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The Effect of U.S. Health Insurance Expansions on Medical Innovation

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Abstract

I study the effect of health insurance expansions on medical innovation. Practitioner-dominated innovation (Roberts, 1988) creates an important role for the incentives in local payment systems as drivers of medical technology development. I show that, over the 15 years following Medicare and Medicaid's passage, U.S.-based medical-equipment patenting rose by nearly 50 percent relative to both other U.S. patenting and foreign medical-equipment patenting. No such increase occurred among pharmaceutical patents, for which markets were not directly affected. Subsequent expansions in insurance against health care costs are also associated with increases in U.S.-based patenting relative to foreign patenting in the relevant areas. The dynamic effect of U.S. insurance expansions may account for 25 percent of recent global medical-equipment innovation and 15 percent of the rise in U.S. health spending in hospitals, physicians' offices, and other clinical settings from 1960 to 2010.

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What forces led U.S. health spending to rise from 5 to 18 percent of GDP from 1960 to 2010? The divergence of U.S. spending from that in other advanced economies suggests that U.S. insurance arrangements may play an important role. Insurance affects health spending through several channels. First, by reducing out-of-pocket costs, it increases beneficiaries' willingness to consume available services. Insurance also confronts providers with financial incentives that can be designed to encourage either high levels of care provision or cost-effective treatment choices (Chandra and Skinner, 2012).[1] In addition to these contemporaneous effects, insurance shapes the incentives for innovators to develop new medical products by influencing providers' willingness to adopt new health care technologies. Quantifying this dynamic effect, a topic of much interest since Weisbrod's (1991) classic essay, is this paper's primary aim.

Past work has generated substantial evidence characterizing the static effects of insurance on the behavior of health care consumers and providers (Baicker and Goldman, 2011).[2] Experimental studies, including the Rand and Oregon health insurance experiments, have shown that consumers increase their utilization of health care both when they obtain insurance and as the comprehensiveness of their insurance increases (Manning et al., 1987; Finkelstein et al., 2011). While the estimated demand responses are positive, they are modest in size. Work by Finkelstein (2007) and Glied and Zivin (2002) shows that aggregate changes in insurance may generate larger responses when physicians and hospitals respond to the coverage held by their typical patient.[3] Finally, and most relevant to this paper, a growing body of evidence shows that financial incentives influence health-care providers' technology adoption decisions. Such effects have

[1]Chandra and Skinner (2012) highlight the importance of these technology adoption and usage incentives for explaining differences in health spending both over time and across countries.

[2]Baicker and Goldman (2011) provide an excellent overview of much of the relevant literature.

[3]Such responses can be driven by either purely financial motives or by an altruistic physicians' interest in their patients financial well being as well as in their physical health.

been observed in the hospital setting in response to both the origins of Medicare and the later adoption of the Prospective Payment System (Finkelstein, 2007; Finkelstein and Acemoglu, 2008). They have also been observed in independent physicians' offices in response to changes in reimbursement rates (Clemens and Gottlieb, 2012).

Past work has less to say about the dynamic effect of insurance on health care spending via its effects on technology development. When insurance results in technology adoption, it increases the size of the markets for new technologies. If innovation pursues potential markets, it follows that insurance can accelerate the development of new health care technologies (Acemoglu, 1998). Finkelstein (2004) finds evidence for this phenomenon in the context of vaccine development. Within the broader pharmaceutical context, Acemoglu and Linn (2004) find that innovation responds to demographically-driven changes in the relative sizes of markets for particular classes of drugs.[4]

Two factors make it difficult to relate these past results to trends in overall health spending. The first is that these results may describe upper bounds on the potential effects of industry-wide changes in potential market size. Within the pharmaceutical sector, in particular over the short-to-medium run, responses of relative levels of innovation to relative market size may be driven in part by substitution across drug manufacturers' research lines.[5] Second, while important for independent reasons, the pharmaceutical sector accounts for less than 20 percent of total health spending and expanded little until the late 1980s. This study's analysis of medical-equipment innovation involves the technologies most directly associated with global and U.S.-specific trends in health expenditures. Medical-equipment innovation may also be of independent interest due to

[4]More recently, De Mouzon, Dubois, Scott Morton, and Seabright (2011) similarly find that increases in potential market size lead pharmaceutical companies to invent larger numbers of new chemical entities.

[5]Over the short-to-medium run, the importance of these substitution patterns will depend on the relative sizes of fixed costs associated with expanding capacity and reallocating existing capacity. Longer run impacts may better isolate the aggregate capacity-expansion effects that are of present interest. Even over the long run, however, aggregate medical innovation may be constrained by a relatively inelastic supply of truly innovative talent in the medical sciences (i.e., a necessary input in fixed supply).

its distinguishing characteristics (Roberts, 1988), some of which are detailed below.

A rich body of work on medical-equipment innovation points to a principal role for innovation by practitioners.[6] Physicians play an essential role in the process, often through engineering efforts targeted at the needs of their own practices (Roberts, 1988). In detailed case-studies of 34 medical-equipment innovations, for example, Shaw (1985, 1986, 1991) finds that half stemmed from physician-produced prototypes while an additional third (for a total of 85 percent) involved the transfer of an initial idea from a physician to a manufacturer.[7] The presence of end-users is thus crucial to the process, creating a primary role for home-country payment systems as drivers of medical-equipment innovation.

I investigate the dynamic effect of insurance on innovation by estimating the effect of the Great Society health programs on patenting activity. I show that, following Medicare and Medicaid's introduction, U.S.-based medical-equipment patenting surged by nearly 50 percent more than both other U.S. patenting and foreign medical-equipment patenting.[8] This core result is robust to a broad range of methods for controlling for more general, U.S.-specific trends towards health-sector innovation. Both point estimates and confidence intervals are robust to the use of ordinary least squares regression mod-

[6]This contrasts sharply with pharmaceutical innovation, which has its origins in the basic research efforts of governments and large, often multi-national, corporations.

[7]Studying more recent innovations, Chatterji, Fabrizio, Mitchell, and Schulman (2008) find that physicians directly accounted for 20 percent of medical-device patents filed during the early 1990s and for a greater fraction of high impact patents in this area (also see Chatterji and Fabrizio (2011)). Recent case studies of "radical innovation projects" in medical equipment technology by Lettl, Herstatt, and Gemuenden (2006) affirm the dominance of practitioners in driving relatively novel innovations in this area.

[8]Responsive categories of patents include surgical equipment, encompassing such historically important innovations as the balloon catheters used in angioplasty (Fogarty, Finn III, and Kinney, 1986; Palmaz, 1988), and diagnostic imaging equipment, encompassing such innovations as nuclear magnetic resonance imaging (NMRI) and computerized tomography (CT) scanners (Damadian, 1974; Ledley, 1975). The relevant categories also encompass a variety of relatively exotic cost drivers with dubious health benefits relative to alternative treatments. This includes a series of patents related to the systems of proton beam therapy discussed by Baicker and Chandra (2011).

els, alternative count models, and a synthetic control framework.[9] Consistent with the proposed mechanisms, expansions in U.S. medical-equipment patenting were largest in areas that had large numbers of physicians per capita, large numbers of (pre-Medicare) uninsured elderly individuals, and large expansions in state governments' spending on health.

While Medicare and Medicaid substantially reduced cost sharing for health care in hospitals and physicians' offices, they did not directly affect the markets for most pharmaceuticals.[10] Consequently, analysis of the evolution of pharmaceutical patenting can serve as a falsification exercise. Consistent with Acemoglu, Cutler, Finkelstein, and Linn (2006), I find no evidence of an effect of Medicare and Medicaid on pharmaceutical innovation. Shifts in patenting towards surgical and diagnostic equipment thus do not appear to reflect a more general, U.S.-specific shift towards health-sector innovation.

My estimates are of the differential effect of Medicare and Medicaid on U.S. medical-equipment patenting relative to their effect on foreign medical-equipment patenting. To the extent to which foreigners pursued the markets created by U.S. insurance arrangements, this differential will place a lower bound on the total effect of U.S. insurance expansions. The evolution of health-sector patenting across sub-groups of foreign countries provides suggestive evidence on the importance of these foreign-country responses. I find that the spread between the growth of U.S.-based medical-equipment patenting and foreign medical-equipment patenting becomes increasingly large as I restrict the

[9] Inference in the synthetic control framework involves constructing a distribution of placebo "treatment" effects by assigning treatment status to randomly selected subsets of the control units in the full sample (Abadie and Gardeazabal, 2003; Abadie and Hainmueller, 2010).

[10] Physician-administered medications, including chemotherapy drugs, are a notable exception as they are covered by Medicare Part B. Consistent with the broader point, Finkelstein and McKnight (2008) find evidence that, relative to the "near elderly," Medicare increased the elderly's total consumption of services in hospitals and physicians' offices while having no impact on prescription drug spending. Aggregate health spending statistics also reveal substantial growth in spending in hospitals, physicians offices, and other settings during the late 1960s and 1970s, with no growth in drug spending as a share of GDP at this time.

sample of foreign countries to those more culturally removed from the United States. Taking health-sector patenting in non-European, non-English speaking countries as a counterfactual, U.S. insurance expansions appear to have increased U.S.-based medical-equipment patenting by around 50 percent; this accounts for 25 percent of recent global medical-equipment innovation.

I conclude by estimating the impact of insurance-induced innovation on the trajectory of U.S. health expenditures. In an early discussion of insurance's dynamic impacts, Weisbrod (1991) notes that insurance can create incentives for innovation focused primarily on either quality enhancement (without regard for cost) or on cost reduction (at a given level of quality).[11] Retrospective payment systems, which reimburse physicians and hospitals on what is essentially a cost-plus basis, should tend to induce the former. Prospective payment systems, which provide fixed reimbursements based on patients' initial diagnoses, should tend to induce the latter.[12] The predominance of fee-for-service reimbursements over the time period under study makes insurance-induced innovation a potentially important driver of rising health expenditures.[13] I estimate that the dynamic effect of U.S. insurance arrangements on medical innovation accounts for around 15 percent of the rise in U.S. spending in hospitals, physicians' offices and other clinical settings over the last half century.

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[11]Weisbrod's (1991) analysis also provides an interesting lens through which the co-evolution of insurance and innovation can be interpreted. He describes a dynamic through which insurance accelerates the development of costly technologies, which increase demand for insurance by increasing the value of having resources when sick, and so on.

[12]For tracking the relevant incentives it is important to keep in mind that capitated systems can retain features of marginal-cost reimbursement. In the Prospective Payment System for U.S. hospitals, for example, diagnostic groups, and thus payments, are in part a function of the procedures the patient receives (Cutler, 1995).

[13]Baicker and Goldman (2011) and Cutler (1998) provide illustrations of the evolution of insurance plan-types over time, highlighting that traditional fee-for-service insurance plans remained dominant in the private-sector through the late 1980s.

1 U.S. Insurance Expansions and Consumer Cost Exposure

This section characterizes the effect of the mid-to-late 20th century rise of U.S. health insurance on consumer exposure to out-of-pocket costs. With the insurance of this era primarily involving cost-plus, fee-for-service reimbursement for providers, these insurance expansions can be viewed as unambiguous increases in the size of the U.S. markets for new health care technologies. In parallel with the subsequent empirical analysis, I consider consumer exposure to the costs associated with hospitals and physicians' offices separately from their exposure to the cost of prescription drugs.

Panel A of Figure 1 shows the fraction of spending at hospitals and physicians' offices that consumers paid out of pocket from 1960 to 1980.[14] It also reports the percentage change in this share from 1960 to each of the subsequent years. The implementation of Medicare and Medicaid resulted in a large, nearly immediate decline in this share, by 40 percent, from 1965 to 1967. By 1970 it had declined by more than 50 percent. Declines continued over subsequent years, approaching 90 percent by 1980, in part reflecting the expansion of Medicaid to the disabled and to those on Supplemental Security Income in 1972.

Panel B reports series similar to those in Panel A, but for consumer exposure to the cost of prescription drugs. The percent change in the out-of-pocket share for prescription drugs is much smaller than it was in the case of spending at hospitals and in physicians' offices. The change approaches a 25 percent reduction by 1980, with a reduction of less than 15 percent from 1960 to 1970. By as late as 1980, consumers remained exposed to an average of 70 percent of the cost of their prescription drugs.

Panels C and D report the same series as Panels A and B, but for the period extending

[14] This section's figures were constructed using data on total and out-of-pocket health spending from the National Health Expenditure accounts reported by the Centers for Medicare and Medicaid Services (CMS).

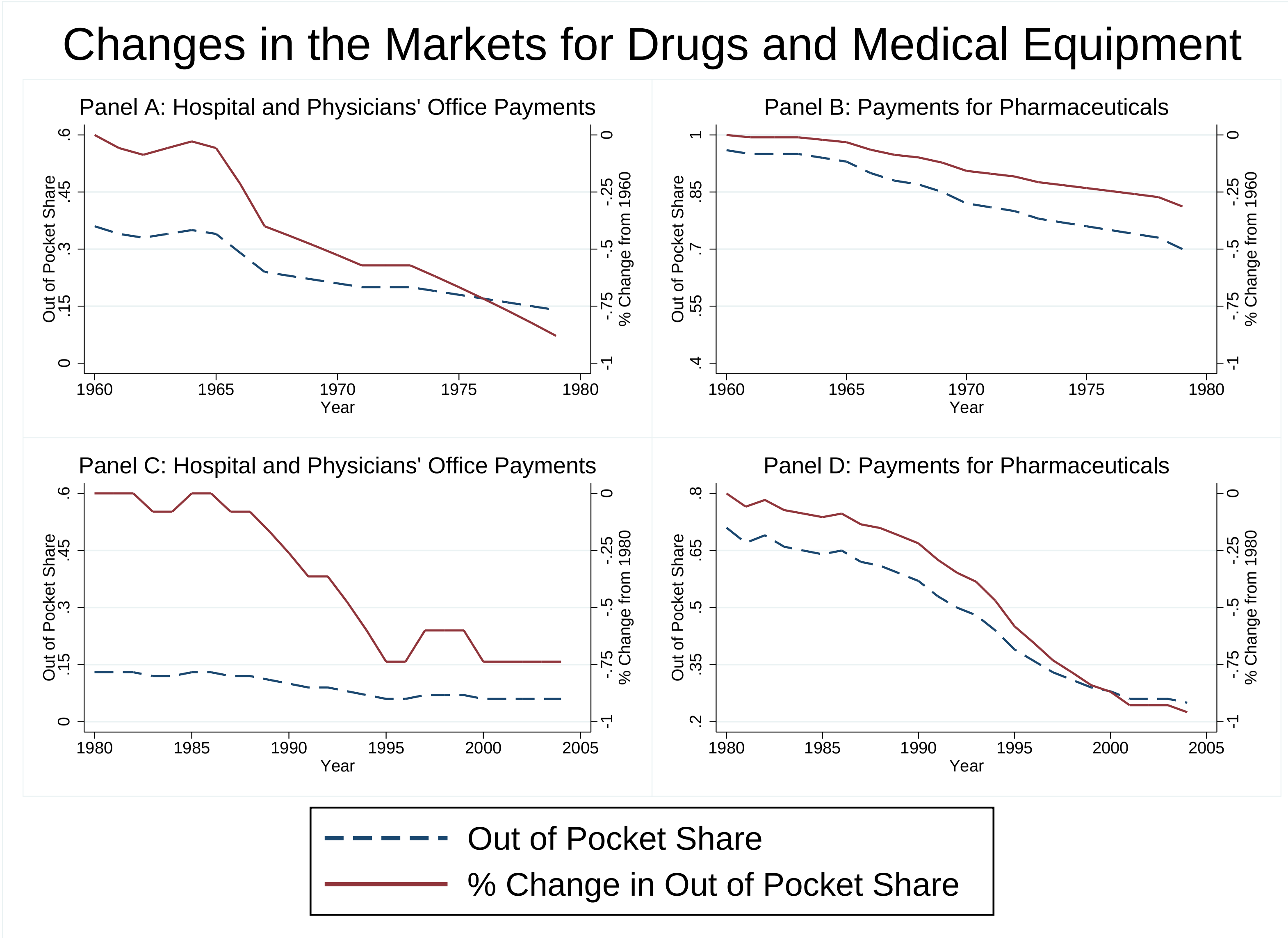

Figure 1: **Declines in Exposure to Out of Pocket Medical Costs:** All series were constructed by the author using the historical National Health Expenditure data reported by the Center for Medicare and Medicaid Services (CMS). Percent changes are calculated as $\frac{\text{Current Year - Base Year}}{(\text{Current Year + Base Year})/2}$, with 1960 serving as the base year in Panels A and B and 1980 serving as the base year in Panels C and D.

from 1980 to 2005. This period saw substantial declines, in percent terms, in exposure to the cost of health spending in both of the relevant environments. The out-of-pocket share for spending in hospitals and physicians' offices declined from an already low base of 15 cents on the dollar to roughly 5 cents on the dollar. For prescription drugs, the out-of-pocket share declined from around 70 cents on the dollar to 25 cents on the dollar, with the most dramatic movement taking place during the early 1990s.

2 Using Medicare and Medicaid's Origin As a Natural Experiment in Incentives for Health-Sector Innovation

This section describes my empirical approach for using declines in consumer exposure to out-of-pocket costs to estimate the effect of U.S. health insurance expansions on medical innovation. Exposition of the estimation framework is facilitated by first describing the data set used in the analysis. The following sub-section also describes key features of innovation in the medical-equipment sector that shape my empirical strategy.

2.1 The NBER Patent Database

The analysis utilizes the NBER Patent Database, which contains several relevant pieces of information on all patents granted by the U.S. Patent and Trademark Office (USPTO) from 1963 to 1999 (Hall, Jaffe, and Trajtenberg, 2001). The first relates to the classification of each patent to technological categories and sub-categories. The patents are grouped into 6 broad technological categories, of which category 3 encompasses most health-sector patents, and 36 technological sub-categories. The sub-categories are sufficiently narrow to allow health-sector patents to be divided into those related to prescription drugs and those related to the medical equipment underlying physicians' practices in hospitals and independent outpatient settings.

