Medical Progress and Health Care Financing: Research in Academic Medical Centers Following the 1997 Medicare Cuts

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Abstract

We ask whether reforms designed to contain the growth of health care expenditures have the unintended consequence of changing the level and altering the composition of research performed inside academic medical centers. We study the effect of the Balanced Budget Act of 1997, which changed the formula used to reimburse Medicare inpatient claims. We compare teaching hospitals' relative exposure to the reform and how these differences affect their researchers' ability to attract grants from government and industry sources. We find that the elasticity of NIH grant awards with respect to an exogenous change in reimbursement levels is about 0.15. There is no discernable effect on clinical trials grants from pharmaceutical firms. Research performed by physician-scientists is more affected than that of PhD investigators. Similarly, research dealing with human subjects is more affected than non-clinical research. Our analysis implies that government-funded research and hospital cross-subsidies from clinical care are complements rather than substitutes, and suggests that health care financing might impinge on future health outcomes, through its effect on the rate and direction of technological change.

Keywords: Academic Medical Centers, biomedical research, NIH, Medicare, technological change.

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1 Introduction

Recent research has confirmed the essential role of technological change for bringing about improvements in health outcomes. Technological advances account for the bulk of increases in medical care expenditures, but appear, on net, to be well worth it (Cutler and McClellan, 2001). It follows that the economic value of advancing the state of medical knowledge is likely to be enormous (Murphy and Topel, 2001). Indeed, the doubling of the National Institutes of Health in the past decade, the publication of the initial sequence and analysis of the human genome in 2001, and advances in molecular biology, neuroscience, immunology, and biomedical engineering would appear to herald a new era for medical progress.

In this paper, we argue that the wedge between the promise of basic science and the translation of scientific findings into clinically useful innovations is shaped by the environment for the reimbursement and financing of health care. In particular, we provide evidence that seemingly small cuts in the reimbursements to health care providers may induce large distortions in the allocation of research funds along the vertical chain of biomedical innovation.

Medical advances spring from many sources. Public health interventions, improvements in instrumentation and diagnostic techniques, advances in surgery and anaesthesia all have played a role in bringing about massive reductions in mortality and morbidity during the 20^{th} century. However, there is little doubt that the discovery of new treatments, and in particular new drugs, has accounted for a large share of this progress (Fuchs and Sox, 2001).

In the prototypical view of biomedical research, innovative therapies undergo a sequential development process. First, researchers trained in the basic life sciences discover a new molecule, and show that it inhibits a particular disease pathway in vitro. Then, they develop animal models and gather initial data on safety and efficacy. The new molecule is subsequently turned over to physicians, who clinically test the purported treatment on a large sample of patients. In this linear view of treatment discovery, innovation and creativity reside in the discovery phase of research; its heroes are chemists or molecular biologists working in pharmaceutical companies or universities. In turn, clinical development is a routinized

operation whose main goal is to determine whether the development of any particular project should be aborted or continued until approved by the regulatory authorities. It is this stylized view which underlies the broad-based congressional support enjoyed by the National Institutes of Health for the continuous public funding of basic research in the life sciences, and most of the discussion about science policy in the lay media and the pharmaceutical industry.

As has been emphasized by Rosenberg, this linear model of innovation, "however flattering to the scientist and the academic, is economically naïve and simplistic in the extreme" (Rosenberg, 1994: 139). Indeed, in the biomedical field, a closer examination of major treatment discoveries reveals a significantly more complex picture. In numerous cases, the first biological insight is acquired in a clinical setting, and only subsequently do "basic" scientists make sense of the mechanisms by which treatment is effective (Gershon, 1998). For example, scientists discovered the first antidepressant drug, iproniazid, because a related compound used to treat tuberculosis made patients so euphoric that they stopped taking it. Subsequent research on iproniazid led to the chemical theories of depression that have generated all later antidepressant agents (Wurtman, 1995). In other cases, such as the development of AIDS triple therapies, successful treatments resulted from the ongoing dialog between bench and bedside scientists (Wurtman, 1997). Still other times, new clinical uses are discovered for therapies already introduced into clinical practice (Gelijns et al., 1998).

According to this alternative view of the treatment-discovery process, medical innovation is not confined to any one discipline or any one phase of development. In particular, a basic form of clinical investigation plays a critical role, but is substantially and methodologically distinct from large scale randomized controlled trials sponsored by pharmaceutical firms for drug approval. Moreover, a complex web of institutional arrangements supports the bidirectional flow of scientific knowledge between the laboratory bench and the clinic.

In the United States, 30% of health-related research, and most clinical research, is performed inside academic medical centers (Commonwealth Fund, 1999). Academic medical centers (AMCs) are institutions that consist of a medical school and an owned or closely

affiliated clinical facility. They have a triple mission of patient care, teaching, and research — of both the clinical and non-clinical varieties — and play a central role in the American system of biomedical innovation.

Traditionally, support for the research function inside AMCs has come from three different sources: grants from the NIH and private foundations, contracts from the pharmaceutical industry for the conduct of clinical trials, and "institutional funds" — cross-subsidies from patient-care activities. The academic medical establishment strongly believes that these cross-subsidies act as an essential lubricant of the research enterprise. First, institutional funds provide young investigators the possibility to establish research careers while they acquire necessary grant-writing skills; second, they allow more seasoned investigators to ride out funding "dry spells" that are the inevitable byproducts of the peer-review system and its vagaries (Martin, 1999). However, a more jaded view emphasizes the risk that such "easy money" simply crowds out the funds attracted through the competitive process, and mostly benefit a small coterie of particularly well-connected faculty members. The primary goal of our paper is to determine whether institutional funds complement or substitute external sources of funding — both public and private.

We know of no comprehensive source quantifying the extent of hospital cross-subsidies. As a result, we follow an indirect approach. Substantial changes in the financing and insurance of hospital care during the 1980s and 1990s have eroded the revenues of inpatient care providers. First, Medicare switched from fee-for-service reimbursement to a Prospective Payment System (PPS) in 1983. Under the PPS, Medicare reimburses hospitals a fixed rate per patient (for a given diagnosis), as compared to basing reimbursements on the actual services rendered. Second, managed-care insurance plans grew at the expense of traditional Blue Cross/Blue Shield plans (Glied, 2000). These changes, which were designed to contain the growth of health care expenditures, may have had the unintended consequence of decreasing the availability of institutional funding for research. We choose to focus on the enactment of the Balanced Budget Act (BBA) of 1997, which led to considerable reductions in the level of Medicare reimbursements to hospitals. Teaching hospitals were disproportionately affected because the reform significantly decreased the add-on payments made to support graduate

medical education (Dickler and Shaw, 2000). Among teaching hospitals, some institutions were harder hit by the reform than others because of differences in teaching intensity, patient mix, and reliance on Medicare (MedPAC, 2003).

The intricacies of the Medicare PPS system and the change in the formula used to compute reimbursements for inpatient care provides a source of exogenous variation in the impact of the BBA on different hospitals. We compare hospitals' relative exposure to the reform and measure the change in their research outputs, as measured by the amount of NIH and industry grants awarded to their investigators, before and after 1997.

We find that the elasticity of NIH grants with respect to an exogenous decrease in reimbursement levels is about 0.15. There is no discernable effect on clinical trials grants from pharmaceutical firms. Furthermore, the effect we identify appears to be more acutely felt by clinical investigators than laboratory scientists. Physician-scientists typically split their time between clinical care and research, and investigator-initiated clinical research has often been seeded by hospitals' operating margins from patient-care activities, in contrast to PhD-holding faculty who must fund their research activities and their own salaries solely from research grants (Weissman et al., 1999; Martin, 1999).

Our analysis suggests that health care financing impinges on the effectiveness of the American system of biomedical innovation. While cost containment efforts may not affect current health outcomes (Cutler, 1995), they may shape future health outcomes, through their effect on the pace of technological change. Furthermore, while science policy makers and legislators have long analyzed the issue of the optimal allocation of research funds across diseases (Lichtenberg, 2001), our results highlight the importance of correcting potential funding imbalances along the vertical chain of biomedical research.

The rest of the paper proceeds as follows. The next section provides an overview of the public funding of clinical research since 1970. Section 3 briefly reviews the literature on hospital objective functions to discuss the relationship of hospital cross-subsidies with shocks to hospital finances. Section 4 explains how Medicare reimburses hospital care under the PPS and describes the cuts in subsidies to teaching hospitals enacted by the BBA. Section 5

describes the construction of the sample and data sources, and presents descriptive statistics. Section 6 presents our statistical framework and main econometric results. Concluding remarks are offered in Section 7.

2 Public and Private Funding of Clinical Investigation

A working definition of clinical investigation refers to "those activities within medical research wherein the physician and the patient interact directly in an ongoing fashion for experimental purposes" (Crowley and Thier, 1996). Interventions in humans are inherently limited by ethical considerations, the vicissitudes of patient participation, and difficulties in recruiting suitable controls. Although there is no consensus in the academic medical community with regard to what type of research activities can justifiably be termed "clinical," three broad types are often mentioned:

- **Clinical trials** are commonly performed under contracts between institutions and commercial sponsors. The demand for such trials is driven by the needs of pharmaceutical and medical device firms to meet regulatory requirements for product safety and efficacy, although the NIH occasionally funds such trials (for example, when a new clinical use is discovered for an off-patent drug);
- **Outcomes research** focuses on the evaluation of medical outcomes and treatment effectiveness, especially within the context of cost-benefit analyses of therapies and technologies. This kind of research has become more relevant with the increasing focus on reducing health care costs;
- **Translational research** converts insights provided by basic science into new methods of diagnosis and therapy. While recognizing the importance of subcellular phenomena, it concerns itself with intact patients, unlike *in vitro* studies. The physician formulates hypotheses regarding mechanisms, asking how and why certain phenomena occur in diseases.

If it is the nature of the question that determine the basic or applied character of research, translational studies constitute the most "basic" form of clinical investigation (Ahrens, 1992). This type of research has experienced a long-run decline over the last thirty years. Whether due to financial constraints, legal issues, or fundamental change in the nature of the life

sciences, the meticulous and deliberate study of hospitalized patients for the purpose of generating questions about disease is now rarely undertaken.

Since examining in detail the 512,630 extramural grants awarded to medical schools and independent hospitals by the NIH since 1970 is impractical, we rely on two characteristics to classify grants into clinical and non-clinical research: the degree of the principal investigator (MD, PhD, or MD/PhD), and whether the study deals with human subjects. This method probably overestimates the commitment of public funds to clinical research. First, it is often suspected that NIH grantees holding MD and especially MD/PhD degrees share the scientific interests and much of the background of PhDs. Second, the "human subject" category employed by NIH includes projects using human blood and tissue. Many of these studies would not be considered clinical upon closer inspection.

With these limitations in mind, and using data and procedures described in Section 5, we examine trends in the funding of clinical research in medical schools and independent hospitals. Figure 1 displays the awarded amounts by investigator degree between 1970 and 2001.[1] The share of funds disbursed to MDs decreased from 60% to 40% over the last 30 years. This decline can be explained in large part by changes in the composition of the applicant pool. Nathan (1998) reports that in 1972, the total number of applications to NIH was about 10,000, 40% of which were submitted by MDs (the success rates of MDs and PhDs were equal). Twenty-five years later, in 1995, grant applications from MDs had risen slowly by 50%, but applications from PhDs had increased 300% to 18,000 (note that these figures do not apply solely to medical school investigators). The massive increase in applications drove down the success rates of both MDs and PhDs. This decline is also significant in light of the fact that the share of physicians among medical school faculty members has remained constant at about 65% since 1981.

