What if Congress Doubled R&D Spending on the Physical Sciences?

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Abstract

Many business, academic, and scientific groups have recommended that the Congress substantially increase R&D spending in the near future. President Bush's American Competitiveness Initiative calls for a doubling of spending over the next decade in selected agencies that deal with the physical sciences, including the National Science Foundation. We consider the rationale for increased R&D spending in the context of the globalization of economic activity. To assess the likely consequences of a large increase in R&D spending, we examine how the 1998-2003 doubling of the NIH budget affected the bio-medical sciences. We find that the rapid increase and ensuing deceleration in NIH spending created substantial adjustment problems in the market for research, particularly for younger investigators and failed to address long-standing problems with scientific careers that are likely to deter many young persons from choosing a scientific career. We argue that funding agencies should tilt their awards to younger researchers on the grounds that any research project does two things: it produces knowledge and adds to the human capital of researchers, which has greater value for younger persons because of their longer future career life-spans.

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In his 2006 State of the Union Address President Bush announced the American Competitiveness Initiative – a program that promised to spend substantial federal moneys to redress perceived US weaknesses in science and technology. One of the centrepieces of the Initiative was a commitment to double basic R&D spending over the next decade at the National Science Foundation (NSF), Department of Energy's Science Core programs, and the National Institute of Standards and Technology. Another component called for $4.6 billion in R&D tax incentives, intended to induce greater R&D spending by private firms. Much of the President's program was based on the National Academy of Sciences' 2006 "Gathering Storm" report, which called for large increases in federally funded R&D in physical sciences, among other policies, to keep the US in the forefront of science and technology.

Congress responded to the Competitiveness Initiative by authorizing increased R&D spending but it did not appropriate the funds. The authorization signaled a desire to increase R&D support. Failure to appropriate the money reflected partisan disagreements in Washington and the greater importance of other budgetary and political considerations. The result was a modest change in federal spending for R&D in the physical sciences and stagnant federal support of R&D overall that reduced spending in real terms. Congress did, however, extend tax incentives for corporate R&D spending.

Between 2000 and 2006 many studies and reports called for improvements in the country's capacity in scientific and technological activity (Freeman, 2006) by increasing R&D spending and investing more in science and engineering education. The call for increased resources for science and engineering was based on a general widespread belief that "the solutions to many of the challenges facing society have their roots in our scientific understanding, where technology increasingly drives the global economic engine, and where many other nations are gaining rapidly in scientific and engineering capabilities." (NSF, 2007) Business leaders particularly in high-tech sectors were worried about increased foreign competition and the decline of comparative advantage in the R&D intensive sectors of the economy. The science community decried a decreased rate of funding basic research proposals, that "may be negatively impacting the academic

research community, resulting in increased workload and diminished S&E capacity" (IPAMM, 2007) The National Institute of Health (NIH) complained that it could not support as many high quality research proposals as it had in the past, and NIH and NSF reported that their peer review systems were over-burdened with a growing number of research proposals. The military and defense establishment, whose hires are often limited to US citizens, feared that not enough citizens and residents were choosing science and engineering careers.[1] Given general recognition that the career incentives for entering science and engineering were too low to attract more US students, most studies favor educational initiatives designed to improve science in schools as well as spending increases that boost demand for scientists and engineers. The National Academy of Sciences' Board of Life Sciences recommended that NIH "take steps to provide PostDocs and early-career investigators with more financial support for their own research and establish programs for new investigators and staff scientists among other mechanisms." (NAS, 2005). The American Academy of Arts and Sciences (2008) report on alternative models for funding the sciences called for new research funding for young investigators and for risky projects that could have high payoffs.

The widespread support for increasing the US investment in science and engineering, particularly in the physical sciences, makes it likely that in the near future Congress will substantially boost R&D spending. There are precedents for a surge in R&D spending to meet perceived national opportunities or needs. In 1998 a bipartisan coalition in Congress pressed the Clinton Administration to increase the R&D budget substantially, with particular emphasis on the NIH. The coalition favored a doubling of NIH spending over ten years but the Administration chose an even more rapid increase-- a doubling in the budget over the next five years. In 2003 the Bush administration completed the doubling, but then kept the budget roughly stable in nominal terms. The Soviet sputnik spurred a similar huge increase in federal R&D spending between 1956 and 1962. There have been smaller bursts of financial support for particular programs deemed of special national interest in given time periods such as the War on Cancer,

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[1] An alternative to broad based incentives to increase supply would be for military and defense sectors to attract more US citizen scientists and engineers by raising their pay, which would reallocate more citizens to those jobs even if the number of US-born scientists did not change).

Apollo, and the Nano-technology Initiative.

What are the consequences of large increases in R&D spending in a short period of time? How might an increase be best structured to produce a bigger sustainable research system? Is increased spending likely to improve the job market for young scientists and engineers and attract more Americans into the fields as it has done in the past?

This paper examines these questions. It reviews some of the evidence on the state of science and engineering that motivated the Competitiveness Initiative and the diverse reports that called for increased R&D spending. Then it assesses the doubling of the NIH budget from 1998 to 2003 and the ensuing deceleration in spending, focusing on the adjustment problems that rapid acceleration and deceleration of spending creates for the research community. Based on those experiences, we consider ways for the federal government to boost R&D spending in the future more efficiently

Our main conclusions are:

1. Increased R&D spending by itself is unlikely to resolve problems with the American scientific research endeavor. More funds are necessary but not sufficient to improve the opportunities for young researchers and to place basic research onto a long-term sustainable growth path.

2. One-time surges in spending, which produce a deceleration in spending after the surge, have sizable adjustment costs. Instead of making "doubling" spending a goal, policy-makers would do better to determine a desired R&D to GDP and increase funding *smoothly* to attain that goal. In the absence of this, agencies and universities need "bridge funding" or stabilization policies to buffer research activity from rapid changes in spending.

3. Researchers submit more proposals when a funding agency increases the number and value of research grants. They tend to respond to cutbacks in the number of awards in the short-run by making multiple submissions, which can stress the peer review process and stability of the research market. Funding agencies thus have to balance changes in the number and value of grants carefully to reduce the adjustment costs of changes in budgets.

4. Viewing research grants as investments in the human capital of the researcher as well as in the production of knowledge, funding agencies should support proposals by younger researchers over equivalent proposals of older researchers. Younger researchers are more likely to use their increased human capital in future research than older researchers because they have a longer career ahead of them.

1. UNDERSTANDING THE CONCERN
The Background

The U.S. share of science and engineering activity around the world is declining (see Table 1). This decline is surely inevitable as the rest of the world catches up to the US in higher education and R&D. In 1970, with just 6% of the world's population the US had 30% of world's college students and graduated about 40% of science and engineering PhDs. In 2005, as countries around the world invested heavily in higher education, the US share of college enrollments was just 13%. The U.S. share of the world's science and engineering graduates declined more rapidly than its share of college students because science and engineering attract large proportions of students overseas than in the US. At the doctorate level, the US share of scientist and engineering degrees fell to 20% in 2000 and is expected to reach 15% in 2010. The US contributed about half of the world's R&D spending in the 1970s, but this dropped to about a third by 2003.

Partly in response to the growth of scientific and engineering talent around the world, the multinational firms who undertake most industrial R&D are increasingly investing in R&D outside the US as well as in the US. The large number of scientific and engineering graduates in China and India combined with the lower wages in those countries make them attractive sites for multinational R&D facilities. In 2004 China reported that multinationals had established over 750 R&D facilities whereas in 1990, they had none. In 1991 the US spent 13 times as much on R&D as China. In 2003 it spent 3.4 only times as much (Freeman, 2006).

About 60% of basic research in the US is conducted in universities, largely funded by the federal government.[2] The major federal funding agencies for basic research in the

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[2] National Science Foundation, National Patterns of R&D Resources: 2006 Data Update , table 2 shows

physical sciences are the NSF, Department of Defence, Department of Energy, and National Institute of Standards, while NIH is the main funder of basic research in the biological sciences. The NSF supports over 50% of the Federal non-medical fundamental research at U.S. colleges and universities. From 1990 to 2006 the share of R&D funded by the federal government fell from 40.5% to 28.4%. Compared to GDP federal R&D fell from 0.112% to 0.073%.[3]

As the US share of scientists and engineers and R&D worldwide has trended downward, so too has the US share of scientific publications and citations. Data from the Chemical Abstracts Services shows that in 1980 the US had 73% of papers in the field whereas in 2003 US researchers had only 40% of the papers (Freeman, 2006). The US share of science articles published fell from 38.5% in 1988 to 30.3% in 2003 while the US share of citations dropped from 51.8% in 1992 to 42.4% in 2003 (NSF, Science and Engineering Indicators, 2006)

Given the demography of the world, it is virtually impossible for the US to maintain the dominance in science and technology that it enjoyed in the last half of the Twentieth Century. Still, the country can be a leading center of excellence of basic R&D if it invests more in R&D and in making science and engineering careers attractive to young Americans and to immigrant scientists and engineers.

Why care?

