science and Innovation Policy program and that it has been my most recent line of work.[4]

In each of these projects, I should recognize the contributions of my co-authors, most notably, Fiona Murray and Scott Stern of MIT's Sloan School and Megan MacGarvie, my colleague at Boston University.

My understanding of my invitation today is that my charge is to talk about two main issues: (a) the Federal role in Science and Innovation Policy and (b) America COMPETES Act. I address these issues in turn.

II. The Federal Role in Science & Innovation Policy

II.1 . History & the general argument for federal support for science & innovation

Although the aim of "promot[ing] the progress of science and useful arts" was articulated in the U.S. Constitution as a power of Congress, this power was expressly linked to providing incentives to authors and inventors.[5] Consistent with the specificity of these aims, the U.S. federal government federal government

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[3] See, e.g., J.L. Furman and Megan MacGarvie (2009) "Organizational Innovation & Academic Collaboration: The role of universities in the emergence of U.S. Pharmaceutical research laboratories," *Industry & Corporate Change*; J.L. Furman & M. MacGarvie (2008) "When the pill peddlers met the scientists: The antecedents and implications of early collaborations between U.S. pharmaceutical firms and universities," Essays in Economic & Business History; J.L. Furman & M. MacGarvie (2007) "Academic science and early industrial research labs in the pharmaceutical industry," *Journal of Economic Behavior & Organization*; and J.L. Furman, M. Kyle, I. Cockburn, & R. Henderson (2005) "Public & Private Spillovers, Location, and the Productivity of Pharmaceutical Research," *Annales d'Economie et de Statistique*.

[4] J.L. Furman, F. Murray, & S. Stern (2012) "Growing Stem Cells: The Impact of U.S. Policy on the Organization of Scientific Research," *Journal of Policy Analysis & Management*; J. Furman, K. Jensen, & F. Murray (2012) "Governing knowledge production in the scientific community: Quantifying the impact of retractions," *Research Policy*; J.L. Furman & S. Stern (2011) "Climbing atop the shoulders of giants: The impact of institutions on cumulative research," *American Economic Review*; J.L. Furman, F. Murray, & S. Stern (2010) "More for the research dollar," *Nature*; S. Stern & J.L. Furman (2004) "A penny for your quotes?: The impact of biological resource centers on life sciences research," in *Biological Resource Centers: Knowledge Hubs for the Life Sciences*, ed. S. Stern, Washington, DC: Brookings Institution Press.

[5] *U.S. Constitution*, Article I, Section 8, Clauses 1 & 8: "The Congress shall have Power…To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries." Clause 1 precedes the ellipsis; Clause 8 follows the ellipsis.

administered the patent system but did not engage in much centralized policy-making regarding science and technology during its first century.[6] During and following the Civil War, the federal government began to expand its role in promoting science and technology by developing some key institutions, including the development of research-oriented universities under the Morrill Acts of 1862 and 1890, the Hatch Act of 1887, the National Academy of Sciences (NAS). The second major wave of federal science- and technology-related investments began during the first two decades of the 20th century and accelerated during World War I. This effort included the establishment of the National Bureau of Standards (1901), the Public Health Service (1912), and the National Advisory Committee for Aeronautics (1915), the Naval Consulting Board (1915), and the National Research Council (1916).

The argument for active government participation in funding and guiding basic scientific research was made famously by Vannevar Bush, Director of the Office of Scientific Research and Development under Franklin Delano Roosevelt during World War II, in his monograph, *Science: The Endless Frontier*.[7] Bush argued both that the scientific enterprise was a key to economic growth and improvements in social welfare.[8] His logic for suggesting federal support for science funding was straightforward and reflected an understanding of positive externalities: Since investments in basic scientific research invariably diffuse to other organizations in way that limits the ability of for-profit firms to capture sufficient returns from such investments, society overall faces higher incentives to invest in basic research than do for-profit firms. Thus, basic research can be usefully classified as a public good and, in the absence of government support, the private sector will provide an inefficiently low investment in science and risky innovation. Bush argued that government should step into the void and assume an active role in supporting scientific research. Bush's vision resulted in the creation of the National Science Foundation in 1950 and has constituted the rationale for government investment in basic science since that time.[9] The arguments have taken on an additional salience during the debates on national competitiveness that surfaced during the 1980s, when American economic preeminence in several industries, including automobiles and consumer electronics, faced challenges from imports from numerous countries, including Germany and Japan, and during the 2000s, in light of the

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6 The Federal government did engage support some efforts related to science and technology, however. For example, Federal support for the exploration of Lewis and Clark yielded numerous contributions to scientific knowledge, including contributions to natural history (including discoveries of new plants and animals), meteorology, and cartography (Ambrose, Stephen E. (1996) *Undaunted Courage: Meriwether Lewis, Thomas Jefferson, and the Opening of the American West,* (1996) New York, NY: Simon & Schuster; Cutright, Paul Russell (1969) *Lewis & Clark: Pioneering Naturalists*, Urbana, IL: University of Illinois Press).

