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Are the returns to technological change in health care declining?

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ABSTRACT Whether the U.S. health care system supports too much technological change—so that new technologies of low value are adopted, or worthwhile technologies become overused—is a controversial question. This paper analyzes the marginal value of technological change for elderly heart attack patients in 1984–1990. It estimates the additional benefits and costs of treatment by hospitals that are likely to adopt new technologies first or use them most intensively. If the overall value of the additional treatments is declining, then the benefits of treatment by such intensive hospitals relative to other hospitals should decline, and the additional costs of treatment by such hospitals should rise. To account for unmeasured changes in patient mix across hospitals that might bias the results, instrumental–variables methods are used to estimate the incremental mortality benefits and costs. The results do not support the view that the returns to technological change are declining. However, the incremental value of treatment by intensive hospitals is low throughout the study period, supporting the view that new technologies are overused.

What is the value of technological change in health care? More use of more intensive medical technologies is the principal cause of medical expenditure growth (1, 2). While technological change is presumed to be socially beneficial in most industries, judgments about technological change in health care are mixed. On one hand, declining competition or a worsening of other market failures hardly seems able to explain more than a fraction of medical expenditure growth. In this view, the remainder appears to reflect optimizing judgments by purchasers about new and improved technologies, suggesting they are better off (3). On the other hand, many unusual features of the health care industry—including health insurance, tax subsidization, and uncertainty—may support an environment of health care production that encourages wasteful technological change (4). In this view, the value of health care at the margin should be low and falling over time, as minimally effective technologies continue to be adopted, leading to growth in inefficiency in the industry. Given the potential magnitude of the welfare questions at stake, which of these views is correct is a crucial policy question.

This paper presents new evidence on the marginal value of changes in medical technology. The analysis estimates the incremental differences in mortality and hospital costs resulting from treatment by different types of hospitals for all elderly patients with acute myocardial infarction (AMI) in 1984, 1987, and 1990. The marginal effects are estimated using instrumental-variables (IV) methods developed and extensively validated previously (5, 6). The methods applied here use similar IVs, based on differential physical access to different types of hospitals. But the methods differ somewhat from the previous studies, in that they are designed to estimate the consequences of all technological changes during the time period. In particular, the methods compare trends in the net effects on mortality and costs of treatment by more intensive hospitals for "marginal" patients, patients whose hospital choice differs across the IV groups. Thus, the IV methods estimate the effects of the additional technologies available at more intensive hospitals on incremental AMI patients, those whose admission choice and hence treatment is affected by differential access to intensive hospitals.

The dimensions in which intensity of medical care can vary are numerous, ranging across many drugs, devices, and procedures even for a particular medical condition such as AMI. The principal goal of this paper is not to assess returns to the adoption or diffusion of a particular technology, but to assess how technological changes in all of these dimensions are contributing collectively to changes in the expenditure and outcome consequences of being treated by more intensive hospitals. Because new technologies tend to be adopted first and applied more widely at such hospitals, comparing fixed groups of hospitals that differ in technological capabilities over time provides a method for summarizing the total returns to technological change. If the more intensive hospitals are applying more technologies over time that increase expenditures but have minimal benefits for patients, then the differential returns to being treated by a more intensive hospital over time should decline. On the other hand, if the technological developments are comparable in value to or better than existing technologies, then the differential returns to treatment by a more intensive hospital should not fall. In addition, the levels of the marginal expenditure/benefit ratios in each year provide quantitative guidance about whether the level of technological intensity at a point in time is too high or too low.

Data

Patient cohorts with information summarizing characteristics, treatments, costs, and mortality outcomes for all elderly Americans hospitalized with new AMIs (primary diagnosis of ICD9 code 410) in 1984, 1987, and 1990 were created from comprehensive longitudinal medical claims provided by the Health Care Financing Administration. Claims included information on principal and secondary diagnoses, major treatments, and costs for all hospital discharges through 1992. Measures of observable treatment intensity included the use of intensive cardiac procedures (catheterization, angioplasty, and bypass surgery), number of hospital admissions, total number of hospital days, and total days in a special care unit (intensive care unit or coronary care unit) during various time periods after AMI. Survival dated from the time of AMI was measured using death date reports for all patients validated by the Social Security Administration.

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Abbreviations: AMI, acute myocardial infarction; IV, instrumental-variables.

Hospital costs for various time periods after AMI were calculated by multiplying reported departmental charges for each admission by the relevant departmental cost-to-charge ratio, and adding in per diem costs based on each hospital's annual Medicare cost reports (7). Reported costs reflect accounting conventions and potentially idiosyncratic cost allocation practices, and so may differ from true economic costs. However, as the results that follow illustrate, reported costs are highly correlated with real resource use, and the methods that follow focus on differences in cost trends rather than absolute cost levels.

Application of exclusion criteria developed in previous work led to an analytic sample of ≈646,000 patients. These AMI cohort creation methods have been described and validated in detail previously (8, 9); for example, validation studies using linked medical record data indicate that >99.5% of cases identified using these criteria represent true AMIs.

Two principal dimensions of hospital technological capabilities were measured: hospital volume and capacity to perform intensive cardiac procedures. A hospital's capability to perform catheterization and revascularization over time was determined from hospital claims for performing these procedures, using techniques applied previously (7). For example, a hospital was categorized as a "catheterization hospital" in a given year if at least three catheterizations were performed on elderly AMI patients. Hospitals performing catheterization after 1984 but not in 1984 were categorized as acquiring catheterization capability. Procedure capability was emphasized because previous research has documented that technology adoption has a substantial impact on technology use and costs. Hospitals were classified as high-volume or not by summing their total number of initial elderly AMI admissions and dividing them into two groups based on whether or not their volume was above the median volume over the entire time period (≈75 AMIs per year).