We attempt to refine our taxonomy by considering the extramural funds flowing to MDs and MD/PhDs for projects involving human subjects. According to this measure, funds devoted to clinical research remained flat in constant dollars until 1997, as can be seen on

[1]The dollar amounts have been deflated by the Biomedical R&D Price Index. The reference year is 1994.

Figure 2 (the uptake of recent years may be attributed to new types of grants specially designed to support the career of clinical investigators). As a fraction of total amounts awarded, the commitment to clinical research fell rapidly during the 1980s, and has remained stable since. Figure 3 graphs the evolution of funds disbursed by the pharmaceutical industry to investigators for the conduct of clinical trials, and breaks the total amount down between academic and non-academic investigators. A marked trend is the growing prominence of "for-profit experimental medicine." Under the competitive pressure of commercial testing sites, industry-supported research in AMCs has remained stable or even slightly decreased during the 1990s.

The fact that NIH allocates the bulk of its funds to PhD scientists, whose careers tend to be devoted to the exploration of disease mechanisms at the molecular level using "reductionist" laboratory techniques, has been a long-standing concern of the medical establishment (Wyngaarden, 1979; Rosenberg, 1999). An often-heard grievance is that NIH's peer-review system shortchanges clinical investigation and more "integrative" types of research (Ahrens, 1992). As a result, the traditional clinical scientist, capable of studying human physiology and pathophysiology, is fast giving way to gene cloners and structural biologists. This evolution could simply reflect an efficient response to changes in scientific opportunities. In the future, scientific advances most relevant to the amelioration of human disease may no longer be generated by clinicians, although clinicians will use products generated by the findings of laboratory scientists for the care of their patients (Bell, 1986). Similarly, the rise of commercial testing centers outside of academia could reflect the increased diffusion and codification of the skills necessary to perform a clinical trial — as well as the fact that non-academic investigators might enjoy a comparative advantage over their academic counterparts for most late-stage testing.

In this paper, we isolate an event that influences the allocation of funds to different types of research to study the balance between clinical and non-clinical research and speculate on its adequacy. We examine the effect of a discrete shock to hospital finances on the level and composition of NIH- and industry-funded research within AMCs. There is no reason for such hospital-level variation to correlate systematically with disease-level changes in scientific

opportunities nor with changes in the structure of the testing industry. Hence, we are able to identify the causal effect of health care financing on research activity.

3 Hospital Cross-subsidies: Rationale and Relationship with Hospital Finances

A relationship between medical research and hospital inpatient revenues at the hospital level arises when patient-care revenues are used to cross-subsidize research activity. It is worth asking about the rationales for such practices, as well as about their relationship with price and income changes.

One theory of firm behavior holds that the key distinction between non profit and for-profit firms is that non-profits are barred from distributing residual earnings to owners. Instead of keeping the profits, the non-profit entrepreneur uses them to increase firm perquisites, which are less valuable than cash (Hansman, 1980; Glaeser and Shleifer, 1998). Such status weakens profit-maximizing incentives, and this might be valuable in markets where owners can take advantage of their customers, employees, or donors. In this view, hospitals could just as well invest in lavish office space than research, as both these types of expenditures are equally useful to convince consumers that the firm does not care exclusively about profit. Other rationales for subsidizing research out of patient care emphasizes instead its labor market implications. Cross-subsidies might attract more talented investigators and might also be a source of compensating differential (Stern, 1999). Hospital decision-makers might be altruistic and have genuine preferences for research (Rose-Ackerman, 1996). Other possible motives for this practice include fostering a "Medical Arms' Race" (Robinson and Luft, 1985) or using research as signal of quality.

These rationales have different implications with respect to the efficiency of partially financing research out of rents earned from clinical care. If institutionally-funded research is simply a staff perquisite, it is more likely that these funds will be allocated according to the whims of powerful department chiefs, rather than on the basis of the greatest marginal social return. One could argue that internal funding simply crowds out external sources of research

funds. In this view, cross-subsidies bear a resemblance with academic "earmarks," whereby universities lobby legislators to write funds into appropriation bills and allocate them directly to specific projects, bypassing the competitive peer-review process (de Figueiredo and Silverman, 2002). One could also hold the view that cross-subsidies complement external funding. The NIH peer-review process is arcane, and investigators often take a long time to acquire the grant-writing skills necessary to navigate the system effectively. Institutional funding of research is a practice that has evolved over time, with informal norms governing the allocation of funds among investigators. While prone to abuse, this system affords a modicum of protection to young investigators while they are establishing their careers. Similarly, it might help keep experienced investigators who temporarily lost out in the NIH grant competition from abandoning research entirely.

We face an important obstacle in our attempt to ascertain whether cross-subsidies complement or substitute external sources of funding: these intraorganizational financial transfers are not observed. According to a survey performed in 1992-93, $816 million of the faculty-practice plan revenues of AMCs were used for research, an amount equal to 21% of the total NIH funding to these institutions during the same period (Jones and Sanderson, 1996). To our knowledge, there exists no systematic source of evidence documenting their extent or how such transfers vary across hospitals.[2]

As a result, when examining the linkage between health care financing and medical research, one can think of a two-stage framework whereby the generosity of the reimbursement regime determines the amount of financial "slack" for the hospital and therefore the extent of cross-subsidies, which in turn influence the level and composition of research within the hospital. Therefore, the interpretation of the sign and magnitude of $\frac{\partial Research}{\partial Slack}$ relies on the assumption that $\frac{\partial Xsubs}{\partial Slack} > 0$. Because this assumption is so crucial, it is worth discussing in detail.

[2]Even if it were available, relying on hospital accounting data would be suspect since sharing of research indirect costs and "excess" clinical revenues also takes place between *medical schools* and their affiliated hospitals.

Anecdotal evidence, as expressed in alarming editorials by academic medical leaders, strongly supports the view that hospital cross-subsidies decrease in response to financial pressures (Martin, 1999). The only piece of systematic evidence documenting a positive relationship between financial slack and hospital cross-subsidies is a survey showing that the number of faculty engaged in "unsponsored research" is lower in areas with high managed-care penetration, taken here as a proxy for financial pressures faced by AMCs (Weissman et al., 1999). Past research has also demonstrated that hospitals respond to negative financial shocks by cutting care to the indigent (Gruber, 1994). While medical research is also a social mission of AMCs, it is different from care to the poor to the extent that the federal government pays recipient institutions generous indirect cost recovery rates.

At a theoretical level, the sign of the relationship between reimbursement and cross-subsidies depends on the relative magnitudes of the income effect and the substitution effect. McGuire and Pauly (1991) have clarified the role of multiple payers in a theory of induced demand, while the idea of strong income effects in physician labor supply behavior has been given some empirical backing by Yip (1998). Drozd (1999) documents that teaching hospitals engage in cost-shifting to private payers in response to Medicare reforms identical in flavor to those studied in this paper. Whether these insights extend to the research setting depends on whether one can think of NIH and the pharmaceutical industry as "payers" akin to insurers. In what follows, we maintain the assumption that the income effect dominates the substitution effect in shaping the allocation of investigator effort between research and patient care activity.

4 Medicare Reimbursement of Inpatient Hospital Care

We provide a brief description of how Medicare reimburses hospitals for care provided to beneficiaries, which will be useful to understand the impact of the reform analyzed in this paper. Inpatient hospital care is covered under Part A of Medicare, and reimbursements since 1984 have been set based on a Prospective Payment System (PPS). Under the PPS, hospital are paid a prospectively-determined administrative price per discharge, adjusted for

the diagnosis of the patient. These diagnoses are divided into approximately 502 groups, called Diagnosis Related Groups (DRGs). These DRGs are then assigned weights according to hospitals' aggregate historical costs of treating patients in each DRG. The total PPS payment received by hospital i in year t can be expressed as:

$$\begin{aligned} PPS_{it} &= \sum_j [P_{it} \times DRG_j + OUTLIERS_{ijt}] \times ADJUST_{it} \\ &= [P_{it} \times \#DISCHARGES_{it} \times CMI_{it} + OUTLIERS_{it}] \times ADJUST_{it} \end{aligned} \quad (1)$$

where i indexes hospitals, j indexes discharges, and t denotes calendar time. P_{it} is a standard amount reimbursed per discharge, and was designed to grow at the rate of a "market basket" of goods and services purchased by hospitals. In an effort to reduce Medicare spending, the increases in the conversion factor since the late 1980s have often been less than the market basket (Cutler, 1998). DRG_j is the DRG weight for discharge j, and $ADJUST_{it}$ correspond to a number of hospital-specific adjustments described below. These adjustments also apply to so-called outlier payments, reimbursements made to compensate providers for patients with exceptionally costly stays (Keeler, Carter and Trude, 1988). Alternatively, reimbursements under the PPS can be expressed in terms of the average DRG weight — also referred to as case-mix index (CMI) — and $\#DISCHARGES_{it}$, the number of Medicare discharges for hospital i in year t.

$ADJUST_{it}$ is the combined effect of various subsidies to hospitals. The largest adjustments, and those that were affected by the reform we analyze, are the indirect medical education (IME) subsidy and the disproportionate share (DSH) subsidy. These adjustments correspond to payments received by hospitals for training physicians and treating poor patients, and are calculated by multiplying Medicare inpatient revenues with a term equal to $1 + \%IME_{it} + \%DSH_{it}$. Medicare also makes other payments to hospitals. These are generally not directly related to inpatient care, such as direct teaching costs, care provided in a skilled nursing facility, and capital-related costs. In this study, we focus on changes made to the subsidies for training residents and treating poor patients included in the PPS.

4.1 Indirect Medical Education Subsidy

In 1998, Medicare provided the 1,250 US teaching hospitals with payments of $5.9 billion for graduate medical education (GME). The 200 largest teaching hospitals received an average of $19.5 billion each in GME payments, which represented 7% of their operating revenues (Nicholson and Song, 2001). Teaching hospitals receive two supplemental payments from Medicare: direct medical education (DME) and indirect medical education (IME) payments, which accounted for 38% and 62% respectively of total GME payments in 1998. DME payments reimburse a teaching hospital for Medicare's share of the direct costs of training residents. The effects of the DME will not be examined in this paper, since the policy was not amended substantially by the reforms of the late 1990s.

The IME subsidy is meant to compensate teaching hospitals for indirect expenses stemming for example from use of diagnostic services by clinically inexperienced residents or decreased productivity of nurses and support staff involved in the teaching of residents.[3] Since 1989, the DRG payment a hospital receives for admitting a Medicare patient increases non-linearly with the hospital's resident-to-bed ratio according to the following formula:

$$\%IME_{it} = \alpha_t \cdot \left[\left(1 + \frac{RESIDENTS_{it}}{BEDS_{it}} \right)^{.405} - 1 \right] \tag{2}$$

where α_t is a multiplier set at 1.89 in the pre-reform period. This corresponds to a price increase of approximately 7.65% for every 10% increase in a hospital's resident-to-bed ratio.