Throughout the analysis, I group sub-categories 31 and 33, which contain Drug and Biotechnology patents respectively, to characterize patenting associated with pharmaceutical innovation. I group sub-categories 32, 39, and 44 to characterize patenting associated with innovation in medical equipment. Sub-category 32 contains all Surgical Equipment patents, including such historic developments as the balloon catheter and subsequent advances in stent technology (Fogarty, Finn III, and Kinney, 1986; Palmaz, 1988; Wall, 1993). Sub-category 39 is a relatively small category of Miscellaneous Drugs & Medicine patents associated with dentistry, optometry, and prosthetic devices. Although sub-category 44, Nuclear & X-rays, is not included in the broader Drugs and Medical technological category, it contains such innovations as computed tomography (CT) scanners and a variety of advances in X-ray technology (Damadian, 1974; Ledley, 1975). Given the importance of diagnostic testing as a driver of both the benefits and costs of modern medicine, inclusion of this category is essential for characterizing medical-equipment innovation.

A brief review of several detailed studies of medical-equipment innovation will help to motivate this paper's empirical framework. Highlighting crucial distinctions between medical-equipment and pharmaceutical innovation, Roberts (1988) summarizes the relevant literature as follows:

> [My] personal experience, supported by the few relevant studies on innovation, indicates that... innovation in medical devices is usually based on engineering problem solving by individuals or small firms, is often incremental rather than radical, seldom depends on the results of long-term research in the basic sciences, and generally does not reflect the recent generation of fundamental new knowledge. It is a very different endeavor from drug innovation, indeed.

The research referenced by Roberts includes several studies by Shaw (1985, 1986, 1991). In a random sample of 34 medical-equipment innovations, Shaw (1985, 1986, 1991) finds that just over half (18) stemmed from physician-produced prototypes while an additional third (11) involved direct transfer of the initial idea from a physician to a manufacturer. Shaw (1986) further reports that two-thirds of these innovations were ultimately developed through a process of "multiple and continuous user-manufacturer interaction." Local incentives, and by extension the presence of end-users, thus appear to play an essential role in the development of the relevant technologies. Von Hippel (1976) reports similar findings in a study of innovation in scientific instruments. Most relevant to the current setting, he finds that 11 out of a sample of 14 major innovations in Nuclear Magnetic Resonance spectrometry were user, rather than manufacturer, dominated.[15] Figure 2, which shows that innovation tends to be medical-equipment intensive in states with large numbers of physicians per capita, provides suggestive evidence consistent with this line of research.

The prevalence of practitioner-driven innovation makes it reasonable to expect U.S. insurance expansions to have an outsized influence on U.S.-based innovation relative to foreign innovation. As discussed in some detail below, this motivates my estimation of the differential effect of Medicare and Medicaid on U.S-based innovation relative to foreign innovation. This differential will understate, and thus place a lower bound on, Medicare and Medicaid's total effect to the extent to which foreigners also pursued expanded U.S. markets.

The NBER Patent Database reports the location of each patent's primary filer. When the primary filer is located in the United States, the database reports his or her state of residence; when located abroad, it reports his or her country of residence. Table 1

[15] Recent case studies of "radical innovation projects" in medical equipment technology by Lettl, Herstatt, and Gemuenden (2006) find a similar pattern of practitioner dominance.

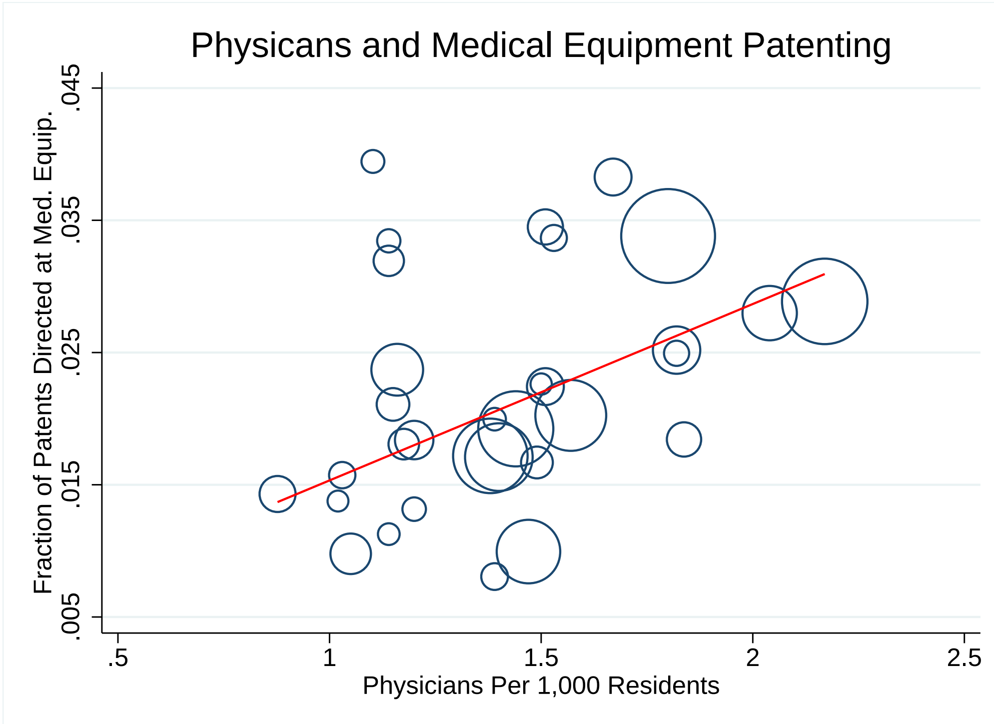

Figure 2: **Physicians Per 1,000 Residents and Medical Equipment Patenting Across States:** Data on physicians per 1,000 residents in 1965 come from the 1967 edition of the Statistical Abstract of the United States. The Medical Equipment share of all patents was calculated by the author using all data on patents granted to residents of U.S. states from 1963 through 1968 in the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). A description of the system for classifying Medical Equipment patents can be found in the note to Table 1. The regression results in a coefficient of 0.0133 (standard error of 0.0032) on the measure of physicians per 1,000, with an r-squared of 0.316. Observations are weighted by each state's contribution to the total number of patents appearing in the database over the sample period.

presents summary statistics describing the patenting activity of U.S.- and foreign-based patenters as I group them for subsequent regression analysis.[16] I have aggregated relatively small U.S. states on the basis of census regions, leaving a total of 32 geographic units in the United States.[17] The aggregation reduces the noise associated with proxying

[16]In addition to a standard regression analysis, I report complementary results from a synthetic control analysis. For purposes of statistical inference, the synthetic control analysis characterizes the United States as a single treated unit. Inference is conducted by comparing changes in U.S. patenting to a distribution of placebo treatment effects generated by running the synthetic control procedure while assigning treatment status to randomly selected sub-groups of foreign countries.

[17]The aggregate of small Western states, for example, joins Alaska, Hawaii, Idaho, Montana, Nevada, New Mexico, and Wyoming, while leaving California, Colorado, Oregon, and Washington as distinct entities. In addition to four region-specific aggregates of small U.S. states, I have created two aggregates

for the relative intensity of innovative effort on the basis of small samples of patents; it further allows me to construct a balanced panel of states without losing patent data when taking logarithms or expressing the relative intensity of medical innovation using shares.

From 1963 through 1980, 5.5 percent of all patents filed by foreigners were health-sector patents, as were around 4.4 percent of patents filed by US residents. Medical equipment patents accounted for under half of the health-sector patents held by foreigners and over two-thirds of those held by Americans. Among both foreign and U.S.-based patenters, close to one quarter of patents were associated with the Chemicals technological category. An additional quarter of patents were associated with the Mechanical category and around one-sixth with the sum of Electronics and Computing. The remaining quarter of patents were associated with a residual category that includes agriculture, durable goods manufacturing, clothing, and other miscellaneous sub-categories. By the late 1990s there had been substantial increases in the Medical and Computing shares of total patents. Categories with declining shares included Chemicals, Mechanical, and the residual Other.

The years referenced in Table 1 describe the year in which each patent was granted. The NBER Patent Database reports the grant year for all patents granted from 1963 to 1999. The database reports information on the application year for all patents starting with those granted in 1967. This is unfortunate because the application year clearly comes closer than the grant year to representing the time at which each innovation occurred.[18] I use the later years of the database to estimate the average lag between filing years and grant years. This lag averages 2.3 years for health-sector patents and

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of relatively small foreign countries. These aggregates are not included in most specifications because I do not have reliable data for constructing a control for GDP per capita across these countries. Inclusion of these aggregates has essentially no effect on specifications that leave out this control variable.

[18]An additional lag is associated with the time between an innovator begins working on a project and the time at which he or she files for a patent.

Table 1: **Patent Share Summary Statistics: Mid 1960s through 1980**

	(1) Foreign Countries	(2) US States
Fraction Medical	0.0553	0.0438
	(0.0115)	(0.0108)
Fraction Med. Equipment	0.0250	0.0302
	(0.00743)	(0.0104)
Fraction Phamaceutical	0.0303	0.0136
	(0.00962)	(0.00890)
Fraction Non Medical	0.945	0.956
	(0.0115)	(0.0108)
Fraction Chemicals	0.271	0.218
	(0.0579)	(0.112)
Fraction Computing	0.0520	0.0522
	(0.0197)	(0.0312)
Fraction Electronics	0.136	0.137
	(0.0295)	(0.0476)
Fraction Mechanical	0.276	0.260
	(0.0318)	(0.0605)
Fraction Other	0.209	0.289
	(0.0500)	(0.0625)
GDP Per Capita (10000s)	1.866	2.107
	(0.354)	(0.249)
Observations	7	32

Note: All patent shares were constructed by the author using the NBER Patent Database. Following the classification system described by Hall, Jaffe, and Trajtenberg (2001), medical patents include technological category 3 and sub-category 44. I decompose this into pharmaceutical patents, which include sub-categories 31 and 33 (Drugs and Biotechnology), and Medical Equipment patents, which include sub-categories 32, 39, and 44 (Surgical Equipment, Miscellaneous Drugs & Medical, and Nuclear & X-rays). Chemicals corresponds to technological category 1, Computing to category 2, Electronics to all sub-categories of category 4 but sub-category 44, Mechanical to category 5, and Other to technological category 6. GDP per capita comes from the Penn World Tables and regional accounts of the Bureau of Economic Analysis. The 32 US state units include the four regional aggregates, namely Small Western (MT, ID, WY, HI, AK, NV, and NM), Small Northeastern (ME, VT, NH, RI, DC, WV, and US territories), Small Central (ND, SD, KS, NE, UT), and Small Southern (AR, AL, MS, KY, and SC). The foreign countries are Canada, the UK, France, Germany, Switzerland, the Netherlands, and Japan.

is relatively stable within the years covered by the database.[19] Significant impacts of Medicare and Medicaid on the patents appearing in the database would thus be expected no earlier than with those granted around 1968.[20]

In most of the analysis presented below, I aggregate groups of years to further reduce the noise associated with observations based on small numbers of patents. Accounting for the lag between patent filing and granting, I typically treat the period running from 1963 to 1968 as the pre-Medicare period, with 1969 to 1974 describing the short- to medium-run post-Medicare period and 1975-1980 describing the post-Medicare long run.

2.2 Estimation Framework

In my initial analysis, the estimating equations take the following basic form:

$$\begin{aligned}\text{Health Share}_{s,t} = {} & \beta_1 \text{Post Great Society}_t \times \text{US State}_s \\ & + \beta_{2_s} \text{State}_s + \beta_{3_t} \text{Period}_t + X_{s,t}\gamma + \varepsilon_{s,t}, \end{aligned} \tag{1}$$

where $State_s$ is a state- or country-specific fixed effect, $Period_t$ is a time effect, and $X_{s,t}$ is a vector of time varying controls, typically including a measure of each area's per capita income. $Health\ Share_{s,t}$, the outcome of interest, is the fraction of all patents filed in state s during period t that are associated with a particular portion of the health sector. β_1 is

[19] Popp, Juhl, and Johnson (2004) note that, more generally, the lag between patent filing and granting can vary substantially due, among other factors, to the volume of patents submitted to the USPTO at any given time.

[20] Small effects may still be expected in the earlier years since the lag between patent filing and granting exhibits substantial variance across patents. Additional lags, again of varying lengths across innovations, should also be expected for the time between the initiation of innovative effort and the arrival of a patentable idea. A relatively brief idea-development lag is consistent with Roberts's (1988) conclusion that, contrary to common conceptions fueled by images of the pharmaceutical industry, "innovation in medical devices is usually based on engineering problem solving by individuals or small firms, is often incremental rather than radical, seldom depends on the results of long-term research in the basic sciences, and generally does not reflect the recent generation of fundamental new knowledge."

an estimate of the differential change in this health-sector share in the U.S. states relative to foreign countries. I arrive at point estimates and conduct statistical inference using both ordinary least squares (OLS) regressions and synthetic control methods.[21]

It is known that, for several reasons, patent counts can be poor measures of differences in levels of innovative activity across time, sectors, and countries (Trajtenberg, 1990a). The number of patentable ideas generated by a given amount of research effort may, for example, vary substantially due either to the number of innovations on the horizon of a sector's technological frontier or to sector-specific changes in patent law.[22] The financial motivation for patenting any given innovation can also vary with the nature of a sector's technical frontier.[23] Such developments are accounted for by the inclusion of time effects since they apply with equal weight to both foreign and domestic innovators. Also relevant is that there has been a secular increase in the share of total USPTO-granted patents that are filed by foreigners (see Panel A of Appendix Figure A.1).[24] Analysis of within-state and within-country patent shares eliminates this secular trend.[25] Equation (1) is motivated by the fact that, in spite of these issues, changes in the health-sector share of patents by U.S.-based innovators net of changes in the health-sector share of

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[21]Using synthetic control methods, the U.S. states are aggregated into a single "treated" unit. Inference in this framework is designed to be conservative relative to the ordinary least squares framework, in which I treat the United States as consisting of 32 independent geographic units.

[22]A benefit of working entirely within the context of the NBER patent database is that the patents were uniformly subject to U.S. patent law.

[23]Moser (2011), for example, finds that patenting became relatively popular in the late 19th century chemicals industry when the publication of the periodic made secrecy a poor means of restricting access to intellectual property.

[24]International patent filing has long been common practice, as highlighted elsewhere by Moser and Voena (2012) in an analysis of compulsory licensing under the 1917 Trading With the Enemy Act and (Moser, Bilir, and Talis, 2011) in an analysis of the Paris Convention for the Protection of Industrial Property. Patent-granting has had some degree of standardization across countries as far back as the signing of the Paris Convention in 1883.

[25]For the forces underlying this secular increase to pose a threat to this paper's identification strategy, they would have to exert a differential influence on health-sector patenting relative to patenting in other areas. If this were the case, I can still account for the secular component of such forces by controlling for a U.S.-specific linear time trend.

patents by foreign innovators can nonetheless capture relative changes in the direction of innovative activity.

I also estimate the effect of Medicare and Medicaid on patent counts using log-linear, poisson, and negative binomial models. While taking shares places all states and countries on a similar scale, which aids visual transparency, estimating parameters that describe the effect of Medicare and Medicaid on the rate at which patentable medical-equipment ideas arrive may be more theoretically satisfying. When estimating count models, the issues discussed in the previous paragraph can be controlled for using a triple-difference methodology. The log-linear model of patent counts appears below:

$$\begin{aligned}\ln(\text{Patent Count})_{c,s,t} = {} & \gamma_1 \text{Post Great Society}_t \times \text{US State}_s \times \text{Medical Equipment}_c \\ & + \gamma_{2_{s,t}} \text{State}_s \times \text{Period}_t + \gamma_{3_{t,c}} \text{Period}_t \times \text{Category}_c \\ & + \gamma_{4_{s,c}} \text{State}_s \times \text{Category}_c + X_{s,t}\theta + \varepsilon_{c,s,t}. \end{aligned} \tag{2}$$

Patent $\text{Count}_{c,s,t}$ describes the number of patents granted in technological category c, in state s, during period t. γ_1 is an estimate of the differential evolution of U.S. medical-equipment patenting relative to other U.S.-based patenting net of any changes in foreign medical-equipment patenting relative to other foreign patenting. It is thus nearly equivalent to the estimate of the differential evolution of patent shares in equation (1)'s difference-in-differences framework. For the presented estimates of equation (2), I aggregate the patent categories into Medical Equipment and All Other patents. I obtain similar results when aggregating more finely to the NBER Patent Database's 36 technology sub-categories.

The most compelling natural experiment in the data comes from the origin of Medicare and Medicaid. These programs provide a compelling source of variation in potential market size in part because they substantially altered the incentive to produce new medical equipment and devices while having little impact on incentives for the invention of new pharmaceuticals. This generates a setting in which there was a substantial change in incentives for innovation in one type of health-sector innovation and not for another. I thus estimate equations (1) and (2) separately for medical equipment and pharmaceutical patents, using the estimated effect on pharmaceutical patenting as a falsification test. I also run specifications in which I include the pharmaceutical share as an element of the vector of control variables. This can be interpreted as a direct control for any state- or country-specific shifts in patenting towards the health sector broadly construed. I also construct the dependent variable as the medical-equipment share net of the pharmaceutical share, effectively imposing a coefficient of 1 on the pharmaceutical share.[26]

In interpreting estimates of equations (1) and (2), an important question that arises is the extent to which foreign innovators have joined U.S. innovators in responding to changes in the size of U.S. health care markets. Some foreign response is surely expected, since innovations are marketable on a world-wide basis. β_1 is, quite literally, an estimate of the differential change in health-sector patenting as a share of total patenting among residents of U.S. states relative to residents of foreign countries. It should thus be interpreted as a lower-bound estimate of the total effect of U.S.-specific insurance expansions on health-sector innovation.