Patient zip code of residence at the time of AMI was used to calculate each patient's distance to the nearest hospital with each level of procedure capability (no procedure capacity, procedure capacity, acquired procedure capacity) and to the nearest high-volume hospital. The patient's differential distance to a specialized type of hospital was the difference between the estimated distance to the nearest hospital of that type minus estimated distance to the nearest hospital. These distance measures are highly correlated with travel times to hospitals (10), and in any case random errors in distance measurement do not lead to inconsistent estimation of treatment effects using the grouped-data methods developed here.

Trends in AMI Treatments, Costs, and Outcomes

Table 1 describes the elderly AMI population in 1984, 1987, and 1990. The number of new AMIs declined slightly over time and average age increased, consistent with national trends in AMI incidence. Though the demographic composition of the cohorts was otherwise similar over time, comorbidities recorded at the time of initial admission suggest that the acuity of AMI patients may have increased slightly. In particular, the incidence of virtually all serious comorbidities increased steadily between 1984 and 1990. These trends may also reflect increasing attention to coding practices over time, though evidence from chart abstractions suggests that "upcoding" has declined (11). A growing share of patients were admitted initially to hospitals that performed catheterization and revascularization. This trend reflected both substantial adoption of these technologies by hospitals—around 19% of patients were admitted initially to hospitals that adopted technology between 1984 and 1990—and a more modest trend toward more initial selection of these intensive hospitals for AMI treatment. As a result, the share of patients admitted to hospitals that did not perform catheterization declined from 44% to 39%, and the share of patients admitted to high-volume hospitals increased from 45% to 48%.

The AMI cohorts differed substantially in treatment and costs. Catheterization rates in the 90-day episode of care after AMI increased from 9% in 1984 to 34% in 1990. Use of coronary artery bypass surgery (bypass) also increased

Table 1. U.S. elderly AMI patients, 1984–1990: Trends in characteristics, treatments, outcomes, and expenditures

	Year of AMI		
Variable	1984 (n = 220,345)	1987 (n = 215,301)	1990 (n = 211,259)
Age (SD)	75.6 (7.0)	75.9 (7.2)	76.2 (7.3)
Female	48.7	49.9	49.8
Black	5.3	5.6	5.7
Rural	29.5	30.4	30.1
Cancer	1.1	1.5	1.6
Pulmonary disease	8.3	11.3	12.8
Dementia	0.7	1.0	1.2
Diabetes	13.9	17.9	18.8
Renal disease	3.3	5.1	6.1
Cerebrovascular disease	2.1	2.6	2.8
Initial admit to hospital with catheterization by 1984	37.5	38.4	40.7
Initial admit to hospital adopting catheterization 1985–1990	18.1	19.0	20.0
Initial admit to high-volume hospital	44.9	46.0	48.7
90-day catheterization rate	9.3	24.0	33.9
90-Day PTCA rate	1.1	5.6	10.5
90-Day CABG rate	4.8	8.3	11.7
1-year admissions	1.96	1.99	2.10
1-year total hospital days	20.5	19.4	20.4
1-year total special care unit days	6.0	6.8	7.3
1-day mortality rate	8.9	8.3	7.2
1-year mortality rate	40.0	39.0	35.6
2-year mortality rate	47.3	46.0	42.5
1-year total hospital costs (1991 dollars)	$12,864	$14,228	$16,788
2-year total hospital costs (1991 dollars)	$14,142	$15,571	$18,301

PTCA, percutaneous transluminal coronary angioplasty; CABG, coronary artery bypass graft surgery.

steadily, from 4.8% to 11.7% of patients, and use of percutaneous transluminal coronary angioplasty (angioplasty) grew dramatically, from 1% of patients in 1984 to 11% in 1990. These major changes in AMI treatment intensity were associated with substantial cost growth: total hospital costs for elderly AMI patients increased by >4% per year in real terms, and most of this expenditure growth was associated with more frequent use in intensive cardiac procedures (2). Of course, the use of other technologies also changed during this period. Substantial changes in cardiac drug use occurred, including the widespread adoption of thrombolytic drugs after 1987 (12). These substantial changes in the intensity of treating AMI in the elderly have had little impact on time spent in the hospital; average hospital days in the year after AMI declined slightly between 1984 and 1987, and increased slightly since. However, average days spent in an intensive care unit or critical care unit have increased by around 20%, from 5.2 to 6.2 days during the 90-day episode after AMI and from 6.0 to 7.3 days during the year after AMI.

The growth in intensity of treatment has been associated with improvements in survival: 1-year mortality fell by 4.4 percentage points (from 40.0 to 35.6%) and 2-year mortality fell by 4.8 percentage points (from 47.1 to 42.3%). More than one-third of this mortality decline arose within the first day after AMI. Though procedure use grew throughout the sample period, and especially before 1987, the mortality changes were concentrated after 1987. For example, 1-year mortality declined by an average of 0.3 percentage points per year between 1984 and 1987, and by 1.1 percentage points per year between 1987 and 1990.