4.2 Disproportionate Share Hospital Subsidy

In order to describe fully the impact of the reform we study, we also include a brief discussion of the DSH subsidy. The Medicare DSH adjustment provision was enacted by the Consolidated Omnibus Budget Reconciliation Act of 1985 and became effective in 1986. As with the IME subsidy, the DSH subsidy is calculated as a multiple of Medicare reimbursement for inpatient care. The key determinant of whether a hospital is eligible for this subsidy

[3]This stated rationale is not consistent with economic theory, since residency training constitutes a human capital investment that is general rather than specific (Newhouse and Wilensky, 2001). For a detailed history of the subsidy and its effects, one can refer to Nicholson and Song (2001) and Drozd (1999).

is essentially the fraction of total patient-days spent in the hospital due to poor patients. Above a certain threshold, hospitals become eligible for a DSH payment adjustment, which varies according to whether the hospital is urban or rural and the number of beds.[4]

4.3 The Balanced Budget Act of 1997 and its Refinements

The Balanced Budget Act (BBA) was passed in 1997 in an attempt to reduce the federal budget deficit. Medicare alone accounted for 112 of the projected $127 billion of savings over a five-year period from 1998 through 2002. The historical rate of growth for Medicare suggested that financing the program would face difficulties, especially after 2010 when the baby-boomers would become eligible, and its financing became a major issue in the 1996 presidential campaign.

The BBA contained a number of provisions that affected PPS payments. These provisions accounted for about 28.6% of the projected savings for the program (Guterman, 1998). More than one-half of the savings were to be generated by decreases in the update applied to the standardized PPS price — P_{it} in equation (1). The remainder of the savings were obtained by decreasing the capital payments made to hospital under PPS, and by altering the formula used to compute the IME subsidy and by reducing the DSH add-on factor. Finally, outlier payments were taken out of the base upon which IME and DSH adjustments are applied.

We focus only on the reductions in IME and DSH subsidies, since they did not affect all hospitals to the same extent. Specifically, the BBA changed the multiplier α_t in equation (2) from 1.89 in 1997 to

$$\alpha_t = \begin{cases} 1.72 & \text{for discharges occurring in fiscal year 1998,} \\ 1.60 & \text{for discharges occurring in fiscal year 1999,} \\ 1.47 & \text{for discharges occurring in fiscal year 2000,} \\ 1.36 & \text{for discharges occurring in fiscal year 2001 and thereafter.} \end{cases}$$

[4] A more complete discussion of this policy can be found in Nicholson and Song (2001) and Drozd (1999). The exact schedule is published in the *Code of Federal Regulations* (42 CFR 412.106).

The important point is that, even though α_t does not vary across hospitals, the impact of the reform varies considerably across hospitals according to their teaching intensity (as measured by the resident-to-bed ratio) and the number of Medicare discharges.[5]

The BBA also created the Medicare+Choice program, under which Medicare managed care contracts operate. IME payments to teaching hospitals for Medicare+Choice discharges, based on the same formula as described earlier, were phased in over five years (an additional 20% each year from 1998 to 2002). Medicare managed care plans enrolled about 8% of Medicare beneficiaries in 1995, reaching a peak of 16% in 2000, and falling since. In light of the fact that healthier Medicare Beneficiaries are more likely to enroll in managed care plans (Newhouse, 2001), Medicare+Choice enrollees probably represent an even smaller percentage of hospital discharges. In the analysis below, we ignore Medicare+Choice IME payments, about which we have no information. Given the elements above, we doubt that including their effects would substantially alter our conclusions.

The impact of the BBA was argued to be harsher than intended by congress and hospitals saw their financial status deteriorate significantly in 1998 and 1999 (Iglehart, 1999; Dickler and Shaw, 2000). In response to the plea for relief by teaching hospitals, the Balanced Budget Refinement Act (BBRA) of 1999 slowed down the scheduled decreases, a process continued by the Benefits Improvement and Protection Act (BIPA) of 2000. As a result of these "give-backs," α_t remained set at 1.60 from 1999 to 2002, before decreasing to 1.36 in 2003.

The BBA also decreased the DSH adjustment factor by 1% a year for five years (cumulating at 15% at the end of five years), while leaving the basic formula intact. Subsequently, the BBRA and BIPA mostly restored the BBA cuts in the DSH program; there was only a 2% cut in 2001, a 3% cut in 2002, and no reductions at all after 2003. Like the IME adjustment, the DSH adjustment factor varies substantially between hospitals. However, the cuts in DSH payments were smaller than that of IME payments. While our empirical analysis

[5]The BBA also capped the number of residents that a hospital could count towards reimbursement at 1996 levels. Thus, a hospital could no longer gain by expanding its residency programs, but it could lose by contracting. However, the stabilization of the number of residents after 1993 suggests that this cap was not very binding (Newhouse, 2001).

fully incorporates changes in the DSH subsidy, the discussion will focus on the change in the IME subsidy.

5 Data and Description of Variables

The data was compiled from a variety of sources. For all the variables, we obtained a time series starting in 1994 and ending in 2001. We first describe the construction of the main variables before presenting descriptive statistics.

5.1 Measures of Hospital-level Research Activity

While the ultimate outputs of biomedical research cannot be traced to a single institution, such an exercise is possible with intermediate outputs — scientific publications and research grants. In this paper, we focus on NIH and industry grants. This choice is motivated by data availability and the fact that these sources account for more than 80% research expenditures within AMCs (Commonwealth Fund, 1999).

NIH-funded Research. NIH Grant information stems from the Consolidated Grant Application File (CGAF), which provides information on amounts awarded, investigators, their institution, and a number of project characteristics. To construct the set of relevant grants, we limit our analysis to research project awards (NIH activity code R), research career awards (NIH activity code K), program projects and centers (NIH activity codes M and P), cooperative agreements between NIH and a group of investigators (often a clinical trial, NIH activity code U01), and R&D contracts to evaluate a product or device (NIH activity code N01). While this list accounts for the bulk of extramural awards, it excludes educational grants, as well as programs designed to support whole institutions, as opposed to individual investigators or small groups of investigators.

The main limitation of NIH data in the context of this study is the need to construct hospital-specific — as opposed to medical school-specific — aggregate measures of research activity. This is essential since the policy experiment we analyze makes use of an hospital-

level shock. Furthermore, within a medical school, a large proportion of grants are awarded to faculty unaffiliated with clinical facilities, typically in basic science departments such as anatomy, microbiology, or pharmacology. Whenever hospitals are owned independently of the medical school to which they are affiliated, NIH assigns the grant to the hospital in which the research takes place. However, independent hospitals accounts only for about 20% of the grants. In all other cases, the data records only the medical school, making it difficult to assign the grant to the hospital with which the investigator has its primary affiliation.

When medical school is listed but hospital affiliation is not, we proceed in two steps. First, we retain only grants flowing to faculty in clinical departments, such as medicine and surgery. We reason that these faculty will have a clinical affiliation, and therefore comprise the set of investigators potentially affected by the reform. Unfortunately, medical school are often affiliated with multiple hospitals, and we cannot divine investigators' hospital affiliation from their academic appointments. For these cases, it is better to think of an observation in our sample as an "hospital aggregate." For instance, the "hospital" for Johns Hopkins School of Medicine in fact aggregates the grants of three hospitals affiliated with the medical school: Johns Hopkins Hospital, Franklin Square Hospital and Howard County General Hospital.[6]

We exclude from our sample federal facilities (such as army and Veterans Administration hospitals), because they are financed very differently from other centers. We omit pediatric, psychiatric, cancer, and rehabilitation hospitals, which are not subject to the PPS and whose research opportunities may not follow trends similar to that of general acute hospitals, since they cater only to patients with certain diagnostics.[7] Finally, we eliminate hospitals with less than 10 grants between 1994 and 2001. We are left with a sample of 163 teaching and research hospitals. Of these 163 hospitals, all but three are located in urban areas; 42 are

[6]The other teaching/research affiliates of JHU (Johns Hopkins Bayview Medical Center, Good Samaritan Hospital, Greater Baltimore Medical Center, Sinai Hospital of Baltimore, and Kennedy Krieger Children Hospital) appear as independent hospitals in the CGAF data.

[7]For hospital "aggregates," this creates a problem when the grant figure corresponds to both affected and exempt facilities. For example, the grant amounts awarded to investigators in the clinical departments of UCSF School of Medicine comprise those of UCSF Medical Center, San Francisco General Hospital, and Langley Porter Psychiatric Institute; only the first two institutions are subject to the PPS. In the empirical work, we verify that these 19 "problematic" observations do not drive the results.

located in California, New York or Massachusetts; and 43 are in fact "hospital aggregates" as explained above.

The average yearly amount of NIH grants received by these hospitals was $ 20.2 million. As can be seen in Figure 3, the distribution of awards is extremely skewed. The complete list of the hospitals in our sample, ranked by average yearly NIH awards between 1994 and 2001, can be found in Table 1.

Industry-funded Research. The clinical trials data come from a confidential dataset of investigator contracts made available by FastTrack Systems, Inc. Since 1991, this firm has gathered trial information from subscribing pharmaceutical companies in order to help them better plan and negotiate investigator grants. The breadth of the data's longitudinal and cross-sectional coverage is impressive, with 26,414 grants awarded to US medical schools and their affiliated hospitals between 1994 and 2001. Compared with the NIH data, the main limitation of the industry grant information is that it does not represent the universe of grants, but only a sample corresponding to the firms subscribing to the service. Although no company can be identified by name under our confidentiality agreement, subscribers include nearly all large pharmaceutical companies (US- and foreign-based), as well as most large biotechnology firms. As a result, the industry grant information is noisier than the NIH data, but we have no reason to think that participating and non-participating firms differ in their choice of clinical sites for the trials they sponsor.

The average yearly amount of industry grants received by the hospitals in our sample was $ 1.6 million. As can be seen in Figure 3, the distribution of industry awards is also skewed, although less so than the NIH grant distribution.

5.2 Measuring the Impact of the Reform

To assess the impact of the BBA and its refinements on each hospital's inpatient Medicare reimbursements, we used the Medicare cost reports in combination with the IMPACT files publicly available on the web site of the Center of Medicare and Medicaid Services (CMS), along with various issues of the Federal Register. These data include the variables required

for calculating Medicare PPS operating payments: the number of Medicare discharges, the resident-to-bed ratio, the case-mix index, as well as other variables who play a minor role in the calculation (Frank (2003) provides more details on the exact calculations).

A key feature of our analysis is to make use of the substantial cross-sectional variation in the extent to which hospitals subject to the PPS were exposed to the reform. In our attempt to parameterize the impact of the BBA, we acknowledge that hospitals could respond to the reform, for example by reducing their number of beds or "upcoding," an accounting practice which consists in shifting a patient's DRG to one that yields a greater reimbursement.[8] In order to avoid introducing endogeneity in our measure of exposure to the BBA, we compute a variable which we term "Counterfactual Medicare Payments" (CMP). It attempts to estimate the payments the hospital would have received based on the reforms, but fixing the hospital-level determinants of reimbursement (patient case-mix, number of residents, beds and Medicare discharges) at their average level *before* the reform. CMP_{it} is equal to actual Medicare payments up to 1997, and from 1998 onwards is defined as:

$$\begin{aligned} CMP_{it} &= P_{it} \times \overline{\#DISCHARGES}_{i,before} \times \overline{CMI}_{i,before} \times ADJUST_{it} \\ &\quad + \overline{OUTLIERS}_{i,before} \end{aligned} \tag{3}$$

where the IME adjustment factor in any post-reform year t is computed as:

$$\%IME_{it} = \alpha_t \cdot \left[\left(1 + \frac{\overline{RESIDENTS}_{i,before}}{\overline{BEDS}_{i,before}} \right)^{.405} - 1 \right] \tag{4}$$

The overbar denotes averages over the pre-reform period (1994-97), α_t and P_{it} correspond to the *actual* prices and multiplying factor used by CMS in year t, and the DSH adjustment factor $\%DSH_{it}$ is calculated following a similar principle. Note that CMP_{it} is defined entirely as of the pre-reform period: nothing that the hospital does after the reform can affect the measure.