The calls for increased federal spending on basic science and related policies are motivated by economic and national security concerns. On the economic front, there is widespread belief that the US is more likely to maintain production and jobs in high tech sectors if the US pioneers scientific advances than if other countries pioneer those advances. The growth of high tech employment in Silicon Valley and in University-based locations of scientific excellence suggests that innovation, production, and employment

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reports that the US spent $63.6 on basic research in 2006 and that $36.9 billion was in colleges and universities, of which $24.5 billion was funded by the federal government (66%)
http://www.nsf.gov/statistics/nsf07331/pdf/tab2.pdf
[3] U.S. R&D increased by 6% in 2006 according to NSF Projections (NSF, 07-317, April 2007 projected; 1990 from NSF, National Patterns of R&D Resources, 1994, March 1995)

in high tech occur largely in areas with excellence in science.[4] Since leading edge industries have the fastest long run productivity growth, pay higher wages to production workers,[5] and offer spillovers of knowledge to other sectors, there is global competition for these industries. Advocates of more public spending for basic R&D also argue that the more basic R&D performed in the US, the more likely is it that the country will attract industry in research-intensive sectors[6].

Taking the argument a step further, many analysts note that the US's comparative advantage in global markets lies in high tech, research-intensive industries. Were the US to lose comparative advantage in those sectors, it would have to sell goods or services with lower technological content on the global market and compete with countries with similar technology and low wages. The gains from trade would lessen and wages would fall for American workers.

In terms of national security, proponents of increased US investment in science and engineering note that current "technologies for counter-terrorism and homeland security are outcomes of earlier US investments in science, technology, and education"(Jackson, 2003), and argue that science and technology offers the best defense against terrorist threats based on chemical, biological, or radiological attack. The National Security Agency and various Defense Department laboratories and contractors hire only US citizens for critical research tasks, which make them particularly sensitive to the supply of citizens in the relevant fields. The scientist and engineering work force in security areas has become top heavy with older workers, which will create large replacement demands for citizen researchers.

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[4] Zucker, Darby and Brewer (1998) show that there are clusters of biotechnology activity around "star researchers" in nearby universities. Similarly, US states with greater supplies of university graduates have been in the forefront of the "new economy" (Progressive Policy Institute, 2002). For evidence on the impact of the aggregate impact of R&D on productivity see Jones and Williams (2001) and Griliches (1998).
[5] Earnings of production and non supervisory workers in the three highly R&D intensive sectors, aerospace, chemicals, and computers and electronic products averaged $ 20.00 per hour compared to $ 15.97 per hour for production and non supervisory workers in the country as a whole.
http://www.bls.gov/web/empsit.supp.toc.htm#historical
[6] The idea that other parts of the value chain locate close to R&D is widespread. This may be much less true in today's more globalized world as the value chain can increasingly be disaggregated. For example, in pharmaceuticals drug discovery may be done in the US, but clinical trials may be located in Eastern Europe

A more critical assessment

Economic analysis provides some support for these arguments but also offers serious caution. For reasons of *knowledge spillovers* and *economic competitiveness*, investments in basic research can pay off in ways that require major public investments[7]. But to determine whether the US is currently at, below, or above, the socially optimal level of public spending on basic research is not an easy task. In a global economy, where other countries are also investing in basic and applied research, and where historically US-owned firms have become "global firms", it has become more difficult than in the past to assess the optimal level of public support for basic research.

Knowledge spillovers

Economists focus on knowledge externalities as the main reason for public spending on research. Because of the public good nature of knowledge, research "spills over" to other agents and is not fully captured by the person or firm who originally invested in it. The result is that the private market will invest less in R&D than is optimal socially, giving a strong rationale for government spending on R&D in various ways. A large body of evidence shows that knowledge spillovers are statistically and economically significant[8]. Such spillovers are the foundation of modern growth theory (e.g. Aghion and Howitt, 1990; Romer, 1989).

While knowledge has always spilled across international boundaries[9], the spread of higher education and transfer of technology by multinational firms from advanced countries has made R&D more international than ever before (Freeman, 2006). If knowledge spread instantly across boundaries, the rationale for government subsidies to research would decrease in favor of global subsidies[10]. In reality there is some localization or "stickiness" to research so that the country or region within a country that

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and drug manufacturing in India.
[7] There may be other market failure justifications, such as imperfections in financial markets.
[8] For a classic survey see Griliches (1992) and for more recent evidence see Bloom, Schankerman and Van Reenen (2006).
[9] See Keller (2004) for a survey and Griffith, Harrison and Van Reenen (2006) for recent evidence.
[10] More generally, the rationale for country support depends on the relative rate of diffusion of knowledge within a country and across countries. If diffusion rates increase proportionately the social vs. private margin for national investments would be stable.

does the research disproportionately benefits from the spillover. Modern communications such as the Internet and falling transport costs appears to have reduced this advantage (Griffith, Lee and Van Reenen, 2007). Consequently, the spillover justification for R&D subsidies has declined in importance. By a similar logic, the growth of an international labor market for scientists has meant that many US universities attract PostDocs and faculty from the international market that reduces the necessity of using US taxpayers' money to train the next generation.

Economic "Competitiveness"

Firms compete in the marketplace: when one firm does better it is often at the expense of other firms. Countries do not "compete" in the same sense. While there are situations in which one country's gain is another country's loss (e.g. Baumol and Gomory, 2004) when one country improves its productivity through R&D-induced or other innovations, the benefits are likely to flow to persons in other countries as well. Given the public goods nature of R&D and trade in goods and services, the expansion of modern scientific and technological activity in the rest of the world should improve the lives of people worldwide regardless of the location of the innovative activity. If a medical scientist in China, India, the UK, or anywhere else finds a cure for cancer, we will all benefit. If a German innovation lowers the price of household goods and services, we will all benefit. If scientific advances and innovations overseas lead foreign firms to set up production facilities in the US or if US firms exploit overseas innovations to produce in the US this will create jobs as well as better products.

At the same time, countries can use publicly funded R&D to boost their country's strategic position in some sectors, potentially creating comparative advantage in those areas that would not exist absent the public support (e.g. in the commercial airline market). Strategic trade theory has models in which R&D subsidies can help countries attract and retain rent-generating R&D intensive sectors (e.g. Brander and Spencer, 1985)[11]. At the same time, the fall of transportation costs and entry barriers has made

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[11] Convincing empirical evidence of the quantitative importance of these strategic R&D competitions is rare. Those that have studied it generally find that the strategic R&D competition effect is dwarfed by the knowledge spillovers effect (e.g. Bloom, Schankerman, Van Reenen, 2006).

multinational R&D more internationally mobile. For example, "footloose" R&D may be able to move more quickly to jurisdictions offering a more favorable tax regime for R&D (see Wilson, 2008, for evidence of this in the US context). This should make it easier to attract R&D and sharpens the case for subsidizing science on economic competitiveness grounds.

These arguments are summarized in Table 2. In our view, knowledge spillovers are the strongest argument for R&D subsidies, especially for basic research compared to applied research. Nonetheless, globalization has probably weakened the case for such basic subsidies, whereas (to the extent they matter) it has strengthened the case for subsidies to applied research. There are two caveats to this assessment. First, if basic research is complementary to applied research, then subsidies to basic research could "crowd in" more applied research. There is a little evidence on this from the positive local effects of university research (e.g. Jaffe, 1989). However, at some point basic and applied research are substitutes – in terms of Federal subsidies for example, spending more on one means cutting back funding on the other. Secondly, the normative argument for strategic R&D subsidies is weakened by the fact that other countries may well respond to US R&D with their own subsidies. When countries compete in subsidizing R&D to attract high tech firms, it is like an auction for multinational R&D. The main winners of this auction are likely to be multinational companies and their shareholders rather than taxpayers.

The US position

While the US share of world R&D and the scientific and engineering work force has fallen as other countries have invested higher education and research, the US remains the world leader in scientific and technological competence. The US spends more on R&D in total dollars and has more scientists and engineers doing research, basic and applied, than any other country. The ratio of R&D to GDP in the US is higher than in other major advanced countries, save for Japan (NSF, 2008, Appendix table 4-35). Despite the EU's "Lisbon Agenda" push to raise the R&D/GDP ratio to 3%, the large countries in the European Union continue to fall far short of the US's level of 2.6% in

2005. European countries have increased government investment in R&D relative to GDP but European firms invest a much smaller share of revenues on R&D than do US firms, who have raised their R&D budgets even as the federal government has invested less.

How has the US done in the high tech industries where R&D is a critical aspect of company success? Table 3 shows that from 1980 through 2003 the US did well by several measures of innovativeness and production in high tech even with declining shares of the world's scientists and engineers and scientific papers. The share of USPTO patent applications going to first-named US persons remained roughly constant from 1985 to 2005 while the share of European Patent Office applications going to first-named US persons shows only a slight decline over time. In high-tech manufacturing[12] the US share of *world* gross revenue and of value added rose during the 1990s boom and remained high through the early 2000s. In the global economy where firms outsource parts of activities to different places in the world, the most meaningful measure of US economic activity relative to other countries is value added. The US share of world value added in high tech rose from 25% in 1990 to 42% in 2003.

Where US performance has been less impressive is in the balance of trade. In 1980 and 1990 the US ran a large balance of trade surplus in high tech, which partially counterbalanced the country's trade deficit in other goods. The trade balance in high tech turned negative in 2000 and has gone more negative since, along with the rest of the country's balance of trade (Weller and Wheeler, 2008).

Since patents and production depend on past scientific advances, it is possible that the positive picture of US performance in high tech scientific-intensive sectors shown in table 3 reflects the advantages of US investments in R&D in past years. From this perspective, the call for increased federal R&D spending and the investment in science and engineering work force is more of a pre-emptive warning than a response to any economic disaster. Given that research is exploration of the unknown with payoffs in the future, this is arguably the only way to approach the competitiveness initiative and plethora of calls for additional R&D spending.

