THE JAMES A. BAKER III INSTITUTE FOR PUBLIC POLICY
RICE UNIVERSITY

DOES CERTIFICATE OF NEED AFFECT CARDIAC OUTCOMES AND COSTS?

BY

VIVIAN HO, PH.D.
JAMES A. BAKER III INSTITUTE CHAIR IN HEALTH ECONOMICS,
JAMES A. BAKER III INSTITUTE FOR PUBLIC POLICY, RICE UNIVERSITY;
ASSOCIATE PROFESSOR, DEPARTMENT OF ECONOMICS, RICE UNIVERSITY;
AND ASSOCIATE PROFESSOR, DEPARTMENT OF MEDICINE, BAYLOR UNIVERSITY

JULY 2007

Does Certificate of Need Affect Cardiac Outcomes and Costs?

International Journal of Health Care Finance and Economics, 6:4, 300-324.

DOI 10.1007/s10754-007-9008-9

The original publication is available at www.springerlink.com.

This research was supported by grant number R01 HL073825-01A1 from the National Heart, Lung and Blood Institute. I am grateful to Huifeng Yunn for helpful research assistance and to Richard Boylan, Leemore Dafny, Andrew Epstein, Ciarin Phibbs, two anonymous referees, participants at the fourth IHEA World Congress, the Department of Health Administration and Policy at the Medical University of South Carolina, and the Departments of Economics at Rice University and Texas A&M for helpful comments.

Does Certificate of Need Affect Cardiac Outcomes and Costs?

ABSTRACT

Several U.S. states enforce Certificate of Need (CON) regulations, which limit the number of hospitals performing open heart surgery or coronary angioplasty. CON regulations were intended to restrain cost growth and improve quality of care. This study compares mortality rates and costs for cardiac care in states with and without CON. CON appears to raise hospital procedure volume and lower the average cost of care. However, CON is associated with little reduction in inpatient mortality, and it may lead hospitals to operate on more patients than they would otherwise. The claimed welfare benefits of CON regulations require careful reconsideration.

Keywords: Regulation; Certificate of Need; Outcomes Assessment; Cardiac Surgery; Costs

JEL codes: I110 Analysis of Health Care Markets; I180 Health: Government Policy, Regulation, Public Health

I. INTRODUCTION

Several U.S. states enforce Certificate of Need (CON) regulations for cardiac care, which limit the number of hospitals that may perform open heart surgery or coronary angioplasty. These rules were originally implemented by regulators who argued that controlled entry into markets for new technologies would restrain cost growth and improve the quality of care. Limiting the number of providers would avoid unnecessary duplication of costly, highly specialized manpower and facilities. Medical evidence suggested that minimum case loads were essential to maintaining and strengthening the skills required to perform complex cardiac procedures. Therefore, restricting the number of facilities that patients could choose from also insured that each certified facility had enough patients to maintain their expertise in complex cardiac care. Because provision of open heart surgery and angioplasty require a substantial fixed cost investment, greater centralization of services through CON was also likely to yield economies of scale.

Many potential providers without CON approval argue that these regulations are anti-competitive. With fewer competitors performing open heart surgery and angioplasty in a market, certified providers can charge higher prices for their services. Because publicly available data on charges for cardiac procedures does not accurately reflect the prices actually paid by insurers and patients for the care they receive, this hypothesis cannot be directly tested. However, past studies cast doubt on the argument that CON regulations restrain cost growth or improve quality in the cardiac care market. For instance, greater competition (as opposed to regulation of entry) has been found to lower average expenditures per patient and mortality among Medicare patients being treated for heart attacks in the 1990's (D. P. Kessler, M. B. McClellan 2000).

Other research suggests that the evidence supporting the clinical benefits of higher procedure volume is tenuous. Analysis of longitudinal data suggests that all facilities performing angioplasty improve over time regardless of patient volume; and within-hospital increases in procedure volume over time provide minimal benefits in terms of patient outcomes (V. Ho 2000;Ho V. 2002). However, the impact of cardiac CON regulations on hospital procedure volume, patient outcomes, and costs has not been studied systematically.

This study uses AHRQ HCUP data to compare patient outcomes and costs for cardiac care in those states with and without cardiac CON regulations. The study first tests whether hospitals in states with CON regulation perform higher numbers of open heart surgeries and angioplasties relative to states without CON. The impact of increased procedure volume associated with CON on inpatient mortality and average costs is then assessed. Because CON regulations often include minimum volume standards (e.g. Providers must perform at least 200 open heart surgeries per year), these rules may lead providers to perform surgery on patients that they would otherwise have treated with medications. Therefore, the analysis also tests whether states with CON have a greater number of individuals overall receiving these cardiac interventions.

The results suggest that CON regulations increase patient volume. However, CON regulations are associated with only small reductions in inpatient mortality for open heart surgery patients, and they have no tangible effect on inpatient mortality for patients undergoing angioplasty. The regulations lead to noticeable reductions in average cost. However, CON also increases the propensity to perform cardiac surgery, which may raise total expenditures for these procedures.

The results have important implications for understanding the role that regulations can play in controlling health care costs and influencing the quality of patient care. The CON regulations for cardiac care appear to have only a marginal impact on patient mortality. The regulations have been more effective in reducing average costs through economies of scale. However, increases in the propensity to perform cardiac procedures with CON may still lead to higher expenditures for the health care system as a whole.

Section 2 provides background on cardiac CON regulations and previous related research. Section 3 describes the dataset to be used for analysis and provides descriptive statistics. Section 4 outlines the models to be estimated, and section 5 presents results. Conclusions are provided in Section 6.

II. BACKGROUND

The National Health Planning and Resources Development Act of 1975 (Public Law 93641) authorized funding for state CON programs. CON programs required that certain proposed capital expenditures, changes in health facilities or services provided, or purchases of major medical equipment were subject to the review and approval of a designated state agency. If a state did not implement a CON program, then no providers in the state were eligible to receive funds under the Public Health Service Act for the development, expansion, or support of health resources in the state.

CON programs were originally adopted in part to achieve cost containment. However, a study of hospital regulation over the period 1966 to 1982 found that CON appears to *increase* per capita hospital expenditures in the long run (J. A. Lanning *et al.* 1991). Using annual state-level data collected from the American Hospital Association and other sources, Lanning et al. found that per capita hospital expenditures were 20.6 percent higher in states with CON versus states without CON. The authors suggest that CON programs may act to protect inefficient hospitals from competition.

More recent studies have been able to analyze health care expenditures after the repeal or sunset of various state CON laws. Conover and Sloan examined annual state-level data from 1980 to 1993 to test whether lifting of CON regulations led to changes in per capita hospital spending (C. J. Conover, F. A. Sloan 1998). This study found no evidence of lower hospital costs per capita in states with mature CON programs; or a surge in hospital costs following removal of CON regulations. Similarly, Grabowski et al. found no evidence of increased nursing home expenditures in states which repealed CON regulations or construction moratoria (D. C Grabowski *et al.* 2003).

These studies provide no support for the argument that CON laws are helpful in restraining expenditure growth. CON laws may in fact increase market power, enabling high volume providers to raise the prices they charge for procedures. CON laws have been found to deter entry and allowed hospitals to raise prices 4.0 to 4.9 percent (M. Noether 1988). However, none of these studies have examined the impact of CON regulations on expenditures for a particular treatment class, such as cardiac surgery. It is particularly interesting to study the impact of CON for cardiac surgery, because these patients represent an extremely high proportion of total inpatient care for large hospitals; and caring for them can be extremely profitable. In addition, with the exception of Grabowski et al., these studies do not analyze the impact of CON laws on both the total quantity of services provided and average costs per patient. Although CON may be successful in helping unit costs to decline (through economies of scale), an offsetting increase in the total number of procedures performed may be cause for concern, if the marginal benefit of these procedures is low. Although this study does not directly address the issue of the marginal benefit of increased access to cardiac surgery, it does attempt to measure the potential for changes in the total population receiving intervention as a result of CON legislation.

In 1978, the Federal government issued the National Guidelines for Health Planning, which included standards on the minimum numbers of open heart procedures and cardiac catheterizations that should be performed annually in cardiac care facilities. The guidelines stated that there should be a minimum of 200 open heart procedures performed annually, within three years after initiation, in any institution in which open heart surgery is performed in adults. This recommendation was made in order "to maintain quality of patient care and make most efficient use of resources." In addition, the guidelines stated, "In order to prevent duplication of costly resources which are not fully utilized, the opening of new units should be contingent upon existing units operating, and continuing to operate, at a level of at least 350 procedures per year."

Open-heart surgery is performed while the bloodstream is diverted through a heart-lung bypass machine. The overwhelming majority of these operations are coronary artery bypass graft (CABG) procedures. Standards were set for cardiac catheterization as well: "There should be a minimum of 300 cardiac catheterizations, of which at least 200 should be intracardiac or coronary artery catheterizations, performed annually in any adult cardiac catheterization unit within three years after initiation." This standard effectively regulates percutaneous transluminal coronary angioplasty (PTCA), because a cardiac catheterization laboratory is required to perform angioplasty. State CON review criteria were expected to reflect these national standards.

The Federal law supporting CON expired in 1986, leading many states to discontinue their CON programs. Currently, 35 states and the District of Columbia fund and administer a CON program. Of these, 28 continue to explicitly regulate cardiovascular services. A 2000 Maryland Health Care Commission survey found that no state reported studying the effect of its repeal (Maryland Health Care Commission 2000). Even for those CON states without explicit requirements for cardiac services, the general presence of CON regulations (e.g. restrictions on bed supply) may limit the number of hospitals in the market, which could lead to higher volumes for CABG and PTCA among existing providers. However, this hypothesis has not yet been examined in the literature.

Meanwhile, applications to establish new cardiac programs in states which maintain CON regulations are attracting growing attention in the press (B. Wysocki 2002;S. Hensley 1997;K. Pallarito 1998). Increased competition in the health care market along with the high profitability of performing cardiac surgery imply great financial returns to those facilities which are able to gain certification or prevent the entry of new competitors in a local market. For example, Coliseum Health System's application to perform high-end cardiac care in Macon, Georgia has been denied, granted or appealed seven times since 1999, in part due to legal actions by Macon's existing provider of these services, Medical Center of Central Georgia (B. Wysocki 2002).