This paper's analysis is predicated in part on the assumption that home-country incentives have a more powerful impact on medical-equipment innovation than do incentives elsewhere in the world. The previous sub-section's discussion of detailed studies of medical-equipment innovation provides evidence for this assumption. Successful efforts to develop and commercialize medical-equipment innovation involve extensive interac-

[26]This specification imposes a one-for-one relationship between patents in these categories. As discussed previously, such treatment of patent counts may be inappropriate. In recent years it is notable, for example, that while there are more pharmaceutical patents than medical-equipment patents, pharmaceutical innovation drives a much smaller share of total health spending than other health-sector innovation.

tions between providers and manufacturers (Shaw, 1986), and the vast majority of such innovations appear, at least historically, to have been initiated by providers themselves (Shaw, 1985, 1986, 1991). Local information about the the relevant regulatory processes is likely to play an additional role in enabling innovators to take advantage of market opportunities.

In Section 4.2 I further explore the importance of foreign responses to U.S. insurance expansions by comparing the evolution of patenting across subsets of foreign countries. I compare countries with strong cultural ties to the United States to those with relatively weak cultural ties. This analysis shows that European countries, and in particular other English speaking countries, saw their patenting shift towards medical equipment to a degree that, while significantly smaller than the shift that occurred in the United States, was also greater than the shift occurring elsewhere in the world.

3 Effects of Medicare and Medicaid on Innovation in the Health Sector

Panels A and B of Figure 3 present the patent data underlying subsequent estimates of equations (1) (the panels of Appendix Figure A.1 do the same for equation (2)). The figure shows the evolution of medical-equipment and pharmaceutical patents as shares of total patents, plotting separate series for U.S.-based innovators and foreign innovators. Panel A shows that, during the early-to-mid 1960s, medical-equipment patents made up a modestly smaller share of total patents by U.S.-based innovators than of those by foreign innovators. While the foreign share is stable through the early 1970s, the U.S. share rises by roughly 1.2 percentage points (from a base of just over 2 percentage points) from 1966 to 1970, surpassing the foreign share for the first time in 1969. The U.S. share stabilizes at between 0.6 and 1.0 percentage point higher than the foreign share from

1970 through 1980. As noted previously, there is, on average, a 2.3 year lag between health-sector patent filing and granting during the years of the NBER patent database for which both of these pieces data are available. The late 1960s surge in U.S.-based medical equipment patenting thus occurs roughly when one would expect an initial Medicare- and Medicaid-induced change in patenting activity to reveal itself in the data.[27]

Panel A of Figure 4 shows that neither this basic pattern nor the magnitude of the relative shift in U.S. medical-equipment patenting are affected by re-weighting the foreign countries to more closely match the pre-Great Society level of the U.S. share. Panel B shows that a similar result is obtained when re-weighting the U.S. states to more closely match the pre-Great Society level of the foreign share.[28] A fuller synthetic control analysis, which also addresses statistical inference, can be found in Appendix 2.

Panel B of Figure 3 shows the evolution of pharmaceutical patenting, the incentives for which were not directly affected by Medicare and Medicaid. The pharmaceutical share of patents granted to U.S.-based and foreign innovators move similarly over most of the relevant time period. The surge in U.S.-based medical equipment patenting thus does not appear to have been associated with a more general increase in health-sector innovation in the United States. If anything, it appears that foreign patenters were faster than their U.S.-based counterparts to participate in the surge in pharmaceutical patenting that began during the late 1970s.

---

[27]The timing is consistent with a delay of one to two years during which an initial wave of post-Medicare innovative efforts translate into patentable ideas, with an additional two to three years between patent filing and patent granting. To again quote the description of medical-equipment innovation by Roberts (1988), "innovation in medical devices is usually based on engineering problem solving by individuals or small firms, is often incremental rather than radical, seldom depends on the results of long-term research in the basic sciences, and generally does not reflect the recent generation of fundamental new knowledge. It is a very different endeavor from drug innovation, indeed." In this sector, relatively modest idea-development lags should be expected.

[28]The latter approach allows for a bit more flexibility in the re-weighting scheme since the final sample contains a larger number of U.S. states that can be used in the re-weighting than foreign countries.

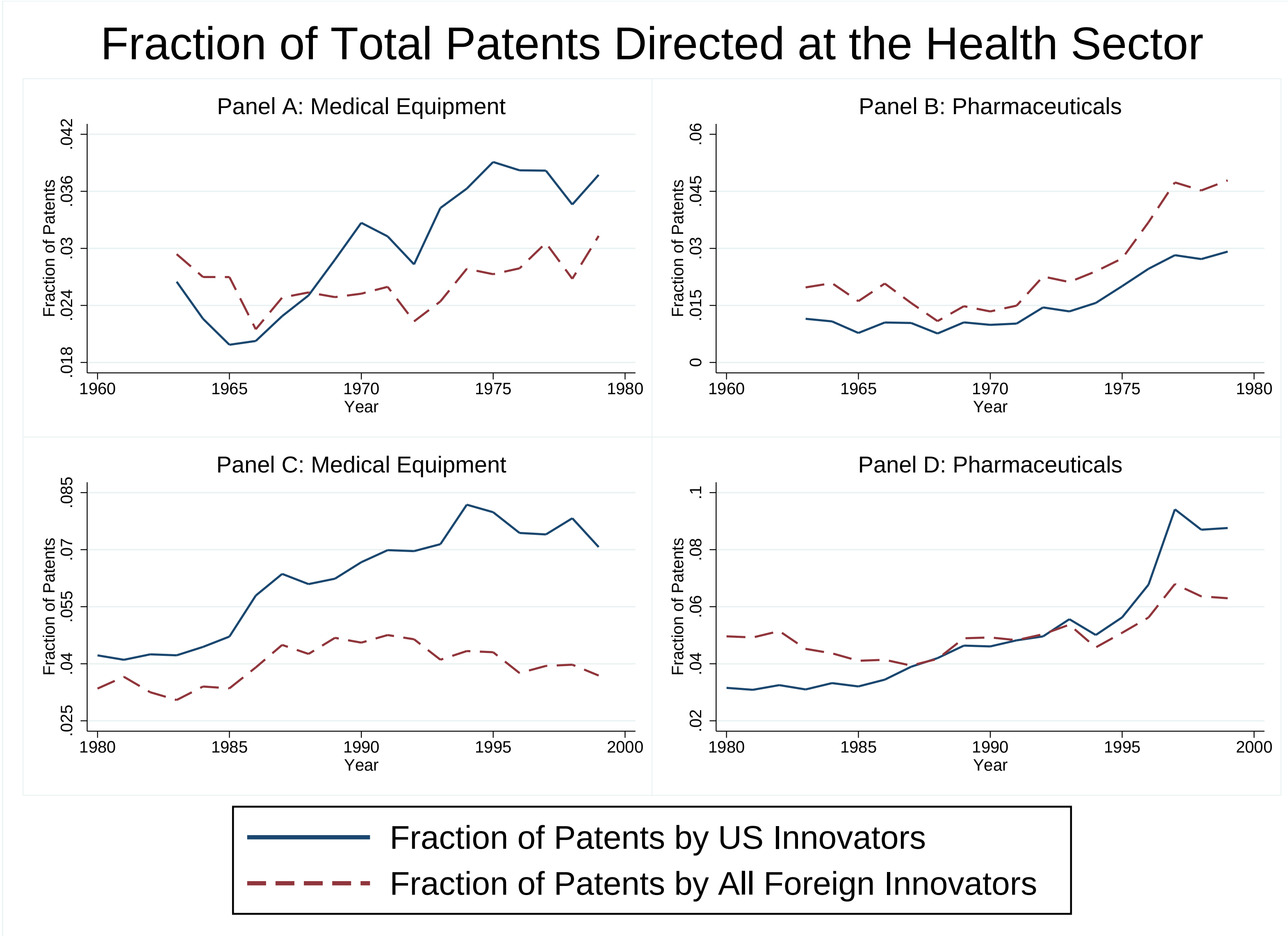

Figure 3: **Fraction of Patents Directed at the Health Sector (U.S. vs Foreign):** Series were constructed by the author using data from the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). A description of the system for classifying Medical Equipment and Pharmaceutical patents can be found in the note to Table 1. The years in the figure refer to the year in which each patent was granted. In later years of the patent database, grant years lag filing years by an average of 2.3 years for health-sector patents (roughly 2.0 years for patents more generally).

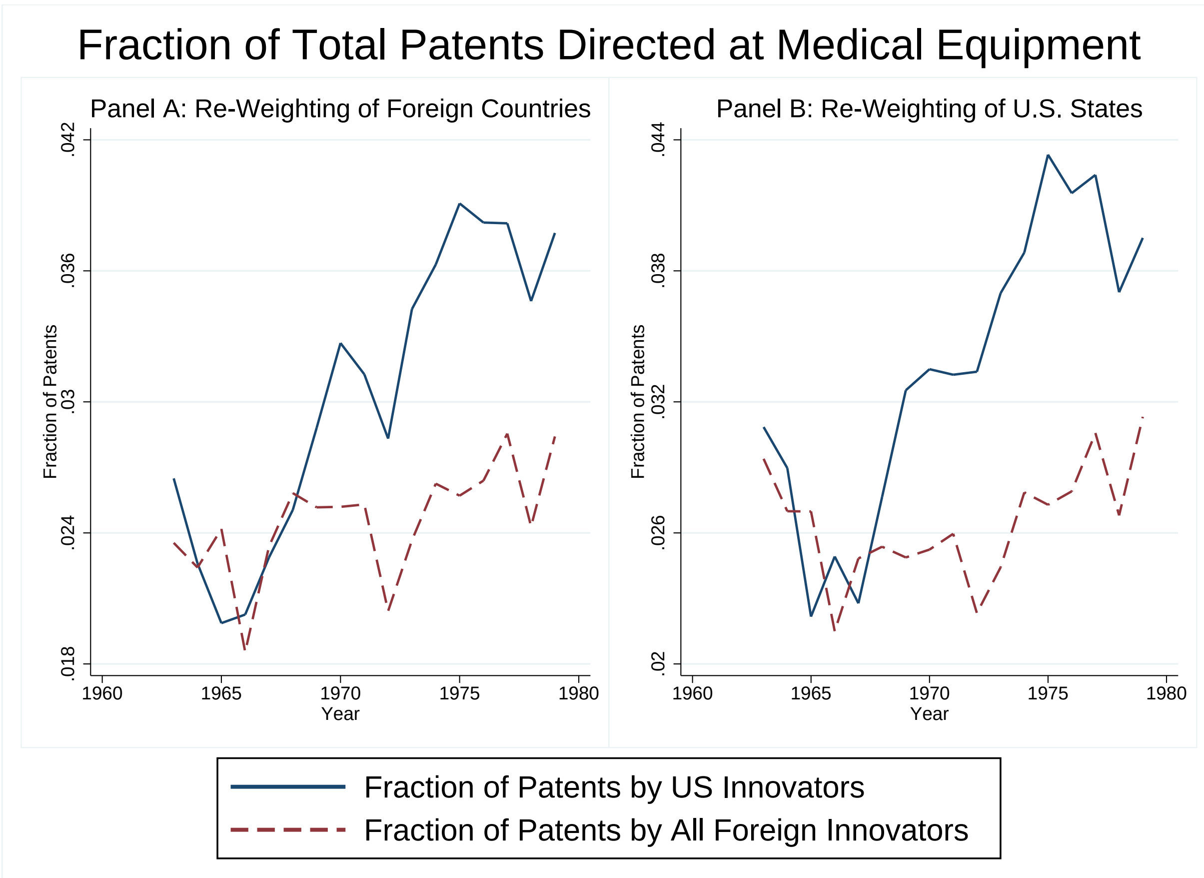

Figure 4: **Fraction of Patents Directed at Medical Equipment (U.S. vs Foreign):** Series were constructed by the author using data from the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). A description of the system for classifying Medical Equipment and Pharmaceutical patents can be found in the note to Table 1. The years in the figure refer to the year in which each patent was granted. In later years of the patent database, grant years lag filing years by an average of 2.3 years for health-sector patents (roughly 2.0 years for patents more generally). In Panel A, country-level aggregates of foreign patents have been re-weighted to more closely match the pre-Medicare level of U.S. medical-equipment patents as a share of total patents using Abadie, Diamond, and Hainmueller's (2011) "synth" package. In Panel B, state-level aggregates of U.S. patents have been re-weighted to more closely match the pre-Medicare level of foreign medical-equipment patents as a share of total patents, again using Abadie, Diamond, and Hainmueller's (2011) "synth" package.

3.1 Difference-in-Differences Estimates of the Effect of Medicare and Medicaid on Medical-Equipment Patenting

Table 2 presents estimates of equation (1) in which observations are weighted according to each state or country's share of all USPTO-granted patents over the sample period. The estimates in column 1 thus reflect precisely what one would anticipate based on a visual inspection of Figure 3's Panel A. The results indicate an increase in U.S. medical-equipment patenting relative to foreign medical-equipment patenting (as shares of total patents) of roughly 1.25 percentage points over the medium run and of just over 1.3 percentage points over the longer run. The standard errors, which are calculated treating the observations as being independent across states and countries, while allowing for arbitrary autocorrelation within each state or country over time, show these point estimates to be highly statistically distinguishable from 0. The confidence interval for the estimate of the medium-run impact of Medicare and Medicaid on medical-equipment patenting ranges from 0.65 to 1.85 percentage points.

The result in column 2 shows column 1 to be robust to controlling for changes in each state or country's GDP per capita over time. GDP per capita enters positively, and at a level that, in this specification, is statistically distinguishable from 0. This result is consistent with a role for the forces emphasized by Hall and Jones (2007) and Jones (2011), who argue that demand for life-extending health innovations will rise faster than demand for innovations in other areas as income increases. Column 3 expresses the result from column 2 in log terms. The result implies that, controlling for changes in income per capita, the medical-equipment share of patents in the U.S. states rose by 40 to 50 percent more from the mid-1960s to the 1970s than did the medical-equipment share of patents by innovators in foreign countries.

The remaining columns of Table 2 show that the results discussed above are not driven by a more general shift in U.S. patenting towards the health sector. Column 4,

Table 2: **Change in Fraction of Patents Directed At Medical Equipment: Post Great Society**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Ln(Eq Share) Coeff./SE	Rx Share Coeff./SE	Equip Share Coeff./SE	Equip Net Rx Coeff./SE
US State × 1968 to 1974	0.0125**	0.0133**	0.4583**	0.0038	0.0132**	0.0096*
	(0.0029)	(0.0024)	(0.0912)	(0.0035)	(0.0023)	(0.0037)
US State × 1975 to 1980	0.0133**	0.0146**	0.4760**	-0.0074	0.0148**	0.0219*
	(0.0029)	(0.0032)	(0.1054)	(0.0105)	(0.0037)	(0.0102)
GDP Per Capita (10000s)		0.0184*	0.3408	-0.0335	0.0195+	0.0519+
		(0.0087)	(0.2791)	(0.0306)	(0.0112)	(0.0300)
Fraction Pharmaceutical					0.0315	
					(0.1356)	
R^2	0.920	0.926	0.936	0.846	0.926	0.886
N	116	116	116	116	116	116
Number of Clusters	39	39	39	39	39	39
Weighted	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares estimates of equation (1). In columns 1, 2, and 5 the dependent variable is the fraction of total patents that are categorized Medical Equipment patents. In column 3 the dependent variable is the natural logarithm of this fraction. In column 4 the dependent variable is the fraction of total patents that are categorized Pharmaceutical patents. Finally, in column 6 the dependent variable is the fraction of total patents that are categorized Medical Equipment patents minus the fraction categorized as Pharmaceutical patents. A description of the classification system can be found in the note to Table 1. Relatively small U.S. states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each U.S. state or foreign country. Data sources are described in the note to Table 1.

which can be interpreted as a falsification test, shows that, relative to foreign patenting, the share of U.S. patents directed at pharmaceuticals did not change following Medicare's implementation. Over the longer run it appears that, if anything, the U.S. pharmaceutical share declined relative to the foreign pharmaceutical share, although the relevant coefficient is estimated with low precision. Column 5 shows that controlling directly for the pharmaceutical share has no impact on the baseline result. The pharmaceutical share enters positively, but its coefficient is not estimated precisely. In column 6 the dependent variable is expressed as the medical-equipment share net of the pharmaceutical share. The estimated effect of Medicare and Medicaid is, once again, statistically and economically indistinguishable from the baseline result in column 2. The point estimates are statistically significantly different from 0, but are less precisely estimate than the result from column 2.

3.2 An Exploration of the Mechanisms Behind Medicare and Medicaid's Impact on Medical Innovation

I next explore correlates of variation in the size of U.S. states' increases in medical-equipment patenting. The Great Society programs' principal effect was to alter incentives for health-sector innovation in the United States (as a whole) relative to foreign markets. Nonetheless, positive correlations between the size of states' increases in medical-equipment patenting and proxies for the intensity of the proposed mechanisms may bolster our confidence that these mechanisms are truly at work. I explore the strength of the relevant relationships by estimating the following equation:

$$
\begin{aligned}
\text{Health Share}_{s,t} = \alpha_1 &\text{Mechanism Intensity}_s \times \text{Post Great Society}_t \times \text{US State}_s \\
&+ \alpha_2 \text{Post Great Society}_t \times \text{US State}_s \\
&+ \alpha_{3_s} \text{State}_s + \alpha_{4_t} \text{Period}_t + X_{s,t}\gamma + \varepsilon_{s,t}. \qquad (3)
\end{aligned}
$$

In equation (3), α_1 is an estimate of the partial correlation between the size of a state's expansion in health-sector patenting and proxies for the potential importance of the relevant mechanisms within that state (represented by *Mechanism Intensity*$_s$).[29]

I consider several variables that proxy for the size of the potential impact of the Great Society programs. The first, *Physicians Per 1,000*, is a measure of physicians per 1,000 state residents in 1965; it captures the presence of the potential physician-innovators emphasized in Section 2. The second, *Uninsured Elderly*, proxies for the size of the insurance expansion associated with Medicare. I take this measure directly from Finkelstein (2007), who tabulated regional survey estimates of pre-Medicare coverage rates among the elderly. The third, $\triangle$*State Health Spending*, describes the change in health spending (in 1000s of dollars) by state governments from 1962 to 1972, which was driven primarily by states' integration into the Medicaid program.[30] Two additional variables involve composites in which the initial three variables have been made comparable through standard normalization. The first of these, *Demand Side Composite*, captures the total size of the Great Society programs' demand-side impact by summing the standard-normalized ver-

[29]Note that the mechanism proxies are time invariant and that, consequently, their main effects are subsumed by the state fixed effects. To avoid loss of intuition, note that similar results can be (and are) obtained by regressing changes in the health share on *Mechanism Intensity*$_s$ while restricting the sample to the U.S. states.