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[12] This is defined by the OECD to include aerospace, communications equipment, office machinery and

2. THE NIH DOUBLING

Background

To see how a rapid increase in R&D spending on the physical sciences might affect researchers, we examine the 1998-2003 doubling of the NIH research budget and the subsequent deceleration of NIH funds.[13] Figure 1 displays the level and percentage change in NIH funds from 1995 through 2007. In the 1998-2003 period the NIH budget grew by double-digit amounts in nominal terms. This raised annual NIH spending from about $14 billion to $27 billion. In constant CPI dollars real research funding increased by 76%. By contrast, real NIH funding from 1987 to 1997 (NSF, 2004, Table 1H) increased by only 40% (deflated by the CPI). Thus the doubling essentially raised NIH spending by twice as much in five years as it had done in the previous decade. In constant dollars measured by the Biomedical R&D Price Index (BRDPI), which rose more rapidly than the CPI, the doubling increased spending by 66%.

When the doubling ended, the Bush Administration recommended a rapid deceleration in NIH funding, which Congress largely followed. The rate of increase dropped in nominal terms from double digits to 3% in 2004, then to 2.2% in 2005, to -0.1% in 2006 and to 0% in 2007. Using the CPI deflator, real NIH spending was 6.6% lower in 2007 than in 2004. Using the BRDPI deflator, real spending was down 10.9%. The drop in the real NIH budget shocked the agency and the bioscience community, as it undid much of the extraordinary increase in funding from the doubling. NIH director Elias Zerhouni said that even in "the worse scenario, people really didn't think that the NIH budget would go below inflation" (Couzin and Miller, 2007). NIH responded first by reducing the number of grants awarded, and then by reducing the amounts of grants.

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computers, pharmaceuticals, and scientific instruments

[13] The experience of the NIH doubling is more relevant to a future increase in R&D than the doubling of federal R&D spending following the Sputnik. In that period the supply of S&E workers was primarily domestic, so that the increase raised salaries greatly, inducing more native students to enter the field and increase supply in the future (Freeman, 1975). Today, with the international market in science and engineering workers, supply is more elastic so that increased spending will likely have a greater impact on quantities than wages.

For the Post Doctorate researchers trained during the doubling period and for the young researchers who had obtained first independent research grants during the doubling, the deceleration created a career crisis. For principal investigators (PI's) with NIH support, it created major problems, as the probability of continuing a grant and making a successful new application fell and as the size of grants shrunk. Research labs were pressured to cut staff. At NIH, which is the single largest employer of bio-medical researchers in the country, with over 1,000 principal investigators and 6,000-7,000 mostly PhD researchers the reduced funding led to a contraction in the number principal investigators by 9%. "A completely new category of nightmare" was the description given by a researcher in the National Institute of Child Health and Development, which was especially hard hit (*Science*, March 7, 2008, p 1324). Others in the scientific and university community also reacted with dismay or horror. Typical examples are:

"The marvellous engine of American biomedical research that was constructed during the last half of the 20th century is being taken apart, piece by piece." -- Robert Weinberg (founder of Whitehead Institute) *Cell*, July, 2006.

"Without effective national policies to recruit young scientists to the field, and support their research over the long term, in 10 to 15 years, we'll have more scientists older than 65 than those younger than 35. This is not a sustainable trend in biomedical research and must be addressed aggressively."-- NIH Director Zerhouni.

While most of the scientific community views the doubling as having increased the rate of bio-medical knowledge creation above what it otherwise would have been, Sachs (2007) has pointed out that the number of biomedical publications from US labs carried on growing at a steady rate after 1999 (as did the rest of the world). Indeed, the share of US S&E articles in the biological and medical sciences in the 1995 to 2005 period (NSF, 2007, Appendix table 5-36) shows no indication of any shift in publications toward these areas, despite their increased share of the nation's basic research budget. To be sure, without a careful assessment of the quality of articles and a well-specified counterfactual of what would have happened absent the doubling, we cannot rule out the possibility that the funding did in fact spur more and better science. But the data seem consistent with the notion that by increasing spending quickly in a short period, NIH did

less to increase scientific production than if it had been able to increase spending more evenly over time.

As this rendition indicates, the NIH doubling experience was flawed. The problems induced by rapid increase in spending followed by a real decline in NIH budgets offer lessons that can guide future increases in government R&D spending. One lesson is that frontloading an increase in spending in a short period of time creates large adjustment costs that produce "less bang for the buck" than would a smoother pattern of spending. Another lesson is that the way in which agencies divide changes in funding between the size of grants and the number of grants and between younger and older researchers can exacerbate or ameliorate the long-term impacts of the adjustment problem.

Big Push vs. Gradual Change

On the first lesson, we note that a rapid acceleration in spending followed by a rapid deceleration is an inefficient way to get to a permanently higher level of research activity and stock of research scientists. To see why this is so we apply the classic accelerator model of investment in physical capital to increasing R&D. We treat the stock of research by the "perpetual inventory formula" $K_t = I_t + (1-\delta)K_{t-1}$, where K is the number of scientists engaged in research; I is the number of newly trained scientists (Post Docs) who enter into research and δ is the proportion of scientists who leave research each year for retirement or other reasons. In this model K_t is the stock of activity in year t, I_t is the flow of new activity and δ is the depreciation rate. K and I are related to the number of trained scientists or new scientists by some fraction θ, which measures the proportion that work in academia doing basic research. The rest are engaged in other activities – working in industry, government – or teaching, doing administration, and so on.

In the simplest accelerator model of investment, an increase in the demand for output induces firms to seek a higher capital stock to meet the new demand. This increases investment spending quickly. When firms reach the desired capital stock, they reduce the rate of investment sharply. Analysts of business cycles have long used this

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model to explain greater volatility of investment than of consumption spending, which contributes to the cyclical fluctuations in the economy. In the case of basic R&D, assume that society wants to increase the stock of research activity from K^{OLD} to the new desired level of K^{NEW}. Note that the goal is to increase the stock of research activity, not to "double" or otherwise increase the flow of spending. While it may be useful to package an increase in R&D as a spurt in spending to attract public or political support, the goal should be the sustainable stock of research activity, not a semi-arbitrary target increase in spending.

The optimal path to the higher stock depends on the costs of adjustment, which will include such things as disruptions to labs, hiring new staff, buying new equipment, and so on. Most empirical studies find evidence that adjustment costs for R&D are substantial compared to other forms of investment[14]. We assume that the costs rise more than proportionately with the size of the change in any period. Building one new R&D lab involves disruption; building five new labs at the same time is likely to be more than five times as disruptive[15]. Many economic models of adjustment use a quadratic term to measure the likely cost of adjustments, so that if a 5% increase in activity costs $10 a 10% increases costs more than $20. If adjustment costs take any convex form of this type *the ideal adjustment path is a slow incremental movement to the new desired level*. In terms of increasing R&D funding this would mean increasing demand slowly in order to reach K^{NEW} rather than increasing it in a sudden burst.

Figure 2 shows the difference between the optimal relatively smooth adjustment to the new level of *K* and adjustment that more closely mirrors the NIH doubling. At the start of the period investment is just equal to the depreciated old capital (e.g. new Post Doc flow exactly balances the retiring older scientists so $I_t = \delta K_{t-1}$). The dotted line of circles shows the ideal increase to the new level K^{NEW}. The line of triangles is closer to what actually happened. The area in between shows the difference and will determine the inefficiency of the system. The inefficiency means that society could have greater total

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[14] Hall (1992), Himmelberg and Peterson (1994) or Bond and Van Reenen (2008).

[15] Adjustment costs come in many forms. There certainly was a very rapid increase in building new R&D labs which caused campus disruption. But the costs of advertising, training an hiring new staff like Post Docs over a rapid period is also a significant cost. Finally, there are system wide adjustment costs that we discuss below.

R&D activity in the long run if it increased spending more gradually. With quadratic adjustment costs, the inefficiency can be substantial[16].

The way bio-medical research works, with senior scientists running labs in which Post Doctorates and graduate students perform most of the hands-on work, much of the adjustment costs fall onto young researchers. An increase in R&D, as with the NIH doubling, increases the number of Post Docs hired and the number of graduate students that principal investigators seek to attract to their labs. Paralleling the rapid rise of investment when demand for output rises in the accelerator model of physical capital, the number of Post Docs/graduate student researchers grows sharply with increased basic R&D. The benefits or costs of the adjustment fall disproportionately on the new entrants into the market. On the benefit side, increases in demand tend to raise pay and job opportunities more for new graduates than for older scientists. On the cost side, young persons trained during an upsurge in spending who enter the job market after the upsurge will compete with a larger supply of young biomedical researchers with no greater or even fewer independent research opportunities than when they were attracted to the field.

Part A of Figure 3 shows that during the doubling period the number of Post Docs increased rapidly while the number of principal investigators barely changed. Part B shows that much of the increase in Post Docs during the doubling period came from foreign-born PhDs, of whom about half were trained outside the US. To conduct their research, principal investigators recruited Post Docs outside the US when the domestic supply was limited.