A recent study published examined the short-term impact of the termination of cardiac surgery CON laws in Pennsylvania in 1996 (J. L. Robinson *et al.* 2001). In the three years prior to the termination of CON in Pennsylvania (1994-1996), the number of open-heart surgery programs rose from 43 to 44. In contrast, in the three years following CON termination, the number of programs increased from 44 to 55. The study found no significant change in the inpatient mortality rate for CABG. The impact of CON termination on mortality for PTCA was not reported. The authors speculate that the sharing of surgeons between open-heart surgery programs established before and after CON termination may have helped to prevent an increase in inpatient mortality with the opening of 11 new cardiac programs.

In contrast, a more in-depth analysis of Medicare data found a substantial association between cardiac CON laws and reduced mortality for patients undergoing CABG. Vaughan-Sarrazin et. al. used Medicare Provider and Analysis Review (MedPAR) Part A data from 1994 through 1999 from all 50 states to examine the impact of CON laws on delivery of care for CABG patients (M. S. Vaughan-Sarrazin *et al.* 2002). The analysis found that hospital volumes in the 26 states with continuous CON was 84 percent higher than in the 18 states with no CON (191 cases per year vs. 104 cases per year). The study also reports the remarkable finding that risk-adjusted in-hospital mortality was 22 percent higher for patients in states with no CON regulation versus states which maintained CON.

The authors acknowledge an important limitation in their analysis; any associations between CON regulation and study outcomes may represent confounding due to other factors which may differ according to CON status. That is, the 22 percent mortality differential between CON and no-CON states may in fact be due to other factors which are correlated with the extent of regulation in a state (e.g. level of managed care penetration, local physician practice styles, etc.). In contrast, this study will employ fixed effects in all regression analyses to control for unobserved hospital and state characteristics. Although the Vaughan-Sarrazin et al. analysis is based on data from all 50 states, the Medicare dataset lacks information on patients under age 65, as well as those enrolled in Medicare managed care. Therefore, the differences in hospital volume and mortality identified in this study may be upward biased due the higher rate of managed care penetration in states without CON regulation in their sample (V. Ho 2003). Although this study lacks data from all states, the sample includes patients of all ages, regardless of insurance type. It is important to test whether these notable differences in volume and outcomes for CABG persist with these differences in both the sample and method of analysis.

III. DATA AND DESCRIPTIVE STATISTICS

This study uses data from the AHRQ HCUP Nationwide Inpatient Sample (NIS) database to compare hospital procedure volumes and costs for PTCA and CABG in states with and without cardiac CON laws. The NIS data is analyzed for the years 1988 to 2000. Ideally, one would conduct an analysis of changes in procedure volume and costs in states before and after repeal of CON legislation, using states that never repealed CON as a control group. Unfortunately, all of the states in the HCUP sample except one discontinued their cardiac CON program prior to 1988. Therefore, analyses in this study will focus on examining differences in hospital procedure volume or costs, as a function of the number of years since CON legislation was repealed in a given state.

The HCUP NIS data is a stratified random sample of community hospitals in the United States. The dataset contains a 20 percent sample of acute care hospitals in each of five strata (geographic region, ownership, location, teaching status, and bedsize). The first release of the NIS for the years 1988 to 1992 contained information from 11 U.S. states, and the 2000 release contains information on over 1,000 hospitals in 28 states. Although the sampling strategy for the NIS re-sampled many hospitals over several years, very few facilities are included for all 13 years. On average there are four years of data for each hospital in this study.

The NIS contains patient-level clinical and resource use information included in a typical discharge abstract. All discharge abstracts from each sample hospital are included, so that one can obtain accurate counts of PTCA and CABG volume for each facility. All patients with a procedure code for CABG (ICD-9-CM 36.1x) or PTCA (ICD-9-CM 36.01, 36.02, or 36.05) were included in the sample for this study.

Information on CON status for each state was drawn from the 2000 Maryland Health

Care Commission survey. The survey lists the 28 states which maintained a cardiac CON program through the year 2000 (18 are in the NIS sample), as well as the eight states which never implemented a CON program (2 are in the NIS sample). The survey also lists the 15 states which repealed their cardiac CON legislation and the year in which the repeal occurred (seven are in the NIS sample). See the Appendix A for a summary of CON programs as reported by the Maryland survey.

Figure 1 graphs mean PTCA and CABG volume by year for hospitals in states with and without cardiac CON. Note that in both cases that procedure volume in CON and non-CON states were remarkably similar in the years just following repeal of the Federal CON legislation. However, procedure volume begins to diverge between CON and non-CON states in 1992, and mean hospital volumes in CON states remain higher through 2000. These data are consistent with the hypothesis that CON restricts entry, allowing CON hospitals to grow larger on average. One may be concerned that this observed difference is attributable to the increasing number of states and hospitals added to the NIS sample over time. The graph was repeated including only hospitals in states that were in the NIS for all years from 1988 to 1992. The pattern in the graph remains almost the same.[1]

Figure 1 excludes data from Pennsylvania, which repealed its cardiac CON legislation in 1996. Procedure volumes by year are reported for Pennsylvania in Figure 2. Note the dramatic decline in average procedure volume for both PTCA and CABG after 1996.[2] These changes in average volume are consistent with a previous study which noted that the average number of open-heart surgery programs in Pennsylvania increased from 44 to 55 between 1997 and 1999 (J.

[1] Results are available from the author upon request.

[2] An unusually large rise in PTCA and CABG volume occurs just prior to CON repeal in Pennsylvania in 1996, as well as a relatively large drop in average costs for CABG. Hospitals with CON may have aimed to boost

L. Robinson *et al.* 2001). Figure 3 presents graphs of the average costs per patient in hospitals performing PTCA and CABG. Costs for each patient were derived by multiplying the reported charge for each patient by a hospital-specific cost-to-charge ratio obtained from Medicare Cost Reports.[3] These costs were then deflated by the All-Urban Consumers CPI to reflect 2000 dollars. Past studies of disease-specific costs have also relied on aggregate hospital cost-to-charge ratios rather than department-level data (D. Meltzer *et al.* 2002;D. M. Cutler, R. S. Huckman 2003). As one of these studies notes, analysis of a specific treatment with large fixed costs such as CABG and PTCA yields a more homogeneous sample of hospitals, which is likely to mitigate any bias created by the use of hospital-level data. Further, costs computed using aggregate hospital cost-to-charge ratios have been found to be generally within 10 percent of costs obtained from department-level cost data (D. Dranove 1995).

Note that average costs tend to be lower in hospitals in states with CON, particularly for CABG procedures. If there are economies of scale in performing PTCA and CABG, then higher procedure volumes in CON states may lead to lower costs of care per patient.[4] Figure 4 presents average costs for hospitals in Pennsylvania. The graph for PTCA suggests a sharp increase in PTCA costs after the repeal of CON legislation, although the effect is not lasting. Average costs for CABG also rise somewhat after the repeal of CON legislation; although again the effect does not appear to persist.

---

their cardiac procedure numbers in anticipation of repeal, in an attempt to deter potential entrants. Volume growth has been identified as a method of strategic entry deterrence in previous research (L. Dafny 2005).

[3] The hospital cost-to-charge ratio was calculated excluding outpatient service cost centers, as well as inpatient service cost centers that were not likely to be used by cardiac care patients (e.g. nursery, delivery room, and labor room costs).

[4] Average costs for both PTCA and CABG declined over the period 1988 to 1996 for both CON and non-CON states. Average hospital volume for both of these procedures tended to increase for all hospitals during this time period. Because annual and cumulative hospital procedure volume are highly correlated, prior research has not been able to determine whether this decline is attributable to economies of scale or learning by doing (Ho V. 2002).

IV. MODEL SPECIFICATION

The previous figures do not control for differences in patient populations across states which may explain differences in procedure volume for PTCA and CABG. The following regression specification is estimated to identify the effect of CON legislation and other factors on hospital PTCA procedure volume:

$$(1) \qquad \log(\text{PTCA})_{ht} = f(\text{yrsnoCON}_{ht}, Z_{ht}, \text{Year}_t, \theta_h)$$

where $\log(\text{PTCA})_{ht}$ is the natural log of the number of the of PTCA procedures performed by hospital h in year t. The explanatory variable yrsnoCON_{ht} is the number of years since state CON legislation has been repealed for hospital h in year t. This variable is set equal to 0 for hospitals which maintained cardiac CON legislation through 2000. For Oregon and Wisconsin, which never imposed cardiac CON legislation, the year of repeal was coded as 1987, when the general Federal CON program was dismantled.[5]

A vector of control variables Z_{ht} are hypothesized to capture differences in demand for cardiac procedures across hospitals. These include the natural log of the population age 65 plus per square mile and the HMO penetration rate in hospital h's county of operation in year t.[6] State-level annual data on smoking rates, per capita income, and the percent of the population uninsured were also included in preliminary regressions. However, per capita income and uninsurance rates are excluded from the reported estimates, because they had poor explanatory power and did not influence the other regression estimates. See Appendix B for a list of summary statistics for these data and data sources.

[5] In the absence of specific CON rules for cardiac care, general Federal CON legislation in these two states was likely to restrict the number of providers performing PTCA and CABG up through 1987. All of the estimation results were robust to exclusion of these two states. In all but one case, the coefficient estimates remained unchanged up to at least the second decimal point, and in most cases up to the third decimal point. Precision changed only slightly.

Hospital-level counts of the number of heart attack patients and the number of patients admitted with chest pain were also available. However, preliminary regressions indicated substantial multicollinearity between these two variables and the population per square mile. Therefore, only the population per square mile is included in the regressions.

The regression includes a vector of year dummies and a vector of hospital-specific fixed effects. Thus, the coefficient on yrsnoCON can be interpreted as the within-hospital increase in PTCA volume associated with each additional year past repeal of state CON legislation. A similar regression is estimated to determine the association between the number of years since CON repeal and hospital CABG volume. As explained previously, only Pennsylvania switched its cardiac CON status during the sample period. Therefore, the sample size is insufficient to estimate hospital-specific fixed effects regressions with only a dummy variable for CON as the explanatory variable of interest.