Taking into account the decrease in the multiplier α_t implied by the BBA, BBRA, and BIPA, the mean decrease in the subsidy factor was 5%, but this average conceals wide

[8] Newhouse (2001) notes that the BBA coincided with an increase in the resources devoted to fraud and abuse in the Medicare program, reducing the ability of hospitals to manipulate the payment system.

variation across hospitals in the impact of the reform.[9] This can be seen on Figure 6, which displays the distribution of $\%IME_{it}$ for all hospital-year observations in the PPS sample. Figure 7 incorporates all elements of the PPS system to graph the evolution over time of hospital-level counterfactual Medicare payments. These averages mask large variations, both across hospitals and within hospitals over time. This is shown on Figure 8, which displays the distribution of CMP_{it} for all hospital-year observations. Most relevant to our empirical approach, however, are *changes* in CMP_{it}. Figure 9 displays the distribution of ΔCMP_{it} between 1996 and 2000 for our sample. These hospitals faced a reduction in Medicare payments of $8.5 million on average, or 14% of Medicare revenues.

In short, while the reform did not constitute a large financial shock for many hospitals subject to the PPS, some teaching and research facilities were severely affected. We use this source of variation to identify the relationship between health care finance and research outputs.

5.3 Control Variables

We collected control variables from a variety of other data sources. The number of hospital employees — our measure of hospital size — was obtained from the American Hospital Association annual survey of acute-care hospitals. From the Area Resource File (Bureau of Health Professions, 2002), we gathered demographic variables, using Health Service Areas (HSAs) to cluster hospitals in distinct geographic markets.[10] These variables included per capita income, total population, fraction of the population above 65 years of age, hospital employment in the HSA, and HMO penetration in the HSA.[11] This last variable was included since the rapid growth of managed care has been alleged to decrease the amount of institutional funds available to support clinical research within AMCs (Hellerstein, 1998). The mean and standard deviation for all variables are presented in Table 2.

[9] In robustness checks, we conducted all empirical analyses first ignoring the give-backs of BBRA and BIPA, and second under the assumption that the BBA cuts were fully phased-in as of 1998 (*i.e.,* setting $\alpha_t = 1.36$ after 1998). The results were qualitatively very similar to those presented below.

[10] HSAs correspond to agglomeration of counties that are relatively self-contained with respect to the provision of routine hospital care (Bureau of Health Professions, 2002). This seems appropriate to define the geographic area from which a teaching hospital is expected to draw its patients.

[11] We are indebted to Laurence Baker for allowing us to use the measures of HMO enrollment he developed (Baker, 1995).

6 Empirical Analysis

6.1 Empirical Framework

We now present the formal econometric framework for analyzing the effect of the BBA. Our approach is similar in flavor to a "differences-in-differences" strategy with the important difference that we use a continuous variable to measure the "intensity of treatment" for each hospital in our sample. We estimate the following equation:

$$\begin{aligned} Ln(Research_{it}) &= \beta_0 + \beta_1 Ln(CMP_{it}) + \beta_2 \left[Ln(CMP_{it}) \times AFTER_t\right] \\ &\quad + \beta_3 Ln(\#EMPLOYEES_{it}) + \beta_4 X_{it} + \gamma_i + \delta_t + \varepsilon_{it} \end{aligned} \tag{5}$$

where i denotes hospitals and t denotes calendar year, so that we have a total of 1,301 observations. $AFTER_t$ is a dummy for the post-reform era (1998 onwards), X_{it} is a vector of time-varying control variables for the HSA in which hospital i is located, γ_i is a set of hospital fixed effects, and δ_t is a set of year fixed effects. Different versions of (5) are estimated corresponding to different measures of research activity.

In this specification, β_2 captures the effect of the reform: the magnitude of the change in research activity in response to an exogenous change in Medicare reimbursement levels. A positive coefficient is consistent with the view that institutional funds complement external sources of research funding, while a negative coefficient would indicate that internal funds crowd out NIH or industry grants.

Two econometric caveats deserve mention. First, the specification uses logs for both the dependent variable and the main independent variable of interest. Since (5) also includes unit fixed effects, we are in fact analyzing the percentage change in research activity caused by a given percentage change in reimbursement levels. There are reasons to think that the residuals of such a model will exhibit heteroskedasticity, since the loss of a single grant for a "small" hospital will represent a large percentage change for its research portfolio.[12] Figure 10 presents the scatter plot of the residuals corresponding to OLS estimates (with log

[12] "Smallness" refers here not to traditional measures of hospital size, such as number of beds or revenues, but to the size of the research enterprise within the hospital.

of NIH grants as the dependent variable) against the average amount of NIH grants in the pre-reform period for the hospital. In light of the pronounced pattern of heteroskedasticity, we estimate (5) by weighted least squares.[13]

Second, because the residuals of the models corresponding to different definitions of the dependent variable may exhibit contemporaneous correlation, estimation is performed using seemingly unrelated regression (Zellner, 1962). This estimation method also enables us to perform formal statistical tests to determine the research margins along which AMCs responded to the reform in a more pronounced fashion.

6.2 Results

Table 3 reports the results from estimating equation (5). Model (1) corresponds to the joint estimation of NIH grants and industry grants by seemingly unrelated least squares. In the NIH equation, the coefficient on $Ln(CMP) \times AFTER$ is positive and significant, while it is positive and not significantly different from 0 in the industry grant equation. Model (2) attempts to consolidate these two results by using as dependent variable the log odds of the fraction of research funds flowing to MDs accounted for by industry grants. In this specification, β_2 is negative and statistically different from 0 at the 10% level. NIH grant amounts grew less rapidly in those hospitals that were more exposed to the BBA, compared to "controls" to whom the BBA dealt a less severe financial blow. Because industry grants did not respond to the reform, more affected hospitals experienced a rebalancing of their research portfolio towards more "applied" research, relative to less affected hospitals.

Model (3) reports the estimates obtained by jointly estimating equations corresponding to the grants from NIH flowing to MDs, PhDs, and MD/PhDs, respectively. While we find a statistically significant effect for all three types of investigators, the effect is most pronounced for MD/PhDs, followed by MDs, and finally PhDs. We perform inequality tests to gauge whether these differences are statistically significant. We cannot reject the hypothesis that the MD/PhD coefficient is greater than the PhD coefficient at the 5% level of significance; and

[13]We verified that our results are robust to the choice of particular weights, by using instead the average number of grants or the average amount of investigators. None of our results were substantially affected.

we cannot reject the hypothesis that the MD coefficient is greater than the PhD coefficient at the 10% level of significance. Model (4) performs a similar analysis by looking separately at NIH-funded clinical research (defined as grants to MD or MD/PhDs for research dealing with human subjects) and non-clinical research. We find an effect only on clinical research, and we cannot reject the hypothesis that β_2 in the clinical equation is in fact greater than β_2 in the non-clinical equation at the 5% level. Reassuringly, the estimate in model (1) lies between the lowest and highest values for β_2 in models (3) and (4).

The robustness of the main result for NIH grants is explored further in Table 4, which reproduces the first column of Model (1) in Table 3, our baseline specification. Column (2) adds to the model a full set of state-specific time trends. This should control for the impact of contemporaneous Medicaid reforms that might have affected hospital finances. The β_2 coefficient increases in magnitude while remaining statistically significant at the 1% level. Column (3) drops from the sample the 19×8 observations corresponding to hospital aggregates that include a provider exempt from the Medicare PPS. These problematic observations do not appear to drive our results. Column (4) attempts to address the concern that our measure of hospital size, employment, is endogenous to the passage of the act. We note that it is difficult to think of a control for scale that would be totally exogenous to changes in health care financing. We interact the log of hospital employment with a full set of year effects in an attempt to alleviate concerns about endogeneity. While this shrinks the magnitude of β_2 by a third, the estimate remains positive and significantly greater than 0, at least at the 10% level. Finally, column (5) adds as a control an alternative measure of scale: the log of total inpatient revenue for the hospital. This does not affect our results. In summary, our main result — that of a positive elasticity of NIH research activity with respect to reimbursement levels — appears quite robust.

Table 5 provides a more detailed look at the timing of the effect identified in Table 3, by interacting $Ln(CMP)$ with a full set of year dummies. For NIH grants, these interaction terms are positive in all years, but statistically different from 0 only in the post-reform years 1998-2001. Model (2) repeats the exercise separately for grants flowing to MDs, MD/PhDs, and PhDs. Using this more parsimonious specification, we find no effect at all for grants to

PhD-investigators, and an effect for MDs that is both large in magnitude and monotonically increasing over time in the post-reform years. For MD/PhDs, we find a large and positive effect in all years but the year 1995, but the effect is imprecisely estimated in some years. This could reflect noisiness in the time series for grants to MD/PhDs at most hospitals. Model (3) finds a similar pattern of results when splitting grants along the clinical/non-clinical dimension: There appears to be no effect of the reform on non-clinical research if the passage of the Act is modelled using year-specific slopes as opposed to a single dummy variable for the post-reform period.

The results in Tables 3 and 5 provide strong evidence that cuts in Medicare reimbursements influence both the level and the composition of research inside AMCs, and are suggestive that, even within *clinical* departments of medical schools, cuts in cross-subsidies from patient care are more keenly felt by physician-scientists than by laboratory investigators. The magnitudes of these effects are economically as well as statistically significant: NIH grants decrease by 10 to 30 cents for every $1 decrease in the amount of Medicare reimbursements, depending on the specification considered and the particular dependent variable of interest.

However, the timing of these effects is perplexing. NIH awards are disbursed to successful applicants within 9 months of application. Factoring in the time to generate preliminary results and to prepare the grant, one would have expected the reform to be felt only one and a half to two years after being enacted. Instead, the effect manifests itself already in 1998, and appears to persist throughout the post-reform period. The most likely explanation is that Medicare cuts were widely anticipated by administrators, who tightened hospital finances ahead of the reform. It does seem likely that such anticipatory behavior was more widespread in more exposed hospitals, as policy makers had long singled out the IME subsidy as having both a poor economic rationale and providing substantial rents to teaching institutions (Congressional Budget Office, 1995).[14]

[14]In unreported regressions, we examined whether operating expenses per discharge were trending down already in the pre-reform period in those hospitals that experienced a large decrease in CMP after the reform. While directionally supportive of this hypothesis, the results failed to reach statistical significance, even at the 10% level.

One possible mechanism behind the finding of a differential effect of the reform on research by MDs and PhDs lies in the substance of the cuts. The cuts in the IME multiplier had the effect of increasing the real price of residents in teaching hospitals. Hospitals might have responded to the reform by decreasing the size of their residency programs and increasing the time spent by full-time faculty members on inpatient care. If this were the case, the effect we measure would tell us very little about the importance of hospital cross-subsidies, and no lessons could be drawn that would apply to other forms of financial pressures experienced by teaching hospitals, included reductions in the outpatient Medicare Fee Schedule (MFS) or lower reimbursements by managed care providers. This possibility is explored in Table 6, which reports fixed effects regressions of the log of FTE residents on the log of number of beds, $Ln(CMP)$, $Ln(CMP) \times AFTER$, and a set of HSA-level control variables. In column (1), we find no evidence that residency programs shrunk more rapidly in hospitals that suffered large cuts as a result of the BBA. We find some very weak evidence of an effect, but only for hospitals whose average number of residents in the pre-reform was above the hospital-specific cap enacted by the Act (column 2); there is no evidence of any downward adjustment of the resident count for hospitals that were below the cap (column 3).