[30]The choice of years is driven in part by the relatively detailed information on sub-national government budgets made available through the Census of Governments, which occurs in years ending with 2 and 7. Using the change in spending through 1972 helps to fully account for the impact of Medicaid because 1972 was the first year during which states' Medicaid programs were required to cover individuals receiving Disability or Supplemental Security Insurance payments through Social Security.

sions of *Uninsured Elderly* and $\triangle$*State Health Spending*. The final variable, *Total Composite*, is the sum of all three standard-normalized variables and is thus the most comprehensive measure of the Great Society programs' potential impact.

Table 3 reports estimates of α_1 when *Mechanism Intensity*$_s$ is represented by the variables discussed above. Columns 1 through 3 show that *Physicians Per 1,000*, *Uninsured Elderly*, and $\triangle$*State Health Spending* are each positively correlated with the size of states' shifts towards medical-equipment patenting. For the individual variables, however, the correlations are not particularly strong. Accounting for these variables jointly, as in columns 4 and 5, yields statistically stronger results. In column 4, the composite of the demand-side changes associated with Medicare and Medicaid has a positive relationship with shifts towards medical-equipment patenting that is statistically significant at the 0.05 level. The coefficient implies that a state at the 95th percentile of the Great Society programs' demand-side effects experienced a shift towards medical-equipment patenting that exceeded the shift at the 5th percentile by 0.34 percentage point. This difference equals roughly 1/4th of the baseline estimate from column 2 of Table 2. The presence of an additional physician per 1000 residents (which also corresponds to the difference between the 5th and 95th percentiles of the relevant variable) was associated with a shift towards medical-equipment patenting of an additional 0.6 percentage point (an amount equal to nearly 1/2 of the baseline estimate from column 2 of Table 2). The coefficient on *Total Composite* has similar implications for the magnitudes of states' shifts towards medical-equipment patenting. This final coefficient, presented in column 5, is estimated with sufficient precision to be statistically distinguishable from 0 at the 0.01 level.[31] Graphical illustrations of the correlation between states' increases in

[31]It is worth noting that these results are robust to a variety of changes in the manner in which the variables are constructed. Taking the measure of physicians per 1,000 residents from different years, making reasonable alterations to the measure of changes in state government health spending, using Finkelstein's alternative measure of the size of Medicare's impact on coverage, and further adjusting for the elderly's share of each state's total population have negligible impacts on the presented results.

Table 3: **Change in Fraction of Patents Directed At Medical Equipment: Mechanisms**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Share Coeff./SE
Physicians Per 1,000 × Post Great Soc.	0.00539			0.00601*	
	(0.00370)			(0.00268)	
Uninsured Elderly × Post Great Soc.		0.00659			
		(0.01198)			
△State Health Spending × Post Great Soc.			0.01025		
			(0.01306)		
Demand Side Composite × Post Great Soc.				0.00085*	
				(0.00039)	
Total Composite × Post Great Soc.					0.00109**
					(0.00037)
N	116	116	116	116	116
Number of Clusters	39	39	39	39	39
Weighted	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes	Yes	Yes
US State x Period FE	Yes	Yes	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. The dependent variable in each column is the fraction of total patents that are categorized Medical Equipment patents. A description of the classification system can be found in the note to Table 1. Relatively small U.S. states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each U.S. state or foreign country. *Physicians Per 1,000* residents was taken from the 1967 edition of the Statistical Abstract of the United States, and the data apply to 1965. *Uninsured Elderly* variable was taken directly from Finkelstein (2007) and varies at geographic units that are slightly less dis-aggregated than U.S. census divisions. △*State Health Spending* is the change in state government spending (in 1000s of dollars) on health (through Medicaid and direct spending to subsidize hospitals) as reported by the Census of Governments. *Demand Side Composite* is the sum of the standard-normalized versions of *Uninsured Elderly* and △*State Health Spending*, while *Total Composite* is the sum of the standard-normalized versions of each of the first three variables.

medical-equipment patenting and the mechanism variables can be found in Figure A.2 in Appendix 1.

3.3 Robustness within the *Shares* Estimation Framework

Results presented in Appendix Tables A.1 through A.4 further support the robustness of the baseline estimates. Table A.1 shows that the results in Table 1 are robust to running each regression without weighting each state or country's observations for their contribution to the total count of patents during the sample period. Table A.2 shows that the baseline specification from Table 2's column 2 is not significantly altered by shifting the year that separates the base period from the period representing the medium-run after Medicare and Medicaid's implementation. The "medium run" effect becomes moderately smaller as it is made to start closer to 1965. It declines monotonically from 1.2 percentage points in the baseline specification, which ends the base period in 1968, to 0.9 percentage point when the base period ends in 1965. The results show that the full effect of Medicare on the distribution of patents emerges several years after its implementation, consistent with empirically realistic lags for both the development of patentable ideas and the granting of patents once they have been filed.[32]

Table A.3 shows that the results in Table 2 are robust to estimating equation (1) using annual observations rather than observations aggregated to the level of 5 and 6 year periods. Estimation on annual observations allows me to control directly for a differential U.S.-specific trend towards medical-equipment patenting. Controlling for such a trend has no appreciable impact on the baseline results. In Table A.3, the results in which the dependent variable is the medical equipment share net of the pharmaceutical share are less precisely estimated than in Table 2. While these results are not statistically signifi-

[32]See Roberts (1988), quoted in some detail earlier in the paper, for a discussion of the short-horizon, non-revolutionary nature of most medical-equipment innovation.

cantly different from 0, the estimates of the long run effect fall stably between 1.2 and 1.9 percentage points in each specification. Table A.4 shows that the results in Table A.3 are not sensitive to enforcing a balanced-panel requirement, which becomes relatively stringent when working with annual observations rather than with observations that aggregate patent data over several years.

3.4 Robustness to Estimation of Count Models

Tables 4 and 5 present estimates of count models that take the form of equation (2). In both tables, the results include a log-linear model of patent counts along with comparable poisson and negative binomial models. Table 4 presents estimates of the effect of Medicare and Medicaid on medical-equipment patenting while Table 5 presents falsification tests for an effect of Medicare and Medicaid on pharmaceutical patenting.

The results in Table 4 are readily compared with that from column 3 of Table 2, which showed that Medicare increased the log of medical-equipment's share of total patents by 40 to 50 percent. All three of the models presented in Table 4 yield similar results; the evidence implies that Medicare and Medicaid increased the arrival of medical-equipment innovations within this same range of 40 to 50 percent. The poisson and negative binomial models are estimated with greater precision, reflecting superior fits of the data.

The results in Table 5 have implications similar to the result from Table 2's column 4. In no case is there statistically significant evidence for an effect of Medicare and Medicaid on U.S.-based pharmaceutical patenting. It remains the case, however, that estimates involving pharmaceutical patenting are sufficiently imprecise that large effects cannot be ruled out. This is particularly true for estimates of Medicare and Medicaid's medium-to-long run effect.

Table 4: **Changes in Arrival Rates for Medical Equipment Patents**

	Ln(Equip) Coeff./SE	Poisson Coeff./SE	Neg. Binom. Coeff./SE
US State × Med. Equip. × 1969 to 1974	0.4647**	0.4961**	0.4969**
	(0.1493)	(0.0730)	(0.0739)
US State × Med. Equip. × 1975 to 1980	0.5442**	0.4665**	0.4666**
	(0.1705)	(0.0846)	(0.0841)
N	232.000	232.000	232.000
Number of Clusters	39	39	39
Period x Equipment FE	Yes	Yes	Yes
Period x State FE	Yes	Yes	Yes
State x Equipment FE	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from regressions using the models described in the column headings. Column 1 reports estimates from a log-linear model of patent counts, column 2 from a poisson model, and column 3 from a negative binomial model. For the poisson model, the p-values for the Deviance Pearson tests of goodness-of-fit are 0.0070 and 0.0052 respectively, suggesting that the data are over-dispersed. Point estimates and standard errors are stable, however, when replacing the poisson model with the negative binomial model. The dependent variable in all three specifications consists of patent counts. Observations have been aggregated at the level of time periods (as in the regressions previously reported) geographic regions (again as in previous regressions) and patent categories. The patent categories are simply Medical Equipment and All Other, resulting in twice as many observations as in the regressions reported in previous tables. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table 5: **Changes in Arrival Rates for Pharmaceutical Patents**

	Ln(Equip) Coeff./SE	Poisson Coeff./SE	Neg. Binom. Coeff./SE
US State × Pharma × 1969 to 1974	0.2356	0.1671	0.1341
	(0.2448)	(0.1706)	(0.1694)
US State × Pharma × 1975 to 1980	0.0071	0.1481	0.0897
	(0.4650)	(0.3533)	(0.3519)
N	232.000	232.000	232.000
Number of Clusters	39	39	39
Period x Pharma FE	Yes	Yes	Yes
Period x State FE	Yes	Yes	Yes
State x Pharma FE	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from regressions using the models described in the column headings. Column 1 reports estimates from a log-linear model of patent counts, column 2 from a poisson model, and column 3 from a negative binomial model. For the poisson model, the p-values for the Deviance Pearson tests of goodness-of-fit are 0.0000 and 0.0000 respectively, strongly implying that the data are over-dispersed. Point estimates change modestly and standard errors are stable when replacing the poisson model with the negative binomial model. The dependent variable in all three specifications consists of patent counts. Observations have been aggregated at the level of time periods (as in the regressions previously reported) geographic regions (again as in previous regressions) and patent categories. The patent categories are simply Medical Equipment and All Other, resulting in twice as many observations as in the regressions reported in previous tables. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

3.5 An Investigation of the Quality of Insurance-Induced Medical-Equipment Patents

The literature on patents and innovation highlights a need to use caution when translating observed shifts in patenting activity into impact-adjusted levels of innovation.[33] Best practice continues to draw on work by Trajtenberg (1990a), who found in the case of patents associated with computed tomography that there is "a close association between citation-based patent indices and independent measures of the social value of innovations in that field." Evidence on the effect of using citations to adjust for patent quality can be found in Table 6. The dependent variables in the regressions reported in Table 3 replace the dependent variables from Table 2 with citation-weighted patent shares. The Medical Equipment share, for example, is calculated as the sum of all citations received by a state's medical-equipment patents divided by the sum of all citations received by all of that state's patents. The results in Table 3 are little changed from those in Table 2.

The results in Tables A.5 through Table A.7 provide additional evidence on patent quality. Table A.5 shows results describing Medicare's impact on patent quality as measured by the average number of citations associated with each patent. The results show that there was a moderate, but statistically insignificant, increase in the mean number of citations associated with U.S.-based medical-equipment patents (relative to foreign medical-equipment patents), but that there was a moderate decline (on the order of one half of a standard deviation) in the ratio of mean citations for medical-equipment patents relative to all patents.[34]

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[33]For example, cross-sectional evidence reported by Moser (2011) shows that low quality (or less important) innovations are more likely to go unpatented than high quality innovations. It is thus important to consider the possibility that expansions in the markets for health technologies may, in part, have increased the rate of patenting for existing innovations rather than increasing total innovation.

[34]This ratio, which proxies for the quality of health-sector patents relative to all patents, would be the preferred measure if patent-citation norms change differentially across countries over time. Such changes cannot be distinguished from across the board changes in the relative quality of patents across countries.

Table 6: **Change in Fraction of Citation-Weighted Patents Directed At Medical Equipment**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Ln(Eq Share) Coeff./SE	Rx Share Coeff./SE	Equip Share Coeff./SE	Equip Net Rx Coeff./SE
US State × 1968 to 1974	0.0145**	0.0154**	0.3107*	0.0031	0.0151**	0.0123*
	(0.0045)	(0.0052)	(0.1182)	(0.0025)	(0.0047)	(0.0046)
US State × 1975 to 1980	0.0150*	0.0165*	0.2724	-0.0059	0.0172*	0.0224**
	(0.0068)	(0.0075)	(0.1665)	(0.0080)	(0.0082)	(0.0081)
GDP Per Capita (10000s)		0.0212	0.0422	-0.0342	0.0245	0.0554*
		(0.0234)	(0.4709)	(0.0221)	(0.0228)	(0.0228)
Fraction Pharmaceutical					0.0973	
					(0.2510)	
R^2	0.894	0.897	0.915	0.845	0.898	0.886
N	116	116	116	116	116	116
Number of Clusters	39	39	39	39	39	39
Weighted	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. The dependent variables differ from those in Table 2 only in that each patent is now weighted by the number of future citations it had received as of 1999. For example, the Medical Equipment share is now calculated as the sum off all citations received by an area's medical-equipment patents divided by the sum of all citations received by all of an area's patents during the relevant time period. A description of the classification system can be found in the note to Table 1. Relatively small U.S. states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

The NBER database includes two additional metrics that speak to patent quality. The first is a "generality" index that rewards patents subsequently cited by patents granted across a broad range of technological categories (Hall, Jaffe, and Trajtenberg, 2001).[35] Table A.6 reports estimates of the effect of Medicare on patents categorized as having a high level of "generality". The point estimates in Table A.6 are moderately smaller than those in Table 2, implying a Medicare-induced increase in medical-equipment's share of relatively general patents on the order of 0.8 percentage point in U.S. states relative to foreign countries. Although the difference between this estimate and the estimate from Table 2 is not statistically significant, further analysis of Medicare's impact on the average generality score of medical-equipment patents (see Appendix Table A.7) reveals a negative effect (on the order of 1 standard deviation of the index). Taken together, the results urge caution in translating insurance-induced shifts in patenting activity into absolute, impact-adjusted levels of innovation. This issue becomes particularly salient in Section 6.

4 Late 20th Century Developments in Medical Innovation

Panels C and D of Figure 3 show the evolution of health-sector patenting from 1980 to 1999. Recall from Panels C and D of Figure 1 that this was a period during which consumer exposure to the cost of both pharmaceuticals and care provided in hospitals and physicians' offices declined substantially. Figure 3 shows that, relative to the health-sector's share of foreign patents, U.S. patenting of both medical equipment and pharmaceuticals rose over this time period. The rise of U.S. pharamceutical patenting was particularly sharp during the 1990s, reflecting the rise of the U.S. biotechnology

[35]The second metric looks backward at the range of technological categories cited by the patent in question. Because it is backward looking, this measure is either unavailable or assembled on the basis of limited information during the database's early years. I examine this measure when analyzing patents from the last quarter of the 20th century.

industry.

4.1 Regression Estimates

Table 7 reports estimates similar to the estimates of equation (1) reported in Table 2. The dependent variable is again the fraction of total patents associated with medical equipment. All that has changed from the prior specification is the time period under analysis. Since there is no sharp natural experiment during this period, only a gradual, continuing decline in consumer exposure to out-of-pocket costs, the estimates cannot be viewed as causal estimates of the effect of any particular change in insurance arrangements. Rather, the estimates can be characterized as descriptive summaries of the evolution of patenting in the United States relative to foreign countries.

The estimates in Table 7 show that the share of U.S. patents associated with medical equipment rose substantially relative to the foreign share over the last two decades of the 20th century. The relative share rose by roughly 0.7 percentage point from the early 1980s to the late 1980s, and by just over 2 percentage points by the late 1990s. The relative movement is statistically significantly different from 0 in all cases, with the 95 percent confidence interval on the long run movement extending from 1 percentage point to 3.4 percentage points.

Table 8 reports estimates similar to those in Table 7, but with the dependent variable describing the fraction of total patents that are associated with pharmaceuticals. Here again we see strong statistical evidence of relative increases in the health-sector's share of total patents. The relative share rose by roughly 1.3 percentage points from the early 1980s to the late 1980s, and by 3.6 percentage points by the late 1990s. The relative movements are again statistically significantly different from 0, but less precisely estimated than in the medical-equipment regressions. The 95 percent confidence interval on the long run movement extends from 0.1 percentage point to 7.1 percentage points.

Table 7: **Change in Fraction of Patents Directed At Medical Equipment: Late 20th Century**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Share Coeff./SE
US State × 1986 to 1990	0.0074*	0.0074*	0.0078*
	(0.0032)	(0.0032)	(0.0032)
US State × 1991 to 1995	0.0185**	0.0184**	0.0193**
	(0.0049)	(0.0052)	(0.0054)
US State × 1996 to 1999	0.0222**	0.0222**	0.0232**
	(0.0059)	(0.0060)	(0.0059)
GDP Per Capita (10000s)		-0.0007	-0.0001
		(0.0121)	(0.0130)
R^2	0.918	0.918	0.918
N	156	156	148
Number of Clusters	39	39	37
Weighted	Yes	Yes	Yes
Period FE	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes
Anglosphere?	Yes	Yes	No
Base Period	1980 to 1985	1980 to 1985	1980 to 1985

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. The dependent variable is the fraction of total patents that are categorized Medical Equipment patents. A description of the classification system can be found in the note to Table 1. Relatively small U.S. states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each U.S. state or foreign country. Data sources are described in the note to Table 1.