Specifying a linear relationship between the number of years since CON repeal and hospital volume procedure volume seems reasonable, given that Figure 1 suggests a gradual divergence in both PTCA and CABG volume between CON and non-CON states in the 1990's. The figures are consistent with the hypothesis that limited entry in CON states enabled hospitals to markedly increase procedure volume year after year, while volume in non-CON states grew more slowly or remained constant.[7]

I also test whether changes in hospital procedure volume attributable to CON legislation have a noticeable impact on inpatient mortality for PTCA and CABG. Given that

[6] County-level information was drawn from the Area Resource File. Six states did not report hospital identifiers in the NIS (GA, HI, KS, SC, TN, and TX). State-level data was assigned in place of county-level information for hospitals in these states.

higher procedure volume is associated with better patient outcomes, it is hypothesized that an increase in hospital procedure volume associated with CON will be associated with lower inpatient mortality. To test this hypothesis, I estimate regressions of the following form:

$$(2) \qquad (\text{RAMR}_{PTCA})_{ht} = f((\text{PTCA Volume})_{ht}, \text{Year}_t, \theta_h)$$

where $(\text{RAMR}_{PTCA})_{ht}$ is the risk-adjusted inpatient mortality rate for patients undergoing PTCA in hospital h in year t, and $(\text{PTCA Volume})_{ht}$ represents the number of PTCA procedures performed by hospital h in year t. The remaining variables on the right-hand side of this equation have definitions identical to those provided for equation (1).

The data are aggregated to the hospital-year level for estimation of the mortality regressions in order to obtain results which are interpretable for policy purposes. Estimation of the relationship between hospital volume and mortality at the patient level would require a logit specification. However, one cannot compute partial effects from a hospital fixed-effects logit equation, because the distribution of the unobserved hospital heterogeneity component is unknown (J. M. Wooldridge 2002). Aggregation to the hospital level yields the mortality rate as the dependent variable, so that fixed effects estimates are readily interpretable.

An RAMR is calculated as the hospital's observed mortality rate for a given procedure in a given year, divided by its expected mortality rate, all multiplied by the entire sample's average mortality rate in that year. This figure provides an estimate of what the hospital's inpatient mortality rate would have been if it had served a mix of patients identical to the entire sample's mix.

The hospital's expected inpatient mortality in a given year is calculated using the coefficient estimates of a logistic regression of inpatient mortality on patient-specific

---

[7] The data for Pennsylvania in Figure 2 also appears consistent with this hypothesis. After repeal of CON

characteristics. Thus, a separate logistic regression is estimated for each year in the sample, where the unit of observation is a patient in that year and the dependent variable equals 0 if the patient was discharged alive and equals 1 if the patient died in hospital. Separate logistic regressions are also estimated for PTCA and CABG patients. The patient characteristics included in the logistic regression are: age (dummy variables for ages 65 to 69, 70 to 74, 75 to 79, 80 to 85, and 85+ versus those under age 65), as well as indicator variables for female, black, emergency admission, transfer from another hospital, primary diagnosis of acute myocardial infarction (AMI, commonly known as a heart attack). Indicator variables are also included for the individual comorbidities that comprise the Charlson comorbidity index (P. S. Romano *et al.* 1993), which are: prior AMI, peripheral vascular disease, dementia, chronic obstructive pulmonary disease, rheumatologic disease, liver disease (mild), liver disease (moderate/severe), diabetes (mild/moderate), diabetes with complications, kidney disease, cancer, and metastatic solid tumor. For the regressions for PTCA patients, indicator variables for stent insertion and performance of multiple-vessel PTCA were also included.

As with prior studies, I hypothesize that the coefficient on procedure volume will be negative. That is, higher procedure volume will be associated with lower inpatient mortality. Specification tests are run to determine whether the relationship between hospital volume and risk-adjusted mortality is best represented with the log of volume or polynomials of hospital volume.[8] The specification with the best fit is reported in the tables.

Regressions with average hospital costs per patient for both PTCA and CABG are also

in 1996, average procedure volume for both PTCA and CABG fell dramatically, then remained relatively constant, similar to non-CON states in Figure 1.

[8] The standard errors for volume in logs and polynomials are compared in regressions including both volume specifications. In addition, predicted mortality based on log volume is added as a regressor in a mortality regression with polynomials of procedure volume to determine whether it yields any additional explanatory power. Likewise, predicted mortality based on polynomials of volume is added as a regressor in a mortality regression with volume expressed in logs to evaluate its explanatory power.

estimated. The same patient characteristics which are used to construct risk-adjusted mortality rates are included as explanatory variables in the cost regressions for PTCA and CABG patients. Patient-specific factors such as age, gender, presence of comorbidities, and urgency of the procedure are all likely to affect costs.

The presence of minimum procedure volume standards in cardiac CON legislation may lead hospitals to perform more cardiac procedures than they otherwise would have. To test this hypothesis, one needs accurate measures of statewide procedure volume for both PTCA and CABG. One could then determine whether states that maintain CON rules experienced higher growth in procedure volume versus those states that repealed the rules. Unfortunately, the HCUP NIS does not contain information on all hospitals in any state, so that this dataset cannot be used to obtain accurate statewide procedure volume estimates. However, the AHRQ maintains an interactive tool on its website which allows one to determine the total number of PTCA and CABG procedures performed by all hospitals in select states that participated in the NIS for the years 1997 to 2002. I supplemented this information with PTCA and CABG counts based on comprehensive hospital discharge abstract covering the years 1988 to 1996 for California, Florida, New Jersey, and New York, as well as data from 1990 to 2001 for Colorado and Pennsylvania.[9] The resulting sample contains 145 state-year observations.

Regressions are then estimated to identify the impact of number of years beyond repeal of CON legislation on procedure volume at the state level. These regressions include year dummies, the log of population age 65 plus per square mile, the HMO penetration rate, the smoking rate,

---

[9] Obtaining comprehensive discharge abstract data from individual states is time consuming and costly. I chose to collect data from four large states, which represent 27 percent of the population in the United States. Because so few states in the NIS discontinued their cardiac CON programs, I also purchased the state-level data which was available for this time period from Colorado and Pennsylvania.

per capita income, and the percent uninsured at the state level. State-level estimates of the number of heart attack patients and the number of patients admitted with chest pain each year were also available. However, similar to the hospital-level analyses, preliminary regressions indicated substantial multicollinearity between these two variables and the population per square mile. Therefore, only the population per square mile is included in the regressions.

The state-level results are first reported including state fixed effects, then with first-differencing. Correlation of the error term with the explanatory variables in any time period (current, past, or future) leads to inconsistent estimates (J. M. Wooldridge 2002). Therefore, for each specification, a Wald test was performed to test for strict exogeneity of the explanatory variables with respect to the error term.

The fixed effect estimates of the determinants of annual procedure volume and costs are estimated using the areg command in Stata 8.0. This approach allows for the estimation of fixed effects, as well as heteroskedasticity-robust standard errors which also account for the correlation of the error terms across time within hospitals. Regressions estimated at the hospital level incorporate hospital-level fixed effects; and regressions at the state level incorporate state-level fixed effects.

In cases where the dependent variable is risk-adjusted mortality, the regressions are first estimated by OLS with standard errors robust to clustering within hospitals, but no hospital-specific fixed effects. These estimates provide a standard of comparison to volume-outcome effects for CABG and PTCA which are commonly reported in the medical literature. The effects of procedure volume on mortality with hospital-specific random effects, then fixed effects are also reported. Although the risk-adjusted mortality rates control for observable differences in casemix across hospitals, the discharge data may not fully capture more detailed clinical characteristics of patients that may be correlated with hospital volume and risk of death. Regression estimates based on fixed effects will provide consistent estimates of the effect of procedure volume on mortality, whether or not unobservable differences in patient casemix are correlated with volume. However, random effects estimates will yield smaller standard errors if unobserved heterogeneity across hospitals is uncorrelated with hospital volume. Therefore, Hausman tests are performed to determine whether the random effects or fixed effects specification is more appropriate when examining the impact of hospital volume on mortality for both PTCA and CABG.

Past studies suggest that hospital procedure volume may be an endogenous regressor. The association between high procedure volume and favorable patient outcomes may be driven in part by selective referral. For complex procedures, doctors may refer their patients to facilities that they perceive to provide higher quality care. If hospital volume is endogenous in regressions analyzing the determinants of inpatient mortality, then an alternative estimation strategy is to estimate a two-stage instrumental variables equation. The number of years since CON repeal is a likely candidate for an instrument that predicts procedure volume, but is unlikely correlated with unobserved differences in mortality across hospitals. The population per square mile in a hospital's county and the number of patients admitted with a heart attack are also hypothesized to influence the demand for cardiac care and therefore serve as instruments. If in fact hospital procedure volume is not an endogenous regressor in the mortality regressions, then this approach will yield inefficient estimates. Hausman specification tests were conducted to test for the endogeneity of procedure volume. In each case, one could not reject the null hypothesis that the preferred random or fixed effects estimates treating volume as exogenous were consistent and efficient. Therefore, only these estimates are reported in this study.

V. RESULTS

Table 1 contains regression estimates for the determinants of hospital PTCA and CABG procedure volume. In general, later years are associated with increases in procedure volume for both PTCA and CABG. County population age 65 plus per square mile increases volume for these procedures, although the coefficients on other factors hypothesized to influence demand (HMO penetration and the smoking rate) are imprecisely estimated.[10]

The coefficient on yrsnoCON is negative and precisely estimated in both the PTCA and CABG regressions, although the coefficient on yrsnoCON has a p-value of only 0.07 in explaining hospital CABG volume. The average value of yrsnoCON for the states in the sample which repealed CON legislation is equal to 14 years in 2000. The coefficient estimate on yrsnoCON in the PTCA regression is equal to -0.033. This estimate implies that on average, PTCA volume for hospitals in states which repealed cardiac CON legislation was 37 percent lower than it would otherwise have been by the year 2000 if CON rules had been maintained (using the $\% \hat{\Delta} y = 100 \cdot [\exp(\hat{\beta} \Delta x) - 1]$ formula) (J. M. Wooldridge 2000). Similarly, the estimates for the CABG regression suggest that average hospital CABG volumes were 27 percent lower by 2000 than they otherwise would have been.