7 Bush, Vannevar (1945) "Science The Endless Frontier," A Report to the President by Vannevar Bush, Director of the Office of Scientific Research and Development, Washington, DC: United States Government Printing Office.

8 "Advances in science when put to practical use mean more jobs, higher wages, shorter hours, more abundant crops, more leisure for recreation, for study, for learning how to live without the deadening drudgery which has been the burden of the common man for ages past. Advances in science will also bring higher standards of living, will lead to the prevention or cure of diseases, will promote conservation of our limited national resources, and will assure means of defense against aggression" (Bush, 1945, p. 10).

9 Building on Bush's ideas, economists beginning with Nelson (1959) and Arrow (1962) described as a public, non-rivalrous, non-excludable good which creates higher social welfare than private benefits. Considering the central role of scientific and technical knowledge play a central role in economic growth and social welfare (Solow, 1956; Abramovitz, 1956), the fact that scientific knowledge evidences the properties of a public good suggest that the creation and accretion of knowledge should be central goals for national policymakers.

substantial economic development of several countries that had been historically imitation oriented than innovation-driven, including South Korea, China, and India.

II.2 . National leadership and the role of location

The argument that science and early-stage innovation are public goods requiring government support to achieve optimal levels is especially compelling in a world in which there is only one country or in which one country is the clear leader in science and technology, as the U.S. was during the years following World War II, or in which there is no trade between countries. In such a scenario, if the unchallenged leader country (or the global science investment body) were to curtail investments in science and technology or were to slow the rate at which it built on prior research advances, global technological improvements would stagnate, as would global economic growth.[10]

If a number of countries have relatively similar levels of scientific development, national decisions regarding scientific investment become more interrelated. This complicates matters, as one country's optimal investment decisions will depend on the investments of other nations and on the rapidity and completeness with which knowledge diffuses. If scientific and technical knowledge diffuses slowly and incompletely (or if it is particularly expensive for non-innovator countries to imitate leader countries, i.e., if catch-up is slow), then a leader country is likely to obtain high returns to its investments in science. If, however, scientific and technical knowledge diffuses sufficiently swiftly and effectively, then there may not be a substantial benefit to being a leader country, as fast-follower countries can free ride on the investments of leaders.

Thus, unless it is the unchallenged global technological leader, it will only be valuable for a country to pursue a strategy of scientific and technical leadership in the presence of relatively strong increasing returns to science and technology investment and relatively local knowledge diffusion. Stated somewhat differently, in order for locally-generated knowledge to be translated into scientific and/or technical leadership, researchers in close proximity to an original discovery must be able to exploit that discovery more rapidly, intensively, and, ultimately, successfully, than researchers who are further away.[11]

Despite improvements in information technology that have lowered the communication costs and made it easier to spread information, the often-anticipated "death of distance" has failed to materialize. Indeed, proclamations that the world is flat (Friedman, 2005) overlook the importance of local knowledge spillovers, which are quite strong, even in science, one of the areas in which ideas are most likely to flow most effectively.[12] While transportation costs have declined for physical goods and cost of direct communication has also declined, empirical evidence suggests value of proximity has increased in most industries and most sectors as well. Research suggests that investments in science and technology at the world's frontier yield

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[10] See Jones, Charles I. (1995) "R&D Based Models of Economic Growth," *Journal of Political Economy,* 103: 739-784.

[11] Furman, Jeffrey L. (2011) "The Economics of Science and Technology Leadership," *Leadership in Science and Technology*: *A Reference Handbook,* William Sims Bainbridge, Editor, Sage Publications, Chapter 3.

[12] Friedman, Thomas L. (2007) *The World is Flat: A Brief History of the Twenty-first Century.* New York, NY: Farrar, Straus and Giroux.

spillovers that are constrained to geographically proximate regions (Jaffe, Trajtenberg, & Henderson, 1993) and that even small barriers to diffusion can explain large differences in productivity levels among the most advanced nations (Eaton & Kortum, 1999).[13] Thus, there are at least some reasons to believe that investments in scientific and technical leadership may yield high rates of return than investments encouraging fast-follower approaches. Within the United States, those regions that have been historically knowledge-intensive have experienced greater economic success, even as the information economy has developed further (Glaeser and Ponzetto, 2010).[14] As well, there is also evidence that U.S. federal science and innovation policies, including the Bayh-Dole Act have both a local and national impact on economic outcomes, such as patenting and job creation (Hausman, 2012; Saha & Weinberg, 2011).[15]

More broadly, research suggests that those countries and geographic regions that have invested most heavily in scientific and technological infrastructure and adopt innovation-oriented policies have substantially improved their science bases and innovative capacity (Furman and Hayes, 2004).[16] The evidence suggests, though, that while many leader countries have continued to make science and technology investments at increasing rates, a number of former follower countries have increased their commitments to innovation at even greater rates. This has contributed to the globalization of science and technology and has contributed to the erosion of the gap between the leader and emerging innovator countries. Concerns about American competitiveness in the wake of such advances by other countries were among the factors prompting the Gathering Storm Report, the Bush Administration's American Competitiveness Initiative, and the America COMPETES Act. I turn to the lattermost of these in my next comments.