Table 8: **Change in Fraction of Patents Directed At Pharmaceuticals: Late 20th Century**

	Pharma Share Coeff./SE	Pharma Share Coeff./SE	Pharma Share Coeff./SE
US State × 1986 to 1990	0.0125**	0.0125**	0.0130**
	(0.0038)	(0.0039)	(0.0040)
US State × 1991 to 1995	0.0164*	0.0169+	0.0201*
	(0.0070)	(0.0084)	(0.0089)
US State × 1996 to 1999	0.0361*	0.0362*	0.0431**
	(0.0172)	(0.0175)	(0.0157)
GDP Per Capita (10000s)		0.0031	0.0055
		(0.0211)	(0.0221)
R^2	0.845	0.845	0.845
N	156	156	148
Number of Clusters	39	39	37
Weighted	Yes	Yes	Yes
Period FE	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes
Anglosphere?	Yes	Yes	No
Base Period	1980 to 1985	1980 to 1985	1980 to 1985

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. The dependent variable is the fraction of total patents that are categorized Pharmaceutical patents. A description of the classification system can be found in the note to Table 1. Relatively small U.S. states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each U.S. state or foreign country. Data sources are described in the note to Table 1.

Appendix Tables A.8 through A.11 report results characterizing the quality of the innovations associated with these expansions in the health-sector's share of all U.S. patents. Tables A.8 and A.9 report results similar to those from Table 3, which described post-Medicare changes in the direction of innovative effort as measured by citation-weighted patent shares. The results are quite similar to those in Tables 4 and 5, in particular for changes from the early 1980s to the late 1980s. Longer-run estimates may not be particularly informative in these specifications because the patents granted in the later years of the database will have had relatively few years to accumulate citations (Hall, Jaffe, and Trajtenberg, 2001). Tables A.10 and A.11 show that, among patents that generate positive scores on the NBER patent database's originality index, the increase in the shares associated with both medical equipment and pharmaceutical patents are similar to the increases found for the full set of patents.[36] Taken together, the results are consistent with stability in the relative quality of U.S. health-sector patents over this time period.

As noted above, it would be erroneous to describe the results from Tables 7 and 8 as causal estimates of the effect of any particular insurance expansion. Nonetheless, they contribute additional evidence to the overall argument that U.S. insurance expansions played an important role in shaping the course of medical innovation. To see why, recall that the panels of Figure 1 describe 4 episodes in the evolution of cost sharing in U.S. health-care markets, mirrored by the panels of Figure 3, which show the equivalent episodes in the history of health-sector patenting. As the figures and regression estimates have shown, U.S. patenting shifted substantially more towards the health sector than did foreign patenting during all 3 of the episodes during which cost sharing in the relevant health care markets declined substantially. During the 1 episode during which cost shar-

[36]The originality index is a backward looking measure, which is high when a patent cites earlier patents from a diverse range of technological categories. Since it is backward looking, the originality index is unavailable during the early years of the patent database while the forward-looking generality index is available but relatively uninformative for the later years of the base.

ing changed little, namely the pharmaceuticals market of the 1960s and 1970s, U.S. and foreign patenting moved nearly in parallel. U.S. pharmaceutical patenting only accelerated relative to foreign pharmaceutical patenting over the episode during which U.S. insurance arrangements substantially expanded their coverage of prescription drugs.

4.2 Cross-Country Breakdowns by Closeness to the United States

Estimating the total size of the effect of U.S. insurance expansions on health-sector innovation requires establishing an appropriate counterfactual. As emphasized previously, the regression estimates have described the differential evolution of U.S. health-sector patenting relative to foreign health-sector patenting. To the extent to which foreign patenters have joined U.S. patenters in responding to the incentives associated with U.S. markets, these estimates constitute a lower bound on the total effect of U.S. insurance expansions. Figure 5 provides suggestive evidence on the potential importance of the relevant spillover effects.

Figure 5 displays the patent shares seen in Figure 3, but with a finer disaggregation of foreign patenters. Specifically, I divide foreign patenters into 3 groups: patenters in English speaking countries (the Anglosphere), patenters in non-English speaking European countries, and patenters elsewhere in the world (a category dominated by patents filed by residents of Japan). The categories are meant to roughly capture degrees of cultural closeness to the United States, which should correlate with each patenter's inclination towards, and ease of marketing (or dealing with regulators) in, the United States. If foreign patenters are responding to changes in the size of U.S. markets, such responses should be largest among the English speakers and smallest among those outside of both Europe and the Anglosphere.

The figure shows that health-sector patenting's share of total patents rose more dramatically in English-speaking countries and other countries in Europe than elsewhere in

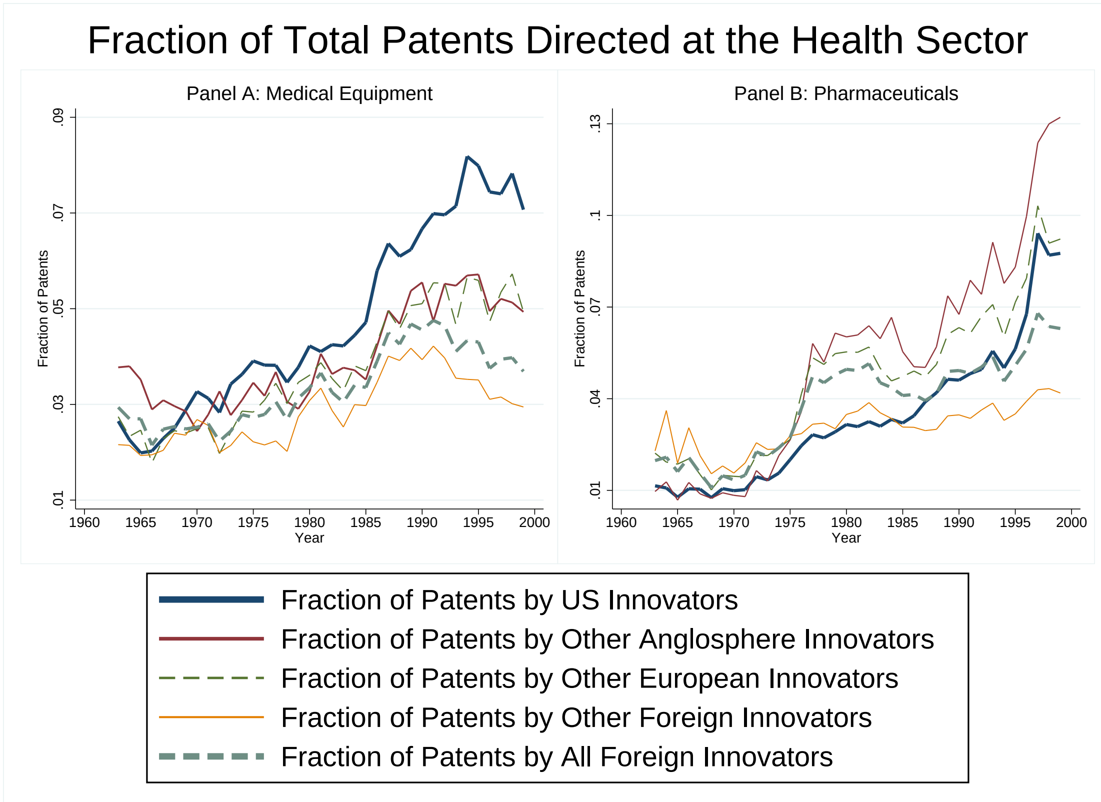

Figure 5: **Fraction of Patents Directed at the Health Sector (U.S. vs Foreign Country Groups):** Series were constructed by the author using data from the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). Patents are classified as coming from the Anglosphere if the patenter lives in Canada, Australia, Great Britain, or Ireland. "Other European" innovators are those from European countries that are not included in the Anglosphere. A description of the system for classifying Medical Equipment and Pharmaceutical patents can be found in the note to Table 1. The years in the figure refer to the year in which each patent was granted. In later years of the patent database, grant years lag filing years by an average of 2.3 years for health-sector patents (roughly 2.0 years for patents more generally).

the world. From the mid-1960s through the late-1990s, the medical-equipment share of patents rose from roughly 3 percent of all patents to 5 percent of all patents in English-speaking countries and other countries in Europe (relative to a rise from just above 2 percent to just over 7 percent in the United States). Elsewhere in the world, this share rose from roughly 2.5 percent to just over 3 percent after peaking at a high of 4 percent during the late 1980s. Patenters in the Anglosphere exceeded U.S.-based patenters in terms of their pharmaceutical share, which rose from 1 percent to nearly 13 percent relative to an increase from 1 percent to nearly 9 percent in the United States. Other European patenters have pharmaceutical shares similar to that in the United States, while innovators elsewhere in the world had a pharmaceutical share of just over 4 percent during the late 1990s. The data are suggestive that the patenting of innovators outside of Europe and the Anglosphere may provide a reasonable counterfactual for the path of U.S. patenting in the absence of its insurance expansions. Given the degree of uncertainty associated with establishing this counterfactual, I consider a variety of alternatives in Section 6's calibration of the role of insurance as a driver of innovation and health expenditures.

5 An Accounting Framework for Characterizing the Drivers of Health-Spending Growth

This section presents a simple framework for decomposing the rise in U.S. health expenditures across several contributing forces. Real per capita health spending, H, can be described as the product of a per-unit cost of care, P, and an average quantity of care consumed per person, Q. The average quantity per person can, in turn, be described illustratively as the product of the fraction of individuals, f, who can benefit from existing health-care treatments and technologies and the quantity of care, q, consumed by each of these individuals.

Our primary interest is in the effect of health insurance expansions on health care spending over the long run. This includes both its static impact on desired levels of consumption at a given state of technology and its dynamic impact on the treatments available at each point in time. I summarize insurance by the average coinsurance rate, c, faced by health care consumers. Demand at a point in time is $q_t = q(c_t)$. I write the state of the technical frontier as $f_t = f(t) + f_{\bar{c}}(\bar{c}_t)$, where $\bar{c}_t = \sum_{i=0}^{t} \lambda_i c_i$ is a weighted average of the current and past coinsurance rates. The term $f(t)$ describes a counterfactual, secular advance of health-technologies in the absence of changes in insurance arrangements.

Establishing such a counterfactual was the principal aim of this paper's empirical work. That the remainder, insurance's dynamic effect, depends on the history of coinsurance rates reflects both that innovation does not occur instantaneously and that past innovations may remain relevant to the current technical frontier for some period of time.[37] At a point in time, health spending per capita can thus be expressed as:[38]

$$H_t = P_t q(c_t)[f(t) + f_{\bar{c}}(\bar{c}_t)]. \tag{4}$$

Given the limited role of consumers in medical decision making (Arrow, 1963) this accounting framework may appear to place an excessive emphasis on the role of demand. The quantity per patient, $q(c_t)$, need not be viewed solely as a reflection of consumer-driven demand, however; it could also be written as being a function of the system of provider reimbursements. Again reflecting the prevailing reimbursement systems of the mid-to-late 20th century, I implicitly assume cost-plus reimbursement as a constant feature of the environment. Importantly, within a stable reimbursement environment, quantities will increase as cost sharing falls even if one models patients as passively accepting the recommendations their physicians. So long as physicians act, at least partially, as agents of their patients, their supply curves will have negative slopes with respect to *their patients'* out-of-pocket price.

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[37]Expectations of future arrangements are relevant as well, and are implicitly assumed here to be driven by the past (Weisbrod, 1991).

[38]I have assumed away any effects of insurance arrangements on the per unit cost of care. I rule out one source of such effects to focus attention the long run. Large, short-run declines in coinsurance rates could drive up the per unit cost of care by increasing demand on a horizon over which the supply of physicians and nurses does not have time to adjust. I purposefully focus attention on a long run over which the labor market is in equilibrium. Insurance arrangements could also affect per unit costs by inducing cost-saving productivity advances. While such advances are clearly important, I follow Weisbrod in emphasizing that 20th century insurance expansions were largely associated with cost-plus financing arrangements, which do not provide incentives for cost-reducing changes in technology. Developments of this sort have not been in short supply, but are appropriately considered to be part of the counterfactual evolution of the per unit cost of care. A striking health-sector example involves the productivity revolution in diagnostic imaging with CT scanners as analyzed by Trajtenberg (1989, 1990b).

Differentiating per capita health expenditures with respect to time yields the following expression:

$$\frac{dH}{dt} = \frac{dP}{dt} fq + Pfq' \frac{dc}{dt} + Pq[\frac{df(t)}{dt} + f'_{\bar{c}} \frac{d\bar{c}_t}{dt}]. \tag{5}$$

In this framework, changes in health expenditures per capita can be decomposed into 4 pieces. The first, $\frac{dP}{dt} fq$, reflects changes in input costs and productivity, including administrative loads. The second factor, $Pfq'_c \frac{dc}{dt}$, is the static effect of insurance expansions on demand for care. The remainder of any increases in spending are captured by the pieces of equation (4) that involve technical advances. This paper's empirical work informs a division of this remainder between the secular, counterfactual advance of technology in a stable insurance environment, $Pq \frac{df(t)}{dt}$, and the dynamic effect of insurance expansions, $Pqf'_{\bar{c}} \frac{d\bar{c}_t}{dt}$.

6 Estimating the Dynamic Effect of Insurance Expansions on U.S. Health Expenditures

This section uses Section 5's accounting framework to estimate the contribution of insurance's dynamic effects to the growth of U.S. health expenditures. Panel A of Table 5 presents the inputs used for my calibration of the effect of non-technological factors. The total increase in real per capita spending in hospitals, physicians' offices, and other clinical settings over the last half century was roughly $4,200 (from a base of roughly $700 in 1960 to $4900 in 2010). Estimates from Cutler and Ly (2011) and Pozen and Cutler (2010) suggest that $616 of this increase, or 15 percent, may be attributable to changes in administrative costs.[39] Newhouse (1992) highlights difficulties in attributing

[39]The estimate comes from a comparison of administrative costs in the United States and Canada. Absent reliable historical information on administrative costs in the United States, I essentially take current

changes in spending to other aspects of per-unit cost like physician salaries. In short, it is difficult to disentangle prices and quantities since relatively high physician incomes (both historically and across countries) are also associated with the performance of relatively skill-intensive medical procedures. I follow Newhouse in not attributing spending growth to such factors.

I next calibrate the potential role of insurance's static effect on demand for care. An initial estimate of $335, or 8 percent, comes quite directly from calculations by Manning et al. (1987). As summarized by Newhouse (1992), the Rand health insurance experiment found that "the effect of moving from an average coinsurance rate of 33 percent to a coinsurance rate of zero at a point in time is roughly a 40 to 50 percent increase in demand." The described reduction in coinsurance rates is quite similar to the decline in the out-of-pocket share for spending in hospitals and physicians' offices from 1960 to 2010, which was from 36 percent to 6 percent.[40] The moderate demand elasticities from the Rand and Oregon health insurance experiments are thus consistent with a modest role for static demand effects as drivers of increasing health expenditures. Finkelstein (2007) notes that large-scale insurance expansions may explain a larger share of spending growth than these estimates imply, as they may have general equilibrium effects on the way hospitals and physicians organize their practice of medicine. In an alternative estimate of insurance's static effect, I allow such general equilibrium impacts to triple its size to $1,006.[41]

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administrative costs in the relatively streamlined Canadian system as an estimate of U.S. administrative costs prior to the advance of insurance complexity over the last half century.

[40]Applying a demand elasticity of -0.2 to the change in price of roughly 180 log points produces a similar, but somewhat smaller estimate.

[41]This is moderately smaller than Finkelstein's (2007) preferred calculation, which suggests that the static demand effect may account for as much as half of the increase in hospital spending. While general equilibrium effects are undoubtedly important, Finkelstein's estimate are sufficiently larger than all others that use of an intermediate value may be appropriate. Additionally, and consistent with industry-studies of medical-equipment innovation, this paper's results imply a short lag between Medicare's introduction and increases in medical-equipment innovation. Finkelstein's estimates of Medicare's effect on health

Table 9: **Calibration of the Dynamic Effect of Insurance on Spending in Hospitals and Physicians' Offices**

Total Growth to Explain	$4,197	National Health Expenditure Data
Panel A: Non-Technological Factors		
Spending Per Unit of Care	$616	Cutler and Ly (2011); Pozen and Cutler (2010)
Small Static Demand Effect	$335	Manning et al. (1987); Finkelstein et al. (2011); Newhouse (1992)
Large Static Demand Effect	$1,006	Above plus Finkelstein (2007)
Panel B: Technology Residual		
	Small Static Effect	Large Static Effect
Technology Residual	$3,246	$2,576
Panel C: Scenarios for Allocating Residual between Counterfactual Technological Advance and the Dynamic Effect of Insurance		
Counterfactual Scenario	Due to Insurance	Features of Scenario
Scenario A:	30%	Counterfactual of non-European innovators; only recent innovations matter.
Scenario B:	17%	Counterfactual of non-European innovators; two decades of innovations matter.
Scenario C:	25%	Counterfactual of all foreign innovators; only recent innovations matter.
Scenario D:	12%	Counterfactual of all foreign innovators; two decades of innovations matter.
Panel D: Estimated Contribution of Insurance's Dynamic Effect		
Counterfactual Scenario	Small Static Effect	Large Static Effect
Scenario A:	$978	$776
Scenario B:	$562	$446
Scenario C:	$823	$653
Scenario D:	$375	$297

Note: Author's calculations using sources described in the table and results presented earlier in this paper. Further details of the calibration exercise can be found in the text.

The calibration leaves a residual per capita spending increase of either $3,200 or $2,600 (77 or 61 percent of the total) to be explained by advances in health-care technology. Consistent with analysis by Newhouse (1992), Cutler (2004), and Chandra and Skinner (2012), these estimates attribute the lion's share of the rise in health expenditures to the advance of health technologies. Figures 6 and 7 provide suggestive evidence that such an allocation is reasonable, as they show tight relationships between expansions in health sector patents as shares of total patents and expansions in health spending as a share of GDP. Health spending in hospitals, physicians' offices, and other clinical settings moves quite tightly with medical-equipment patenting, while drug spending escalated significantly during the biotechnology patenting boom of the 1990s.