Table 2 contains regression estimates of the relation between procedure volume and hospital risk-adjusted mortality for both PTCA and CABG procedures. Due to space constraints, the first-stage patient-level estimates of inpatient mortality regressed on patient characteristics

---

[10] Nevertheless, HMO penetration and the smoking rate are included in the regression, because of the strong priors that these variables should influence demand. The coefficients on other explanatory variables are virtually the same in specifications without these variables.

are excluded from the tables.[11] The estimates are similar to those reported in previously published studies. Older patients have higher mortality rates. Black patients, urgent/emergency admissions, and those with severe comorbidities are also more likely to die in hospital.

The first three columns of Table 2 report the association between the annual number of PTCA procedures performed by a hospital and its risk-adjusted mortality. The OLS and random effects estimates suggest that higher hospital procedure volume is associated with lower mortality rates for PTCA patients. However, the coefficient on volume is imprecisely estimated when hospital-specific fixed effects are included. A Hausman test rejects the null hypothesis that the random effects estimates are consistent. This test result suggests that unobserved differences in patient casemix across hospitals are correlated with both procedure volume and mortality. This might be the case if, for example, hospitals that perform higher numbers of PTCA procedures also attract greater numbers of patients with unstable angina or lower ejection fractions. These factors have been demonstrated in previous clinical studies to be risk factors for increased inpatient mortality among PTCA patients (S. E. Kimmel *et al.* 1995;E. L. Hannan *et al.* 1997). Therefore, although CON appears to lead to a sizeable increase in average hospital PTCA volume, there is no evidence that beneficial reduction in inpatient mortality accompanies this volume change.

The last three columns of Table 2 present regression estimates of the impact of hospital procedure volume on risk-adjusted mortality rates for CABG patients. Again, the regression estimates including hospital-specific effects yield an imprecise estimate for the log(volume) coefficient. However, in this case, a Hausman test indicates that one cannot reject the null hypothesis that the random effects estimates are consistent and efficient

[11] The results are available from the author upon request.

($\chi^2(13)=16.1$, $p=0.24$). The volume coefficient in the random effects risk-adjusted mortality regression for CABG is equal to -0.004, indicating a negative and precisely estimated association between increased CABG procedure volume and inpatient mortality. It is notable that the magnitude of the volume coefficient in the random effects regression is two-thirds the size of the volume effect obtained from estimating pooled OLS. Therefore, previous clinical studies based on OLS estimates may have overestimated the benefits of increased volume in reducing inpatient mortality.

To examine the magnitude of this effect in the context of CON legislation, one can substitute equation (1) into equation (2). The RAMR associated with an increase in the number of years past repeal of CON then becomes the coefficient on yrsnoCON in equation (1) multiplied by the coefficient on log(CABG Volume)$_{ht}$ in equation (2), multiplied by yrsnoCON. One finds that for an average hospital in a state 14 years beyond repeal of CON rules, inpatient mortality rates for CABG are 0.1 percentage points higher than they otherwise would have been. In the year 2000, 29,194 patients in the NIS sample underwent CABG in states which had repealed CON rules. In these states, the average risk-adjusted mortality rate was 3.9 percent in 2000. These estimates suggest that retaining CON would have led to 29 fewer inpatient deaths overall in that year.

One can apply a similar exercise to the PTCA results to assess whether the imprecise coefficient estimates relate to the absence of a tangible effect of volume on mortality, or instead an insufficient sample size. The lower bound of the 95 percent confidence interval for PTCA volume in the fixed effects regression in Table 2 is -0.0038. Let this value represent the largest potential effect that hospital volume could reasonably have in reducing mortality for PTCA patients. One then infers that 14 years after CON repeal, the mortality rate for PTCA patients would be .2 percentage points lower if CON had instead been retained. In 2000 there were 51,539 PTCA patients in non-CON states in the NIS sample, and their risk-adjusted mortality rate was 1.6 percent. Therefore, even at the 95 percent confidence limit, the estimates suggest that retaining CON would lead to 103 fewer deaths, a relatively small amount.

Table 3 contains regression estimates of the relation between repeal of CON legislation and mean hospital costs. The estimates indicate that increasing PTCA volume is associated with lower average costs per patient. This result is consistent with the hypothesis of substantial economies of scale in the performance of these procedures. Specification tests indicated that polynomials of hospital volume to the third power (rather than log volume) provided the best fit in explaining the cost of performing CABG. The estimates indicate that within-hospital increases in CABG volume are associated with declining average costs up to an increase of 852 procedures. The mean one-year increase in hospital CABG volume is 15 procedures, and the largest one-year increase is 490 surgeries. In addition, the largest within-hospital increase in CABG volume over the entire time period is 834 procedures. Therefore, the estimates are consistent with economies of scale in performing CABG over the range of procedure volumes observed in the sample.

Applying the same exercise described above, the volume estimate in the PTCA cost regression suggests that on average, hospitals in states that repealed cardiac CON legislation had mean patient costs in 2000 which were 3.0 percent higher than they otherwise would have been. Among states in the sample without CON legislation in 2000, mean CABG volume equalled 300 procedures. The results in Table 1 suggest that average procedure volume for CABG is 27 percent lower than it would have been in 2000 if these states had maintained CON rules; implying that average CON volume would have equaled 411 procedures per year with CON. The cost estimates in Table 3 suggest that a within-hospital increase in CABG volume of 111 procedures (from 300 to 411) is associated with a 6.7 percent decrease in average costs. Given the large number of patients undergoing these procedures, these estimates suggest that by lowering average hospital procedure volume, repeal of CON legislation potentially has a noticeable impact on overall expenditures.

Regressions were also estimated with state-level volumes for PTCA and CABG as the dependent variables. The results are reported in Table 4. For the fixed effect estimates, a test of strict exogeneity for the number of years since CON repeal and the population per square mile involves performing a Wald test on one-year leads of these variables when added to the reported specifications. For the first-difference regressions, a Wald test of the significance of number of years since CON repeal and the population per square mile in levels when added to the reported specification is used to test for strict exogeneity.

For the state PTCA volume regressions, one cannot reject the hypothesis of strict exogeneity of the explanatory variables ($F(6,20)=0.81$), and therefore the fixed effects estimates are the most efficient. Each year beyond CON repeal appears to lower the number of PTCA procedures performed in the state by 3.8 percent. For the CABG regressions, one rejects the null hypothesis of strict exogeneity in the fixed effects estimates. However, one does not reject the hypothesis of strict exogeneity of the explanatory variables in the first-difference regression. The results suggest that each year beyond CON repeal reduces statewide CABG surgeries by 1.6 percent.

For both PTCA and CABG, the repeal of CON appears to be associated with a decrease in the total number of procedures performed statewide. The estimates suggest that 14 years after repeal of cardiac CON laws, statewide procedure volumes for PTCA were 41 percent lower than they otherwise would have been; and statewide procedure volumes for CABG were 18 percent lower.

The sizeable difference in statewide PTCA volume for states which repealed CON laws may be attributable to the limited sample. California and Colorado are the only states which repealed CON and are represented in the sample prior to 1997.[12] Between 1989 and 2001, California's PTCA volume increased from 22,924 to 49,613 procedures per year, or 116 percent. Colorado's PTCA volume rose from 1,996 to 6,046 procedures per year between 1990 and 2001, or 203 percent. In contrast, Florida, New Jersey and New York are represented in all of these sample years and maintained CON regulations. In these states, the average PTCA procedure volume rose from 8,353 to 34,522 procedures per year between 1989 and 2001, or an increase of 313 percent. Analysis of data from a wider range of states would be helpful in confirming this finding.

However, it is also interesting to note that between 1996 (when Pennsylvania eliminated it's CON rules) and 2001, total PTCA procedure volume in Pennsylvania rose 23 percent. During this time period, statewide PTCA volume rose an even higher average of 57 percent for Florida, New Jersey, and New York. Between 1990 (the first year for which Pennsylvania data is available) and 1995, rates of growth for PTCA were more similar for Pennsylvania versus these 3 states that retained CON; 74 percent versus 90 percent, respectively. These data are also consistent with the hypothesis that CON rules lead to higher statewide performance of PTCA.

The reported specifications of the association between years since CON repeal and procedure volume at the hospital and state level are linear, suggesting that repeal of CON has a persistent effect on procedure growth rate through time. To test this assumption, the number of years since CON repeal for all states that repealed CON was divided into tertiles, then quartiles.

The tertiles/quartiles were used to estimate splines to determine whether the relationship between years since CON repeal and PTCA/CABG volume weakened for the years that were furthest from the repeal (i.e. closest to the present).

I tested the hypothesis that the slope of the relationship between volume and years since CON repeal was constant by testing whether the coefficients on the two highest tertiles or three highest quartiles were jointly equal to 0. The results are reported in Appendix C. In seven of the eight cases, one cannot reject the hypothesis that the relationship between years since CON repeal and procedure volume is constant. For state-level PTCA volume, however, the results suggest that the effect of CON repeal weakens at the third quartile, or 12 years after repeal. CON repeal still is associated with lower statewide PTCA volume after 12 years, although the effect is only about one quarter of its magnitude in the first six years.

I also estimated the hospital-level and state-level PTCA and CABG volume regressions adding a quadratic of number of years since CON repeal, then a quadratic and cubed term. In each case the higher order terms were imprecisely estimated, and the standard error for the coefficient on the linear term increased in magnitude. For example, for the quadratic of number of years since CON repeal, the p-values ranged from .189 to .790.

Finally, I re-estimated the hospital and state-level volume regressions using data only through 1995, to examine whether a relatively long follow-up period could be introducing unrelated time series variation. The coefficient on the number of years since CON repeal was -.026 (p=.21) and -.014 (p=.003) in the hospital-level PTCA and CABG regressions, and -.037 (p=.007) and -.030 (p=.08) in the state-level PTCA and CABG regressions. One would expect some drop in precision due to the smaller sample size. However, in each case the direction of the effect remains unchanged, and the precision of the estimates remains relatively high.