Differences in Treatment Intensity Across Hospital Types

Estimating the marginal effects of AMI treatment on outcomes and costs requires comparisons of alternative levels of treatment intensity. Differences in hospital characteristics provide a basis for such comparisons. As Table 2 suggests, hospitals grouped on the basis of catheterization capabilities differ substantially in a range of technological capabilities for AMI treatment. Hospitals that had catheterization and revascularization capabilities by 1984 tended to be high-volume hospitals in urban areas. These hospitals are generally larger and more capable of providing many aspects of intensive treatment, including coronary care unit or intensive care unit care as well as care from specialized cardiology staff, and they are more likely to use medical practices that reflect current clinical knowledge (13). Noncatheterization hospitals tended to be smaller and were more likely to be located in rural areas with fewer emergency response capabilities. Hospitals that acquired the capacity to perform cardiac procedures during the study period appear to have intermediate technological capabilities in these other dimensions.

The hospitals differed to some extent in patient mix: hospitals with catheterization capabilities were more likely to treat younger, male patients, and these differences increased over time. These observable differences in patients selecting each hospital for initial admission are presumably associated with unobserved differences as well (14).

Table 3 shows that patients admitted to hospitals with the most intensive technologies were much more likely to receive these treatments. Catheterization rates for 1984 AMI patients were approximately 7.9 percentage points higher for patients initially admitted to hospitals with catheterization capabilities than for patients initially admitted to hospitals without catheterization. Acquiring catheterization had a fundamental effect on treatment intensity: in 1990, catheterization rates for patients admitted to hospitals that adopted catheterization during the study period were closer to rates at hospitals that had previously adopted catheterization (rates 0.1 percentage points lower than noncatheterization hospitals in 1984 but 10 points higher in 1990). Moreover, catheterization rates grew more rapidly at catheterization than noncatheterization hospitals: 90-day catheterization rates grew by 17 percentage points for patients initially admitted to noncatheterization hospitals and by 28 percentage points for patients initially admitted to hospitals that had or acquired catheterization. Especially because of differential trends in use of angioplasty, revascularization rates also differed proportionally over time (e.g., 4.1% at noncatheterization hospitals versus 7.5% at catheterization hospitals in 1984; 16.1% versus 28.4% at catheterization hospitals in 1990).

The differences in catheterization and revascularization use were correlated with other dimensions of treatment intensity. Hospitals with catheterization used slightly more hospital days and more special-care unit days. However, they used fewer hospital admissions, mainly because of fewer transfers or readmissions associated with performing cardiac procedures, and their readmission rates declined over time relative to noncatheterization hospitals (14). Differences in intensity were also associated with substantial differences in hospital costs. For example, in 1984, total hospital costs in the year after AMI differed on average by $2300 (in 1991 dollars) between hospitals that always performed catheterization and those that never did. By 1990, this difference had increased to $3400.

This comparison suggests that the alternative hospital types provide a gradation of levels of AMI procedure intensity with associated gradations in costs, and that high-volume hospitals are more likely to provide more costly, intensive technologies other than cardiac procedures. Table 3 shows that patients treated by different types of hospitals also differed in mortality outcomes. In 1984, 1-year mortality was 1.6 percentage points lower at hospitals with catheterization capabilities than at nonprocedure hospitals; by 1990, this difference increased to 2.8 percentage points. Mortality rates at hospitals adopting catheterization and revascularization were intermediate between these two groups, but also improved over time relative to the rates for hospitals that did not acquire catheterization.

These simple descriptive results suggest that technological change has been more dramatic at hospitals with catheteriza-

Table 2. U.S. elderly AMI patients, 1984–1990: Hospital and patient characteristics by hospital type at initial admission

Hospital type	*n*	Patient share	Age (SD)	Black, %	Rural, %	High volume, %
1984						
Never adopted catheterization	97,803	44.4	75.9 (7.1)	4.8	50.6	19.3
Adopted catheterization, 1985–1990	39,895	18.1	75.4 (7.0)	4.5	18.6	52.3
Adopted catheterization by 1984	82,647	37.5	75.4 (7.0)	6.4	10.0	71.6
High volume	98,936	44.9	75.5 (7.0)	4.5	11.8	100.0
1990						
Never adopted catheterization	82,896	39.2	76.7 (7.4)	4.8	51.2	22.5
Adopted catheterization, 1985–1990	42,340	20.0	76.1 (7.3)	5.1	19.9	51.5
Adopted catheterization by 1984	86,023	40.7	75.7 (7.2)	6.9	14.9	72.6
High volume	102,908	48.7	75.9 (7.2)	5.1	15.4	100.0

Table 3. U.S. elderly AMI patients, 1984–1990: Patient treatments and outcomes by hospital type at initial admission

Hospital type	90-day catheterization rate, %	90-day PTCA rate, %	90-day CABG rate, %	1-year total hospital cost	2-year total hospital cost	1-day mortality, %	1-year mortality, %	2-year mortality, %
1984								
Never adopted catheterization	6.4	0.6	3.5	$11,371	$12,582	9.6	40.8	48.0
Adopted catheterization, 1985–1990	6.3	0.6	4.0	$12,616	$13,867	8.8	40.0	47.1
Adopted catheterization by 1984	14.3	1.9	6.6	$14,564	$15,929	8.1	39.2	46.4
High volume	10.2	1.3	5.3	$13,656	$15,004	7.9	39.1	46.4
1990								
Never adopted catheterization	23.9	6.9	9.2	$14,953	$16,377	8.1	37.2	44.5
Adopted catheterization, 1985–1990	33.9	9.4	12.1	$17,019	$18,545	6.7	34.8	42.0
Adopted catheterization by 1984	43.6	14.5	13.9	$18,325	$19,913	6.6	34.4	41.0
High volume	37.6	12.1	12.7	$17,582	$19,148	6.3	34.4	41.3