Even before the doubling there was a major imbalance between the number of graduate students and Post Docs working in US labs and the number of tenure-track academic jobs for which they could compete. In 1987 the ratio of Post Docs to tenured faculty in the life sciences was 0.54. That is, there was approximately one Post Doc for

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[16] If R&D spending were mainly an irreversible fixed cost then the optimal adjustment path in Figure 2 would not be smooth adjustment, but rather a sudden shift closer to the actual change. This is unlikely to be a good description of adjustment costs however, especially at the aggregate level. Also note that our analysis assumes ignores any possible advantage to producing new research earlier than later beyond the standard discounting of future benefits -- for instance through spillovers over time that improve the productivity of future research. If there are such gains, they must eventually suffer from diminishing returns so that rising adjustment costs dominate the calculation on the margin where the decision about funding is made.

every two faculty. By 1999, the ratio of Post Docs to tenured faculty had risen to 0.77.
The situation did not change much in the doubling period. The number of full-time
senior faculty in the life sciences grew by 13% (NSF, 2008, appendix table 5-19) while
the number of Post Docs in biological sciences grew by 18% (NSF, 2006, table 49). In
the 1970s about three quarters of Post Docs obtained academic jobs, but at the ratio of
Post Docs to tenured faculty in the 2000s, no more than 20% to 30% of the increased
number in the 2000s can expect positions in academic research. The vast bulk of Post
Docs will end up in non-academic research jobs. The slowdown of NIH spending after
the doubling led to effectively no growth for senior faculty and of the number of Post
Docs.

In sum, the rapid acceleration and deceleration of NIH spending created
substantial problems for researchers and potential researchers. In considering any future
increases in federal support for basic research, policy-makers should focus on attaining a
socially desirable and sustainable rate of scientific activity relative to GDP rather than on
increasing the rate of spending over a short period. The optimal policy is to move slowly
to the desired level of R&D, minimizing as far as possible adjustment costs, rather than
following a "feast then famine" spending policy. We offer some suggestions as to how to
do this in a world where Congress sets budgets annually in our conclusion.

Internal organization of bio-medical research

At the heart of the American bio-medical science enterprise are the R01 grants
that NIH gives to fund individual scientists and their teams of Post Docs and graduate
students. The system of funding individual researchers on the basis of unsolicited
applications for research support comes close enough to economist's views of how a
decentralized market mechanism operates to suggest it should be a generally efficient
way to conduct research – compared, say, to some central planner mandated selection of
research topics. The individual researchers choose the most promising line of research
based on "local knowledge" of their special field. They submit proposals to funding
agencies, where panels of experts – "study sections" in the NIH world – provide
independent peer review of the proposals. The experts rank the proposals in accordance

with criteria set out by funding agencies. Finally, the agency funds as many proposals with high rankings that it can within its budget constraint.

On the funding side, moreover, there is also competition. There are funders besides NIH: NSF and other government agencies, foundations such as the Howard Hughes Foundation, a major supporter of independent researchers, and many foundations focused on particular diseases or issues. NIH itself, moreover, is not a monolith, but a diverse institution with a variety of programs, institutes, and centers that make their own research support decisions. With many agents seeking to support research and many scientists seeking support for their research, the level of competition would seem to be sufficiently broad and wide to yield good economic outcomes.

Within the market for bio-medical research, however, NIH is the 800-pound gorilla. For most academic bio-scientists winning an NIH R01 grant is critical to their research careers. It gives young scientists the opportunity to run their own lab rather than to work in the lab of a senior researcher or to have to abandon research entirely. For scientists who have an NIH grant, winning a continuation grant is often an implicit criterion for obtaining tenure at a research university.

Table 4 provides a statistical overview of how the RO1 granting process operated from 1980, when it was relatively easy for bio-medical scientists to obtain grant support, through the 1998-2003 doubling period and finally through 2007. It presents data for two groups of applicants for research awards. The first group consists of "potential new awardees" -- researchers who had not previously applied for an NIH grant.[17] Because Post Docs are not eligible to apply for the RO1s, the potential first time awardees are primarily newly hired assistant professors in research universities.[18] The second group consists of experienced researchers, those who had previously been funded by NIH.

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[17] Applicants are considered new investigators if they have not previously served as the principal investigators (PI) on any Public Health Service-supported research project other than a small grant (R03), an Academic Research Enhancement Award (R15), an exploratory/developmental grant (R21), or certain research career awards directed principally to physicians, dentists, or veterinarians at the beginning of their research career (K01, K08, and K12). Current or past recipients of Independent Scientist and other non mentored career awards (K02, K04) are not considered new investigators

18 NIH states that: before you seek an independent research grant, you should hold a Ph.D. or M.D; Have a faculty-level position, usually assistant professor or higher; Have a publication record in the field in which you are applying; Work in a research institution that will provide the resources, e.g., equipment and lab space, you will need to complete the project.

They may be applying for a continuation grant or possibly a new grant to undertake a project that differs from what they had been working on.

In 1980 the agency received more applications from potential new awardees than from experienced researchers but gave more awards to previous awardees than to new investigators. It funded 44% of experienced applications vs. 22% of applications from new investigators. As the stock of researchers increased in the 1980s and 1990s, the number of submissions from those with previous NIH funding grew. By 1998 the agency had fewer submissions and gave fewer awards to new researchers than in 1980, while it had more submissions and gave more grants to experienced researchers. During the doubling period, the number of applications from both potential new awardees and experienced researchers increased significantly. NIH gave more grants to both. The deceleration in the funding of NIH produced a sizable drop in number of grants awarded from 2003 to 2006 even as the number of submissions increased, with again the percentage changes being larger for the potential awardees. In 2006 NIH trimmed the amounts it gave for continuing grants by 2.35% despite inflation, and used the funds saved to increase the number of grants to new researchers, though the number of awards still remained below the number in 2003. It did this in an effort to keep new researchers with high quality proposals in research activity.

The lines in Table 4 referring to success rates of potential first time awardees with their original proposal or with a first amendment shows a marked drop in the percentage of applicants who gain a grant with their original submission[19] (55% of awardees did so on the first submission in 1980 compared to 28% in 2007). Increasingly, researchers gain awards after making amendments to the submission to meet with objections or suggestions of the panel that reviewed their proposal. In addition, the percentages in the table for success with the original proposal and the first amendment drop over time, as NIH asked for second or third submissions before giving a grant. This means that projects were delayed for perhaps a year.

While it is common to refer to new RO1 awardees as "young researchers" the

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[19] Much like journals, study groups can choose to accept or reject new submissions outright or ask for a revision of the original submission.

term is somewhat of a misnomer. Because R01s generally go to scientists who are assistant professors or higher, and the length of Post Doctorate has grown over time, the average age of a new recipient was 42.9 in 2005 up from 35.2 in 1970 and 37.3 in the mid 1980s. A sizable number of scientists under the age of 35 received R01s in the early 1980s but since then that number has dwindled (Figure 4). In 1980 22% of grants went to scientists 35 and younger. In 2005, just 3% of grants went to scientists 35 and younger. By contrast, the proportion of grants going to scientists 45 and older increased from 22% to 77% of R01s. Within the 45 and older group, moreover, the largest gainers were scientists aged 55 and older.

While part of this change is associated with an aging of the science work force, far more is due to changing organization of research, which gives older investigators substantive advantages in obtaining funding and places younger researchers as Post Docs in their labs. Taking account of the distribution of PhD bio-scientists by age, the relative odds of a younger scientist gaining an NIH grant compared to someone 45 and older dropped over tenfold. The doubling of research moneys did not cause this pattern. But NIH did not use the extra moneys to improve career prospects for graduate students or Post Docs. The result is considerable malaise among graduate students and Post Docs in the life sciences as well as among senior scientists concerned with the health of their field. (NRC, 1998; NAS, 2005; American Academy of Arts and Sciences, 2008).

Should the country be concerned, as many senior scientists are, about the small and declining share of grant moneys that goes to younger scientists and to the increased number of years that it takes them to obtain independent research support? In terms of economic analysis, there are three reasons for believing that the concentration of research support on older scientists has deleterious effects on research productivity. The first is the possibility that scientists are more creative and productive at younger ages. To the extent that younger scientists are more likely to undertake breakthrough research when they have their own grant support rather than when they work as Post Docs in the labs of senior investigators or than older scientists, the concentration of research support among the older group reduces the productivity of research and the payoff from government

funding.[20]

The second reason is that supporting scientists later in their careers as opposed to earlier in their careers will reduce the pecuniary attractiveness of science and engineering to young persons choosing their life's work because of the normal discounting of future returns. If students who consider science careers had more opportunities to become independent investigators with their own research grant in their thirties rather than in their forties or fifties, the number who chose science would surely be higher than it is today.[21]

The third reason relates to the likely use of new knowledge uncovered by researchers. A research project creates two outputs. It produces research findings that are public information. But it also increases the human capital of the researcher, who knows better than anyone else the new outcomes and probably has better ideas of how to apply them to future research or other activities than other persons. Assume that an older researcher and a younger researcher are equally productive and learn the same additional skills from a research project. Then because the younger person will have more years to use the new knowledge, the social payoff from funding the younger person will be higher than from funding the older person. Put differently, just as human capital theory says that people should invest in education when they are younger, as they do, because they have more years to reap the returns than if they invested when they are older, this line of thinking implies that it would be better to award research grants to younger scientists than to otherwise comparable older scientists.

In sum, economic analysis lends some support to the views of the scientific community that society would likely get more "bang for its research buck" if the internal structure of research funding was more favorable to younger researchers than it currently is.

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[20] There have been some analyses of the relation between age and scientific productivity. See Jones (2005) and the literature cited therein. But there is no analysis of whether working in someone else's lab affects productivity.
[21] Freeman (2005) and Freeman, Chang and Chiang (2005) show substantial responsiveness of young persons to NSF Graduate Research Fellowships. It is hard to imagine if they offered $30,000 awards 20 years into the future, they would apply to the Fellowships as much as they have.