III. The America COMPETES legislation

III.1. Introductory comments

My expertise with the America COMPETES legislation is of a particular kind: I prepared an overview of the legislation's history, components, and funding for a workshop of the National Bureau of Economic Research. The paper had two purposes: (1) to provide an overview of the COMPETES legislation for academic economists who were broadly aware of the legislation but not familiar with its particulars and (2) to lay the groundwork for future projects to assess its impact and effectiveness. I believe that I was relatively successful in the former task, thanks principally to my ability to build on the work of the Congressional Research Service, but the latter task is especially challenging. Economics has made extraordinary progress

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13 Adam Jaffe, Manuel Trajtenberg, Rebecca M. Henderson (1993) "Geographic localization of knowledge spillovers as evidenced by patent citation," *Quarterly Journal of Economics*, 79(3): 577–598 and Eaton, Jonathan and Samuel Kortum, "Trade in ideas patenting and productivity in the OECD," *Journal of International Economics*, 40(3-4), 251-278.

14 Edward L. Glaeser, Giacomo A. M. Ponzetto. (2010) "Did the Death of Distance Hurt Detroit and Help New York?" in Edward L. Glaeser, editor, *Agglomeration Economics,* Chicago, IL: University of Chicago Press.

15 Naomi Hausman (2011) "University Innovation, Local Economic Growth, and Entrepreneurship," working paper; Saha, Subra B. and Bruce A. Weinberg (2011) "A Framework for Quantifying the Economic Spillovers from Government Activity Applied to Science," working paper.

16 Furman, Jeffrey L. and Richard Hayes (2004) "Catching up or standing still: Catching up or standing still? National innovative productivity among 'follower' countries, 1978–1999," *Research* Policy, 33, 1329-1354.

over the past couple of decades in "program evaluation," i.e., evaluating specific public programs, such as job creation programs, and we are beginning to make progress in evaluating science and innovation policy as well. The field finds it much more difficult, however, to evaluate packages of programs and broad-based changes in funding, such as those associated with the COMPETES acts. Thus, I consider the research I have done on the COMPETES legislation as the beginning rather than the end of analysis on this subject and I believe that this is an area in which economists and policymakers can find useful ground for interaction.

III.2. Overview of analysis

The America COMPETES legislation, including the initial America COMPETES Act of 2007 (ACA 2007) and America COMPETES Reauthorization Act of 2010 (ACA 2010), was one of the prominent bipartisan legislative achievements of the past decade and was seen as having the potential to be the most notable science and innovation policy initiative of the new millennium.[17] To date, however, limited systematic analysis of the America COMPETES Acts has been undertaken.[18] My analysis of the Act has left me with two central impressions:

(1) The achievements of the legislation can be reasonably viewed as substantial from the perspective of analyzing what may have happened in the absence of the legislation. Key achievements that were enabled by the Acts include important expansions to the power of Federal agencies to implement innovation prize programs, the creation of Advanced Research Projects Agency – Energy (ARPA-E), funding for the National Institutes of Standards and Technology (NIST), substantial funding for programs at the National Science Foundation (NSF), the harder-to-measure-enabling of agencies to implement programs consistent with the spirit of the COMPETES Acts, and, perhaps most importantly, the maintenance of a tenuous but consistent bipartisan consensus to preserve the funding of physical science and engineering programs even in the face of budgetary difficulties of historical proportions. It is reasonable to conclude that, absent the authorization of funding for science and engineering programs called for by the COMPETES Acts, the level of commitment to these areas would have waned over the past half-decade that U.S. leadership in science and innovation would have suffered as a consequence.

[17] See, for example, Broder, David (2007) "Thankless Bipartisanship," *Washington Post*, May 3, 2007, A18; Ensign, John (2007) "Why the America Competes Act is Vital," *Innovation*, 5(3); National Governor's Association (2007) "NGA Praises Congressional Passage of the America COMPETES Act," press release, August 6, 2007, http://www.nga.org/cms/home/news-room/news-releases/page_2007/col2-content/main-content-list/title_nga-praises-congressional-passage-of-the-america-competes-act.html accessed 15 June 2012; ASTRA (2007) "Congress Passes, President Signs America COMPETES Act," *Alliance for Science & Technology Research In America: ASTRA Briefs*, 6(6), 10-14; and American Physical Society (2008) "Supporters of America COMPETES Bill Praise Its Passage, Urge Federal Funding," *American Physical Society – Capital Hill Quarterly*, 3(1), 1.