PTCA, percutaneous transluminal coronary angioplasty; CABG, coronary artery bypass graft surgery.

tion or acquiring catheterization, and that this differential trend has been associated with somewhat greater mortality reductions and cost growth. Unfortunately, unobserved case-mix differences across these hospital groups complicate inferences about marginal effectiveness based on these expenditure and outcome results. For example, differences in age between patients treated at hospitals capable of performing catheterization and other hospitals increased during this time period; thus, the observable characteristics of their patient mix suggest that these hospitals attracted AMI patients who tended to be better candidates for invasive procedures. If the patients differed in unobserved respects as well, then these conditional-mean comparisons of both expenditures and outcomes would be biased (15). For example, patients with longer survival times, who would tend to have higher costs and longer survival regardless of where they were treated, may have become more likely to be treated at the intensive hospitals over time.

IV Estimates of the Returns to More Intensive AMI Care

The idea of the IV methods, which are described in more detail in previous work (5–7), is to compare groups of patients with similar health characteristics that differ substantially in treatment received for reasons that are unrelated to health status. Table 4, which divides patients into groups with small and large differential distances to alternative hospital types, illustrates the idea. Table 4 describes two IV groups: patients relatively near to or far from catheterization hospitals, and patients relatively near to or far from high-volume hospitals. The subgroups are approximately equal-sized based on whether the

Table 4. U.S. elderly AMI patients, 1984–1990: Trends for differential distance groups

Variable	1984: Adopted catheterization before 1984, Near	1984: Adopted catheterization before 1984, Far	1984: High volume, Near	1984: High volume, Far	1990: Adopted catheterization before 1984, Near	1990: Adopted catheterization before 1984, Far	1990: High volume, Near	1990: High volume, Far
Patient share	43.4	56.6	50.2	49.8	43.2	56.8	50.0	50.0
Age (SD)	75.7 (7.1)	75.6 (7.0)	75.6 (7.0)	75.6 (7.0)	76.2 (7.4)	76.1 (7.3)	76.2 (7.3)	76.1 (7.3)
Female	50.0	47.8	49.7	47.8	50.8	49.1	50.9	48.8
Black	7.2	3.9	5.9	4.8	7.8	4.2	6.4	5.1
Rural	4.9	48.5	7.7	51.7	5.2	48.3	8.6	51.7
Cancer	1.2	1.1	1.1	1.1	1.6	1.5	1.6	1.5
Pulmonary disease	8.1	8.4	7.7	8.8	12.2	13.2	12.4	13.2
Dementia	0.7	0.7	0.6	0.7	1.1	1.2	1.1	1.2
Diabetes	14.1	13.8	13.5	14.3	18.6	19.0	18.9	18.8
Renal disease	3.6	3.1	3.2	3.4	6.6	5.8	6.4	5.8
Cerebrovascular disease	2.1	2.1	2.0	2.2	2.9	2.6	2.8	2.7
Initial admit to hospital with catheterization by 1984	70.2	12.4	51.9	22.9	73.3	16.9	52.7	28.7
Initial admit to hospital adopting catheterization, 1984–1990	11.6	23.0	21.2	15.0	12.7	25.3	23.2	16.7
Initial admit to high-volume hospital	61.3	32.3	75.0	14.5	63.9	37.6	78.1	19.3
90-day catheterization rate	11.2	7.9	9.1	9.6	37.5	31.3	34.5	33.3
90-day PTCA rate	1.3	0.8	1.0	1.1	11.8	9.6	10.5	10.5
90-day CABG rate	5.5	4.2	4.9	4.6	12.3	11.2	11.8	11.6
1-day mortality rate	8.3	9.3	8.1	9.7	6.7	7.6	6.4	8.0
1-year mortality rate	39.8	40.2	39.4	40.6	35.5	35.7	35.1	36.0
2-year mortality rate	47.1	47.4	46.9	47.7	42.3	42.7	42.2	42.9
1-year total hospital costs (1991 dollars)	$14,392	$11,338	$13,897	$11,830	$18,076	$15,566	$17,735	$15,858

patient's distance to the nearest specialized hospital minus distance to the nearest nonspecialized hospital was more or less than 2.8 miles for a catheterization hospital and 1.8 miles for a high-volume hospital. Observable health characteristics including age and the incidence of comorbid diseases are distributed very similarly between the near and far groups, suggesting that unobserved health characteristics are distributed similarly as well (the studies cited previously have evaluated this assumption extensively).

Despite having virtually identical measured health characteristics, the groups have large differences in likelihood of admission to different kinds of hospitals, and as a result differ in intensity of treatment. Patients relatively near to hospitals performing catheterization are much more likely to be admitted to catheterization hospitals for AMI treatment, and they are significantly more likely to undergo catheterization in all years. Similarly, patients near to high-volume hospitals are much more likely to be admitted to high-volume hospitals, and consequently are significantly more likely to be treated by specialized medical staff, in a special-care care unit, and with other dimensions of higher-intensity care. But use of catheterization and revascularization procedures in these patients differs much less than for patients "near" and "far" with respect to catheterization hospitals. Thus, variation in access to a high-volume hospital provides some variation in dimensions of treatment intensity other than cardiac procedure use.