3. THE MARKET FOR RESEARCH GRANTS: AGENCY AND RESEARCHER BEHAVIOR

We now put aside the issue of the speed with which the government changes the level of research spending to reach a new equilibrium stock, and consider the decision to divide a given budget between the number of grants and the sizes of grants. Assume that a funding agency seeks to maximize the research output from a given budget. Should it give fewer large grants or more small grants? Should it favor new research submissions, whether from younger or experienced researchers, or continuance of existing grants, invariably from experienced researchers? How do researchers respond to changes in the dollar value and number of potential research awards?

Table 5 shows that during the doubling, NIH increased the average value and number of awards, particularly for new *submissions* (which includes new projects proposed by experienced researchers as well as projects by new investigators). Holding the success rate of awards at roughly 25% -- a proportion that the agency views as desirable to support on the basis of the quality of proposals, the number of awards increased proportionate to the number of submissions.

From 2003 to 2006 as the budget contracted in real terms, NIH maintained the value of awards in real terms, and reduced the number of new awards by 20%. With the number of new submissions growing, the result was a large drop in the success rate. In 2007 concerned about the flow of new research, NIH squeezed the budgets of existing projects and raised the number of new awards. The data relating to requests for continued funding of existing projects shows a similar pattern – increases in the number and amount awarded during the period of doubling and reductions in numbers awarded relative to submissions afterwards.

Although its budget increased more modestly in the early and mid 2000s, NSF also had to decide whether to change the number of awards or the average size (amount per year and duration) as its budget varied. Responding to a 2001 Office of Management and Budget concern that NSF researchers might be spending too much time writing grant proposals than doing research, NSF decided to increase the amount of research awards while holding fixed or reducing the number of awards. Giving larger grants to a smaller

proportion of researchers would, in NSF's eyes "minimize the time PIs would spend writing multiple proposals and managing administrative tasks, providing increased stability for supporting graduate students" (IPAMM, 2007, p5). Table 6 shows that NSF followed such a strategy. From 1997 to 2006 the mean dollar value of NSF awards increased 72%, from $78,223 to $134,595 while the number of awards rose by just 13%. As the number of research proposals grew over the period, the success rate for funding dropped from 30% to 21%. In 2006, NSF funded 62% of highly rated proposals compared to funding 76% of such proposals in 1997. Proposals that were highly rated but ultimately declined represented $2 billion in requested research support in 2006 (IPAMM, 2007).

How did researchers respond to these changes in the allocation of funds between amounts and numbers? What can we learn from those responses to guide decisions about the division of any future large increase in R&D spending and of the divisions of funding when the rate of spending invariably decelerates?

Researchers responded to the NIH doubling by submitting more proposals to the agency. As NSF spending increased in the late 1990s early 2000s, NSF saw an increase in proposals as well. Given higher grant awards and increased numbers of awards (with roughly constant funding rates), the growth of submissions fits with supply behavior in which the decision to apply for a grant depends positively on the number of awards and the amount of funding.

Turning to responses to reductions in research support, if researchers were limited to a single proposal, reductions in the numbers or size of awards that lower the expect value of a submission would lead to fewer submissions, producing symmetric responses. But researchers can submit more than one proposal to funding agencies. This alters their potential supply behavior. Some researchers can respond to this option by submitting more proposals in periods of low numbers of awards in the hope of improving the chance they will gain at least one award and thus be able to continue their research work.

Table 5 shows that this is precisely what happened in NIH after the doubling period. The average number of submissions for new awards granted and for continuation award granted by investigators who won an award rises sharply from 2003 to 2007 after

changing only modestly during the doubling period. By 2007 NIH awardees were putting in roughly two proposals to get an award. The data on the proportion winning awards on an original proposal in the table tells a similar story. Increasingly, researchers were amending proposals in response to peer review reports with the hope of increasing the chances of gaining a research grant.

The data for NSF in table 6 tells a similar story. The number of research proposals submitted per PI before receiving one award increased by 1.7 in 1998-2000 to 2.2 in 2004-2006. The statistics underlying the averages in the table show that the proportion of PI awardees making only a single submission dropped from 59% to 51% and an increase in the proportion of PI's making three or more submissions from 18% to 26%. The notion that by giving fewer large grants NSF would reduce the time spent writing multiple rewards turned out to be largely wrong. Faced with the risk of losing support and closing or contracting their labs, PIs seem to have made multiple submissions.

In Appendix B we have formalized this notion with a simple model of researcher behavior. Our model gives researchers the option of submitting 0, 1 or 2 proposals to a funding agency. We assume that each researcher wants only a single grant to conduct their work. In this situation, the very best researchers submit one application (since they are virtually assured of getting support), but some researchers choose to submit 2 proposals because they judge their chances of winning as lower but still above the costs of developing a proposal. A third group decides against making a proposal. When the value of awards increases, a larger proportion of scientists make bids and a larger number make two bids, and conversely when the value of awards decreases. The interesting behavior occurs when *the number of awards* granted changes. An increase in the number of awards increases the number of researchers who apply as the chances of winning increases. But when the number of awards decreases, it is likely that a larger proportion of applicants put in two bids. Some highly able scientists put in additional proposals because they are uncertain that they will gain an award and maintain their lab. This produces an increase in the average number of proposals from researchers who ultimately gain an award, consistent with the NIH and NSF data. Overall, the research grant process

consumes a substantial fraction of researchers' time.[22]   A larger proportion of star awardees writing multiple grants can mean that they have less time to spend peer-reviewing the proposals of their colleagues. This puts a strain on the whole system.

It is possible that this process by itself may discourage some young persons from going on in science. Who wants to spend time writing proposal after proposal with modest probabilities of success? Some suspect that it also leads to more conservative science, as researchers shy away from the big research questions in favor manageable topics that may fit with prevailing fashion and be more likely to gain support from study groups.

The lesson is that funding agencies need to have good knowledge of the likely behavior of researchers to alternative allocations of funds. Conceptually, there is an optimal division of budgets between numbers and values of awards that depends on the response of researchers. In recent years NIH and NSF learned some things about researcher behavior from their policies, and have adjusted. Fearful that reduced numbers of new awards would reduce the supply of future researchers, NIH altered its allocation over time. If it were to receive substantial funding to increase physical science R&D NSF would possibly respond differently on the basis of its and NIH's experiences.

4. CONCLUSIONS

This study directs attention at how policy-makers might best undertake any future sizable increase in R&D spending on the physical sciences, per the American Competitiveness Initiative, or any comparable program. We have noted that arguments for increased spending on basic research must consider two ways in which globalization affects traditional justifications for government funding of R&D as a public good. First, as international R&D spillovers have likely increased over time, the ability of US taxpayers to recoup the benefits of R&D subsidies may have declined. By contrast, the greater mobility of high tech research-intensive industries that might be attracted to the US by strong basic research implies *larger* support than in the past Second,   we   have stressed the value of thinking about research spending in terms of the stock of sustainable

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[22] One estimate is that principal investigators spend on the order of 40% of their time making proposals and

activity rather than arbitrary large increases in spending - such as doublings over short time periods – and on the virtues of a smooth approach to higher (or indeed lower) levels of spending. Since Congress determines budgets annually, the question becomes how either the Congress can commit to a longer term more stable spending goal or how agencies and universities can offset large changes in funding. One possibility would be for research grants to contain an extra "stabilization" overhead with the stipulation that those overhead payments would go into a stabilization fund to provide bridge support for researchers when R&D spending leveled off. Another possibility would be to create a fund for smoothing basic R&D spending by assigning some of the R&D tax credits that boost applied research to a basic research fund. There is considerable evidence that fiscal incentives for R&D impact firm's R&D behavior[23]. Whether it is better to support applied research through tax breaks or basic research through grants will depend on how much is spent on each.

Third, our analysis has highlighted the need to consider the way given research budgets are divided between younger and older researchers, and between numbers of awards and sizes of awards. Our argument is that it is economically more sensible to support younger researchers over equally competent older researchers, and that any future surge in spending should allow considerable moneys to supporting new investigators. In addition, given multiple applications and the overstretch of the peer review system, it might increase efficiency by adding program officers and finding ways to deal more efficaciously with proposals, as indeed both NIH and NSF have begun to do.

In sum, if there is to be a new "doubling" of research budgets, there are clear pitfalls to avoid from the NIH doubling experience, and possible new ways to allocate funds to get the most research for the dollar and to improve the career independence of young investigators that would probably do more to attract and retain the young scientists on whom future progress depends and that could improve the flow of new science.

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reporting on the progress of grants.
[23] See Bloom, Griffith and Van Reenen (2002) for international evidence or Hall and Van Reenen (2001) for a survey focusing on US evidence.

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Table 1: Declining US Shares of World Science and Engineering Activity

Measure of Activity	Early Period	Later Period
College Enrollments	30% (1970)	13%(2005)
S&E Undergraduate degrees	~20% (1970)	~9% (2004)
PhDs in S&E granted	40% (1970)	15% (2010)
R&D	~50%(1970)	~35%
ACS Chemical Abstracts	73% (1980)	40% (2003)
All Science Articles	39% (1988)	29% (2005)
All Citations	36% (1992)	30% (2002)

Sources:
College enrollments, Freeman (2008), based on tertiary enrollments from United Nations Educational, Scientific and Cultural Organization, Institute for Statistics (2007). Montreal.