[18] The notable exception to this is the extensive work by the Congressional Research Service, including the efforts of Deborah Stine and Heather B. Gonzalez, who have written regular updates on COMPETES Act policy issues and funding, and John F. Sargent, who has tracked budgeting for COMPETES Act programs relative to historical trends. Their work is cited throughout this paper and it forms the basis of much of the chapter's analysis.

(2) **Relative to the standards established by the COMPETES legislation itself, much of the promise of the Acts is yet to be realized.** Perhaps the most salient observation about the ACA to the external observer is that a substantial fraction of the funds authorized by the 2007 and 2010 Acts was not appropriated by Congress and that many of the specified programs have either not materialized or have been created but at funding levels much lower than their initial authorizations. This appears to be particularly the case for STEM education funding. Table 1 of my testimony reproduces a table from a 2009 Congressional Research Service report identifying programs authorized for funding under the 2007 Act that did and did not receive appropriations between the 2007 Act and 2009.

In my understanding, the COMPETES legislation embraced a broad-ranging series of goals. I will highlight six of these goals and give my impressions of the extent to which progress has been made on these issues. The issues include:

(a) **the "Doubling Path,"** i.e., the aim of doubling the funding for federal investment in the physical sciences and engineering
(b) **ARPA-E**, the establishment and implementation of the Advanced Research Project Agency – Energy, built on the DARPA model
(c) **Improvements in America's STEM education infrastructure**
(d) **Modification of programs at the National Institute of Standards and Technology (NIST)**
(e) **Expansion of Federal Prize authority**, which was a specific initiative of the 2010 Reauthorization Act that was not included in the 2007 Act
(f) **Modifications to other Federal programs and clarification of Federal science and innovation responsibilities**

I address each of these issues in greater detail below.

III.3. The Doubling Path

One of the most prominent features of the COMPETES legislation was the "Doubling Path," the aim of doubling of Federal investment in the physical sciences and engineering between relative to the 2006 baseline. The 2007 Act aimed to achieve this result by 2013, while the 2010 Act re-targeted for 2015. Figures 1 & 2 attached below reflect the extent of funding under the COMPETES Act. Both are based in large measure on the efforts of the Congressional Research Service. Figure 1 documents that realized levels of funding and the extent of funding appropriated and authorized for the future have been systematically revised downwards from the initial aims of the *Gathering Storm Report*, the American Competitiveness Initiative, and the 2007 and 2010 Acts. Indeed, the current rate of funding increase for physical sciences and engineering is not appreciably greater than it was prior to the COMPETES legislation.

Whether one views this as a success or not depends substantially on the perspective that one takes: Federal investment in physical science and engineering has not kept pace with the specifications of either COMPETES Act; however, in contrast to many areas of the federal budget, funding for these areas has not declined. Thus, investment in these areas is relative to other budget priorities is greater than it was prior to the COMPETES legislation and is likely substantially greater than it would have been in the absence of the 2007 and 2010 appropriations.

III.4. ARPA-E

The Advanced Research Projects Agency-Energy (ARPA-E) at the Department of Energy was articulated by both COMPETES Acts, the *Gathering Storm Report*, and the American Competitiveness Initiative. The agency was created in the 2007, received $15 million in the FY2009 budget, but did not receive substantial funding until the 2009 ARRA appropriated $400 million, which enabled ARPA-E to begin to solicit research proposals and fund research projects. ARPA-E's did not receive appropriations in FY2010, although it did receive nearly $180 million in FY2011 and an estimated $275 million in FY2012. These funding levels have enabled ARPA-E to award $521.7 million in grants to approximately 180 awardees as of March 2012. The agency issued a call for $150 million in additional proposals in March 2012.[19] In addition to its research funding, the Agency has held three Energy Innovation Summits that showcase research by ARPA-E awardees, applicants, and other contributors. Although the overall level of funding for ARPA-E has not reached the levels envisioned by *The Gathering Storm* and is substantially lower than the DARPA annual budget ($3.2 billion), ARPA-E can be considered as an important outcome associated with the COMPETES Acts, particularly in light of the fact that the total estimated annual U.S. investment in energy-related R&D is approximately $5.1 billion.[20] It is currently too early to assess the impact of ARPA-E on energy innovation; however, studies like those conducted by Erica Fuchs of the nature of DARPA research[21] and could be insightful and could set the stage for further evaluations of ARPA-E's performance.