---

[12] The AHRQ HCUP website only reports statewide data by procedure volume from 1997 onwards.

VI. CONCLUSIONS

The reported estimates suggest that substantial declines in average hospital PTCA and CABG procedure volume have resulted in states which repealed cardiac CON legislation. Although not explicitly tested in this paper, these declines are likely due to the larger number of new providers entering those states which do not impose minimum volume standards for these procedures through CON laws. Reductions in average hospital volume associated with the absence of CON have a detrimental impact on mortality rates for CABG patients, although the magnitude of the estimated impact is relatively small. For the 29,294 patients who received CABG surgery in states that had repealed CON in 2000, the results suggest that 29 fewer inpatient deaths could have been avoided with CON rules. In addition, the results yield no evidence that the volume effects associated with CON rules led to reduced mortality for patients undergoing PTCA.

Nevertheless, repeal of CON legislation is associated with substantially higher costs per patient. The increase in volume associated with CON regulations is predicted to reduce average costs by 3.0 percent for PTCA patients and 6.7 percent for CABG patients. These results might lead one to favor CON legislation, because it appears to reduce costs and either saves some lives, or leaves mortality rates unchanged.

However, the presence of minimum volume standards may lead hospitals in CON states to increase the number of procedures performed relative to states without CON. The predicted increases in the total number of procedures performed (41 percent for PTCA and 18 percent for CABG in the year 2000) are large enough to offset any potential savings resulting from lower average costs per patient treated as a result of CON regulation. These results are consistent with past research which has found CON regulations do not restrain expenditure growth.

Nevertheless, the estimates of statewide growth in PTCA procedures resulting from CON seem extraordinarily large. I am in the process of surveying states to obtain data on minimum volume thresholds for open heart surgery and cardiac catheterization. Preliminary investigation indicates that minimum volume thresholds vary across states, but little change in thresholds occurs across years within states. In future research, I aim to combine this information with data from more states to revisit the issue of CON and statewide procedure volume.

This study does not attempt to measure the potential impact of CON rules on the substitution of PTCA for CABG procedures, which has increased in the U.S. over time (D. M. Cutler, R. S. Huckman 2003). However, the overwhelming majority of states with cardiac CON rules restrict entry for both CABG and PTCA. Therefore, rates of substitution between these two procedures smay not vary by CON status. This issue is an interesting question for future research.

In the meantime, policy makers must carefully weigh the costs and benefits of CON regulation. Policy makers implemented CON with the dual goals of restraining cost growth and achieving high quality care. The centralization of care which is associated with CON may lead to slightly lower mortality rates for CABG and lower unit costs due to economies of scale. However, these regulations may also inadvertently increase the total number of procedures performed. Future studies with more detailed clinical data should attempt to measure the marginal benefit of increased rates of cardiac surgery in states which have maintained CON legislation. The potential impact of differences in rates of surgery resulting from CON on long term mortality has important consequences for evaluating the welfare benefits of these regulations.

REFERENCES

1. Conover, C. J., Sloan, F. A. "Does removing Certificate-of-Need regulations lead to a surge in health care spending?" *Journal of Health Politics, Policy and Law*, 1998, *23* (3), 455-481.

2. Cutler, D. M., Huckman, R. S. "Technological development and medical productivity: the diffusion of angioplasty in New York state." *Journal of Health Economics*, 2003, *22* (2), 187-217.

3. Dafny, L. "Entry deterrence in hospital procedure markets: A simple model of learning-by-doing." *Journal of Economics and Management Strategy*, 2005, *14* (3), 513-542.

4. Dranove, D. "Measuring costs," Sloan, F. A., *Valuing health care*. New York, NY: Cambridge University Press, 1995, 61-75.

5. Grabowski, D. C, Ohsfeldt, R. L., Morrisey, M. A. "The effects of CON repeal on Medicaid nursing home and long-term expenditures." *Inquiry*, 2003, *40* (2), 146-157.

6. Hannan, E. L., Racz, M., Ryan T.J., McCallister, B. D., Johnson, L. W., Arani, D. T., Guerci, A. D., Sosa, J., Topol, E. J. "Coronary angioplasty volume-outcome relationships for hospitals and cardiologists." *The Journal of the American Medical Association*, March 1997, *277* (11), 892-898.

7. Hensley, S. The patient or the wallet: N.H. hospitals battle over open-heart surgery CONs. Modern Healthcare , 24. 8-25-1997.

8. Ho V. "Learning and the evolution of medical technologies: The diffusion of coronary angioplasty." *Journal of Health Economics*, 2002, *21* (5), 873-885.

9. Ho, V. "Evolution of the volume-outcome relationship for hospitals performing coronary angioplasty." *Circulation*, April 2000, *101* 1806-1811.

10. Ho, V. "Letter to the Editor: Certificate of Need regulations and hospital mortality." *The Journal of the American Medical Association*, February 2003, *289* (5), 551.

11. Kessler, D. P., McClellan, M. B. "Is hospital competition socially wasteful?" *The Quarterly Journal of Economics*, 2000, *115* (2), 577-615.

12. Kimmel, S. E., Berlin, J. A., Laskey, W. K. "The relationship between coronary angioplasty procedure volume and major complications." *Journal of the American Medical Association*, 1995, *274* (14), 1137-1142.

13. Lanning, J. A., Morrisey, M. A., Oshfedlt, R. L. "Endogenous hospital regulation and its effects on hospital and non-hospital expenditures." *Journal of Regulatory Economics*, 1991, *3* 137-154.

14. Maryland Health Care Commission. An analysis and evaluation of Certificate of Need regulation in Maryland, Working Paper: Cardiac Surgery and Therapeutic Catheterization Services. 8-18-2000. Baltimore, MD.

15. Meltzer, D., Chung, J., Basu, A. "Does competition under Medicare prospective payment selectively reduce expenditures on high-cost patients?" *RAND Journal of Economics*, 2002, *33* (3), 447-468.

16. Noether, M. "Competition among hospitals." *Journal of Health Economics*, 1988, *7* 259-284.

17. Pallarito, K. Change of heart: N.J. expansion of cardiac CONs proving controversial. Modern Healthcare , 44. 7-20-1998.

18. Robinson, J. L., Nash, D. B., Moxey, E., O'Connor, J. P. "Certificate of need and the quality of cardiac surgery." *American Journal of Medical Quality*, 2001, *16* (5), 155-160.

19. Romano, P. S., Roos, L. L., Jollis, J. G. "Adapting a clinical comorbidity index for use with ICD-9-CM administrative data: Differing perspectives." *Journal of Clinical Epidemiology*, 1993, *46* (10), 1075-1079.

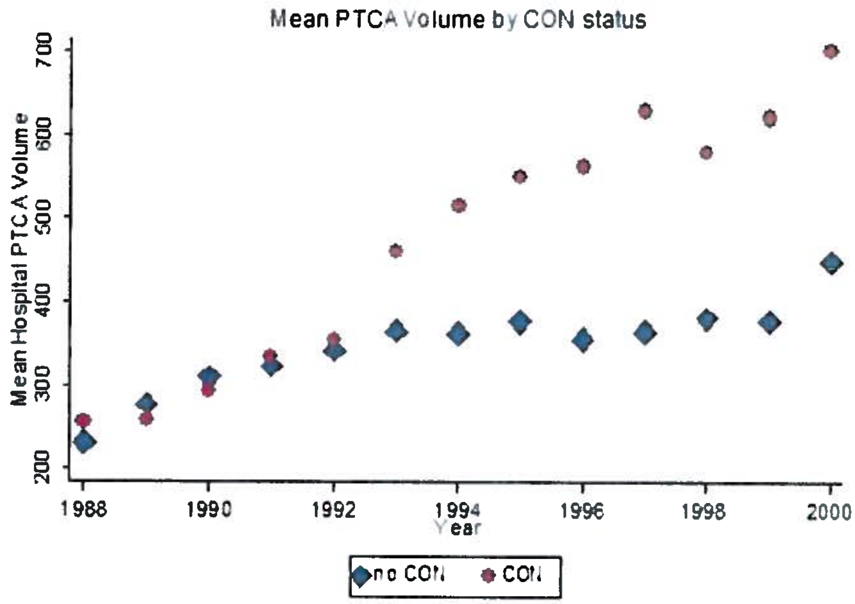
20. Vaughan-Sarrazin, M. S., Hannan, E. L., Cormley, C. J., Rosenthal, G. E. "Mortality in Medicare beneficiaries following coronary artery bypass graft surgery in states with and without Certificate of Need regulation." *The Journal of the American Medical Association*, October 2002, *288* (15), 1859-1866.

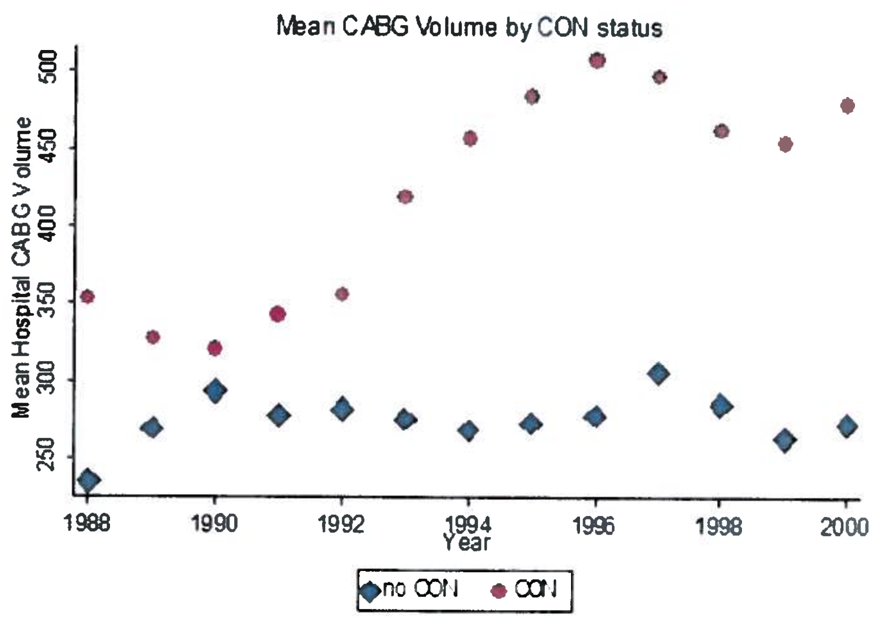
21. Wooldridge, J. M. *Introductory Econometrics: A Modern Approach*. Mason, OH: South-Western College Publishing, 2000.