In contrast to a clinical trial, treatment rates are not 100% and zero percent in the near and far groups; rather, the higher treatment rates in the near group suggest that an incremental subset of patients is treated differently as a result of their differential distance. This is the sense in which the IV comparisons are "marginal." For example, patients near to a catheterization hospital were 56 percentage points more likely to be admitted to a catheterization hospital in 1984 and 54 percentage points more likely to be admitted to one in 1990. The initial admission rates to the various types of hospitals and the incremental differences in these rates are very similar across years. This stability in the relationship of differential distance to hospital choice suggests that the IV methods are contrasting similar incremental patients across years.

Table 4 also shows the implications for outcomes and costs of these incremental differences in treatment intensity. In both IV comparisons, mortality in the "near" (more intensive) group is slightly lower, but the mortality differentials are smaller than the raw mortality differences of Table 3. These IV results suggest that the additional technologies used in treatment at more intensive hospitals lead to small but possibly significant improvements in survival. Moreover, the differences in survival arise early after AMI; 1-day mortality differentials are larger than the longer-term differentials. The mortality differentials are as large or larger in 1990 as in 1984; these simple comparisons do not suggest that incremental mortality effects of more intensive treatments are falling over time.

Table 4 also demonstrates that more use of intensive treatments in both years is associated with substantially higher costs of AMI care, but that the costs differentials are diminishing. For example, average 1-year hospital costs for patients near to catheterization hospitals were $3000 higher in 1984 than patients further away. This difference fell to around $2500 by 1990, even though the differences in admission rates to the alternative hospitals did not change much over time. Costs for patients near to high-volume hospitals were also considerably higher than expenditures for patients farther away in both years, and this difference did not change much over time. In contrast to the comparisons of Table 2 that did not account for changes in patient selection, then, the IV comparisons provide no evidence that the additional technologies used by more intensive hospitals are becoming relatively more costly over time. However, while the health-related characteristics of the IV groups appear more similar than the characteristics of patients treated by different types of hospitals, these simple comparisons do not eliminate all sources of outcome differences other than hospital technologies. For example, the "near" patients were much more likely to reside in urban areas, where prices were higher and more advanced emergency response technologies might be available.

Other potentially important patterns are evident in the simple comparisons of Table 4. First, most of the mortality gains and expenditure growth appear to be "inframarginal," in the sense that the differences across years in costs and mortality are substantially larger than the differences across distance groups within a year. Thus, the 1984–1990 period appears to have been associated with substantial general trends in costs and outcomes that affected the whole of the AMI population.

Second, though intensive cardiac procedures became much more widely used during this period, the results provide little evidence that higher rates of cardiac procedure use are responsible for the mortality gains. The aggregate time trend results showed the largest share of mortality improvements arising after 1987, but the most rapid growth in procedure use occurred before 1987. In addition, mortality differences are somewhat larger for groups near and far to high-volume hospitals, but differences in catheterization rates for these groups are much smaller. Substantial mortality differentials arise within 1 day of AMI. Almost no revascularization procedures were performed within 1 day in 1984, and a relatively small share of the procedures were performed within 1 day even in 1990, suggesting that the use of other technologies is responsible for at least part of the inframarginal and incremental mortality differences.

If the near and far groups are balanced, so that no characteristics that are directly associated with outcomes differ between the groups, then a nonparametric IV estimate of the average incremental effect of admission to a catheterization hospital is given by

$$\hat{\eta}_{IV} = \frac{\bar{m}(near) - \bar{m}(far)}{\bar{r}(near) - \bar{r}(far)}, \qquad [1]$$

where $\bar{m}$ and $\bar{r}$ denote, respectively, conditional mean outcome and initial admission rates in each distance group. For example, from Table 4, the IV estimate of the 1-year incremental mortality effect of treatment by a high-volume hospital in 1984 is $[39.4 - 40.6]/[75.1 - 14.7] = -1.99$ percentage points with a standard error of 0.86 percentage points.

While instructive, these two-group comparisons do not account for some important observable differences between the groups. In particular, patients in the near group are more likely to be urban and more likely to be black, reflecting the fact that differential distances tend to be smaller in urban areas. Urban patients generally have more access to emergency response systems, leading to lower acute mortality, and urban prices tend to be higher, so that expenditure differences reflect price differences. Though observable demographic and health characteristics otherwise appear to be balanced between the two groups, a more careful quantification of their association with mortality and expenditure outcomes conditional on demographic characteristics is worthwhile. In addition, much variation in differential distances, and consequently in likelihood of treatment by alternative hospital types, occurs within the near and far groups. For example, in 1990 patients with a differential distance to catheterization of zero or less have a probability of admission to a catheterization hospital 80 percentage points higher and catheterization rates 10 percentage points higher than patients with a differential distance of over 20 miles. Simple two-group conditional-mean comparisons do not exploit this potentially useful variation. Finally, the two-group methods do not generally permit estimation of the incremental effects associated with multiple hospital types;

because access to different kinds of intensive hospitals is correlated, comparisons that account jointly for access to each type of specialized hospital would help distinguish their incremental effects.