III.5 STEM Education

The aim of expanding and improving U.S. STEM education was another of the signature initiatives of the 2007 and 2010 Acts. The legislation embraced three particular aims: (a) increasing the number of STEM teachers, particularly those of high quality and with exceptional training, and improving the depth of existing teachers' in STEM areas; (b) exposing a larger number of U.S. students to STEM education and attracting

[19] ARPA-E (2012) "ARPA-E issues open call for transformational energy technologies," March 2, 2012, http://arpa-e.energy.gov/media/news/tabid/83/vw/1/itemid/49/Default.aspx; accessed March 2012.

[20] President's Council of Advisors on Science and Technology (2010) "Report to the President on accelerating the pace of change in energy technologies through an integrated federal energy policy," November 10, 2010; http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-energy-tech-report.pdf; accessed January 2012.

[21] Erica R.H. Fuchs (2010) "Rethinking the role of the state in technology development: DARPA and the case for embedded network governance," *Research Policy,* 39(9), 1133-1147.

more into post-secondary STEM education and STEM-linked careers; and (c) improving investments in STEM education among women and historically under-represented minorities, and high-need schools. In this regard, the evidence is mixed. Some programs specified by the COMPETES legislation did receive funding, although few received funding at the levels authorized by either Act. For example, the Teachers for a Competitive Tomorrow: Baccalaureate Degrees and Master's Degrees programs, which were authorized by both COMPETES Acts, received annual average funding of approximately $1 million, although each had been authorized to receive more than $100 million in each fiscal year. Many programs, including the Department of Energy's Experiential-Based Learning Opportunities; Early Career Awards for Science, Engineering, and Mathematics Researchers; Discovery Science and Engineering Innovation Institutes; Protecting America's Competitive Edge (PACE) Graduate Fellowship Program; and Distinguished Scientist Program, each of which was authorized for between $10 million and $30 million in funding in FY2010, did not receive appropriations.

My understanding is that the NSF, which is the agency with the greatest responsibility for STEM education, has been able to support some STEM initiatives, even as the STEM education programs authorized by the COMPETES Acts have been winnowed and real (rather than nominal) for education and training programs have declined from 2003 to 2011. In particular, it appears as if the NSF has able to support postsecondary student funding, through the Graduate Research Fellowship (GRF) and Integrative Graduate Education and Research Traineeship (IGERT) programs by increasing the fraction of funding derived from its Research & Related Activities account.[22]

Overall, however, it does not appear as if the COMPETES legislation has substantially shifted investment in STEM education along the dimensions of its three initially articulated goals. Again, however, it does not appear as if STEM education, or associated outcomes, have declined substantially during the COMPETES era and this, itself, may constitute a substantial victory.

III.5. Modification of NIST programs

The modification of programs at the National Institute for Standards and Technology (NIST) was another clearly articulated goal of the COMPETES Act. While I was not able to conduct a rate-of-return analysis on the changes, it appears as if substantial progress has been made in funding and programs consistent with this aim. The Advanced Technology Program was replaced with the Technology Innovation Program, which was ultimately eliminated; the Hollings Manufacturing Extension Partnership Programs have been extended; and funding for both NIST Core Research and Facilities has been realized at levels not inconsistent with those envisioned by the COMPETES legislation. It is noteworthy that the levels of funding for NIST funding are orders of magnitude below those of other agencies, including the Department of Energy and the NSF.

[22] Gonzalez, Heather B. (2012) "An Analysis of STEM Education Funding at the NSF: Trends and Policy Discussion," *Congressional Research Service reports*, 9 April 2012.

III.6. Prizes

The 2010 COMPETES Reauthorization Act greatly enhanced the ability of federal agencies to reward progress in science and innovation with prizes. Agencies may conduct prize contests of up to $50 million with existing appropriations. The approval of prize authority has led to the establishment of a clearinghouse for federal prize programs, www.challenge.gov, which posts prize descriptions, eligibility conditions, submissions procedures, timelines, and rules. As of March 2012, www.challenge.gov hosted more than 150 prize challenges, representing more than forty federal agencies.[23] One of the most ambitious federal prize efforts was an initiative sponsored by the Department of Health and Human Services. Called the "Investing in Innovation" (i2) initiative, the effort involved a novel $5 million effort aimed at initiating innovations in Health Information Technology. A number of federal prize programs, most notably those operated by NASA, have already become the subject of academic study.[24]

The extent of federal prize programs continues to grow and it is too soon to measure the overall impact of such programs on innovation. The current scope of prize funding is many orders of magnitude smaller than federal intramural research programs; however, it is possible that success with federal prizes may contribute to momentum for yet larger attempts at inducements, such as those described by Kremer and colleagues.[25] More broadly, the opportunity for federal agencies to conduct innovation challenges affords greater latitude for organizational innovation than existed in the past. It is possible that the seeds sown by expanded federal prize authority will redound in ways that exceed the specific dollar value of prizes offered by federal agencies; at the moment, however, it is too soon to evaluate either this possibility or the specific impact of federal prize authority on innovation.