S&E undergrad degrees, 2004 from NSF, Science and Engineering Indicators 2008, appendix table 2-37 excluding social sciences; 1970 estimate from Freeman (2008)
PhDs granted, R&D, ACS chemical abstracts from Freeman (2006)
Science articles, from NSF (2008), table 5-34 and NSF (2006),
Citations from NSF (2008), appendix table 5-38   where 2002 refers to articles written in 2001–03 cited by 2005 articles (%); 1992 refers to 1991–93 articles cited by 1995 articles

Table 2: Rationale for government support of R&D

Rationale for R&D spending	Basic research (federal grants, largely to universities	Applied research (e.g. R&D tax credits)	Globalization impact
Knowledge spillovers	yes	Some	Probably weakens rationale
Economic Competitiveness	None/little	Yes	Probably strengthens rationale

Notes:- See text for a discussion

Table 3: US Shares of USPTO Patents, Shares of World High Tech Output and Trade Balance in Manufacturing

Measure	1980	1990	2000	2003
US first name inventor share USPTO patent applications*	55%	55%	56%	53%
US first name inventor share EPO patent applications*	27	27	26	23
US share of World Gross Revenue in High Tech	28	25	38	39
US share of World Value added in High Tech	25	25	40	42
US share of World Exports in High Tech	30	23	18	15
US share of World Imports in High Tech	13	18	20	17
US trade balance in High Tech ($Billion)	+34	+27	-40	-90

Notes: * Patent statistics refer to 1985 as first year rather than 1980; 2005 (USPTO and 2006 (EPO) as last year rather than 2003

"High-technology manufacturing industries" as classified by Organisation for Economic Co-operation and Development include aerospace, communications equipment, office machinery and computers, pharmaceuticals, and scientific instruments. Value added revenue excludes purchases of domestic and imported materials and inputs. Constant dollar data for foreign countries calculated by deflating industry data valued in each country's nominal domestic currency with a sector-specific price index constructed for that country and then converted to U.S. dollars based on average annual exchange rates.

Source: National Science Foundation (2008) table 6.31 and table 6.32 for USPTO patent data, table 6-41 and 6-42 for EPO patent data; table 6.8 and 6.9 for value added. Table 6.14 and 6.15 for total revenue, exports and imports.

Table 4: Applications, Awards, and Success Rates for RO1 and Equivalent Grants, by status of applicant

	1980	1998	2003	2006	2007
POTENTIAL FIRST TIME AWARDEES					
Applications	8,515	6,817	8,377	9,399	--
Awards	1,903	1,484	1,720	1,384	1,663
Success rate	22.3%	21.3%	20.5%	14.7%	--
% of successful with original proposal	86	61	49	34	28
% of successful with First amendment	13	29	38	40	41
EXPERIENCED (PREVIOUSLY FUNDED) APPLICANTS					
Applications	7,404	13,666	16,325	19,822	--
Awards	3,240	4,782	5,730	4,677	
Success rate	43.8%	35.0%	35.1%	23.6%	

Source: appendix A table, from
grants.nih.gov/grants/new_investigators/Workforce_Info09072007.ppt - 09-19-2007 –

Table 5: The reduced chance of getting NIH R01 grants and the increased number of submissions needed to get an NIH grant

(a) New Submissions

	1997	2003	2006	2007
# Submissions	14,814	18,738	22,150	20,651
# awards	3,476	4,526	3,612	3,961
Success rate	23.5%	24.2%	16.3%	19.2%
For original submission	18.7%	17.0%	7.9%	8.4%
Proportion winning on original submit	55%	51%	32%	28%
Average # submissions per award	1.6	1.7	2.0	2.1
Average Value of Award	$217,348	$345,426	$359,911	$382,782

(b) Continuation Grants

	1997	2003	2006	2007
# Submissions	5,510	5,785	6,830	6,586
# awards	2,624	2,858	2,388	2,468
Success rate	47.6%	49.4%	35.0%	37.5%
For original submission	47.5%	40.2%	25.7%	25.2%
Proportion winning on original submit	44%	61.8%	41.8%	36.8%
Average # submissions per award	1.4	1.5	1.8	1.9
Average Value of Award	$261,662	$357,103	$374,288	$386,507

Source: Office of Extramural Research, NIH, "Success Rates for NIH Type 1 Competing Research Project Applications," http://grants.nih.gov/grants/award/success.htm, excel file, by amendment status.

Table 6: National Science Foundation Research Proposals and Awards, 1997-2006

	1997	2006
Competitive proposals	19935	31514
Competitive awards	5961	6708
Funding rate	30%	21%
Proposal Submitted per PI receiving one award	1.7	2.2
Average mean award size	$78,223	$134,595

Source : IPAMM, figure 2, figure 3, figure 4

Figure 1:
The Acceleration and Deceleration of NIH Spending under the "doubling goal"

Source of Fiscal years 2006 and 2007 is FY 2007 President's Budget

Legend: ■ Appropriation ◆ Percent change from previous fiscal year
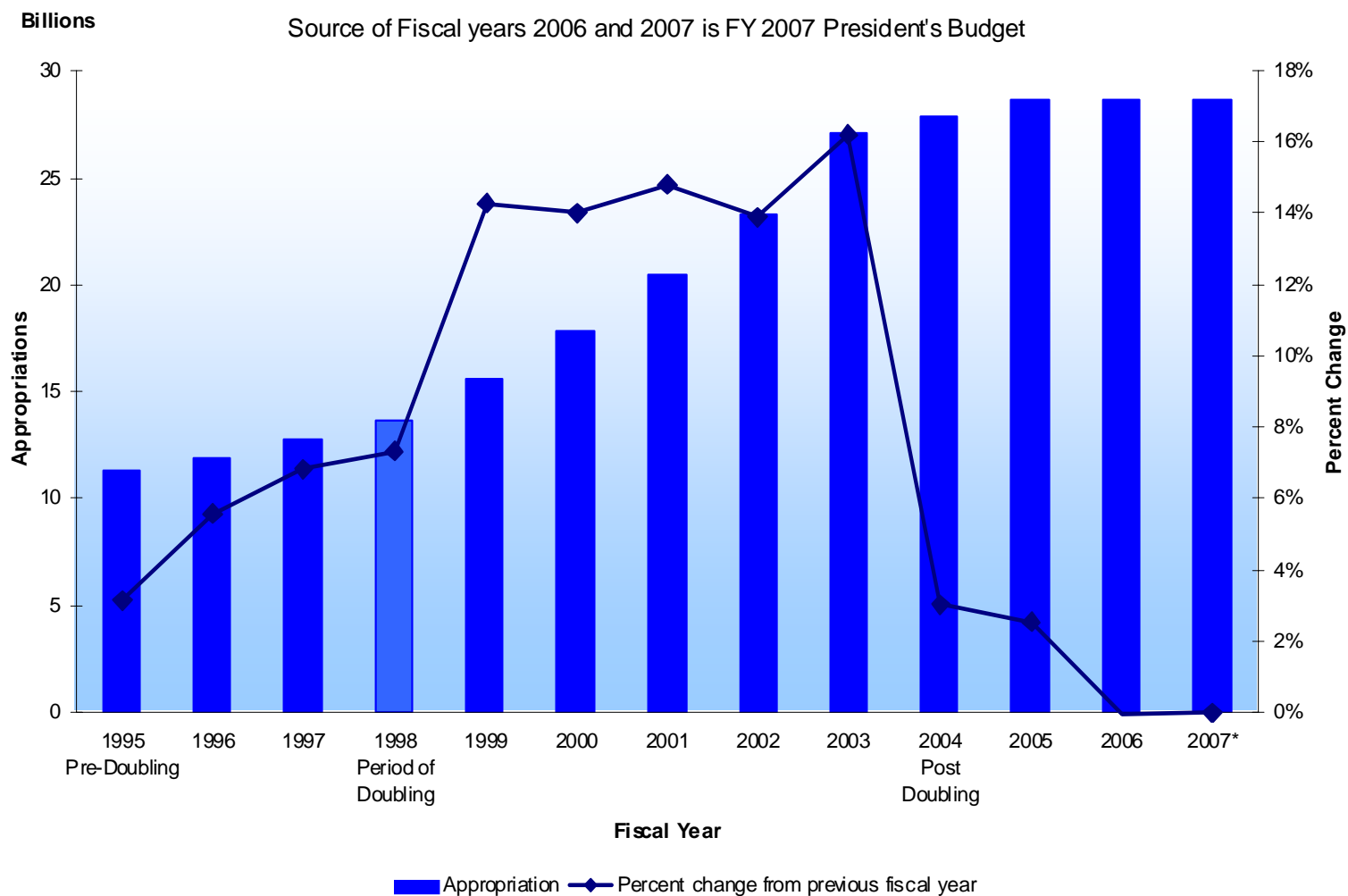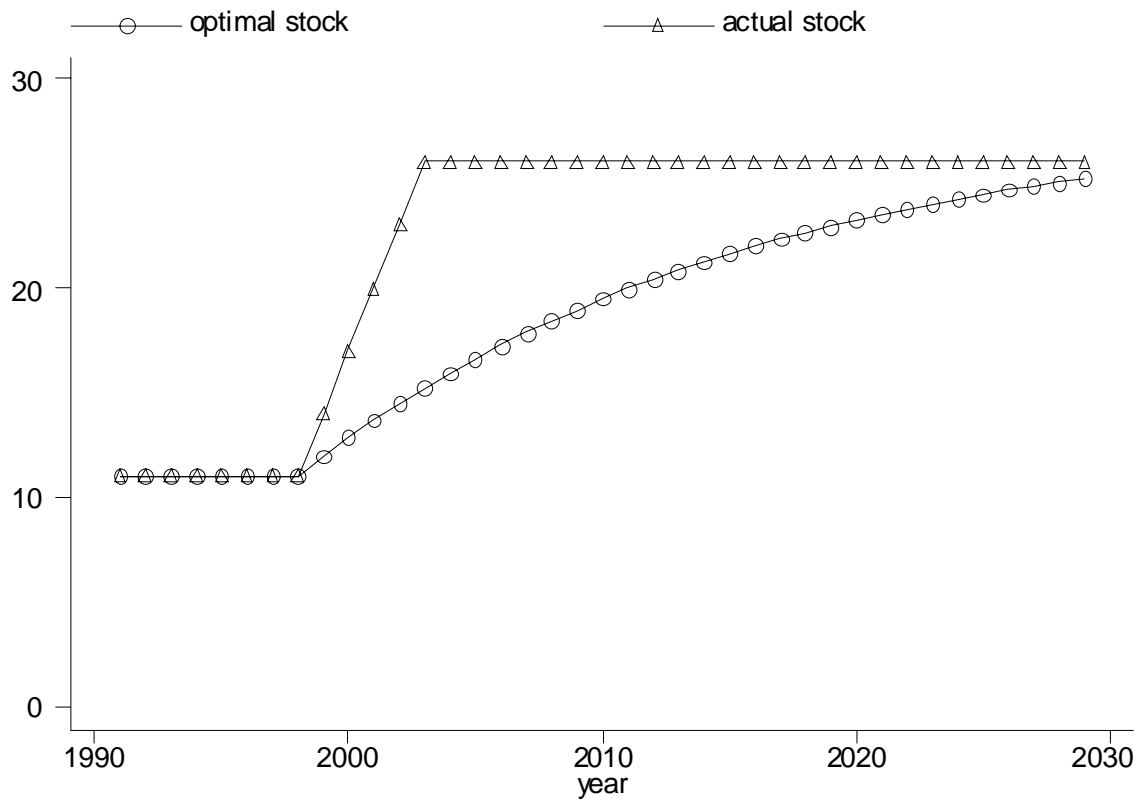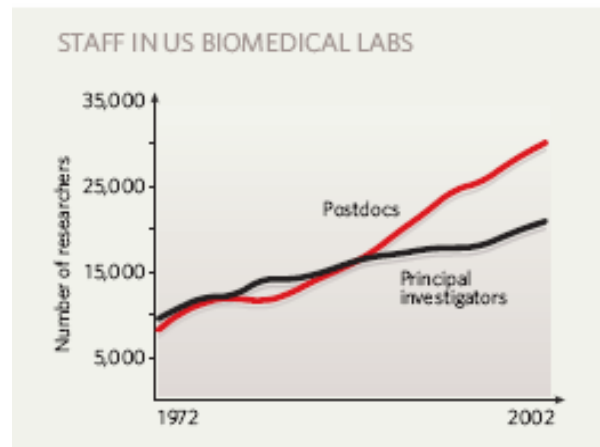
Figure 2: Comparison between Doubling and optimal path