Estimates of the Marginal Effects of Technological Change

More comprehensive IV estimation methods can be used to account for these problems while preserving the minimally parametric, conditional-mean structure of the simple comparisons. The methods are fully described elsewhere (5); they involve estimation of linear IV models of the form

$$y_i = \mathbf{x_i}\boldsymbol{\mu} + \mathbf{h}_i\boldsymbol{\gamma} + u_i. \quad \textbf{[2]}$$

In these models, $\mathbf{x}$ is a fully-saturated vector of indicator variables to capture average demographic effects and their interactions for cells based on the following characteristics: gender (male/female), age group (65–69, 70–74, 75–79, 80–84, 85–89, 90 and over), race (black or nonblack), and urban or rural status. Demographic cell sizes were quite large. For nonblacks they were typically on the order of 6000 or more patients in each year; the smallest cell, rural black males aged 90 and over in 1984, included 82 persons. Because fully interacted cells are included in the model, $\boldsymbol{\mu}$ provides a nonparametric estimate of the conditional mean outcome for each demographic cell. The models also included a full set of effects for metropolitan statistical areas and for rural areas for particular states. The incremental-average treatment effects of interest are represented by $\mathbf{h}_i$, a vector of indicator variables denoting patient's hospital type at initial admission in terms of catheterization adoption (by 1984, between 1985 and 1990, never) and hospital volume, based on average volume across all years (or across the years for which the hospital is included in the sample for hospitals that close). Thus, three incremental treatment effects were included in all models, with low-volume, never-adopting hospitals as the baseline group.

Because hospital choices reflect unobserved patient heterogeneity, differential distances are used as IVs for hospital choice. Differential distances were also incorporated in this model in a minimally parametric way, generalizing the simple two-group IV comparisons of Table 4. The following right-closed intervals were used to construct groups for differential distance to the intensive hospital types (high volume, adopted catheterization by 1984, adopted catheterization between 1985–1990): 0, 0–1.5, 1.5–3, 3–6, 6–10, 10–15, 15–20, 20–25, 25–40, and over 40. To capture potential differences in distance effects for rural patients, rural differential–distance interactions were included based on differential distances of 0–10, 10–40, and over 40. While the zero-distance cells were the largest, all other cell combinations included at least several hundred observations. Results were not sensitive to alternative specifications of the urban and rural differential–distance variables. With all first- and second-stage variables entered as indicators, and with relatively large sample sizes in each cell, the estimation methods were designed to recover weighted-average estimates of the incremental effects without making any substantive parametric or distributional assumptions. The modeling strategy is equivalent to a grouped-data estimation strategy with weighted demographic cell–IV interactions as the unit of observation. The resulting IV estimates are weighted-average estimates of incremental treatment effects, with weights determined by the number of patients whose admission status shifts across the IV groups (16).

Table 5 presents IV estimates of the mortality and cost differences across the alternative hospital types. The incremental mortality effects are all estimated rather precisely (standard errors even for long-term mortality of 0.7 percentage points or less), and generally confirm the findings in Tables 3 and 4 that greater intensity leads to lower mortality in all time periods. However, incremental effects of each hospital type show distinctive trends over time. Admission to a high-volume hospital led to substantially lower short-term and long-term mortality in 1984, compared with every other hospital type. The incremental mortality benefit peaked at −1.4 percentage points at 1 year, but it was substantial (−1.2 percentage points) even at 2 years after AMI. Much of this mortality effect arose within 1 day of AMI. In 1987, the incremental benefits of treatment by a high-volume hospital showed a similar pattern, the 1-year effect was −1.6 percentage points, and the 2-year effect was −1.2 percentage points. In 1990, the acute mortality benefits were slightly larger, but the 2-year mortality benefit was only −0.8 percentage points (with a standard error of 0.6 percentage points). Given the substantial aggregate decline in mortality during the 1984–1990 time period, these results indicate that mortality improvements at other hospital types outpaced improvements at the high-volume hospitals.

In contrast to the estimated high-volume hospital effects, the incremental benefits associated with initial admission to hospitals with catheterization capabilities by 1984 fell over time for short-term mortality and increased over time for long-term mortality. In 1984, mortality effects were negative only during the acute period after AMI. In 1987, mortality effects were negative but not significant for very short-term outcomes, and essentially disappeared at longer time intervals. In 1990, the short-term mortality benefits were small (only −0.2 percentage points at 30 days) but increased over time, to

Table 5. IV estimates of marginal effects of treatment by intensive hospitals

	Mortality			Hospital costs	
	1 day	1 year	2 year	1 year	2 year
1984					
Adopted catheterization before 1984	−0.84 (0.34)	−0.11 (0.58)	0.13 (0.59)	2336 (173)	2397 (191)
High volume	−0.83 (0.31)	−1.36 (0.53)	−1.19 (0.54)	1101 (159)	1200 (175)
Adopted catheterization, 1984–1987	0.37 (0.47)	0.61 (0.79)	−0.22 (0.80)	667 (239)	619 (261)
Adopted catheterization, 1988–1990	−0.33 (0.39)	0.61 (0.66)	0.38 (0.67)	−522 (200)	−637 (219)
1987					
Adopted catheterization before 1984	−0.48 (0.34)	0.41 (0.58)	−0.13 (0.59)	3110 (201)	3164 (217)
High volume	−1.32 (0.30)	−1.61 (0.52)	−1.31 (0.53)	393 (181)	506 (196)
Adopted catheterization, 1984–1987	0.65 (0.45)	−0.85 (0.77)	−0.80 (0.79)	2230 (268)	2351 (290)
Adopted catheterization, 1988–1990	−0.13 (0.38)	1.35 (0.66)	1.66 (0.67)	739 (229)	821 (248)
1990					
Adopted catheterization before 1984	−0.00 (0.33)	−0.46 (0.60)	−1.07 (0.61)	2391 (244)	2582 (263)
High volume	−1.81 (0.31)	−1.29 (0.52)	−0.82 (0.57)	846 (230)	905 (247)
Adopted catheterization, 1984–1987	−0.34 (0.44)	−1.08 (0.79)	−0.65 (0.81)	1798 (322)	1875 (347)
Adopted catheterization, 1988–1990	−0.07 (0.47)	−1.29 (0.67)	−0.82 (0.69)	1324 (420)	1370 (452)

Table reports estimated marginal effect (SD).

over 1 percentage point by 2 years. Additional estimation procedures (not reported here) examined the extent to which the differential trend was concentrated in the most intensive hospitals, those with both procedure capabilities and a high volume of AMI patients. Such interaction effects were never significant, though by 1990 the interaction point estimates were on the order of -0.5 percentage points, suggesting the relative outcome benefits in 1990 were somewhat greater in the largest catheterization hospitals.