III.7. Additional aims

In addition to the objectives I address above, the COMPETES legislation also addressed additional aims, including the support of high-risk, high-rewards projects within each executive agency; and greater coordination of federal science and technology investments. I speak to progress on some of these dimensions in my working paper on the Act, but regret a lack of time to discuss these in greater detail during testimony today.

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[23] Office of Science and Technology Policy (2012) "Implementation of Federal Prize Authority: Progress Report," Executive Office of the President, March 2012.

[24] See, in particular, the work of Karim Lakhani and colleagues, including Kevin J. Boudreau, Nicola Lacetera, & Karim Lakhani (2011) "Incentives and Problem Uncertainty in Innovation Contests: An Empirical Analysis," *Management Science*, 57(5), 843-863.

[25] Michael Kremer and Heidi Williams (2010) "Incentivizing innovation: Adding to the toolkit," in Josh Lerner and Scott Stern, eds., *Innovation Policy and the Economy*, Volume 10, University of Chicago Press, 1-17.

IV. Concluding Remarks

I would like to address three areas in my concluding remarks. First, I would like to provide a quick summary of my attempt to understand the impact of the COMPETES legislation. My impression is the COMPETES Acts have led to a number of truly significant achievements. These include the development of ARPA-E, which seems like it is off to an effective start, the enhancement of Federal prize authority, the energizing of federal agencies around S&E objectives, and, perhaps most importantly in the long-term, the reaffirmation and codification of bipartisan support for physical science and engineering investment. The Acts also appear to have resulted in a substantial positive impact on federal investments in S&E relative to what might have occurred in the absence of these Acts. That said, it is important to recognize that the level of S&E funding has not kept pace with the authorizations of either Act and that a number of the objectives of the Acts, most notably those related to STEM education, have been omitted from appropriations throughout the half-decade since the initial Act.

A second issue that I would love to address is the question, "What is the optimal level of funding for S&E?" While the consensus in economics is that the rate of return to additional Federal investment is still high, unfortunately, it does not appear to me that there is a consensus in economics about the number or fraction of GDP that identifies the optimal level of investment. There is consensus that leadership in science and innovation continues to reap rewards in terms of jobs, productivity, and living standards, even as the world becomes increasingly connected and information flows ever faster across borders. In the spirit of the glass-half-full, I can say that science and innovation policy studies are developing more rapidly than in the past and, although labor studies and other areas of economics have a longer history of policy evaluation, this area of economics is making strides and we should be able to provide more guidance to policy in the future than we have in the past.

The final issue I would like to address regards ideas for what may be done in an era of limited budgets to improve S&E competitiveness. From the standpoint of my profession, this is a bit reckless as I do not link each suggestion directly to a specific study; however, I believe that the ideas have a solid basis in prior research. One issue around which there is consensus in economics is that leadership in the human capital race is important for overall science and engineering leadership. Supporting the ability of universities to attract the world's best, brightest, and most motivated students and then enabling those individuals to remain in the United States, to continue their contributions to science and innovation, and to encourage those individuals to develop growing businesses is an idea around which there is substantial consensus among economists who study innovation. Two other ideas for which there is general support are the initiatives to support industry commercialization of university-generated ideas, potentially through subsidies or tax credits, and continued advocacy of intellectual property abroad. Two additional ideas that I will risk are that it would be helpful for Congressional acts and Federal initiatives to be formulated with an eye towards enabling program evaluation and rate of return calculations and the idea that development of scientific and innovation capabilities abroad does raise all sails, both by contributing to the increasingly rapid pace of technological development and by improving the capabilities of American universities and firms via competition. Science and innovation are not a zero-sum game. Improvements in scientific and innovative capabilities abroad augur well for American consumers and for American firms seeking less-expensive, more valuable intermediate goods. However, the evidence does suggest that the greatest rewards in terms of jobs, productivity advantages, and social welfare (or lifestyle) do accrue to those geographic regions with leadership in scientific and technical capabilities.