22. Wooldridge, J. M. *Econometric analysis of cross section and panel data*. Cambridge, MA: The MIT Press, 2002.

23. Wysocki, B. Care, costs and competition - Medical, business interests spar over state hospital-growth rules. The Wall Street Journal , A.4. 5-7-2002. New York.

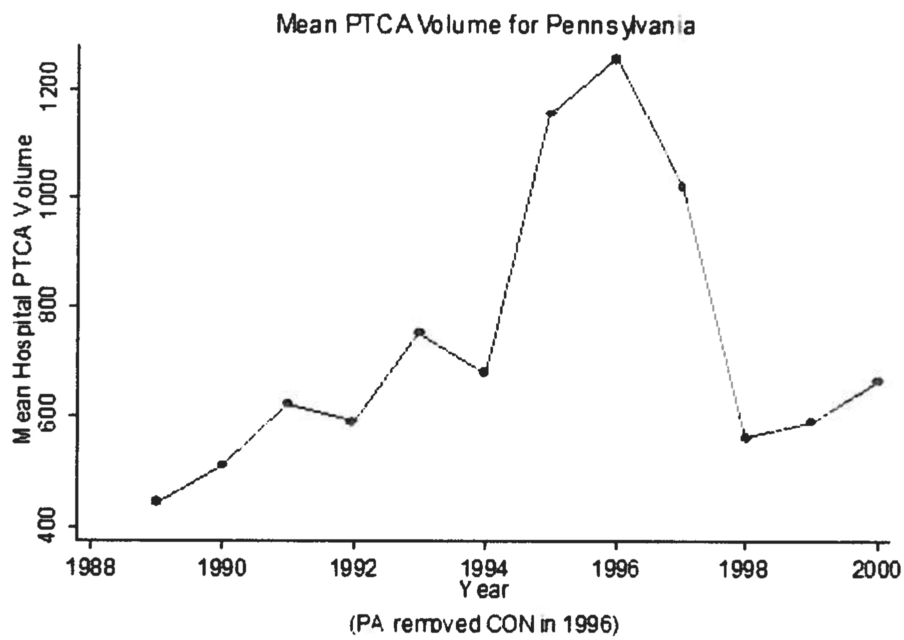
Figure 1





Sample:	All states in NIS dataset, except PA.
CON:	CT, FL, GA, HI, IA, IL, KY, MA, MD, ME, MO, NC, NJ, NY, SC, TN, VA, WA
no CON:	AZ, CA, CO, KS, OR, UT, TX, WI

Figure 2


Mean PTCA Volume for Pennsylvania
Mean Hospital PTCA Volume
400
600
800
1000
1200
1988
1990
1992
1994
1996
1998
2000
Year
(PA removed CON in 1996)

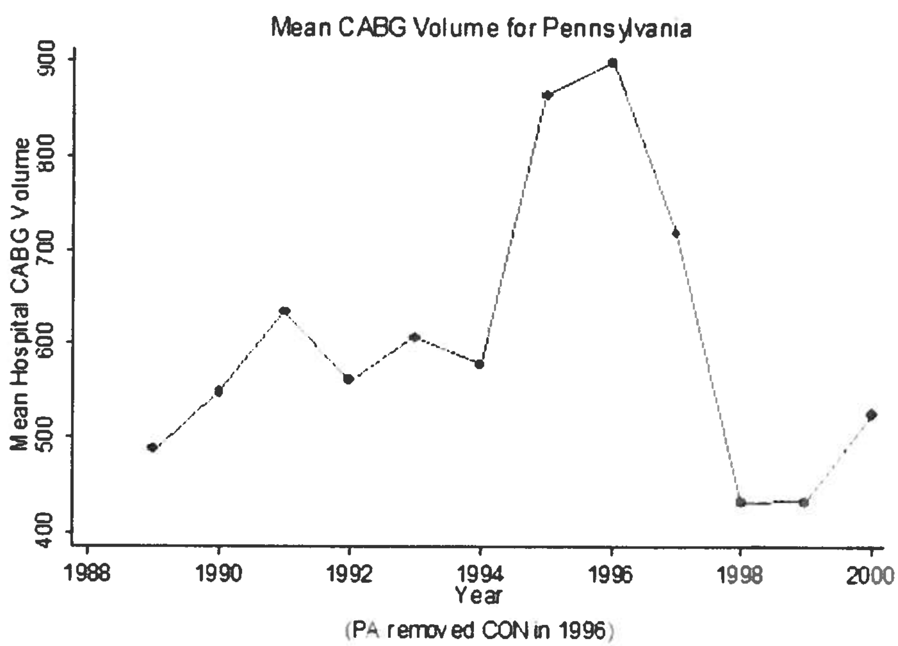
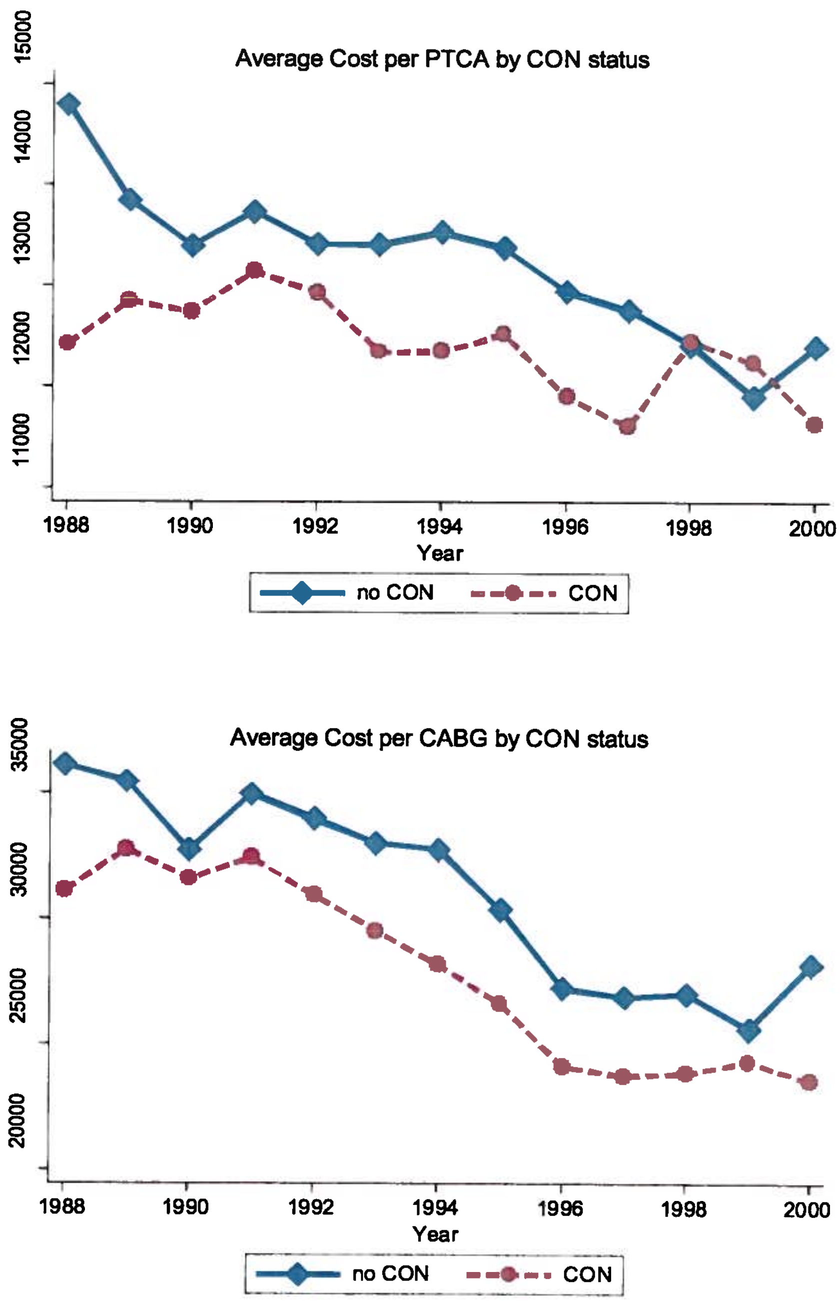
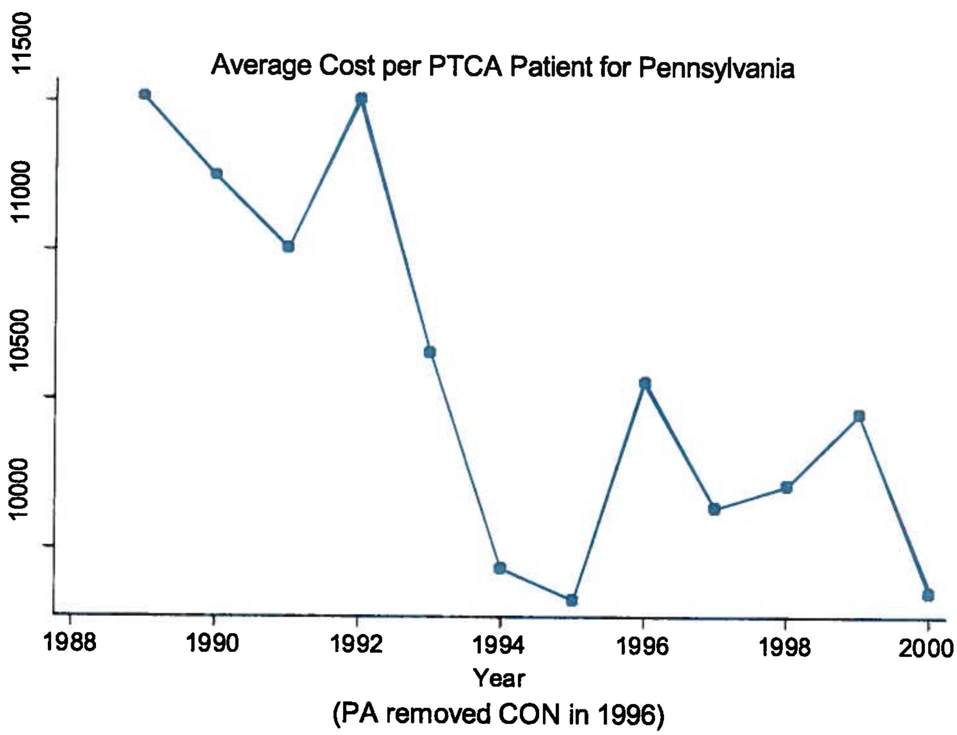