Overall, these results demonstrate that a link exists between the payments received by teaching hospitals for clinical care, and the intensity and composition of their research activities. They are consistent with the hypothesis that hospital cross-subsidies complement external sources of research funding, in particular from the NIH. While clinical research was affected by the BBA, non-clinical research remained relatively immune, as did research performed by academic physicians on behalf of pharmaceutical firms for the testing of new drugs. These results imply that decreases in the reimbursements made to AMCs for inpatient care foster an increasing division of labor between clinical and non-clinical scientists. To the extent that physician-scientists engaged in patient-oriented research are needed in order to translate basic scientific discoveries into treatment advances, reforms designed to contain the growth of health expenditures could have important consequences for the pace of medical progress.

7 Discussion and Conclusion

We examine the relationship between the financing of health care and biomedical research in academic medical centers. Using an exogenous decrease in Medicare reimbursements to teaching hospitals resulting from a policy change, we show that cuts in clinical care revenues decrease the amount of NIH grants flowing to investigators from those hospitals. Moreover, investigators holding a PhD degree, who devote all their time to laboratory research, are less affected than MDs, who typically engage in patient-oriented research and split their time between clinical care and research activities. This finding is consistent with anecdotal and survey evidence suggesting that cross-subsidies of clinical care revenues play a key role in seeding the research performed by physician-scientists within AMCs (Jones and Sanderson, 1996; Weissman et al., 1999).

We do not attempt to make statements about the net welfare effects of the reform. Indeed, there might be more efficient ways to finance clinical research than through add-on payments to Medicare reimbursements, which induce distortions in the market for residents (Nicholson and Song, 2001). Nonetheless, our results suggest that the Balanced Budget Act had consequences that may not have been fully appreciated by policy makers at the time the reform was enacted.

Administered price systems like the Medicare PPS have been found to leave rents to providers because of asymmetric information problems (Newhouse, 2002). Efforts to reduce these rents are seen as successful when they reduce costs without impinging on the quality of care, as appears to be the case (Cutler, 1995). Unfortunately, bringing reimbursements closer in line with the real costs of providing care also affects the delicate scientific and institutional fabric upon which medical innovation flourished since the 1950s.

Past research evaluating public funding of biomedical research has focused on the horizontal allocation of funds across diseases (Lichtenberg, 2001; Toole 2000). Yet NIH places a high priority on basic research that is of no obvious relevance to particular diseases. Moreover, many treatment discoveries spring from unexpected and anomalous results of clinical experience (Gelijns et al., 1998). As a result, correcting funding imbalances along the verti-

cal chain of biomedical research may constitute a more pressing challenge for public policy, avoiding the possibility that knowledge gained through basic scientific discoveries will not be translated into clinical practice (Sung et al., 2003). This issue has received attention from policy makers in recent years, but halting the secular decline in the funding of patient-oriented research promises to be an uphill battle, since the NIH selects peer reviewers from the population of past grantees (Nathan, 1998).

Our research also relates to a recent literature linking health care policy with the rate and direction of private investment in biomedical R&D (Weisbrod, 1991; Finkelstein, 2003). While we focus on publicly-funded research, the effects we identify would be magnified to the extent that such research has spillover effects on the rate of private innovation, as previous studies have reported (Jaffe, 1989).

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Figure 1: Evolution of Extramural NIH Funds, by Degree of Investigator, 1970-2001