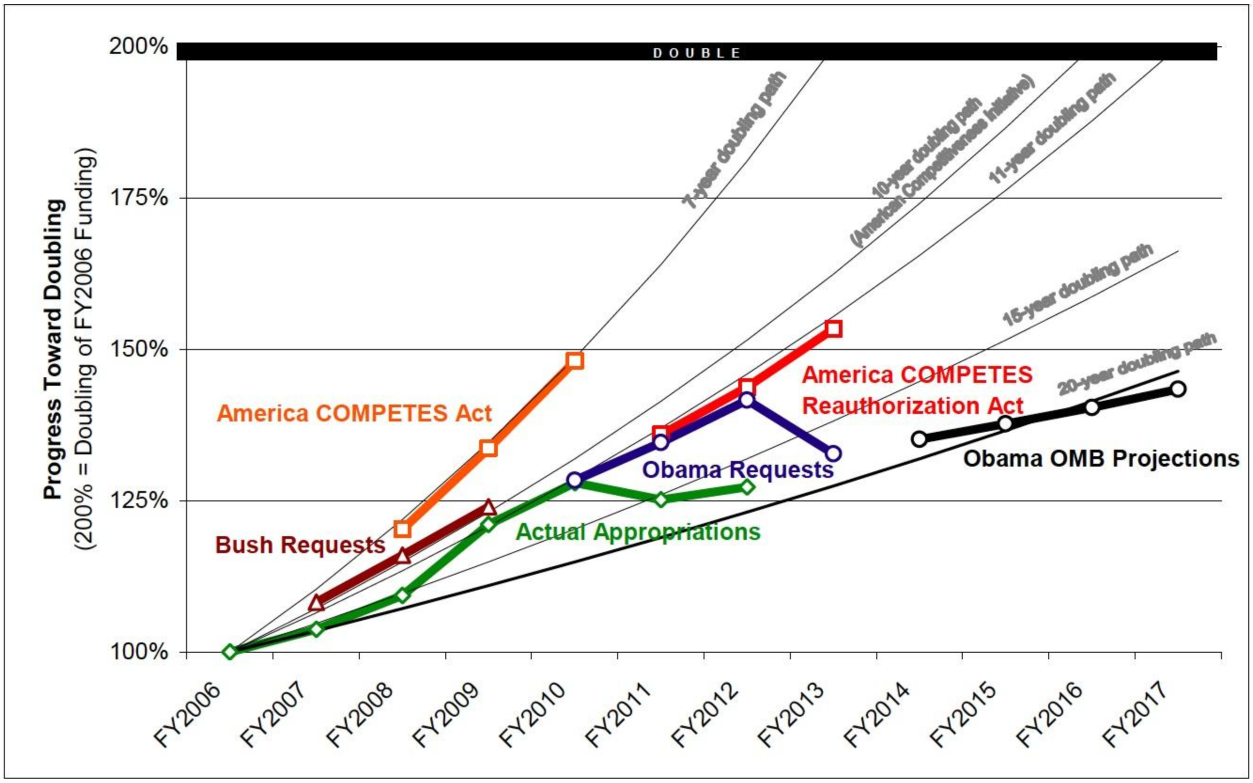
Table 1 – Overview of FY2009 Funding Authorizations for 2007 America COMPETES Act Programs

Funding includes both FY2009 Omnibus Appropriations Act and American Recovery and Reinvestment Act	
Programs Presumably Not Funded in FY2009	**Programs Funded at Authorized Levels in FY2009**
Department of Energy • Pilot Program of Grants to Specialty Schools for Science and Mathematics • Experiential Based Learning Opportunities • Summer Institutes • National Energy Education Development • Nuclear Science Talent Expansion Program • Hydrocarbon Systems Science Talent Expansion Program • Early Career Awards for Science, Engineering, and Mathematics Researchers • Discovery Science and Engineering Innovation Institutes • Protecting America's Competitive Edge Graduate Fellowship Program • Distinguished Scientist Program **Department of Education** • Advanced Placement & International Baccalaureate Program • Math Now • Summer Term Education Program • Math Skills for Secondary Skill Students • Advancing America Through Foreign Language Partnership Program • Mathematics and Science Partnership Bonus Grants **National Science Foundation** • Laboratory Science Pilot Program	**Department of Energy** • Office of Science **National Science Foundation** • Research & Related Activities • Major Research Instrumentation • Professional Science Master's Degree Program • Robert Noyce Teacher Scholarship Program • Graduate Research Fellowship Program • Major Research Equipment and Facilities Construction **NIST** • Scientific & Technical Research and Services • Construction & Maintenance

Source: Deborah D. Stine (2009) "America COMPETES Act: Programs, Funding, and Selected Issues," Congressional Research Service, RL3428, April 17, 2009.

Figure 1. The "Doubling Path" in Research Funding for the Physical Sciences

Figure tracks potential doubling of federal funding for science and technology, including funding for the NSF, DOE Office of Science, and NIST Core Research and Construction relative to FY2006 appropriations levels