Notes: this compares a stylized version of the doubling of NIH funding to an optimal path when adjustment costs are convex

Figure 3: The increase in the ratio of Post Docs to Principal Investigators In US Biomedical Labs and the Increase in Foreign Born Post Docs compared to US pos-docs.

A) Postdocs compared to PIs
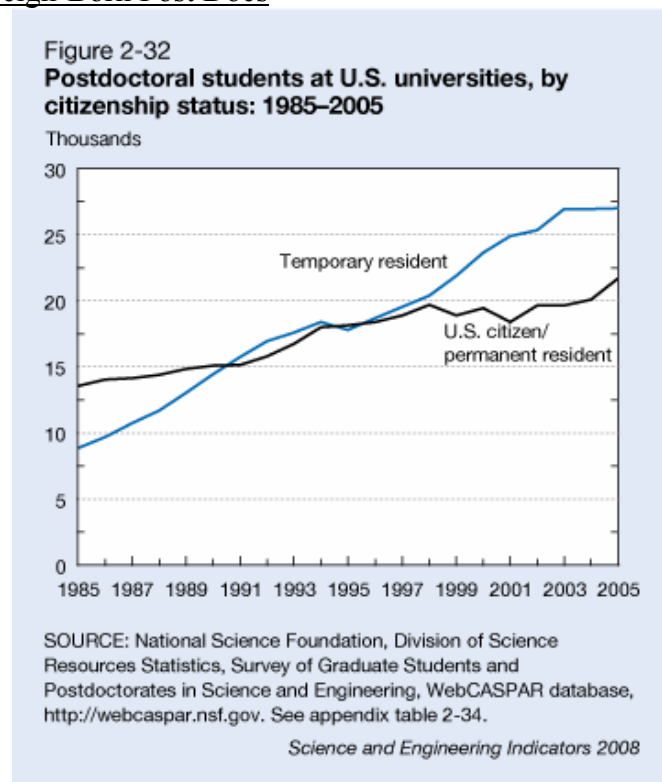

B) US vs. Foreign-Born Post Docs

Figure 4: Number of Persons <35 years old getting RO1s

Appendix A: Additional data

Table A1:
SUCCESS AND FUNDING RATES OF FIRST TIME AND PREVIOUSLY FUNDED APPLICANTS

Fiscal Years 1980 - 2006

FY	Potential First Time Awardee						Experienced (Previously Funded) Applicants					
	Applications	Awarded	Success rate	Applicants	Awardees	Funding Rate	Applications	Awarded	Success rate	Applicants	Awardees	Funding Rate
R01 Equivalent (R01, R23, R29, R37)												
1980	8,515	1,903	22.3%	7,949	1,859	23.4%	7,404	3,240	43.8%	6,093	2,992	49.1%
1981	8,694	1,818	20.9%	8,097	1,766	21.8%	8,739	3,482	39.8%	7,100	3,253	45.8%
1982	8,106	1,598	19.7%	7,523	1,572	20.9%	9,937	3,628	36.5%	7,868	3,361	42.7%
1983	7,568	1,650	21.8%	6,948	1,607	23.1%	9,776	3,777	38.6%	7,797	3,498	44.9%
1984	7,440	1,637	22.0%	6,870	1,612	23.5%	9,934	3,887	39.1%	8,085	3,627	44.9%
1985	7,784	1,845	23.7%	7,013	1,809	25.8%	11,138	4,341	39.0%	8,917	4,021	45.1%
1986	7,305	1,683	23.0%	6,661	1,658	24.9%	11,302	4,328	38.3%	9,105	4,004	44.0%
1987	7,077	1,657	23.4%	6,388	1,629	25.5%	11,151	4,744	42.5%	9,066	4,364	48.1%
1988	7,774	1,780	22.9%	7,083	1,741	24.6%	11,565	4,329	37.4%	9,404	3,989	42.4%
1989	7,752	1,621	20.9%	7,068	1,590	22.5%	11,629	3,782	32.5%	9,430	3,547	37.6%
1990	7,838	1,394	17.8%	7,201	1,371	19.0%	11,997	3,371	28.1%	9,685	3,146	32.5%
1991	7,279	1,560	21.4%	6,652	1,539	23.1%	11,902	3,932	33.0%	9,653	3,679	38.1%
1992	7,200	1,473	20.5%	6,625	1,451	21.9%	12,602	4,262	33.8%	10,247	3,988	38.9%
1993	8,124	1,269	15.6%	7,408	1,246	16.8%	13,465	3,690	27.4%	10,831	3,458	31.9%
1994	8,832	1,453	16.5%	7,932	1,425	18.0%	14,337	4,269	29.8%	11,180	3,931	35.2%
1995	7,968	1,420	17.8%	7,217	1,399	19.4%	14,712	4,514	30.7%	11,458	4,173	36.4%
1996	7,017	1,356	19.3%	6,395	1,336	20.9%	14,043	4,419	31.5%	11,171	4,102	36.7%
1997	6,967	1,484	21.3%	6,313	1,453	23.0%	13,654	4,751	34.8%	10,862	4,413	40.6%
1998	6,817	1,545	22.7%	6,161	1,505	24.4%	13,666	4,782	35.0%	10,978	4,400	40.1%
1999	7,333	1,596	21.8%	6,592	1,561	23.7%	14,802	5,515	37.3%	11,834	5,063	42.8%
2000	7,479	1,642	22.0%	6,741	1,596	23.7%	14,750	5,466	37.1%	11,719	4,998	42.6%
2001	7,494	1,629	21.7%	6,691	1,580	23.6%	14,545	5,361	36.9%	11,625	4,975	42.8%
2002	7,632	1,612	21.1%	6,862	1,574	22.9%	14,640	5,222	35.7%	11,673	4,815	41.2%
2003	8,377	1,720	20.5%	7,380	1,680	22.8%	16,325	5,730	35.1%	12,647	5,243	41.5%
2004	9,413	1,578	16.8%	8,147	1,528	18.8%	18,241	5,457	29.9%	13,863	4,999	36.1%
2005	9,365	1,475	15.8%	8,195	1,441	17.6%	19,175	5,014	26.1%	14,410	4,631	32.1%
2006	9,399	1,384	14.7%	8,180	1,354	16.6%	19,822	4,677	23.6%	14,766	4,350	29.5%

Table A2: NIH CHANGES IN NUMBERS OF GRANTS AND DOLLAR SUPPORT

| Fiscal Year | Total Amount Awarded | Research Grants | |
		Number of Awards	Award Amount
2007	$21,263,805,742	47,181	$20,415,899,325
2006	$23,182,959,918	46,797	$20,154,363,154
2005	$23,410,118,044	47,345	$20,206,478,806
2004	$22,900,576,587	47,464	$19,607,812,023
2003	$21,866,798,411	46,081	$18,461,462,170
2002	$19,074,464,796	43,520	$16,830,194,185
2001	$16,784,681,877	40,666	$14,907,921,291
2000	$14,791,024,329	38,302	$13,002,656,762
1999	$12,855,628,060	35,870	$11,228,665,952
1998	$11,179,749,719	33,703	$9,801,789,027
1997	$10,456,030,704	32,109	$9,046,542,619

Report Date: 2/12/08

Appendix B: Modeling researcher responses to short run changes in numbers of awards - A simple model of scientist behaviour

I. INDIVIDUAL BEHAVIOR

There are a pool of L potential researchers who submit either 0, 1 or 2 research bids[24]. If they submit they have a probability p of winning an award. This will be a function of researcher quality, z, and the number of awards made available by the government, N (we take these as exogenous common knowledge) so $p = f(Z,N,.)$ and is increasing in both arguments. Let us assume that the support of the distribution of researcher quality is [0,1]. A researcher is only allowed to accept a maximum of one award at a time (so if he wins two he can only take one). Winning an award gives value to the researcher (funds) of V, losing is normalized to zero. The cost of putting a bid together is c.