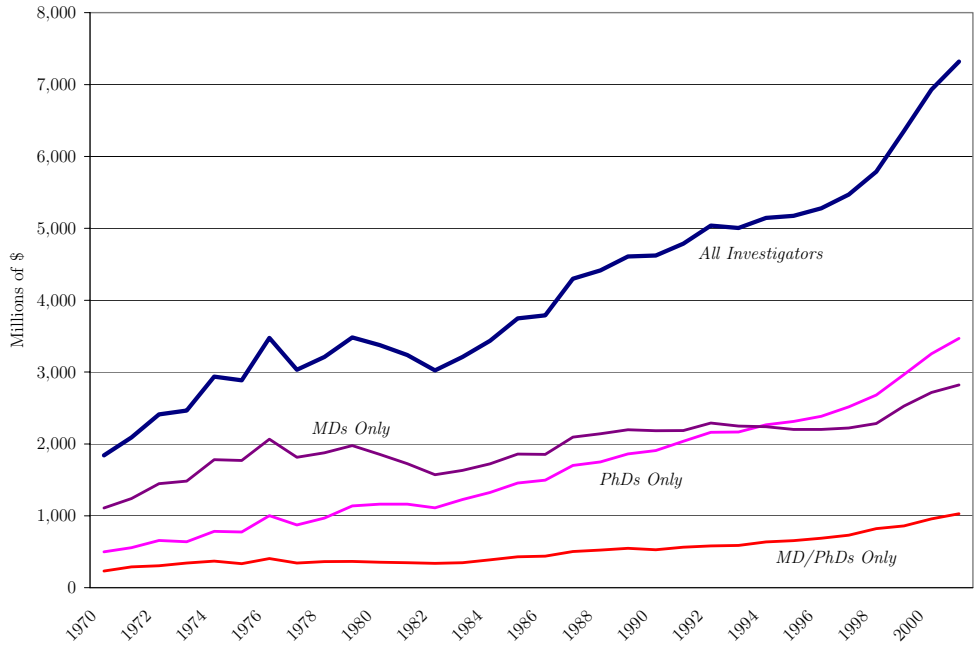

Figure 2: Extramural NIH Funds Devoted to Clinical Research, 1978-2001

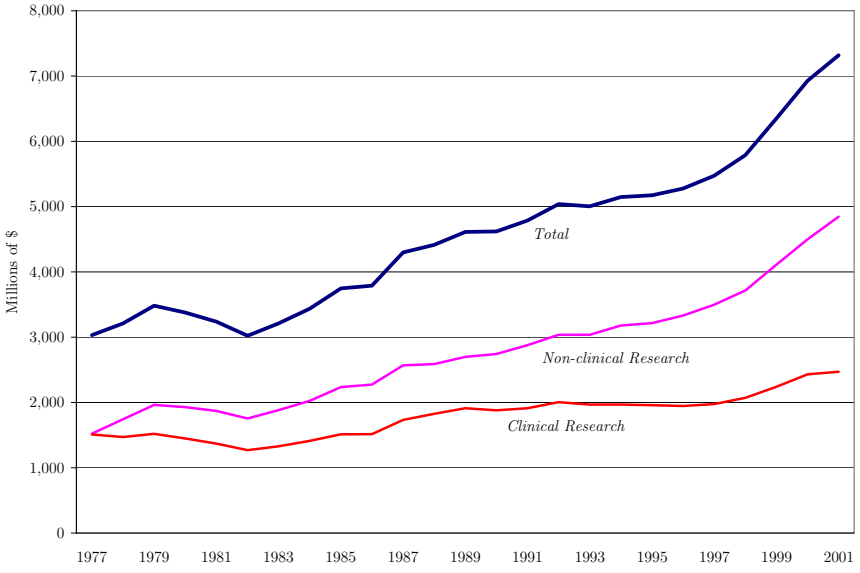

Figure 3: Annual Industry Grant Awards to AMCs and Commercial Testing Centers

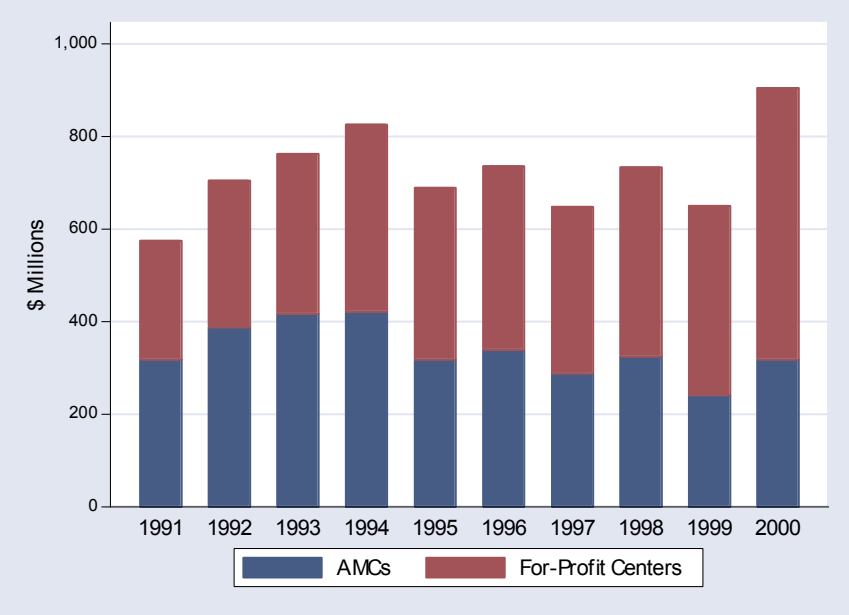

Figure 4: Distribution of Yearly Average NIH Awards to AMCs, 1994-2001

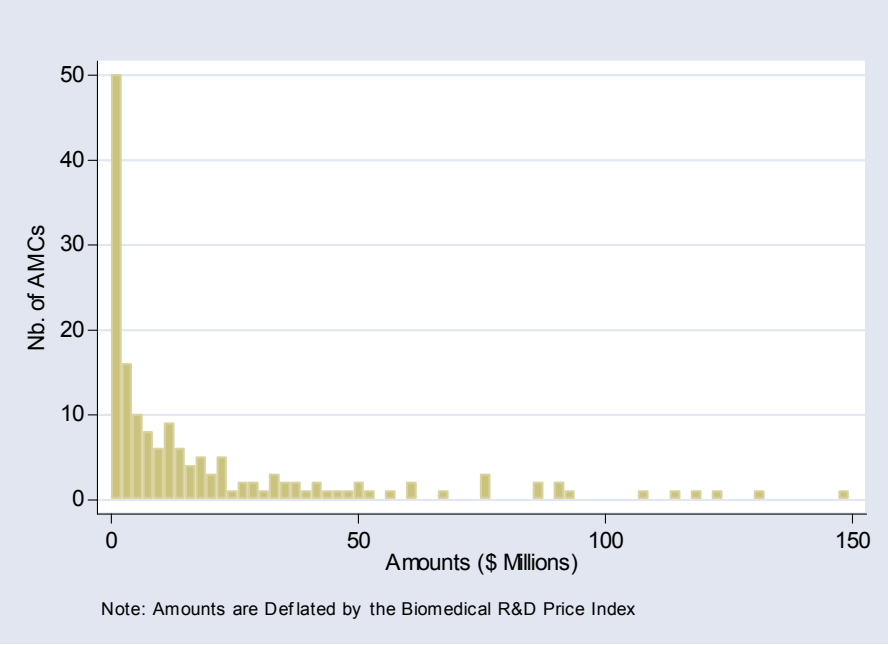

Figure 5: Distribution of Yearly Average Industry Awards to AMCs, 1994-2001

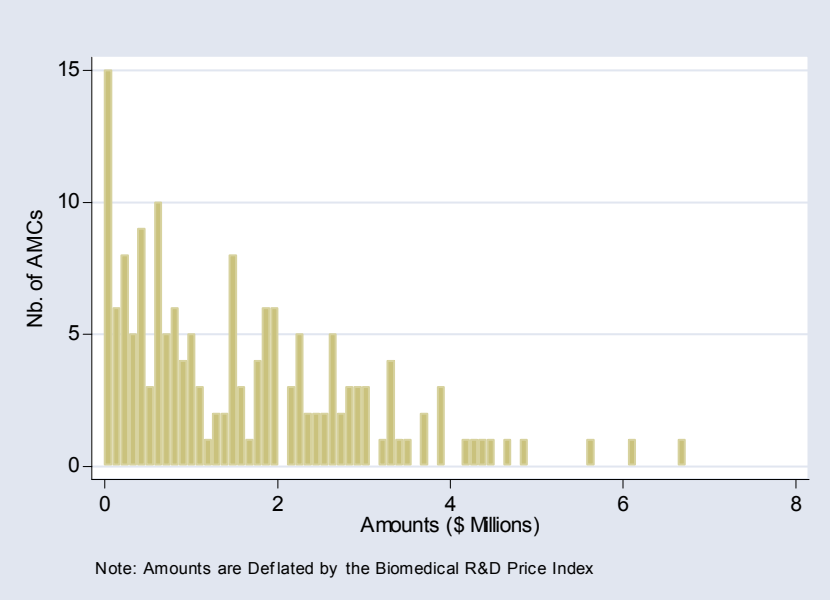

Figure 6: Distribution of Indirect Medical Education Adjustment Factor

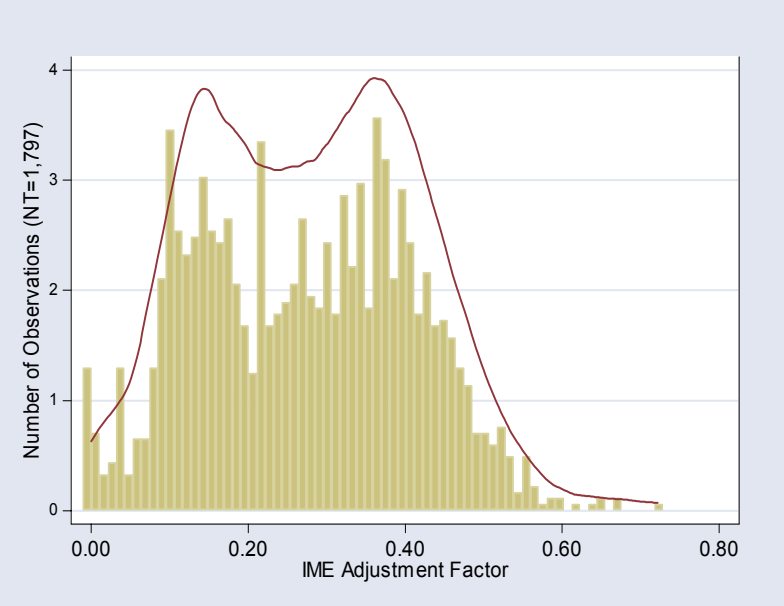

Figure 7: Mean Counterfactual Medicare Payments

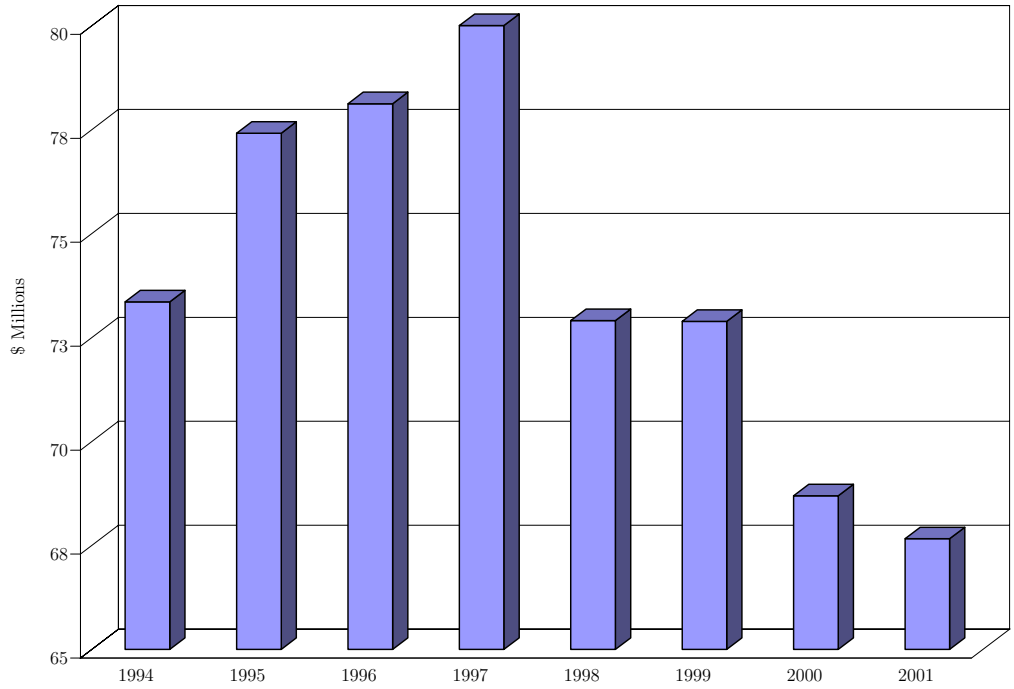

Figure 8: Distribution of BBA Impact – Levels 1994-2001

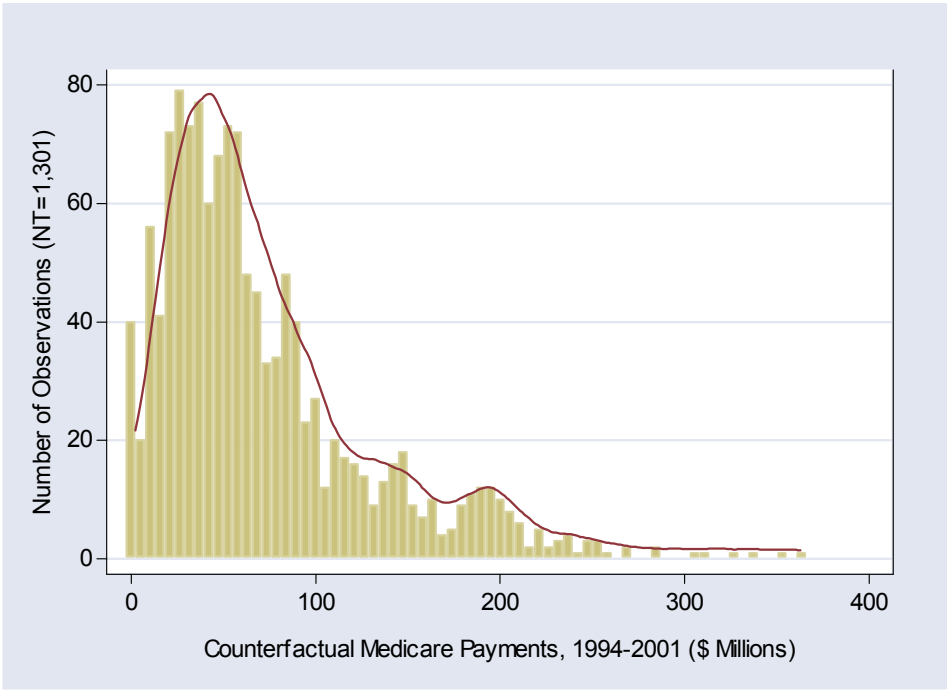

Figure 9: Distribution of BBA Impact – Changes Between 1996 and 2000

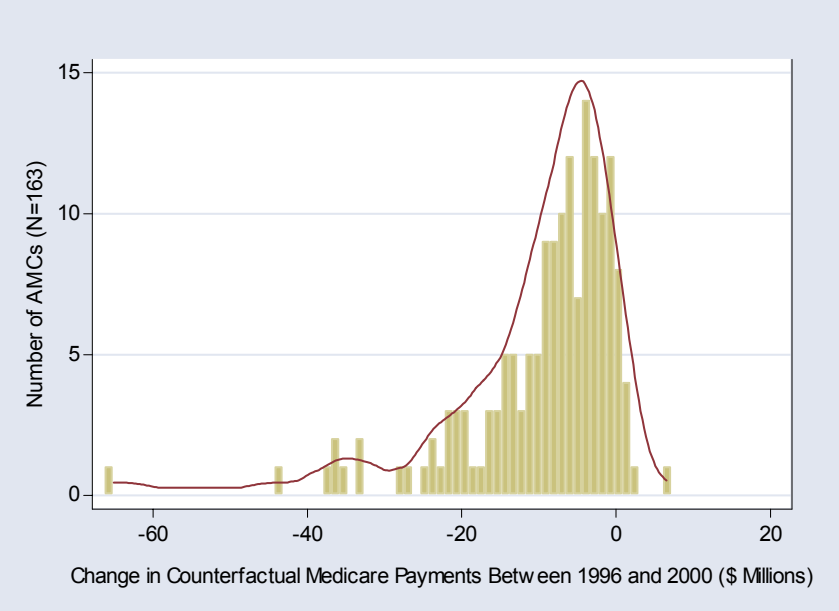

Figure 10: Scatter Plot of Unweighted Residuals Against Chosen Weights

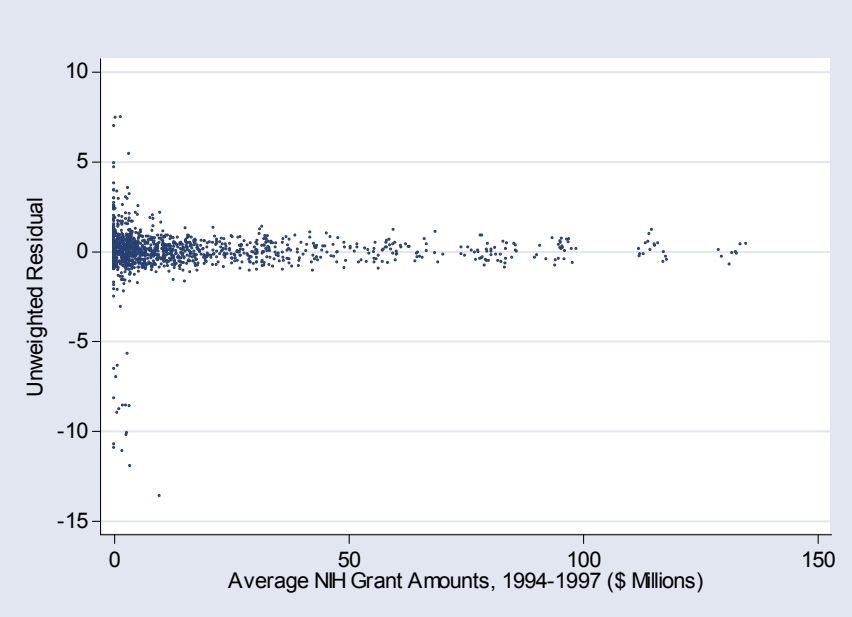

Table 1: Sample

Rank	Hospital/Medical School	State	Mean NIH Awards
1	Johns Hopkins University School of Medicine	MD	$ 149,534,048
2	University of Washington School of Medicine	WA	$ 131,013,456
3	UCSF School of Medicine	CA	$ 122,331,664
4	University of Pennsylvania School of Medicine	PA	$ 119,302,616
5	Massachusetts General Hospital	MA	$ 114,321,768
6	Brigham and Women's Hospital	MA	$ 107,870,752
7	Yale University School of Medicine	CT	$ 92,967,648
8	University of Pittsburgh School of Medicine	PA	$ 89,871,008
9	UCSD Medical Center	CA	$ 89,861,480
10	Duke University Medical Center	NC	$ 86,968,632
11	University of Michigan Hospitals	MI	$ 86,036,464
12	Columbia University College of Physicians and Surgeons	NY	$ 76,931,360
13	UCLA School of Medicine	CA	$ 76,203,936
14	University of Texas Health Sciences Center at Houston	TX	$ 75,313,160
15	Stanford University School of Medicine	CA	$ 67,868,056
16	University Hospitals of Cleveland	OH	$ 61,310,468
17	University of Alabama Health System	AL	$ 61,278,752
18	University of Colorado Health Sciences Center	CO	$ 57,136,280
19	University of Chicago Hospitals	IL	$ 52,605,564
20	University of North Carolina Hospitals	NC	$ 50,861,624
21	Beth Israel Deaconess Medical Center	MA	$ 50,317,984
22	University of Iowa Hospitals and Clinics	IW	$ 47,183,196
23	University of Texas Southwestern Medical Center at Dallas	TX	$ 45,342,668
24	Emory University School of Medicine	GA	$ 43,195,104
25	Baylor College of Medicine	TX	$ 42,406,800
26	University of Minnesota Medical School - Twin Cities	MN	$ 41,824,212
27	Mayo Medical School	MN	$ 40,400,680
28	Joan & Sanford I. Weill Medical College Cornell University	NY	$ 38,071,320
29	Mount Sinai Hospital	NY	$ 37,416,512
30	Indiana University School of Medicine	IN	$ 36,107,472
31	University of Rochester School of Medicine and Dentistry	NY	$ 36,054,760
32	University of Wisconsin Hospital and Clinics	WI	$ 33,664,200
33	Vanderbilt University Medical Center	TN	$ 33,390,260
34	New York University School of Medicine	NY	$ 33,123,056
35	University of Maryland School of Medicine	MD	$ 32,101,804
36	USC Keck School of Medicine	CA	$ 29,952,784
37	University of Utah Medical Center	UT	$ 28,534,206
38	Northwestern Memorial Hospital	IL	$ 26,852,618
39	North Carolina Baptist Hospital	NC	$ 25,831,472
40	University of Arizona Medical Center	AZ	$ 24,449,414
41	University of Virginia Health System	VA	$ 22,747,882
42	Oregon Health Sciences University Hospitals	OR	$ 22,490,790
43	University of Texas Medical School at San Antonio	TX	$ 22,455,352
44	Georgetown University Hospital	DC	$ 21,898,354
45	Wayne State University School of Medicine	MI	$ 21,491,786

46	University of Massachusetts Medical School	MA	$ 21,328,838
47	New England Medical Center	MA	$ 20,770,230
48	University of Cincinnati Hospital	OH	$ 19,430,094
49	Thomas Jefferson University Hospital	PA	$ 19,263,996
50	Shands Hospital at the University of Florida	FL	$ 19,098,672
51	UC Davis Medical Center	CA	$ 18,558,222
52	Medical University of South Carolina Medical Center	SC	$ 18,472,156
53	Medical College of Virginia Hospitals	VA	$ 17,996,426
54	Medical College of Wisconsin	WI	$ 16,836,690
55	Henry Ford Hospital	MI	$ 16,148,139
56	University of Texas Medical Branch Hospitals at Galveston	TX	$ 15,930,139
57	University of Illinois at Chicago Medical Center	IL	$ 15,130,847
58	UC Irvine College of Medicine	CA	$ 14,352,783
59	Ohio State University College of Medicine and Public Health	OH	$ 14,221,296
60	Boston Medical Center	MA	$ 13,912,716
61	The Milton S. Hershey Medical Center	PA	$ 13,674,130
62	Mary Hitchcock Memorial Hospital	NH	$ 13,266,568
63	LAC-Harbor UCLA Medical Center	CA	$ 13,075,461
64	Rush-Presbyterian-St. Luke's Medical Center	IL	$ 12,861,518
65	UMDNJ Medical School	NJ	$ 12,494,314
66	University of Connecticut Health Center	CT	$ 12,207,890
67	Barnes-Jewish Hospital	MO	$ 12,191,532