Mean CABG Volume for Pennsylvania
Mean Hospital CABG Volume
400
500
600
700
800
900
1988
1990
1992
1994
1996
1998
2000
Year
(PA removed CON in 1996)

Figure 3



Sample: All states in NIS dataset, except PA.
CON: CT, FL, GA, HI, IA, IL, KY, MA, MD, ME, MO, NC, NJ, NY, SC, TN, VA, WA
no CON: AZ, CA, CO, KS, OR, UT, TX, WI

Figure 4


Average Cost per PTCA Patient for Pennsylvania
11500
11000
10500
10000
1988
1990
1992
1994
1996
1998
2000
Year
(PA removed CON in 1996)

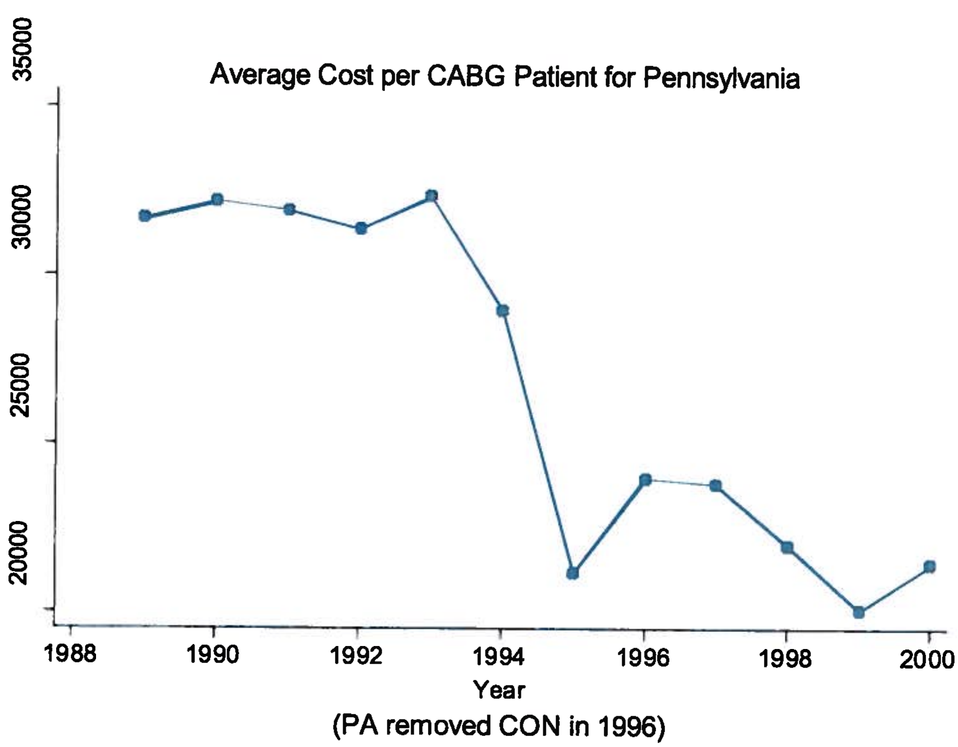

Average Cost per CABG Patient for Pennsylvania
35000
30000
25000
20000
1988
1990
1992
1994
1996
1998
2000
Year
(PA removed CON in 1996)

Table 1: Regression Estimates, Determinants of Hospital Procedure Volume[a]

	ln(PTCA Volume)		ln(CABG Volume)	
	coefficient	t-statistic	coefficient	t-statistic
yrsnoCON	-0.033**	(-2.43)	-0.022*	(-1.81)
log(pop65+/sqmile)	1.166**	(2.09)	1.267***	(2.48)
HMO penetration rate	-0.036	(-0.22)	-0.109	(-0.87)
state smoking rate	1.176	(0.94)	-0.507	(-0.55)
1989	0.075	(1.39)	0.017	(0.29)
1990	0.297***	(4.15)	0.096	(1.44)
1991	0.407***	(5.13)	0.139**	(1.95)
1992	0.540***	(6.21)	0.163**	(2.00)
1993	0.626***	(6.63)	0.189**	(2.19)
1994	0.727***	(7.60)	0.253***	(2.79)
1995	0.849***	(7.89)	0.302***	(3.06)
1996	0.882***	(7.85)	0.385***	(3.67)
1997	0.993***	(8.52)	0.390***	(3.57)
1998	1.092***	(9.05)	0.381***	(3.32)
1999	1.155***	(9.64)	0.332***	(2.85)
2000	1.359***	(10.20)	0.381***	(3.05)
constant	-0.230	(-0.10)	0.102	(0.05)
Obs.	2367		2195	
# hospitals	561		497	

[a]Regressions include hospital-specific fixed effects. All standard errors are estimated with robust standard errors, which account for clustering of patients within hospitals.

*statistical significance at the 10% level.
**statistical significance at the 5% level.
***statistical significance at the 1% level.

Table 2: Regression Estimates, Determinants of Risk-Adjusted Mortality Rates

	PTCA						CABG					
	OLS		Random Effects		Fixed Effects		OLS		Random Effects		Fixed Effects	
$\log(\text{Volume})_{ht}$	-0.0037***	(-2.54)	-0.004**	(-2.38)	-0.0004	(-0.22)	-0.006***	(-3.34)	-0.004***	(-2.62)	-0.004	(-1.27)
1989	-0.0001	(-0.07)	0.0004	(0.26)	0.0004	(0.25)	-0.0009	(-0.35)	-0.001	(-0.57)	-0.001	(-0.53)
1990	0.00002	(0.01)	0.001	(0.41)	0.0001	(0.04)	-0.007**	(-2.27)	-0.006**	(-2.43)	-0.006**	(-1.99)
1991	0.002	(0.95)	0.002	(1.22)	0.001	(0.52)	-0.009***	(-2.97)	-0.008**	(-3.13)	-0.008***	(-2.48)
1992	0.005	(1.41)	0.005	(1.62)	0.002	(0.98)	-0.010***	(-3.20)	-0.010***	(-3.28)	-0.009**	(-2.45)
1993	0.003*	(1.73)	0.004**	(2.23)	0.003	(1.23)	-0.013***	(-4.30)	-0.011***	(-4.33)	-0.010***	(-3.16)
1994	0.005**	(2.35)	0.006***	(2.93)	0.005*	(1.87)	-0.012***	(-3.78)	-0.011***	(-4.09)	-0.010***	(-2.94)
1995	0.007***	(3.25)	0.008***	(3.63)	0.005**	(2.08)	-0.013***	(-3.97)	-0.012***	(-4.51)	-0.011***	(-3.11)
1996	0.006***	(2.77)	0.007***	(3.00)	0.004	(1.35)	-0.014***	(-4.56)	-0.013***	(-5.11)	-0.012***	(-3.52)
1997	0.005***	(2.53)	0.005***	(2.83)	0.002	(1.01)	-0.015***	(-4.71)	-0.014***	(-5.01)	-0.012***	(-3.41)
1998	0.004*	(1.92)	0.004**	(2.08)	-0.001	(-0.20)	-0.017***	(-4.80)	-0.015***	(-4.63)	-0.013***	(-2.90)
1999	0.007*	(1.66)	0.007*	(1.75)	0.003	(0.78)	-0.015***	(-4.56)	-0.013***	(-4.15)	-0.010**	(-2.16)
2000	0.002	(1.13)	0.003	(1.33)	-0.0004	(-0.15)	-0.018***	(-5.45)	-0.015***	(-5.35)	-0.012***	(-3.11)
constant	0.035***	(4.66)	0.035***	(4.30)	0.018**	(2.10)	0.089***	(8.10)	0.078***	(8.19)	0.079***	(4.45)
Obs.			2367						2195			
# hospitals					561						497	

*statistical significance at 10% level.
**statistical significance at 5% level.
***statistical significance at 1% level.