The net utility of submitting one bid is u(1)[25]

$$u(1) = pV - c$$

The net utility of submitting two bids is u(2)

$$u(2) = (1-(1-p)^2)V - 2c = p(2-p)V - 2c$$

A scientist will not submit a bid if $u(1) < 0$, i.e. $p < \dfrac{c}{V}$.

Define the benefit-cost ratio as $\beta = V/c$ and the threshold probability as

$\tilde{p} = \dfrac{1}{\beta}$. Thus if $p < \tilde{p}$ the researcher will choose not to bid.

When will the scientist put in two bids? This will occur if u(2) > u(1). This condition can be written as

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[24] For simplicity we cap the maximum number of bids as two, but consider larger number of bids in the extensions below.
[25] The model assumes risk neutrality. If we incorporate risk aversion the same basic intuitions come

$$-\beta p^2 + \beta p - 1 > 0$$

This quadratic form has two solutions that define two more threshold value of p:

$$\underline{p} = \frac{1}{2}\left[1 - \sqrt{\left(1 - \frac{4}{\beta}\right)}\right] \text{ and } \bar{p} = \frac{1}{2}\left[1 + \sqrt{\left(1 - \frac{4}{\beta}\right)}\right]$$

subject to the regularity conditions that the value of β must allow p to be defined on the (0,1) support (e.g. $\beta > 4$).

These three thresholds define scientist behavior over four regimes (see Figure A1).

(A) $p < \tilde{p}$ researcher will bid zero.

(B) $\tilde{p} < p < \underline{p}$ researcher will make one bid

(C) $\underline{p} < p < \bar{p}$ researcher will make two bids

(D) $\bar{p} < p$ researcher will make one bid.

The intuition is the following. In Regime (A), the probability of winning is too low to cover the costs (in expected terms). In regime (D), "star scientist" the probability of winning is so high that there is not much benefit from a second bid. In Regime (C), the chances of winning are not quite so high, so researcher finds it pays to take out a second ticket. In Regime (B) it is worth making a bid, but because these scientists are on the margin ("marginal quality") of not bidding, they do not find it is worth the cost of two bids.

Comparative statics in β

If the value of the award rises (β up) then this will change the thresholds. $\tilde{p}$ will fall, $\underline{p}$ will fall and $\bar{p}$ will rise. This means (a) there will be a larger number of bids, (b) there will be larger number of scientists making two bids

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through.

II. EQUILIBRIUM

There are M bidders, L potential bidders and a total number N of awards available. In a rational expectations equilibrium the probabilities have to adjust so that the number of awards given out equals the expected ex ante probability of success integrated across all scientists. In our simple case:

$$M \int_0^1 p(z, N) dp = N$$

Since p and M are now endogenous we must solve the model in terms of the exogenous variables z and N. We can define analogous thresholds to ($\tilde{p}$, $\underline{p}$ and $\bar{p}$) in the space of researcher quality ($\tilde{z}$, $\underline{z}$ and $\bar{z}$). These can be written as functions of the benefit-cost ratio, β and the number of potential awards.

Comparative statics in $\underline{\beta}$

If the number of awards falls all the thresholds shift to the right. The probability of winning a bid will fall so fewer scientists will submit any bids. Similarly if the number of awards rises then the thresholds shift to the left and there are more bids.

In terms of the numbers making two bids, this depends on the functional forms and the magnitude of the change in N. The following seems like a reasonable description of the doubling and post-doubling period, however. During the doubling period the thresholds all shift to the left but the proportion of (potential L) scientists in Regime C who make two bids stays the same ($\bar{z} - \underline{z}$).

Compare this to the post-doubling period. We keep ($\bar{z} - \underline{z}$) the same, but all thresholds have moved to the right so there is a smaller margin of scientists in Regime D. This means that of all the winning bids, the proportion of scientists submitting two bids has increased (i.e. ($\bar{z} - \underline{z}$)/(1- $\tilde{z}$) is larger).

The intuition is clear. During the post-doubling period many of the "star scientists" during the doubling period can no longer feel confident in winning an award, so they put in two awards to increase their probability of a successful draw.

These ideas are illustrated in Figures A2 and A3 below.

[Figures A1 to A3 about here]

III. EXTENSIONS

[Still in progress]

Age

Another aspect of heterogeneity (apart from quality z) is age. The value of winning V, will be higher to a young scientist than an older scientist as her career depends on winning an award (so this is a kind of state dependence). In our model he will have a higher V and therefore, a higher probability of (i) making a bid, (ii) making a multiple bid. Reducing N has a particularly strong effect on these scientists
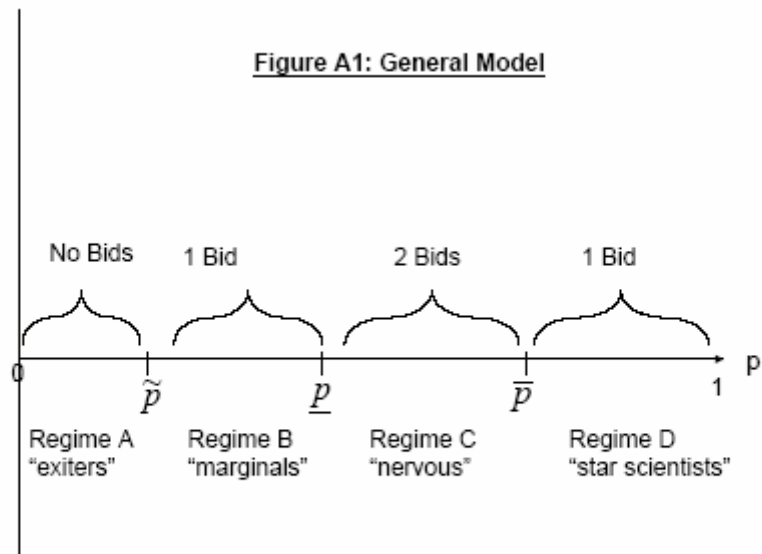
Surprises

We have assumed a rational expectations equilibrium, but there are certainly surprises in reality (such as the pots-doubling cut-back). In particular the rapid cut in real terms R&D was certainly a surprise, and the doubling as well.
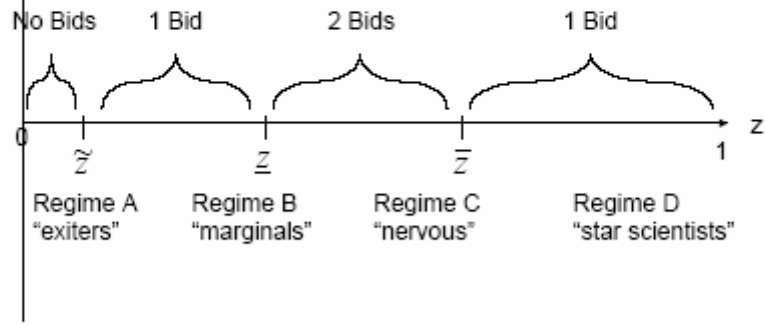
Multiple bids

We have assumed that two is the maximum number of bids. Of course given the model set up, if I have an incentive to bid twice I will also have an incentive to do it thrice with linear costs. But we could allow multiple bids if we assumed that there was some convexity of costs.
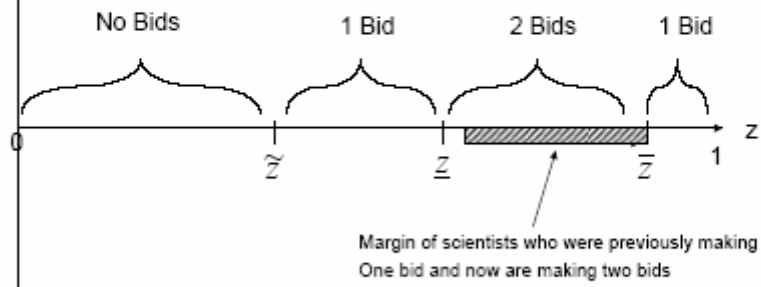
Figure A1: General Model

Notes: p is the probability of winning an award, the three cut-off probabilities Define the thresholds. See text for details

Figure A2: Doubling period – more awards and more bids

Notes: z is researcher quality. See text for details

Figure A3: Post Doubling Period

No Bids   1 Bid   2 Bids   1 Bid

0 $\tilde{z}$ $\underline{z}$ $\bar{z}$ 1 z

Margin of scientists who were previously making
One bid and now are making two bids

Notes: z is researcher quality. See text for details

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