68	Kaiser Foundation Hospital (Oakland)	CA	$ 11,420,082
69	University Hospital of Brooklyn SUNY Health Center	NY	$ 11,160,314
70	University of Kentucky Hospital	KY	$ 10,938,261
71	University of New Mexico Hospital	NM	$ 10,928,214
72	University Hospital of Arkansas	AR	$ 10,901,844
73	Montefiore Medical Center	NY	$ 10,513,390
74	Fletcher Allen Health Care	VT	$ 10,376,617
75	Cleveland Clinic Hospital	OH	$ 9,940,992
76	SUNY Stony Brook School of Medicine	NY	$ 9,939,760
77	Cedars-Sinai Medical Center	CA	$ 9,684,172
78	St. Luke's-Roosevelt Hospital Center	NY	$ 9,542,481
79	University of Tennessee Medical Center	TN	$ 8,486,214
80	Johns Hopkins Bayview Medical Center	MD	$ 8,429,317
81	Rhode Island Hospital	RI	$ 7,907,616
82	Tulane University School of Medicine	LA	$ 7,721,800
83	UMDNJ Robert Wood Johnson Medical School	NJ	$ 7,633,344
84	Massachusetts Eye & Ear Infirmary	MA	$ 7,558,591
85	Medical College of Georgia School of Medicine	GA	$ 7,489,609
86	Temple University School of Medicine	PA	$ 6,981,369
87	Medical Center of Louisiana in New Orleans	LA	$ 6,322,185
88	University of Nebraska Medical Center	NE	$ 6,081,855
89	North Shore University Hospital	NY	$ 5,983,060
90	University of Oklahoma College of Medicine	OK	$ 5,710,935
91	Long Island Jewish Medical Center	NY	$ 5,570,412
92	Miriam Hospital	RI	$ 5,522,142
93	University of Louisville School of Medicine	KY	$ 5,402,170
94	Saint Louis University School of Medicine	MO	$ 5,148,550
95	Magee-Women's Hospital	PA	$ 4,639,038

96	University of Kansas Hospital	KS	$	4,539,310
97	University of South Florida College of Medicine	FL	$	4,286,816
98	Loyola University Medical Center	IL	$	3,912,702
99	SUNY Buffalo School of Medicine	NY	$	3,717,910
100	University of Mississippi Medical Center	MS	$	3,685,821
101	Howard University College of Medicine	DC	$	3,677,560
102	George Washington University Hospital	DC	$	3,651,924
103	Hospital for Special Surgery	NY	$	3,496,308
104	St. Elizabeth's Medical Center of Boston	MA	$	3,364,825
105	California Pacific Medical Center	CA	$	3,348,542
106	Virginia Mason Medical Center	WA	$	3,291,995
107	Beth Israel Medical Center	NY	$	3,179,974
108	Memorial Hospital of Rhode Island	RI	$	2,976,727
109	Medical College of Ohio Hospitals	OH	$	2,534,976
110	University of Missouri Hospitals and Clinics	MO	$	2,442,085
111	Kuakini Medical Center	HI	$	2,373,482
112	Martin Luther King, Jr./Charles R. Drew Medical Center	CA	$	2,309,779
113	St. Joseph's Hospital & Medical Center	AZ	$	2,223,104
114	Good Samaritan Hospital	OR	$	2,204,216
115	Loma Linda University Medical Center	CA	$	2,187,153
116	University Hospital, SUNY Upstate Medical University	NY	$	2,167,527
117	Albany Medical Center Hospital	NY	$	2,136,126
118	Queen's Medical Center	HI	$	2,093,960
119	Grady Memorial Hospital	GA	$	1,870,717
120	Saint Joseph Hospital	NE	$	1,830,481
121	Hospital for Joint Diseases Orthopaedic Institute	NY	$	1,722,851
122	Women and Infants Hospital of Rhode Island	RI	$	1,690,327
123	West Virginia University Hospitals	WV	$	1,616,166
124	Eastern Virginia Medical School	VA	$	1,609,783
125	Evanston Hospital	IL	$	1,437,452
126	Metropolitan Nashville General Hospital	TN	$	1,359,560
127	Albert Einstein Medical Center	PA	$	1,335,338
128	Mount Sinai Medical Center of Miami Beach	FL	$	1,298,317
129	Maine Medical Center	ME	$	1,278,027
130	Bronx Lebanon Hospital Center	NY	$	1,257,854
131	Roger Williams Hospital	RI	$	1,176,128
132	LSU Hospital Shreveport	LA	$	1,108,904
133	Providence Portland Medical Center	OR	$	977,358
134	William Beaumont Hospital	MI	$	961,844
135	Emanuel Hospital	OR	$	959,035
136	Southern Illinois University School of Medicine	IL	$	867,088
137	Baylor University Medical Center	TX	$	815,850
138	University of South Alabama Medical Center	AL	$	798,613
139	University of Nevada Medical Center	NV	$	795,966
140	Swedish Medical Center	WA	$	676,005
141	LDS Hospital	UT	$	644,250
142	Medical Center of Delaware	DE	$	623,186
143	Palmetto Richland Memorial Hospital	SC	$	622,513
144	Cooper Hospital/University Medical Center	NJ	$	603,943
145	Graduate Hospital	PA	$	599,845

146	Alton Ochsner Foundation Hospital	LA	$	598,425
147	Saint Francis Hospital and Medical Center	CT	$	574,381
148	Johnson City Medical Center Hospital	TN	$	519,434
149	Mt. Sinai Hospital Medical Center	IL	$	493,538
150	Texas Tech University Medical Center	TX	$	475,790
151	Mary Imogene Bassett Hospital	NY	$	439,942
152	Lankenau Hospital	PA	$	422,942
153	Michael Reese Medical Center	IL	$	397,493
154	Scott and White Memorial Hospital	TX	$	387,487
155	Good Samaritan Regional Medical Center	AZ	$	374,724
156	Hackensack Medical Center	NJ	$	344,713
157	University of Missouri-Kansas City School of Medicine	KS	$	286,908
158	Winthrop-University Hospital	NY	$	270,885
159	MetroHealth Medical Center	OH	$	245,798
160	Sinai Hospital of Baltimore	MD	$	242,426
161	Wills Eye Hospital	PA	$	199,984
162	Mercy Hospital of Pittsburgh	PA	$	160,949
163	New York Eye & Ear Infirmary	NY	$	98,912