Table 5 also reports incremental effects associated with hospitals that developed the capacity to perform cardiac catheterization between 1984 and 1990. For these adopting hospitals, point estimates of mortality effects in 1984 tended to be slightly less positive than estimates for early-adopting hospitals. In 1987, mortality outcomes for hospitals that adopted catheterization in 1985–1987 were somewhat better than at the early-adopting hospitals, but were statistically insignificant (under 1 percentage point). Hospitals that had not yet adopted catheterization had significantly worse long-term outcomes in this time period. In 1990, compared with early-adopting hospitals, point estimates showed somewhat greater short-term benefits and slightly smaller effect sizes by 2 years. These results are generally consistent with previous studies (16), which found that hospitals adopting catheterization in the late 1980s tended to do so following periods of relatively bad outcomes, and that mortality improvements after adoption tended to arise acutely after AMI (e.g., within 1–3 days).

Trends in incremental costs also differed substantially across the hospital groups. These effects were estimated precisely (standard errors generally under $300). Hospitals adopting catheterization by 1984 were substantially more costly than nonintensive hospitals, by around $2300 to $2500 at 1–2 years, but the difference remained unchanged over time even as average costs grew substantially. Hospitals adopting catheterization between 1984 and 1990 developed substantially higher costs after adoption, suggesting that the adoption of catheterization led to relatively more costly care. For example, in 1984, 1-year hospital costs were only $670 higher at hospitals that would adopt catheterization between 1985 and 1987 compared with nonintensive hospitals; in 1987, after adoption, this difference had increased to $2230. Treatment at high-volume hospitals was associated with somewhat higher costs, around $600 at 1 and 2 years in 1984 and around $900 in 1990, but the incremental differences were considerably smaller than for catheterization hospitals.

Further research using similar methods has examined the contribution of observable dimensions of treatment intensity and expenditures to these incremental mortality and cost differences (see ref. 14 for details). The principal source of the persistent cost differences between catheterization and noncatheterization hospitals appears to be procedure use. For example, hospitals that adopted catheterization early used the procedure much more often than all other hospital types: catheterization rates for patients initially treated at these hospitals were 5.7 percentage points higher than at noncatheterization hospitals in 1984, 11.3 percentage points higher in 1987, and 13.7 percentage points higher in 1990. Further, hospitals adopting catheterization showed the emergence of treatment patterns that rely more heavily on cardiac procedures. In 1984, catheterization rates at these hospitals were the same as catheterization rates at hospitals that did not adopt, but by 1990 patients treated by these hospitals were over 7 percentage points more likely to undergo catheterization than patients admitted to hospitals that did not adopt. For both hospital types, differences in revascularization procedure use were proportional. Differences in cardiac procedure use associated with hospital capabilities have been reported previously (17, 18), but few studies have attempted to account for unobserved differences in patient mix which are likely correlated with procedure use. Here, the effect estimates are approximately one-third smaller than in simple descriptive comparisons (and also smaller than in comparisons adjusted for observable patient mix characteristics), indicating that part of the large differences in practice patterns is attributable to selection bias or "case mix."

Even though absolute differences in procedure use increased between catheterization and noncatheterization hospitals, cost differences did not increase proportionally. As Tables 3 and 4 suggested, this relative reduction in cost differences appears to result from a trend toward fewer transfers or readmissions for AMI patients treated at catheterization hospitals. Patients initially treated at noncatheterization hospitals must be readmitted to undergo cardiac procedures; as the use of intensive procedures has risen substantially for all patient groups, these acute readmissions for procedures have increased. Long-term rehospitalization rates with cardiac complications including recurrent ischemic heart disease symptoms and (to a lesser extent) recurrent AMIs have fallen by several percentage points at catheterization compared with noncatheterization hospitals. Additionally, use of intensive-care days has increased at high-volume hospitals.

As a result of features of Medicare's hospital payment system, hospital expenditure trends have differed substantially from the cost trends. In particular, expenditure differentials that roughly paralleled the cost differential between catheterization and noncatheterization hospitals in 1984 were almost completely eliminated by 1990. Medicare's diagnosis-related group payments are hospitalization-based, and the trends toward fewer transfers and readmissions for patients initially treated by catheterization hospitals reduced expenditure growth. In addition, the Health Care Financing Administration reduced payments for angioplasty by almost 50% before 1990. In contrast, reimbursement policy changes leading to additional payments for smaller hospitals and for major teaching hospitals augmented expenditures for patients treated at these hospitals.