Table 3: Regression Estimates of Determinants of Log(Average Costs per Procedure)

	PTCA		CABG	
	Coefficient	t-statistic	Coefficient	t-statistic
Log(volume)	-0.070***	(-2.78)		
Volume			-0.001***	(-2.85)
Volume 2			5.54e-07**	(2.43)
Volume 3			-1.44e-10**	(-2.11)
1989	0.018	(1.04)	0.030*	(1.76)
1990	0.021	(1.01)	0.016	(0.94)
1991	0.061***	(2.64)	0.055***	(3.11)
1992	0.019	(0.76)	0.011	(0.59)
1993	0.008	(0.28)	-0.015	(-0.69)
1994	-0.012	(-0.39)	-0.063***	(-2.65)
1995	-0.009	(-0.28)	-0.137***	(-5.02)
1996	-0.105***	(-3.28)	-0.192***	(-7.91)
1997	-0.166***	(-5.02)	-0.227***	(-9.34)
1998	-0.156***	(-4.44)	-0.218***	(-8.41)
1999	-0.178***	(-4.70)	-0.228***	(-9.07)
2000	-0.185***	(-4.34)	-0.222***	(-7.79)
Age 65-69 y	0.044***	(22.51)	0.060***	(29.07)
Age 70-74 y	0.066***	(23.41)	0.108***	(41.42)
Age 75-79 y	0.098***	(28.72)	0.156***	(47.24)
Age 80-84 y	0.132***	(25.59)	0.211***	(41.38)
Age 85 y	0.173***	(20.50)	0.259***	(35.02)
Female	0.035***	(17.52)	0.069***	(35.29)
Black	0.015**	(2.30)	0.0391***	(6.89)
AMI	0.282***	(48.19)	0.142***	(42.43)
Emergency admit	0.242***	(26.74)	0.164***	(26.73)
Transfer	-0.001	(-0.06)	0.025***	(4.33)
Prior AMI	-0.041***	(-10.86)	-0.114***	(-30.22)
Peripheral Vascular disease	0.086***	(19.03)	0.016***	(4.02)
Dementia	0.066***	(5.16)	-0.005	(-0.31)
COPD	0.108***	(26.91)	0.088***	(22.79)
Rheumatologic disease	0.036***	(5.69)	-0.039***	(-6.92)
Liver disease (mild)	0.088***	(4.89)	0.148***	(7.98)
Diabetes (mild/moderate)	0.006**	(2.24)	-0.046***	(-16.59)
Diabetes w/complications	0.172***	(28.54)	0.064***	(13.27)
Kidney Disease	0.381***	(31.33)	0.465***	(32.11)
Any malignancy	0.039***	(6.37)	-0.030***	(-7.30)
Liver disease (moderate/severe)	0.382***	(7.93)	0.490***	(12.02)
Metastatic solid tumor	0.278***	(18.82)	0.145***	(8.44)
Multivessel PTCA	0.115***	(25.75)		
Stent Insertion	0.173***	(17.01)		
Constant	9.43***	(63.62)	10.193***	(168.49)
Number of obs.	923725		743172	

*statistical significance at 10% level; **statistical significance at 5% level; ***statistical significance at 1% level

Table 4: Regression Estimates, Determinants of Statewide Procedure Volume

	ln(PTCA Volume)				ln(CABG Volume)			
	Fixed Effects		1 -Difference		Fixed Effects		1 -Difference	
yrsnoCON	-0.038***	(-3.82)	-0.022	(-1.69)	-0.016***	(-3.54)	-0.014*	(-1.78)
log(pop65+/sqmile)	0.376	(0.54)	0.307	(0.48)	1.194***	(4.81)	1.482***	(2.89)
HMO penetration rate	-0.307	(-0.99)	0.027	(0.15)	0.268	(1.22)	0.184	(1.31)
smoking rate	1.228	(1.47)	0.828**	(2.38)	0.757	(1.35)	0.318	(0.96)
per capita income	3.0e-.05	(1.40)	1.71e-05*	(1.89)	1.37e-06	(0.14)	-2.83e-08	(-0.01)
rate uninsured	-0.293	(-0.32)	-0.094	(-0.43)	-0.758	(-1.38)	-0.132	(-0.47)
1989	0.108***	(2.43)			0.009**	(0.27)		
1990	0.294***	(3.86)	0.070	(1.45)	0.084**	(2.42)	0.058*	(1.82)
1991	0.414***	(4.61)	0.010	(0.30)	0.138***	(2.86)	0.058**	(2.11)
1992	0.532***	(4.38)	-0.003	(-0.09)	0.217***	(4.20)	0.058	(1.57)
1993	0.610***	(4.35)	-0.042*	(-1.42)	0.187***	(2.93)	-0.039	(-1.15)
1994	0.721***	(4.98)	-0.008	(-0.36)	0.214***	(3.64)	0.028	(0.81)
1995	0.841***	(5.10)	-0.003	(-0.12)	0.287***	(4.06)	0.062**	(2.29)
1996	0.918***	(4.61)	-0.044	(-1.40)	0.340***	(4.42)	0.053*	(1.90)
1997	0.972***	(4.20)	-0.081**	(-2.69)	0.329***	(3.60)	-0.013	(-0.50)
1998	1.043***	(3.94)	-0.043	(-1.57)	0.289***	(2.97)	-0.038	(-1.19)
1999	1.058***	(3.83)	-0.094***	(-2.72)	0.266***	(2.42)	-0.025	(-0.83)
2000	1.090***	(3.49)	0.063**	(-2.52)	0.231*	(1.92)	-0.028	(-0.74)
2001	1.163***	(3.55)	-0.031	(-0.90)	0.174	(1.35)	-0.060**	(-2.13)
2002	1.210***	(3.54)	-0.053**	(-2.06)	0.125	(0.97)	-0.053	(-1.66)
constant	6.446	(3.01)	0.118***	(3.86)	4.939***	(6.23)	0.001	(0.03)
Exogeneity test	F(6,20)=0.81		F(6,20)=2.75**		F(6,20)=13.60***		F(6,20)=1.93	
Obs.	146		125		146		125	
# states	21				21			

*statistical significance at 10% level; **statistical significance at 5% level; ***statistical significance at 1% level.

APPENDIX A

Reprinted from Working Paper: Cardiac Surgery and Therapeutic Catheterization Services, Maryland Health Care Commission*

Table B1. Status of CON Regulation of Cardiovascular Services by State

CON Program		
Cardiac Covered (28)	Cardiac Not Covered (8)	No CON Program (15)
Alabama		
Alaska		
Connecticut		
Delaware		
District of Columbia		
Florida		
Georgia		
Hawaii		
Illinois		
Iowa		
Kentucky		
Maine		
Maryland		
Massachusetts		*Arizona (1985)*
Michigan		*California (1987)*
Mississippi		*Colorado (1987)*
Missouri		Idaho (1983)
New Hampshire		Indiana (1998)
New Jersey		*Kansas (1985)*
New York		Louisiana
North Carolina	Arkansas	Minnesota (1984)
Rhode Island	Montana	New Mexico (1983)
South Carolina	Nebraska	North Dakota (1995)
Tennessee	Nevada	*Pennsylvania (1996)*
Vermont	Ohio	South Dakota (1988)
Virginia	Oklahoma	*Texas (1985)*
Washington	*Oregon*	*Utah (1984)*
West Virginia	*Wisconsin*	Wyoming (1985)

*States in the AHRQ NIS dataset are italicized.

APPENDIX B
Summary Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
Year	2389	1994	3.66	1988	2000
Hospital PTCA Volume	2367	450.69	431.49	6	3035
Hospital CABG Volume	2195	381.18	321.64	6	2195
yrsnoCON	2389	3.10	4.68	0	17
County Pop 65+/sq mile	2187	272.93	571.35	8.96	6760.21
County HMO pen. rate	2389	0.26	0.16	0	0.91
State smoking rate	2389	0.23	0.02	0.13	0.29
State per capita income	2389	24240.20	7119.49	12027	92378.48
State percent uninsured	2389	0.17	0.05	0.08	0.28
RAMR (PTCA)	2367	0.018	0.024	0	0.73
RAMR (CABG)	2195	0.046	0.026	0	0.31
Cost per Patient (PTCA)	930,327	$11,830	$9,983	$1001	$798,945
Cost per Patient (CABG)	744,156	$27,180	$21,748	$1003	$1,696,385

Population figures were obtained from the U.S. census bureau. HMO penetration rates were obtained from Douglas Wholey at the University of Minnesota. Smoking rates were obtained from the Center for Disease Control's Behavioral Risk Factor Surveillance System. State per capita income was obtained from the Bureau of Economic Analysis. The percent uninsured was obtained from the March Current Population Surveys.

Appendix C

Alternative Specifications of the Association between Years since CON Repeal and Procedure Volume

	Hospital Procedure Volume				Statewide Procedure Volume			
	ln(PTCA Volume)		ln(CABG Volume)		ln(PTCA Volume)		ln(CABG Volume)	
	coefficient	t-statistic	coefficient	t-statistic	coefficient	t-statistic	coefficient	t-statistic
yrsnoCON	-0.023	(-0.65)	-0.012	(-0.48)	-0.063***	(-3.06)	-0.020*	(-1.84)
yrsnoCON^2	-0.001	(-0.27)	-0.001	(-0.41)	0.001	(1.36)	-0.0003	(0.61)
yrsnoCON	0.044	(0.65)	-0.037	(-0.79)	-0.037	(-1.34)	-0.003	(-0.22)
yrsnoCON^2	-0.011	(-1.06)	0.003	(0.47)	-0.002	(-0.65)	-0.002	(-1.22)
yrsnoCON^3	0.0004	(0.96)	-0.0002	(-0.54)	0.0001	(1.16)	0.0001	(1.33)
tertile 1‡	-0.021	(-0.87)	-0.028	(-1.58)	-0.046***	(-3.98)	-0.020**	(-2.75)
tertile 2	-0.022	(-0.65)	0.019	(0.77)	0.006	(0.31)	0.004	(0.40)
tertile 3	0.024	(0.42)	-0.039	(-1.10)	0.042	(1.47)	0.010	(0.58)
F-test†	F= 0.22	p= 0.806	F= 0.65	p= 0.524	F= 1.51	p= 0.245	F= 0.35	p= 0.711
quartile 1±	-0.014	(-0.47)	-0.017	(-0.82)	-0.045***	(-3.33)	-0.018**	(-2.33)
quartile 2	-0.023	(-0.43)	-0.023	(-0.71)	-0.003	(-0.12)	-0.004	(-0.34)
quartile 3	-0.004	(-0.08)	0.043	(1.42)	0.032**	(2.81)	0.017	(1.31)
quartile 4	0.022	(0.25)	-0.077	(-1.53)	0.022	(0.86)	-0.002	(-0.11)
F-test†	F= 0.17	p= 0.915	F= 1.02	p= 0.382	F= 4.55	p= 0.014	F= 0.66	p= 0.588

*statistical significance at 10% level; **statistical significance at 5% level; ***statistical significance at 1% level.
§All alternative specifications of yrsnoCON include the same set of explanatory variables reported in Tables 1 and 4.
‡ Tertile cutoffs are 8 and 14 years without CON for hospital procedure volume and 6 and 11 years without CON for statewide procedure volume.
±Quartile cutoffs are 7, 12, and 15 years without CON for hospital procedure volume and 5, 8, and 12 years without CON for statewide procedure volume.
†F-test for the joint significance of the coefficients on the 2 highest tertiles or 3 highest quartiles.