Table 5's Panel C presents a range of estimates of the fraction of the residual health-spending growth that can be explained by the dynamic effect of insurance on incentives for innovation. The range reflects the possibilities implied by permutations of two coarse assumptions for a) estimating the counterfactual path of U.S. medical-equipment innovation that would have occurred in a world without its insurance expansions and b) translating this counterfactual path of innovation into current health expenditures.

I estimate the counterfactual level of medical-equipment innovation in two ways. The first takes the counterfactual to be the path of innovation among the non-English speaking, non-European countries. The second, which produces more conservative estimates of the effect of U.S. insurance expansions, takes the counterfactual to be the path of innovation among all foreign patenters. In both cases I assume that the United States accounts for half of global medical-equipment innovation. Worldwide patent data from the OECD show this to have been the U.S. share of all medical-equipment patents during the last years of the 20th century. U.S.-based innovators account for closer to 68 percent of all medical-equipment patents (61 percent of all patents) in the NBER Patent

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spending through 1970 will thus incorporate, in small part, some effects of insurance-induced innovation.

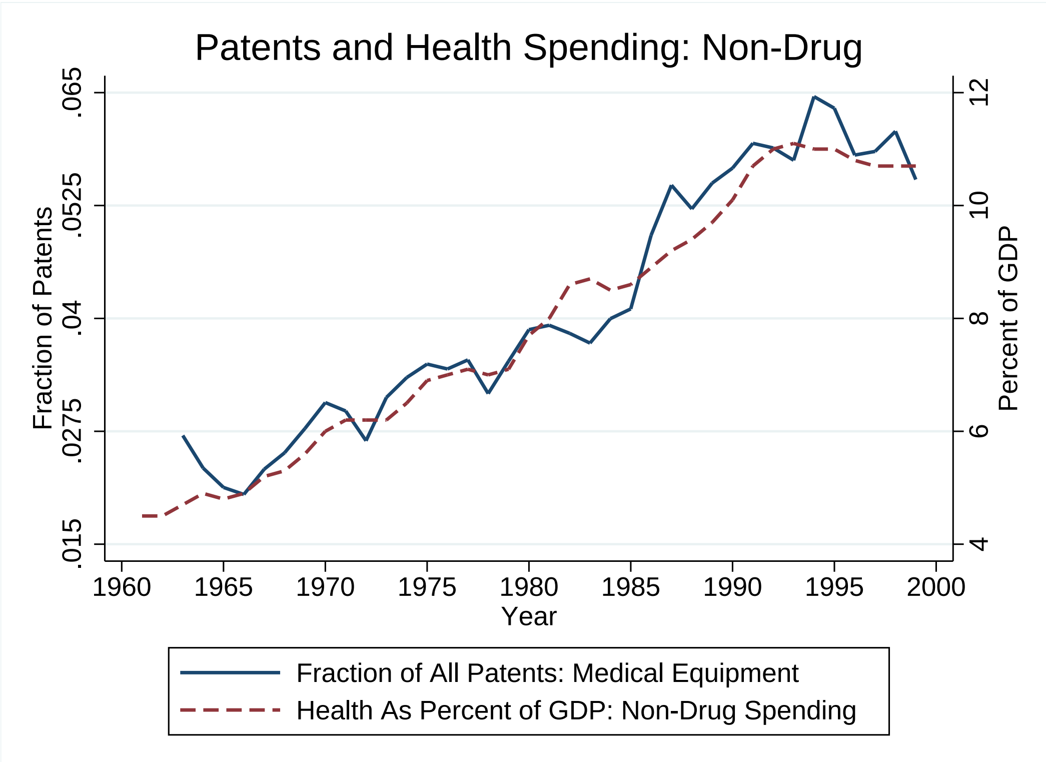

Figure 6: **US Health Spending and Medical Equipment Patenting Over Time:** The patent series was constructed by the author using data from the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). A description of the system for classifying Medical Equipment and Pharmaceutical patents can be found in the note to Table 1. The spending series was calculated using the historical National Health Expenditure data reported by the Center for Medicare and Medicaid Services (CMS). The spending series describes all health spending that takes place in hospitals, physicians' offices, and other clinical settings.

Database, but not all foreign health innovations are patented with the USPTO.

I also employ two assumptions for translating counterfactual paths of innovation into current health expenditures. The first is that only the 5 most recent years of innovation continue to affect current health expenditures. The second is that innovation from the prior two decades affect current health expenditures.

Under Scenario A, in which I take the counterfactual to be the path innovation among the non-English speaking, non-European countries and assume that only the last 5 years of innovation impact current health spending, I estimate that the dynamic effect of U.S. insurance expansions increased global medical-equipment innovation by 30 per-

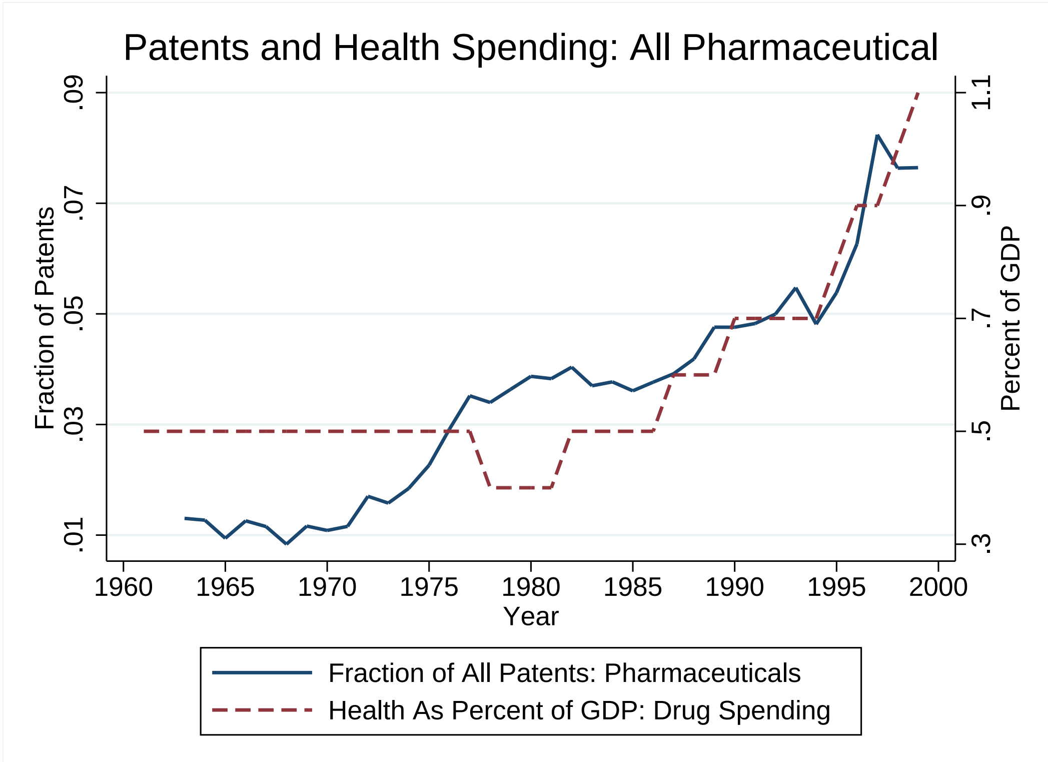

Figure 7: **US Health Spending and Pharmaceutical Patenting Over Time:** The patent series was constructed by the author using data from the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). A description of the system for classifying Medical Equipment and Pharmaceutical patents can be found in the note to Table 1. The spending series was calculated using the historical National Health Expenditure data reported by the Center for Medicare and Medicaid Services (CMS). The spending series describes health spending on pharmaceuticals only.

cent. When the static effect of insurance on health-care consumption is assumed to be relatively small, the results imply that insurance's dynamic effects explain about $1,000 of the $4,200 increase (nearly 25 percent) in real per capita spending at hospitals and physicians' offices. When the static effect of insurance is allowed to be relatively large, the dynamic effect can account for nearly $800 of the increase. Replacing the counterfactual with a counterfactual of patenting in all foreign countries reduces these estimates by about one sixth.

Assuming that a full two decades of medical-equipment patenting influence current health-care spending results in relatively conservative estimates of the dynamic effect of insurance. This assumption reduces the estimates of U.S. insurance expansions' contribution to global medical-equipment innovation by roughly 13 percentage points. Given the tight and nearly contemporaneous tracking of the series for medical-equipment patenting and spending in hospitals and physicians' offices (Figure 6), this assumption seems less realistic than the assumption that current spending is driven by relatively recent innovations.

The estimates in Table 6 highlight the high level of uncertainty associated with translating documented shifts in patenting activity into changes in health care spending. Additional considerations provide plausible arguments for either increasing or decreasing one's preferred estimate of the effect of U.S. insurance expansions on medical spending. Concern that the estimated shifts in patenting overstate shifts in impact-adjusted innovation, for example, would be cause for a downward revision. Concern that the counterfactuals fail to adequately account for effects of U.S. markets on foreign medical-equipment innovation would be cause for an upward revision.

7 Conclusion

This paper provides estimates of the dynamic effect of insurance on broad aggregates of medical innovation. The origins of Medicare and Medicaid provide a compelling natural experiment for estimating such effects, as they sharply expanded the markets for new medical equipment and devices while having little impact on markets for new pharmaceuticals. Motivated by past research, which highlights the importance of practitioner-driven medical-equipment innovation, and thus of home-country incentives, I estimate the differential effect of Medicare and Medicaid on the medical-equipment patenting of U.S.-based innovators relative to foreign innovators. From the mid-1960s through 1980 I find that U.S.-based medical-equipment patenting increased

50 percent more than foreign medical-equipment patenting. Over this same time period, U.S. and foreign pharmaceutical patenting moved roughly in parallel. I more speculatively estimate that insurance's dynamic effects are responsible for roughly 25 percent of recent global medical-equipment innovation and 15 percent of the rise in U.S. spending in hospitals, physicians' offices, and other clinical settings since 1960.

This paper has, thus far, said nothing about the welfare implications of these dynamic effects of insurance expansions. Past work has emphasized that induced technical change may add to any static benefits of associated public policies (Finkelstein, 2004). It has also found evidence that, in a wide range of treatment areas, the benefits associated with new health care technologies far exceed their costs (Cutler, 2004; Cutler and McClellan, 2001; Cutler, Rosen, and Vijan, 2006). While these analyses have demonstrated the high value of new health care technologies, I close by highlighting a reason to reconsider their (opportunity) costs.

Frameworks allowing for directed technical change (Acemoglu, 1998) highlight that innovation in one area of the economy may come at the cost of innovation in others. If all sectors are under-innovated from a social welfare perspective, and if the economy-wide supply of innovation is relatively inelastic, then the opportunity cost of developments in health-care technology may include losses of innovation in other sectors. Of clearer relevance in the current setting is the fact that insurance can influence the types of health-sector innovations we realize (Weisbrod, 1991). When providers are paid on a cost-plus basis, as was historically the case, insurance rewards quality-improving innovation at the potential expense of cost-reducing innovation. Further analysis of historical insurance expansions' effects on the kinds of innovations we have realized and foregone is essential for characterizing their effects on welfare.

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Appendix 1: Supplemental Figures and Tables

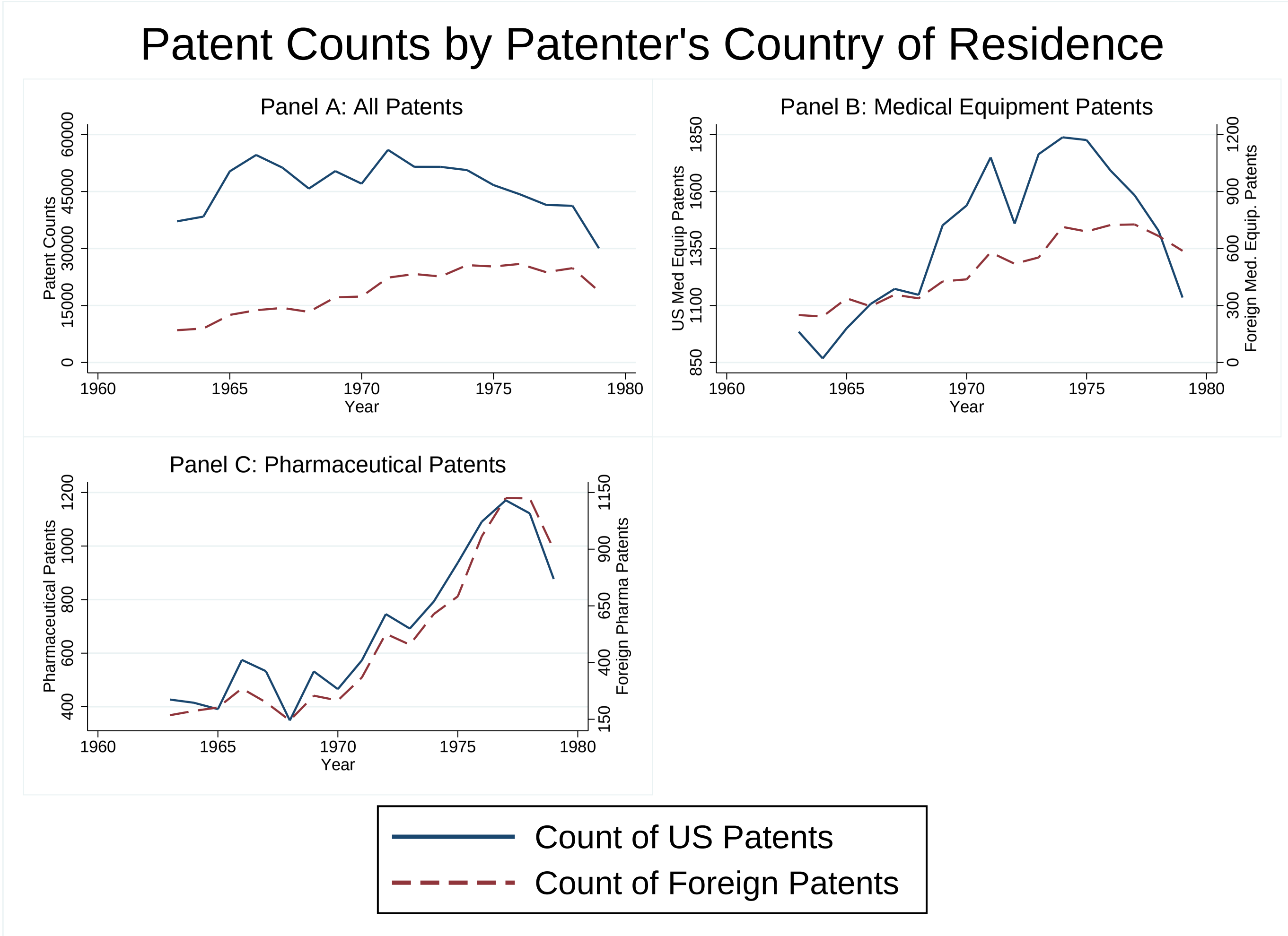

Figure A.1: **Total and Health Sector Patent Counts (U.S. vs Foreign):** Series were constructed by the author using data from the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). A description of the system for classifying Medical Equipment and Pharmaceutical patents can be found in the note to Table 1. The years in the figure refer to the year in which each patent was granted. In later years of the patent database, grant years lag filing years by an average of 2.3 years for health-sector patents (roughly 2.0 years for patents more generally).

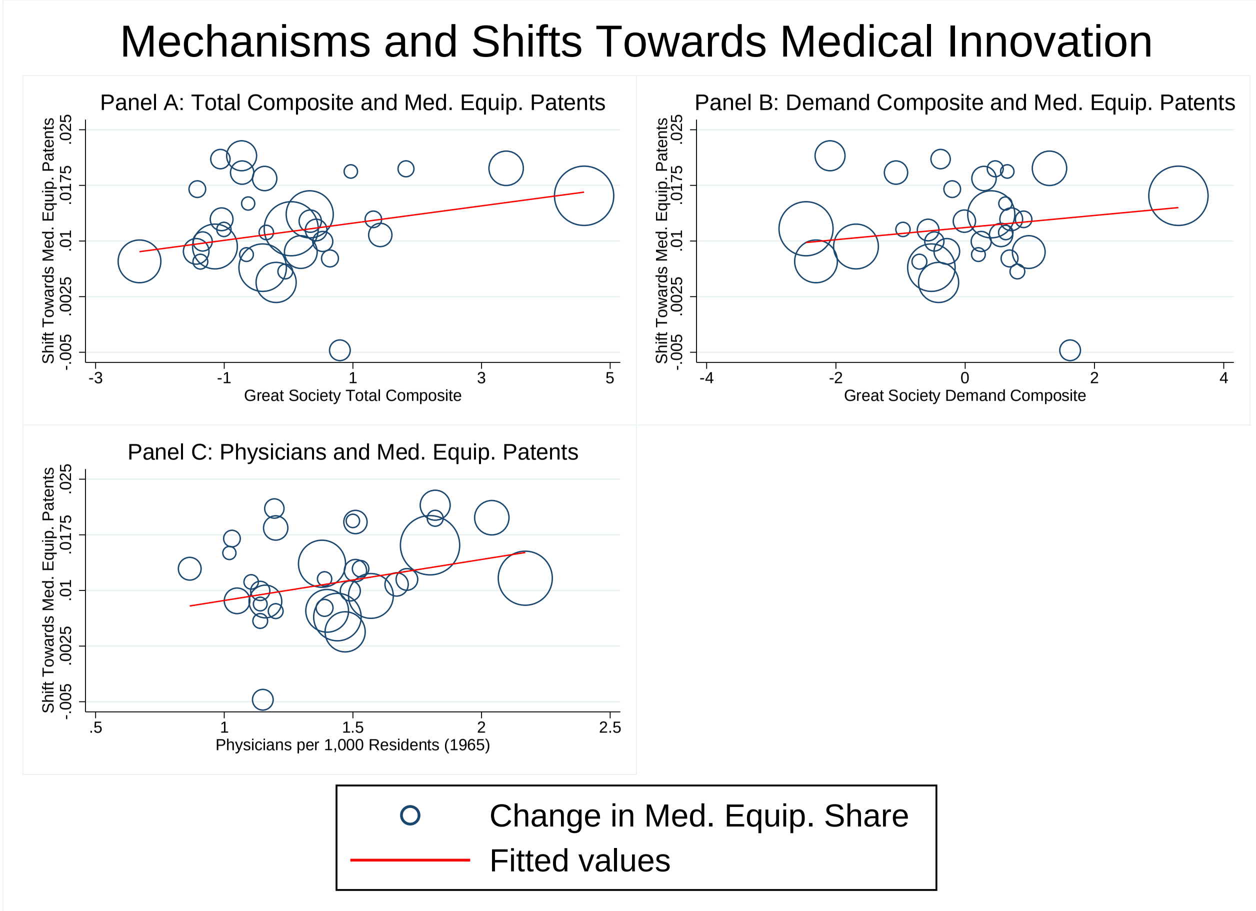

Figure A.2: **Correlations between Mechanism Proxies and Increases in Medical-Equipment Patenting:** The shifts towards medical-equipment patenting were constructed by the author using data from the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). A description of the system for classifying Medical Equipment patents can be found in the note to Table 1. Observations represent U.S. states and state aggregates, again constructed as described in the note to Table 1. The Total Composite, Demand Composite, and Physicians per 1,000 Residents (in 1965) variables were constructed as described in the note to Table 3. Physicians per 1,000 Residents comes from the 1967 edition of the statistical abstract of the United States. The Demand Composite is the sum of two standard-normalized variables; the first proxies for the state-level impact of the origin of Medicare, while the second proxies for the state-level impact of the origin of Medicaid. The Total Composite is the sum of the Demand Composite and a standard-normalized version of the variable describing the number of Physicians per 1,000 Residents. Observations are weighted by each state's contribution to the total number of patents appearing in the database over the sample period. R-squared statistics associated with the best fit lines in Panels A, B, and C are 0.196, 0.126, and 0.077 respectively.