Discussion

These estimates of the incremental effects of treatment by more intensive hospitals over time provide new evidence on the marginal value of technological progress in health care. Technological change in AMI treatment was dramatic in the 1980s. Was this technological change worthwhile? These results provide little support for the view that the marginal value of technological change is declining. Rather, hospitals that adopted catheterization either before or during the study period experienced mortality improvements relative to other hospitals and have had improving expenditure/benefit ratios. The incremental effect of treatment at a high-volume hospital declined slightly between 1984 and 1990, but remained substantial, at least to 1 year after AMI. These incremental mortality benefits have persisted in the presence of substantial across-the-board improvement in AMI outcomes, particularly after 1987.

The incremental mortality effects of more intensive treatment result in higher costs of care. The cost differences associated with more aggressive procedure use have remained stable over time, and there is some evidence that higher initial costs associated with more procedure use lead to later cost savings in terms of avoided readmissions and complications. Based on the estimated expenditures and benefits, the "best-guess" estimate of a marginal cost to mortality effect ratio for hospitals with catheterization capabilities in 1990 was around $250,000 per additional AMI survivor to 2 years; this ratio has improved substantially since 1984. The cost differences associated with high-volume hospitals also improved somewhat over time. In 1990, an analogous cost/mortality effect ratio for high-volume hospitals was around $110,000 per additional

2-year survivor. These estimates are similar to estimates obtained using other IV methods, and would probably be substantially higher if other medical costs (e.g., physician and ambulatory medical costs) were also included.

Thus, there is little evidence that the marginal cost-effectiveness of technological change is declining. On the other hand, the cost-effectiveness ratios are rather large, at least based on judgments by many investigators about ''appropriate'' ratios for guiding medical interventions (19). While the marginal effectiveness of the additional technologies available at the most intensive hospitals appears to be increasing, it may still be low.

The improvements in cost-effectiveness ratios suggests that Medicare policy for hospital reimbursement is having some desirable effects. In particular, the ''high-powered'' incentives provided by fixed payments per hospitalization may be discouraging the adoption of low-benefit, high-cost technologies. Moreover, the substantial improvements in AMI mortality since 1984 do not support the view that the payment reforms have adversely affected outcomes for elderly AMI patients. However, Medicare hospital reimbursement incentives are not high-powered in at least two important respects (1). First, the provision of intensive procedures—including cardiac procedures—leads to a different payment classification, and consequently substantially higher reimbursement. Thus, the higher costs of providing cardiac procedures during an admission may be largely offset. Second, treatment of a chronic disease using methods that require multiple hospital admissions result in higher payments, compared with treatments provided during a single admission. The changes in the effects of incremental technologies described here suggest that, in fact, these incentives may be affecting the nature of new technological change. In particular, technologies developed by cardiac-procedure hospitals appear to be associated with the provision of more intensive procedures, whereas technologies adopted by high-volume hospitals appear to be increasingly associated with multiple admissions for subsequent care. These differential patterns may be coincidental, but they are suggestive of a potentially important underlying relationship with reimbursement incentives.

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1. McClellan, M. (1996) in *Advances in the Economics of Aging*, ed. Wise, D. (Univ. of Chicago Press, Chicago).
2. Cutler, D. & McClellan, M. (1995) in *Topics in the Economics of Aging*, ed. Wise, D. (Univ. of Chicago Press, Chicago), Vol. 6, in press.
3. Newhouse, J. P. (1992) *J. Econ. Perspect.* **6,** 3–22.
4. Weisbrod, B. (1992) *J. Econ. Lit.* **29,** 523–552.
5. McClellan, M. & Newhouse, J. P. (1994) *The Marginal Benefits of Medical Technology* (National Bureau of Economic Research, Cambridge, MA), NBER Working Paper.
6. McClellan, M., McNeil, B. J. & Newhouse, J. P. (1994) *J. Am. Med. Assoc.* **272,** 859–866.
7. McClellan, M. & Newhouse, J. P. (1996) *J. Econometrics*, in press.
8. Udvarhelyi, I. S., Gatsonis, C., Epstein, A. M., Pashos, C. L., Newhouse, J. P. & McNeil, B. J. (1992) *J. Am. Med. Assoc.* **268,** 2530–2536.
9. Pashos, C., Newhouse, J. P. & McNeil, B. J. (1993) *J. Am. Med. Assoc.* **270,** 1832–1836.
10. Phibbs, C. & Luft, H. (1995) *Med. Care Res. Rev.* **52,** 532–542.
11. Newhouse, J. P., Carter, G. & Relles, D. (1992) *The Causes of Case-Mix Increase: An Update* (RAND Corp., Santa Monica, CA).
12. Pashos, C., Normand, S. T., Garfinkle, J. B., Newhouse, J. P., Epstein, A. M. & McNeil, B. J. (1994) *J. Am. Coll. Cardiol.* **23,** 1023–1030.
13. Guadagnoli, E., Hauptman, P. J., Ayanian, J. Z., Pashos, C. L. & McNeil, B. J. (1995) *N. Engl. J. Med.* **333,** 573–578.
14. McClellan, M. (1996) *The Returns to Technological Change in Health Care* (Stanford Univ., Stanford, CA).
15. McClellan, M. (1995) *Am. Econ. Rev.* **85,** 38–44.
16. Imbens, G. & Angrist, J. (1994) *Econometrica* **62,** 467–476.
17. Blustein, J. (1993) *J. Am. Med. Assoc.* **270,** 344–349.
18. Every, N. R., Larson, E. B., Litwin, P. E., *et al*. (1993) *N. Engl. J. Med.* **329,** 546–551.
19. Weinstein, M. C. (1995) in *Valuing Health Care*, ed. Sloan, F. A. (Cambridge Univ. Press, Cambridge, U.K.), p. 95.