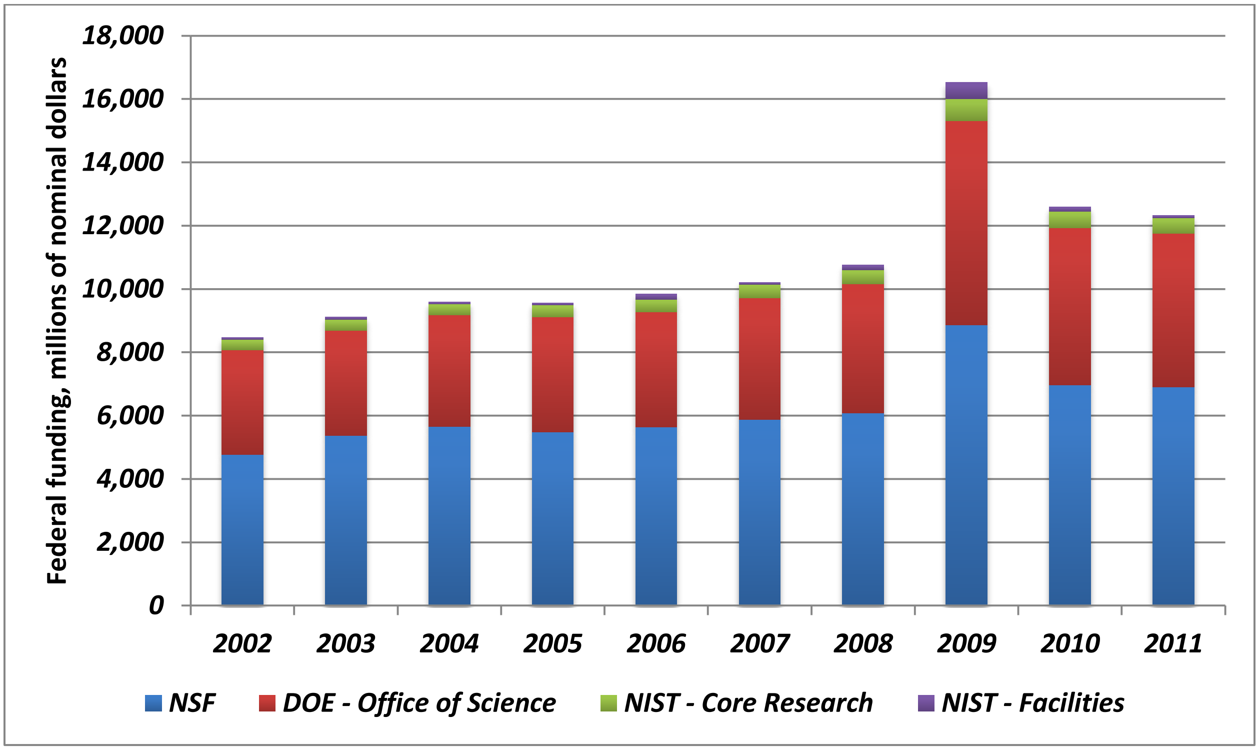
Source for figure & notes below: John F. Sargent Jr. (2012) "Federal Research and Development Funding: FY2013," Congressional Research Service report, R42410, 15 June 2012.

Notes: "The 7-year doubling pace represents annual increases of 10.4%, the 10-year doubling pace represents annual increases of 7.2%, the 11-year doubling pace represents annual increases of 6.5%, the 15-year doubling represents annual increases of 4.7%, and the 20-year doubling represents annual increases of 3.3%. Through compounding, these rates achieve the doubling of funding in the specified time period. The lines connecting aggregate appropriations for the targeted accounts are for illustration purposes only. With respect to "Actual Appropriations," aggregate data for FY2006-FY2012 is based on regular appropriations (funding provided under the American Recovery and Reinvestment Act of 2009 (P.L. 111-5) is not included). America COMPETES Act figures are based on aggregate funding for the target accounts as authorized by the act. America COMPETES Reauthorization Act of 2010 figures for FY2011- FY2013 are based on aggregate funding for the target accounts as authorized by the act" (Sargent, 2012, p. 9).

Figure 2: Funding for "Doubling Path" accounts in millions of nominal (current) dollars, FY2002-20013

FY2002-FY2011 (Actual), FY2012 (Estimated), and FY2013 (Request)

FY2009 combines funding from FY2009 and the American Reinvestment and Recovery Act.



Notes: "NIST - Core Research" reflects funding for the "NIST-Scientific and Technical Research and Services" (NIST-STRS) account. Budget figures for this account and the "NIST - Facilities" account do not include items appearing under the "NIST - Industrial Technology Services" (NIST-ITS), which include programs such as the Advanced Manufacturing Technology Consortium (AMT), Advanced Technology Program (ATP), Technology Innovation Program (TIP), Baldrige Performance Excellence Program (BPEP), and Hollings Manufacturing Extension Partnership (MEP).

Source: FY2002-FY2005 data from NSF, DOE-Office of Science, and NIST annual budget requests (websites listed below); FY2006-FY2013 data from John F. Sargent Jr. (2012) "Federal Research and Development Funding: FY2013," Congressional Research Service report, R42410, 15 June 2012. NSF budget data from www.nsf.gov/about/budget/; DOE-OS data from science.energy.gov/budget/; NIST budget data from www.nist.gov/public_affairs/budget/. Budget data taken from reports in FY+2 (e.g., FY2006 report used for FY2004 budget data); JF verified that this method yielded match with budget data reported by Sargent (2012).