Table A.1: **Change in Fraction of Patents Directed At Medical Equipment: Unweighted Regressions**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Ln(Eq Share) Coeff./SE	Rx Share Coeff./SE	Equip Share Coeff./SE	Equip Net Rx Coeff./SE
US State × 1968 to 1974	0.0114**	0.0124**	0.4387**	0.0007	0.0123**	0.0117**
	(0.0026)	(0.0022)	(0.1053)	(0.0031)	(0.0021)	(0.0029)
US State × 1975 to 1980	0.0145**	0.0156**	0.5396**	-0.0140+	0.0169**	0.0296**
	(0.0026)	(0.0028)	(0.1092)	(0.0073)	(0.0034)	(0.0073)
GDP Per Capita (10000s)		0.0225**	0.1952	-0.0247	0.0248*	0.0472*
		(0.0080)	(0.3230)	(0.0216)	(0.0095)	(0.0218)
Fraction Pharmaceutical					0.0934	
					(0.1185)	
R^2	0.910	0.918	0.921	0.856	0.919	0.905
N	116	116	116	116	116	116
Number of Clusters	39	39	39	39	39	39
Weighted	No	No	No	No	No	No
Period FE	Yes	Yes	Yes	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. In columns 1, 2, and 5 the dependent variable is the fraction of total patents that are categorized Medical Equipment Patents. In column 3 the dependent variable is the natural logarithm of this fraction. In column 4 the dependent variable is the fraction of total patents that are categorized Pharmaceutical Patents. Finally, in column 6 the dependent variable is the fraction of total patents that are categorized Medical Equipment Patents minus the fraction categorized as Pharmaceutical Patents. A description of the classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.2: **Change in Fraction of Patents Directed At Medical Equipment: Robustness To Changing Base Period**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Net Rx Coeff./SE	Equip Net Rx Coeff./SE
US State × 1968 to 1974	0.0089**	0.0108**	0.0115**	0.0121**	0.0120**
	(0.0028)	(0.0027)	(0.0026)	(0.0024)	(0.0022)
US State × 1975 to 1980	0.0139**	0.0143**	0.0138**	0.0131**	0.0123**
	(0.0030)	(0.0030)	(0.0028)	(0.0025)	(0.0022)
GDP Per Capita (10000s)	0.0113**	0.0066**	0.0035	0.0022	0.0040*
	(0.0024)	(0.0021)	(0.0021)	(0.0022)	(0.0019)
R^2	0.729	0.739	0.751	0.760	0.757
N	656	656	656	656	656
Number of Clusters	39	39	39	39	39
Weighted	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes
Year FE	No	No	No	No	No
State And Country FE	Yes	Yes	Yes	Yes	Yes
Balanced Panel	No	No	No	No	No
Base Period	1963 to 1965	1963 to 1966	1963 to 1967	1963 to 1968	1963 to 1969

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. In columns 1, 2, and 3 the dependent variable is the fraction of total patents that are categorized Medical Equipment Patents. In columns 4, 5, and 6 the dependent variable is the fraction of total patents that are categorized Medical Equipment Patents minus the fraction categorized as Pharmaceutical Patents. A description of the classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.3: **Change in Fraction of Patents Directed At Medical Equipment: Annual Observations w/ Trend Control**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Net Rx Coeff./SE	Equip Net Rx Coeff./SE	Equip Net Rx Coeff./SE
US State × 1968 to 1974	0.0121**	0.0120**	0.0112**	0.0047	0.0054	0.0022
	(0.0024)	(0.0024)	(0.0036)	(0.0079)	(0.0062)	(0.0032)
US State × 1975 to 1980	0.0131**	0.0131**	0.0114**	0.0167	0.0186	0.0123*
	(0.0025)	(0.0026)	(0.0039)	(0.0136)	(0.0119)	(0.0056)
GDP Per Capita (10000s)	0.0022	0.0014	0.0079*	0.0022	0.0238	0.0263+
	(0.0022)	(0.0040)	(0.0037)	(0.0075)	(0.0151)	(0.0156)
Linear Trend		0.0001			-0.0023*	
		(0.0003)			(0.0010)	
US-Specific Trend			0.0002			0.0006
			(0.0004)			(0.0013)
R^2	0.760	0.760	0.786	0.740	0.752	0.783
N	656	656	656	656	656	656
Number of Clusters	39	39	39	39	39	39
Weighted	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	No	Yes	Yes	No
Year FE	No	No	Yes	No	No	Yes
State And Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Balanced Panel	No	No	No	No	No	No
Base Period	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. In columns 1, 2, and 3 the dependent variable is the fraction of total patents that are categorized Medical Equipment Patents. In columns 4, 5, and 6 the dependent variable is the fraction of total patents that are categorized Medical Equipment Patents minus the fraction categorized as Pharmaceutical Patents. A description of the classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.4: **Change in Fraction of Patents Directed At Medical Equipment: Annual Observations w/ Balanced Panel**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Net Rx Coeff./SE	Equip Net Rx Coeff./SE	Equip Net Rx Coeff./SE
US State × 1968 to 1974	0.0127**	0.0126**	0.0111*	0.0028	0.0032	0.0011
	(0.0026)	(0.0029)	(0.0040)	(0.0092)	(0.0071)	(0.0035)
US State × 1975 to 1980	0.0133**	0.0130**	0.0104*	0.0133	0.0155	0.0116
	(0.0028)	(0.0030)	(0.0045)	(0.0159)	(0.0139)	(0.0068)
GDP Per Capita (10000s)	0.0017	-0.0011	0.0102*	0.0031	0.0258	0.0333+
	(0.0024)	(0.0046)	(0.0042)	(0.0081)	(0.0180)	(0.0189)
Linear Trend		0.0003			-0.0024+	
		(0.0003)			(0.0012)	
US-Specific Trend			0.0003			0.0004
			(0.0005)			(0.0015)
R^2	0.798	0.799	0.831	0.744	0.757	0.789
N	367	367	367	367	367	367
Number of Clusters	22	22	22	22	22	22
Weighted	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	No	Yes	Yes	No
Year FE	No	No	Yes	No	No	Yes
State And Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Balanced Panel	Yes	Yes	Yes	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. The dependent variable is the fraction of total patents that are categorized Medical Equipment Patents. A description of the classification system can be found in the note to Table 1. Specifications differ solely in terms of the years classified as the "pre-Medicare" period. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.5: **Post Medicare Changes in the Mean Citations of Patents by US Patenters**

	Health Patent Citations	All Patent Citations	Relative Citations
	Coeff./SE	Coeff./SE	Coeff./SE
US State × 1968 to 1974	0.3367	0.1475	-0.1830+
	(0.4057)	(0.1893)	(0.1058)
US State × 1975 to 1980	0.8084	0.4479	-0.2691+
	(0.6108)	(0.3351)	(0.1335)
GDP Per Capita (10000s)	0.7221	0.8308	-0.4294
	(1.9444)	(0.9576)	(0.4200)
R^2	0.930	0.981	0.737
N	116	116	116
Number of Clusters	39	39	39
Weighted	Yes	Yes	Yes
Period FE	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. In column 1 the dependent variable is the mean number of citations associated with each medical-equipment patent. In column 2 the dependent variable is the the mean number of citations associated with all patents. In column 3 the dependent variable is ratio of the medical-equipment and all-patent citation means. A description of the patent classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.6: **Change in Fraction of Patents Directed At Medical Equipment: General Patents Only Post Medicare**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Ln(Eq Share) Coeff./SE	Rx Share Coeff./SE	Equip Share Coeff./SE	Equip Net Rx Coeff./SE
US State × 1968 to 1974	0.0074**	0.0079**	0.2042*	0.0019	0.0077**	0.0059*
	(0.0021)	(0.0023)	(0.0823)	(0.0022)	(0.0021)	(0.0028)
US State × 1975 to 1980	0.0072*	0.0080*	0.1720*	-0.0079	0.0085*	0.0158*
	(0.0028)	(0.0032)	(0.0839)	(0.0064)	(0.0042)	(0.0063)
GDP Per Capita (10000s)		0.0083	0.0865	-0.0234	0.0100	0.0317
		(0.0100)	(0.2779)	(0.0198)	(0.0125)	(0.0197)
Fraction Pharmaceutical					0.0735	
					(0.1963)	
R^2	0.926	0.927	0.946	0.876	0.927	0.914
N	110	110	110	110	110	110
Number of Clusters	37	37	37	37	37	37
Weighted	Yes	Yes	Yes	Yes	Yes	Yes
Period FE	Yes	Yes	Yes	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. In constructing patent shares for this table's regressions, the patent database was restricted to patents categorized by Hall, Jaffe, and Trajtenberg (2001) as having a generality index great than 0.3. In columns 1, 2, and 5 the dependent variable is the fraction of total patents that are categorized Medical Equipment Patents. In column 3 the dependent variable is the natural logarithm of this fraction. In column 4 the dependent variable is the fraction of total patents that are categorized Pharmaceutical Patents. Finally, in column 6 the dependent variable is the fraction of total patents that are categorized Medical Equipment Patents minus the fraction categorized as Pharmaceutical Patents. A description of the classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.7: **Post Medicare Changes in the "Generality" of Patents by US Patenters**

	Health Patent Generality Coeff./SE	Patent Generality Coeff./SE	Relative Generality Coeff./SE
US State × 1968 to 1974	-0.0440*	-0.0044	-0.1687**
	(0.0173)	(0.0043)	(0.0566)
US State × 1975 to 1980	-0.0651**	-0.0060	-0.2290**
	(0.0173)	(0.0061)	(0.0462)
GDP Per Capita (10000s)	-0.0483	0.0153	-0.1905
	(0.0603)	(0.0138)	(0.1717)
Fraction Pharmaceutical	-0.6249	0.0347	-1.7798
	(0.5706)	(0.1194)	(1.3433)
R^2	0.906	0.991	0.778
N	116	116	116
Number of Clusters	39	39	39
Weighted	Yes	Yes	Yes
Period FE	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes
Base Period	1963 to 1968	1963 to 1968	1963 to 1968

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. In column 1 the dependent variable is the mean of the NBER's patent database's generality index for medical-equipment patents only. In column 2 the dependent variable is the mean of the NBER's patent database's generality index for all patents granted. In column 3 the dependent variable is ratio of the medical-equipment and all-patent means of the generality index. A description of the patent classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.8: **Change in Fraction of Citation-Weighted Patents Directed At Medical Equipment**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Share Coeff./SE
US State × 1986 to 1990	0.0207*	0.0208*	0.0216*
	(0.0085)	(0.0084)	(0.0084)
US State × 1991 to 1995	0.0293*	0.0282*	0.0283*
	(0.0113)	(0.0112)	(0.0121)
US State × 1996 to 1999	0.0182+	0.0180+	0.0176
	(0.0106)	(0.0103)	(0.0111)
GDP Per Capita (10000s)		-0.0066	-0.0073
		(0.0191)	(0.0203)
R^2	0.889	0.889	0.889
N	156	156	148
Number of Clusters	39	39	37
Weighted	Yes	Yes	Yes
Period FE	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes
Anglosphere?	Yes	Yes	No
Base Period	1980 to 1985	1980 to 1985	1980 to 1985

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. The dependent variables differ from those in Table 4 only in that each patent is now weighted by the number of future citations it had received as of 1999. For example, the Medical Equipment share is now calculated as the sum off all citations received by an area's medical-equipment patents divided by the sum of all citations received by all of an area's patents during the relevant time period. A description of the classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.9: **Change in Fraction of Citation-Weighted Patents Directed At Pharmaceuticals**

	Pharma Share Coeff./SE	Pharma Share Coeff./SE	Pharma Share Coeff./SE
US State × 1986 to 1990	0.0136*	0.0136*	0.0145*
	(0.0051)	(0.0051)	(0.0053)
US State × 1991 to 1995	0.0139	0.0139	0.0172+
	(0.0092)	(0.0096)	(0.0101)
US State × 1996 to 1999	0.0165	0.0165	0.0207
	(0.0139)	(0.0139)	(0.0133)
GDP Per Capita (10000s)		-0.0000	0.0023
		(0.0197)	(0.0204)
R^2	0.864	0.864	0.860
N	156	156	148
Number of Clusters	39	39	37
Weighted	Yes	Yes	Yes
Period FE	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes
Anglosphere?	Yes	Yes	No
Base Period	1980 to 1985	1980 to 1985	1980 to 1985

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. The dependent variables differ from those in Table 5 only in that each patent is now weighted by the number of future citations it had received as of 1999. For example, the Pharmaceutical share is now calculated as the sum off all citations received by an area's pharmaceutical patents divided by the sum of all citations received by all of an area's patents during the relevant time period. A description of the classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.10: **Change in Fraction of Patents Directed At Medical Equipment: Original Patents Only Late 20th Century**

	Equip Share Coeff./SE	Equip Share Coeff./SE	Equip Share Coeff./SE
US State × 1986 to 1990	0.0042	0.0043	0.0048
	(0.0032)	(0.0033)	(0.0032)
US State × 1991 to 1995	0.0174**	0.0172*	0.0177*
	(0.0061)	(0.0064)	(0.0065)
US State × 1996 to 1999	0.0221*	0.0221*	0.0228**
	(0.0082)	(0.0082)	(0.0083)
GDP Per Capita (10000s)		-0.0015	-0.0016
		(0.0150)	(0.0153)
R^2	0.913	0.913	0.913
N	148	148	144
Number of Clusters	37	37	36
Weighted	Yes	Yes	Yes
Period FE	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes
Anglosphere?	Yes	Yes	No
Base Period	1980 to 1985	1980 to 1985	1980 to 1985

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. In constructing patent shares for this table's regressions, the patent database was restricted to patents categorized by Hall, Jaffe, and Trajtenberg (2001) as having a originality index great than 0.01. The dependent variable is the fraction of total patents that are categorized Medical Equipment Patents. A description of the classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Table A.11: **Change in Fraction of Patents Directed At Medical Equipment: Original Patents Only Late 20th Century**

	Pharma Share Coeff./SE	Pharma Share Coeff./SE	Pharma Share Coeff./SE
US State × 1986 to 1990	0.0127**	0.0126**	0.0123**
	(0.0023)	(0.0022)	(0.0022)
US State × 1991 to 1995	0.0171**	0.0176**	0.0184**
	(0.0046)	(0.0059)	(0.0060)
US State × 1996 to 1999	0.0320**	0.0320*	0.0337**
	(0.0118)	(0.0120)	(0.0119)
GDP Per Capita (10000s)		0.0037	0.0032
		(0.0162)	(0.0166)
R^2	0.877	0.877	0.871
N	148	148	144
Number of Clusters	37	37	36
Weighted	Yes	Yes	Yes
Period FE	Yes	Yes	Yes
State And Country FE	Yes	Yes	Yes
Anglosphere?	Yes	Yes	No
Base Period	1980 to 1985	1980 to 1985	1980 to 1985

Note: **, *, and + indicate statistical significance at the 0.01, 0.05, and 0.10 levels respectively. The table reports coefficients from ordinary least squares regressions. In constructing patent shares for this table's regressions, the patent database was restricted to patents categorized by Hall, Jaffe, and Trajtenberg (2001) as having a originality index great than 0.01. The dependent variable is the fraction of total patents that are categorized Pharmaceutical Patents. A description of the classification system can be found in the note to Table 1. Relatively small US states are grouped into regional aggregates as described in the note to Table 1, where readers can also find a list of the foreign countries in included in the sample. Observations are weighted according to each state or country's average share of all patents in the database over the full sample period. Standard errors, reported beneath each point estimate, allow for arbitrary autocorrelation in the errors associated with the observations for each US state or foreign country. Data sources are described in the note to Table 1.