Table 2:
Descriptive Statistics

	# Obs.	Mean	Std. Dev.	Min.	Max.
NIH Grant Awards, All Investigators	1,301	$20,221,863	$30,200,380	$0	$186,525,440
NIH Grant Awards, MDs only	1,301	$11,275,818	$17,139,616	$0	$105,685,576
NIH Grant Awards, PhDs only	1,301	$5,906,290	$8,673,354	$0	$53,164,632
NIH Grant Awards, MD/PhDs only	1,301	$2,990,594	$5,713,233	$0	$43,639,076
NIH Grant Awards, Clinical Research	1,301	$10,058,137	$15,589,789	$0	$100,212,728
NIH Grant Awards, Non-clinical Research	1,301	$10,114,564	$15,157,625	$0	$94,685,632
Industry Clinical Trials Grant Awards	1,301	$1,580,419	$1,591,144	$0	$10,156,377
% of Research Funds from Industry	1,286	28.55%	27.45%	0%	100%
Resident Cap as per the BBA	1,301	311	221	20	1,080
Number of Beds	1,301	654	457	40	2,660
Number of Residents	1,301	307	215	15	1,162
Hospital Employment	1,301	4,626	3,384	135	28,643
Hospital Employment in the HSA	1,301	36,550	31,228	1,831	104,031
Population in HSA	1,301	2,502,211	2,461,715	166,977	12,527,938
Fraction of the population 65+ in HSA	1,301	12.30%	2.00%	7.40%	21.00%
Per-capita Income in HSA	1,301	27,223	6,725	15,567	53,340
HMO penetration in HSA	1,301	26.60%	12.70%	0.10%	77.80%
Counterfactual Medicare Payment (CMP)	1,301	$ 73,951,984	$ 56,429,525	$ 2,223,885	$ 362,655,768
Total Inpatient Revenues	1,301	$ 508,617,283	$ 401,463,541	$ 6,049,253	$ 2,374,655,768
Mean NIH Grant Awards	163	$ 20,201,996	$ 29,679,145	$ 98,912	$ 149,534,048
Mean Industry Grant Awards	163	$ 1,582,604	$ 1,365,022	$ 0	$ 6,740,156
Change in CMP, 1996-2000	163	$ -9,429,580	$ 9,711,924	$ -65,100,000	$ 6,529,096

Table 3
"After" Dummy Summarizes the Passage of the Reform

Dependent variables are the logs of the real grant amounts in Models (1), (3) and (4). The dependent variable in Model (2) is the log odds of the proportion of external funding to MDs accounted for by industry grants. Models (1), (3) and (4) are estimated by weighted seemingly unrelated regression. Model (2) is estimated by weighted least squares. Each observation is weighted by the average amount of NIH grants in the pre-reform period.

	(1)		**(2)**	**(3)**			**(4)**	
	NIH Grants	**Industry Grants**	**Industry Grants/ Total Grants to MDs**	**MDs Only**	**PhDs Only**	**MD/PhDs Only**	**Clinical Research**	**Non-clinical Research**
Ln(CMP)	-0.077	-0.295	-0.164	0.068	-0.592	0.348	0.049	-0.142
	[0.219]	[0.386]	[0.327]	[0.277]	[0.394]	[0.643]	[0.369]	[0.317]
Ln(CMP)×After	0.147**	0.076	-0.109†	0.224**	0.125*	0.322**	0.247**	0.097†
	[0.035]	[0.062]	[0.056]	[0.045]	[0.063]	[0.103]	[0.059]	[0.051]
Ln(#Employees)	0.220*	0.090	-0.050	0.194	0.284	0.098	0.210	0.167
	[0.100]	[0.176]	[0.172]	[0.127]	[0.180]	[0.293]	[0.169]	[0.145]
Ln(Population in HSA)	0.800	-0.721	-0.353	-0.052	0.300	4.436*	0.503	0.078
	[0.668]	[1.177]	[1.424]	[0.844]	[1.199]	[1.957]	[1.124]	[0.966]
Ln(#Employees in HSA)	0.065	0.143	0.010	0.053	0.003	0.913*	0.061	-0.007
	[0.146]	[0.257]	[0.250]	[0.184]	[0.262]	[0.427]	[0.245]	[0.211]
%65+ in HSA	-0.933	-16.539	-12.208	9.650	-6.933	-5.348	14.872	2.538
	[8.053]	[14.182]	[12.736]	[10.174]	[14.448]	[23.583]	[13.548]	[11.637]
Ln(Average Income in HSA)	0.184	-0.575	-0.916	0.643	0.423	-2.476†	0.803	0.256
	[0.450]	[0.792]	[0.963]	[0.568]	[0.807]	[1.317]	[0.757]	[0.650]
%HMO in HSA	0.254	0.317	-0.210	-0.174	1.522†	-1.214	-0.209	0.646
	[0.462]	[0.814]	[0.908]	[0.584]	[0.829]	[1.353]	[0.777]	[0.668]
Constant	3.844	36.690*	17.356	7.035	16.984	-36.667	-2.867	13.969
	[10.138]	[17.854]	[22.892]	[12.808]	[18.189]	[29.690]	[17.056]	[14.650]
Observations	1,301	1,301	1,158	1,301	1,301	1,301	1,301	1,301
R^2	0.89	0.79	0.82	0.92	0.84	0.84	0.88	0.87

Standard errors in brackets, clustered by medical school
†Significant at 10%; *Significant at 5%; **Significant at 1%.
All models include year effects, hospital fixed effects, and a full set of HMO penetration/year effects interactions.

Table 4
Robustness Checks

In all models, the dependent variable is the log of the real NIH grant amount for the hospital/medical school. Estimation is performed by weighted least squares (each observation is weighted by the average amount of NIH grants in the pre-reform period).

	(1) Basic Specification	(2) State-specific Time Trends	(3) Clean Medical School Only	(4) Hospital Employment/ Year Interactions	(5) Total Inpatient Revenue Control
Ln(CMP)	-0.077	-0.065	-0.062	-0.051	-0.115
	[0.219]	[0.111]	[0.114]	[0.089]	[0.094]
Ln(CMP)×After	0.147**	0.210**	0.159**	0.093†	0.151**
	[0.035]	[0.080]	[0.050]	[0.049]	[0.042]
Ln(#Employees)	0.220**	0.212*	0.242*	0.157†	0.203*
	[0.100]	[0.103]	[0.104]	[0.080]	[0.079]
Ln(Total Inpatient Revenue)					0.094
					[1.059]
Constant	3.844	1,031.277*	-0.851	5.069	4.262
	[10.138]	[403.815]	[11.061]	[6.789]	[7.069]
Observations	1,301	1,301	1,149	1,301	1,301
R^2	0.89	0.90	0.88	0.89	0.89

Standard errors in brackets, clustered by medical school

†Significant at 10%; *Significant at 5%; **Significant at 1%.

All models include year effects, hospital fixed effects, HMO penetration, demographic controls as in Table 3, and a full set of HMO penetration/year effects interactions.

Table 5
Year-specific Slopes for the Impact of the Reform

In all models, the dependent variable is the log of real grant amounts. Estimation is performed by weighted seemingly unrelated regression (each observation is weighted by the average amount of NIH grants in the pre-reform period).

	(1)		(2)			(3)	
	NIH Grants	**Industry Grants**	**MDs Only**	**PhDs Only**	**MD/PhDs Only**	**Clinical Research**	**Non-clinical Research**
Ln(CMP)	-0.082	-0.389	0.033	-0.469	0.129	0.017	-0.097
	[0.222]	[0.392]	[0.281]	[0.399]	[0.649]	[0.374]	[0.322]
Ln(CMP)×1995	0.007	0.125	0.018	-0.195	0.216	0.048	-0.090
	[0.067]	[0.118]	[0.085]	[0.120]	[0.196]	[0.113]	[0.097]
Ln(CMP)×1996	0.030	0.131	0.077	-0.237*	0.327†	0.078	-0.075
	[0.067]	[0.119]	[0.085]	[0.121]	[0.197]	[0.113]	[0.097]
Ln(CMP)×1997	0.046	0.103	0.097	-0.174	0.466*	0.035	-0.054
	[0.068]	[0.120]	[0.086]	[0.122]	[0.199]	[0.115]	[0.099]
Ln(CMP)×1998	0.114†	0.118	0.261**	-0.094	0.523**	0.222†	-0.004
	[0.068]	[0.121]	[0.087]	[0.123]	[0.200]	[0.116]	[0.099]
Ln(CMP)×1999	0.138*	0.250*	0.289**	-0.022	0.764**	0.278*	0.049
	[0.068]	[0.120]	[0.086]	[0.123]	[0.200]	[0.115]	[0.099]
Ln(CMP)×2000	0.153*	0.202†	0.301**	-0.043	0.676**	0.288*	0.056
	[0.069]	[0.122]	[0.087]	[0.124]	[0.202]	[0.116]	[0.100]
Ln(CMP)×2001	0.280**	0.093	0.245**	0.047	0.349†	0.371**	0.069
	[0.070]	[0.123]	[0.088]	[0.125]	[0.203]	[0.117]	[0.101]
Ln(#Employees)	0.229*	0.084	0.180	0.303†	0.035	0.222	0.173
	[0.101]	[0.178]	[0.128]	[0.181]	[0.294]	[0.170]	[0.146]
Ln(Population in HSA)	0.965	-0.644	0.047	0.214	4.797*	0.644	0.079
	[0.673]	[1.188]	[0.852]	[1.209]	[1.968]	[1.135]	[0.975]
Ln(#Employees in HSA)	0.069	0.159	0.077	-0.024	1.007*	0.063	-0.011
	[0.146]	[0.258]	[0.185]	[0.263]	[0.428]	[0.247]	[0.212]
%65+ in HSA	0.277	-17.481	9.650	-6.693	-7.327	15.720	2.747
	[8.076]	[14.248]	[10.228]	[14.501]	[23.617]	[13.621]	[11.703]
Ln(Average Income in HSA)	0.103	-0.630	0.590	0.460	-2.682*	0.728	0.250
	[0.451]	[0.796]	[0.572]	[0.811]	[1.320]	[0.761]	[0.654]
%HMO in HSA	0.203	0.300	-0.217	1.580†	-1.362	-0.244	0.658
	[0.463]	[0.817]	[0.586]	[0.831]	[1.354]	[0.781]	[0.671]
Constant	2.166	37.915*	6.728	15.600	-35.685	-3.726	13.146
	[10.163]	[17.929]	[12.871]	[18.248]	[29.719]	[17.140]	[14.726]
Observations	1,301	1,301	1,301	1,301	1,301	1,301	1,301
R^2	0.89	0.79	0.92	0.84	0.84	0.88	0.87

Standard errors in brackets, clustered by medical school

†Significant at 10%; *Significant at 5%; **Significant at 1%.

All models include year effects, hospital fixed effects, and a full set of HMO penetration/year effects interactions.

Table 6
Resident Response to the BBA

Dependent variables is the log of FTE Residents. Estimation is performed by OLS (with hospital/medical school fixed effects).

	(1) All Hospitals	**(2)** Hospitals Above the BBA Cap in the Pre-Reform Period	**(3)** Hospitals Below the BBA Cap in the Pre-Reform Period
Ln(CMP)	0.250† [0.134]	0.158 [0.136]	0.381 [0.237]
Ln(CMP)×After	-0.005 [0.018]	-0.038† [0.023]	0.022 [0.022]
Ln(Beds)	0.559** [0.158]	0.574** [0.189]	0.427** [0.117]
Ln(Population in HSA)	-0.410† [0.243]	-0.332 [0.299]	-0.396 [0.363]
Ln(#Employees in HSA)	0.013 [0.035]	0.025 [0.068]	0.002 [0.031]
%65+ in HSA	-2.073 [2.981]	-4.961 [3.165]	-2.605 [4.062]
Ln(Average Income in HSA)	-0.295 [0.219]	-0.444† [0.243]	-0.252 [0.275]
%HMO in HSA	0.177 [0.186]	0.079 [0.271]	0.292 [0.253]
Constant	6.347† [3.797]	8.567 [5.584]	4.322 [4.064]
Observations R^2	1301 0.98	640 0.99	661 0.98

Robust standard errors in brackets, clustered by medical school.
†Significant at 10%; *Significant at 5%; **Significant at 1%.
All models include year effects, hospital fixed effects, and a full set of HMO penetration/year effects interactions.