Appendix 2: Synthetic Control Analysis

This appendix presents an analysis of the effect of Medicare and Medicaid on medical-equipment patenting using synthetic control methods. The analysis serves two purposes. First, it shows that the magnitudes of the effects reported above are not sensitive to re-weighting the control units to more closely match medical-equipment's pre-Medicare share of patents in the United States. Second, it provides evidence that the confidence intervals presented in the main text did not understate the appropriate level of uncertainty surrounding the estimates.

Appendix Figure A.3 displays unadjusted, country-level changes in medical equipment's share of each country's USPTO-granted patents. Panel A shows that U.S. patenting shifted towards medical equipment by 0.9 percentage point from its average from 1963-1968 to its average from 1969-1974. This exceeds the increases taking place in any of the foreign countries, whose patent-weighted average change was essentially 0. The remaining panels show that, looking across the technological sub-categories that contribute to the medical-equipment aggregate, the U.S. had the largest change in surgical-equipment patenting, was close to tied with Germany for the 2nd largest increase in patenting in diagnostic equipment, and is in the middle of the distribution of changes in miscellaneous medical-equipment patenting.

Appendix Figure A.4 shows an initial set of results from synthetic-control estimation. The figure shows the distribution of placebo treatment effects obtained when assigning treatment status to each of the control-group countries/units individually. The true synthetic control estimate, in which the United States is appropriately declared the treatment unit, is 0.87 percentage point. This far exceeds the mean of the 9 placebo estimates, which is roughly -0.26 percentage point. The true estimate is exceeded by one placebo estimate, namely the estimate obtained when the placebo unit is Switzerland. Further analysis suggests that this results in part from the variance associated with proxying for

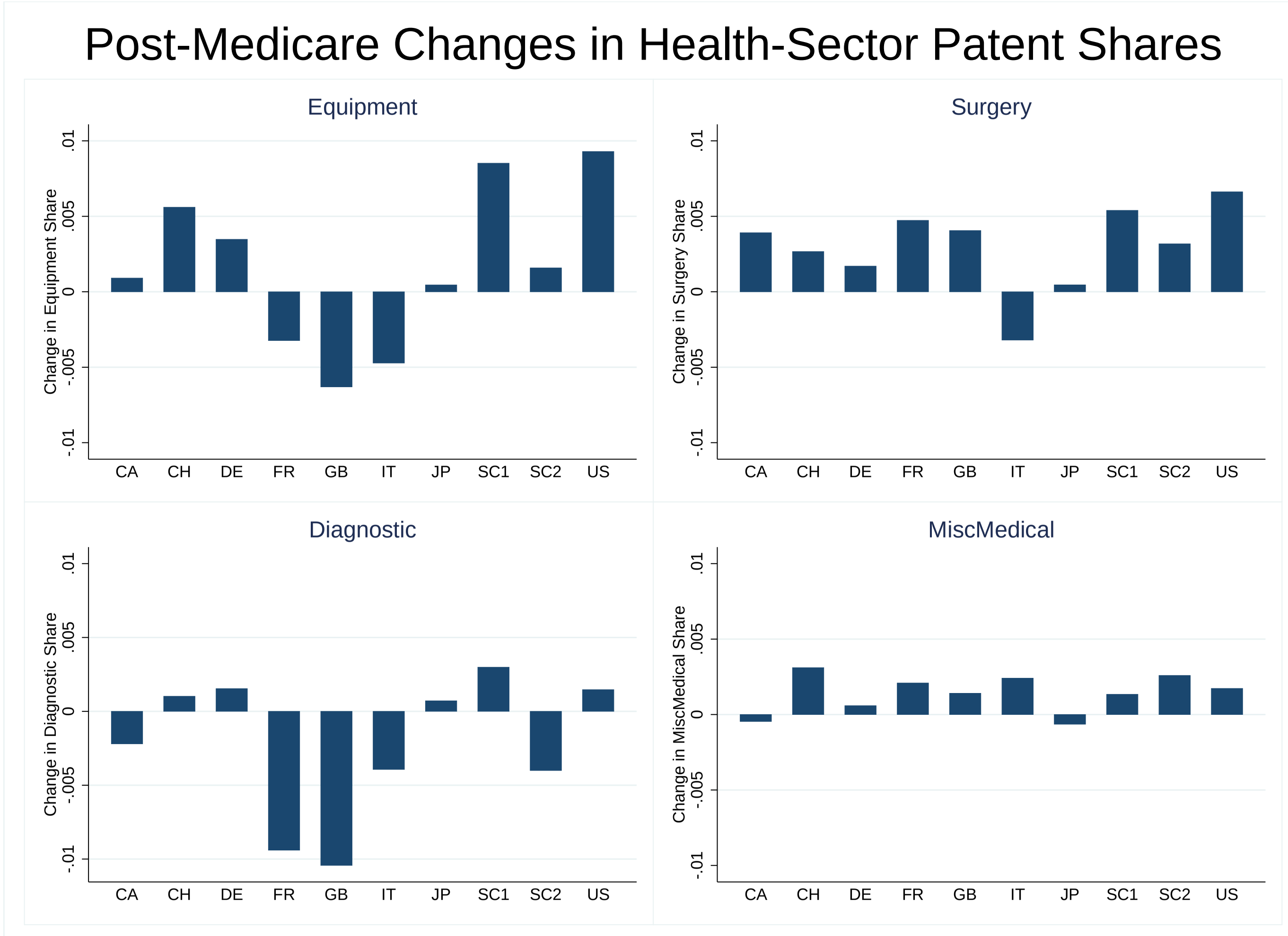

Figure A.3: **Post-Medicare Changes in Health-Sector Patent Shares:** Series were constructed by the author using data from the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). Surgery (sub-category 32), Diagnostic (sub-category 44), and MiscMedical (sub-category 39) sum to Equipment. Changes are constructed as the difference between each country's average from 1963-1968 to 1969-1974, which corresponds to the medium-run changes in subsequent regression analyses. CA corresponds to Canada, CH to Switzerland, DE to Germany, FR to France, GB to Great Britain, IT to Italy, JP to Japan, SC1 to an aggregate of all countries with fewer than 15,000 patents in the entire database, SC2 to an aggregate of countries with between 15,000 and 30,000 patents in the entire database, and US to the United States. All patents in the NBER Patent Database are over the relevant time period are incorporated into the figure.

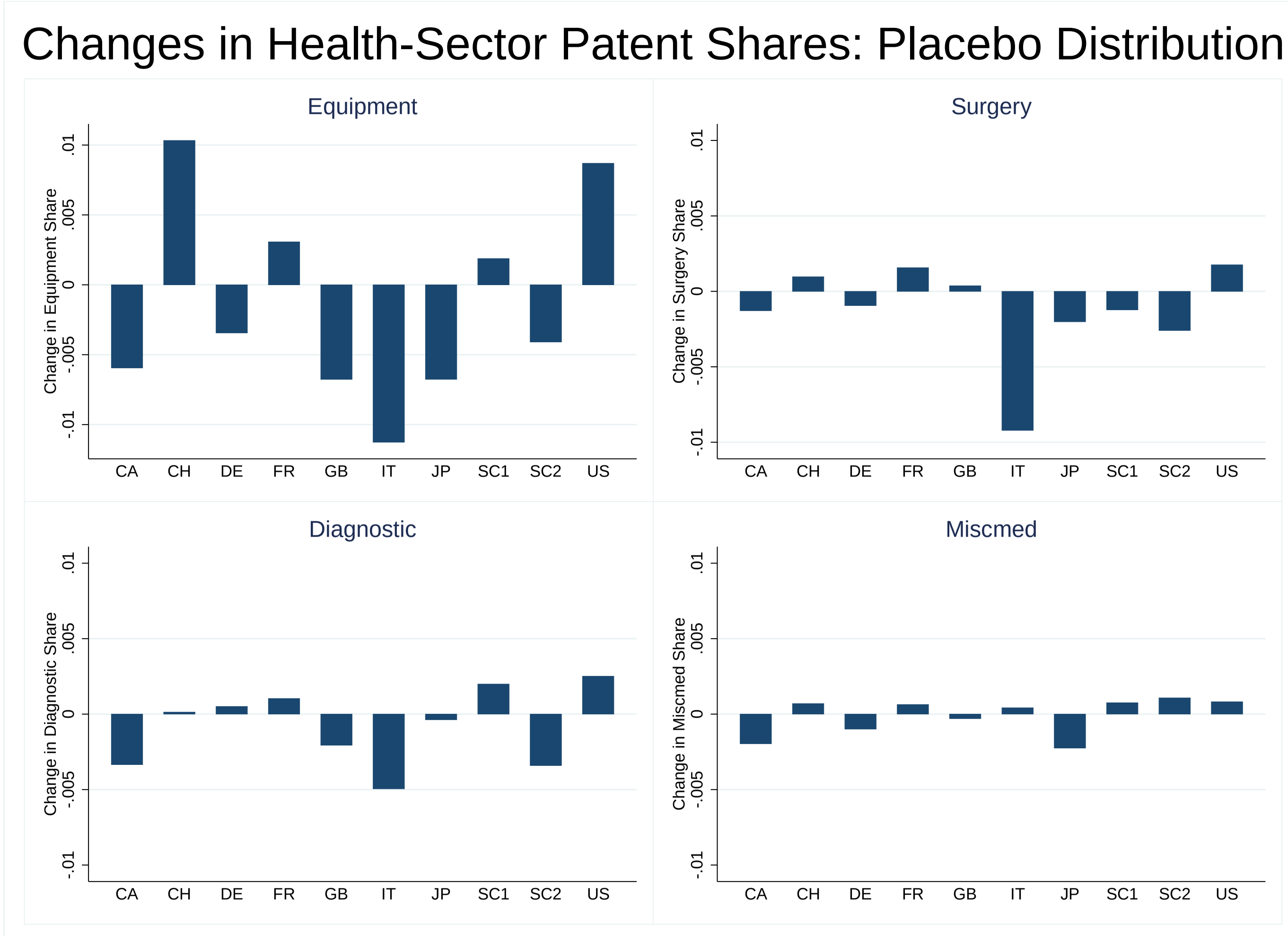

Figure A.4: **Synthetic Control Placebo Estimates of Post-Medicare Changes in Health-Sector Patent Shares:** Series were constructed by the author using data from the NBER Patent Database (Hall, Jaffe, and Trajtenberg, 2001). Surgery (sub-category 32), Diagnostic (sub-category 44), and MiscMedical (sub-category 39) sum to Equipment. Each bar presents an estimate of the relative change in medical-equipment patents (from 1963-1968 to 1969-1974 for the indicated control relative to other countries. The estimates are, in each case, relative to a synthetic control constructed by re-weighting the remaining countries to match the "treatment" country's pre-1969 medical-equipment share. Estimates for all countries other than the United States can thus be viewed as placebo estimates, while the estimate for the United States is an estimate of the effect of Medicare on Medicaid on patenting by U.S.-based innovators relative to foreign innovators. The full list of country acronyms is described in the note to Figure A.2.

the importance of Switzerland's pre-Great Society medical-equipment innovation using a relatively small number of patents. A first indication of this point is that the most extreme negative placebo estimate is associated with Italy, which accounts for the second smallest number of patents in the sample.[42] A second indication is that the Switzerland placebo estimates for the technological sub-categories of medical-equipment are much smaller than one would anticipate given the estimate for the medical-equipment aggregate (see Panels B, C, and D of Figure A.4). For the sub-categories, the true synthetic control estimate exceeds all placebo estimates for both surgical and diagnostic equipment and is near the top of the distribution for miscellaneous medical patents.

To generate a richer distribution of placebo estimates, and to reduce the influence of the statistical noise associated with proxying for some countries' innovation shares with small numbers of patents, I construct additional placebo treatment groups by assigning treatment status to randomly selected combinations of the control countries. Panel A of Figure A.5 reports the distribution of placebo treatment effects resulting from 1000 such assignments. Treatment status was assigned using a random number generator with a uniform distribution running from 0 to 1. In each iteration, all control countries with draws lower than 0.10 were deemed treated.[43] The distribution of placebo treatment effects has a mean of 0.0005 and a standard deviation of 0.0011.[44] The true synthetic

[42]Were I to combine these countries into an aggregate, which is by no means unjustifiable, the distribution of placebo estimates would appear substantially tighter.

[43]If no country received a draw less than 0.10, then the country with the lowest draw was assigned treatment status.

[44]The standard deviation of the resulting distribution is modestly sensitive to moderate changes in the cutoff of 0.10. Significantly increasing the cutoff towards 1 results in a much tighter distribution, since all control-group countries are assigned treatment status in all iterations. This would artificially depress the true level of uncertainty. Reducing the cutoff to 0 results in the distribution observed in Figure A.2, since the treatment group will contain a single control country in each iteration. This distribution overstates the true level of uncertainty to the extent to which its variance is driven by countries like Italy and Switzerland, where changes in the direction of innovative activity are estimated using relatively small numbers of patents. My choice of 0.10 is meant to conservatively balance between these competing concerns. An alternative method, which produces similar results, is to draw countries until the total number of patents associated with those countries meets some minimum threshold. Similar results are

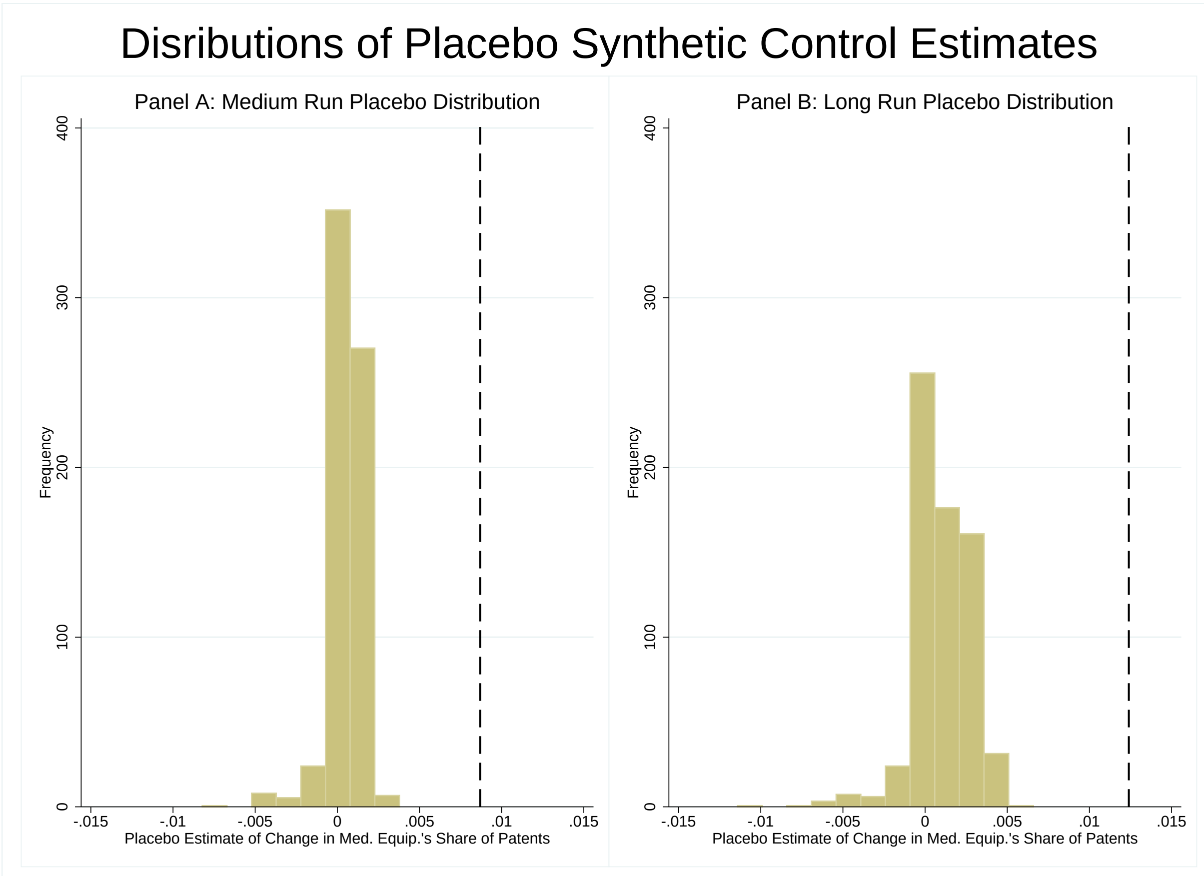

Figure A.5: **Disributions of Placebo Synthetic Control Estimates:** Both histograms present distributions of placebo synthetic control estimates of the relative change in medical-equipment patents in the placebo treatment countries relative to other countries. Placebo treatment countries were selected using a random number generator with draws distributed uniformly from 0 to 1. In each iteration, treatment status was assigned to all countries with random draws of less than 0.10. If no country met this criterion, treatment status was assigned to the country with the lowest draw. The estimates in Panel A are of medium-run changes in medical-equipment patenting following the introduction of Medicare and Medicaid. They compare patents granted over the period 1963-1968 to patents granted over the period 1969-1974. The dashed line at 0.0087 indicates the true synthetic control estimate of the change in medical-equipment's share of patents in the United States. The estimates in Panel B are of long-run changes in medical-equipment patenting following the introduction of Medicare and Medicaid. They compare patents granted over the period 1963-1968 to patents granted over the period 1975-1979. The dashed line at 0.0124 indicates the true synthetic control estimate of the change in medical-equipment's share of patents in the United States.

control estimate (0.0087, or 0.87 percentage point) is thus more than 7 standard deviations above the mean. Panel B of Figure A.3 reports results obtained when conducting the same exercise to estimate the longer-term effect of Medicare and Medicaid on patenting activity. In this case, the true synthetic control estimate is 0.0124, or 1.24 percentage points. The mean of the placebo distribution is 0.0010, and the standard deviation is 0.0017.

also obtained by examining the distribution of treatment effects estimated using all permutations 2 or 3 control countries.