2012

Three Essays on Entry, Volume and Outcomes in Hospital Markets

Suhui Li
Lehigh University

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by
Suhui Li

Presented to the Graduate and Research Committee
of Lehigh University
in Candidacy for the Degree of
Doctor of Philosophy
in
Economics

Lehigh University
April, 2012

Certificate of Approval

Approved and recommended for acceptance as a dissertation in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Economics.

Date

(Signature)

Dissertation Advisor: Shin-Yi Chou

Accepted Date

Committee Members:

(Signature)

James A. Dearden

(Signature)

Mary E. Deily

(Signature)

Yang Wang

Acknowledgements

I would like to express my appreciation to my dissertation committee chair, Dr. Shin-Yi Chou. This dissertation would not have been possible without Dr. Chou, who not only served as my advisor but also encouraged and supported me throughout my academic program. I owe my deepest gratitude to her hard work and excellent guidance.

I am grateful to my committee members, Dr. James A. Dearden, Dr. Mary E. Deily, and Dr. Yang Wang, who were dedicated to supporting my dissertation and many other research projects. I truly appreciate their time and efforts. I would like to extend my gratitude to Dr. Chad Meyerhoefer, Dr. Ernest Lai, and Dr. Jason Hockenberry for generously sharing their experience and providing constructive feedbacks on my work.

I would also like to thank everyone in the Department of Economics. A special thank of mine goes to the department coordinator, Rene Hollinger, who is always so helpful on every detail, from printing a letter to organizing department lunch seminars.

Most of all I wish to thank my family, especially my husband, Le Yin. I am sure I would never be able to make this without his undivided support. Thank you once again.

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Abstract

This dissertation studies the hospital markets in Pennsylvania from three different perspectives. The first chapter examines the consequences of hospital entry in the Pennsylvania cardiac surgery market, which experienced substantial entry after the Certificate of Need (CON) state regulation was repealed in 1996. Results suggest that hospital entry was associated with increased surgery rates. The consequent increase in total costs, however, was offset by the fact that entry led to significantly lower cost per surgery and slightly improved patient outcomes. A welfare analysis implies that free entry in the Pennsylvania cardiac surgery market was welfare improving.

The second chapter investigates the influence of local medical resources on racial disparities in surgery use. The study documents the incidence of the use of coronary artery bypass graft (CABG) and percutaneous coronary intervention (PCI) procedures among Medicare patients who were initially diagnosed with acute myocardial infarction (AMI) from 1995 through 2006. A multilevel statistical analysis reveals that, conditional on individual characteristics, black patients were more likely to live in counties with lower CABG rates and higher PCI rates for both black and white populations. Consequences of inadequate medical resources may be particularly exacerbated for blacks, compared with whites.

The third chapter explores the reasons for an observed positive relationship between hospital procedure volume and surgical outcomes. Results from multivariate logistic regressions show that patients being treated by high-volume surgeons have lower risk-adjusted in-hospital mortality than those treated by low-volume surgeons, regardless of the procedure volume of admission hospital. These results imply that under the

national trend of decreasing hospital CABG volumes, more attention should be paid to build the volume of operating surgeons with the goal of ensuring surgical quality in low-volume CABG hospitals.

1 The Welfare Effects of Free Entry: Evidence from the Pennsylvania Cardiac Care Market

1.1 Introduction

Economists typically believe that free entry, although desirable to consumers, can lead to social inefficiency (Chamberlin 1933; Spence 1976; Dixit and Stiglitz 1977; Mankiw and Whinston 1986). In a free-entry market, firms continue to enter the market as long as their accrued profits exceed the cost of entry, failing to recognize that part of their business is stolen from existing firms. In the extreme case where new products are perfect substitutes of existing products, the marginal entrant creates zero welfare while it adds fixed set-up costs, causing social welfare to decline. On the other hand, if new products are imperfect substitutes for existing products, entry will introduce more product variety, causing social welfare to rise. In general, whether free-entry is socially efficient depends on the extent to which entry expands market demand or increases product differentiation.

This paper studies the welfare impact of entry in the cardiac surgery market in Pennsylvania, where entry occurred rapidly following the repeal of Certificate of Need (CON) regulation in 1996. An issue central to debate over CON policy is that although hospital competition may be beneficial to consumers, the substantial costs of hospital setting up intensive beds and building new facilities can exceed the benefits of competition, causing entry to be socially wasteful. Another concern stems from the potential volume-outcome effect widely documented in the literature of health care (Birkmeyer, Siewers et al. 2002; Birkmeyer, Stukel et al. 2003; Shahian 2004). It is less considered, however, about whether entry affects aggregate demand and differentiation by hospitals. Rises in the supply of surgeries may expand the market demand via increasing access to surgery, affecting the referral recommendation patterns, and lowering barriers to care for sicker patients. Additional social benefits may arise from an enlarged choice set of hospitals, shorter travel distances for treatments (spatial differentiation), and better matches of patients to hospitals (quality differentiation). The extent of spatial and quality heterogeneity in hospital markets suggests that, a free-entry policy, at least in theory, is likely to be welfare improving. Consideration of these market responses to entry may substantially alter the conclusion on the welfare impact of CON policy.

To study the welfare impact of entry, I first estimate a hospital-choice model that captures the impact of individual characteristics, hospital quality and travel distances on the hospital admission decision. Using the parameter estimates obtained from the hospital-choice model, I predict the market share held by cardiac surgery programs that opened after the repeal of CON. An attractive feature of this approach is that hospitals are not constrained in any pre-defined geographic markets, making the estimated entrant share uncorrelated with unobservable patient preferences which potentially cause endogeneity problems. I then exploit the variation in entrant market share to quantify the market-expansion and the business-stealing effects. I further explore the impact of entry on patient outcomes and surgery costs. Finally, I examine how the entry of new surgery programs affects hospital differentiation from three aspects at the hospital level: the average patients' traveling distance for treatment, the dispersion in patient illness severity during admission, and treatment expenditures. The first variable measures the extent of horizontal (spatial) differentiation, and the latter two variables measure the extent of vertical (quality) differentiation.

I find robust evidence that the entry of new hospitals was associated with both market-expansion and business-stealing. That is, entry led to increased rates for coronary artery bypass graft (CABG) and percutaneous coronary intervention (PCI) procedures among coronary artery disease (CAD) patients, and decreased surgery rates at incumbent hospitals. Further, the business-stealing induced by entry was much more pronounced among relatively healthier CAD patients. Higher entrant share was associated with lower in-hospital mortality rates and substantial cost-savings, suggesting improved hospital efficiency. There is some evidence that the efficiency gain may be derived from enhanced hospital differentiation. Based on a back-of-the-envelope calculation, the welfare gain from demand-expansion and cost-saving is substantially higher than the total fixed costs paid by new entrants since 1997, suggesting that the repeal of CON was social welfare improving.

The rest of the paper proceeds as follows. Section 1.2 discusses institutional background behind CON laws. Section 1.3 summarizes existing empirical studies on the effects of free entry. Section 1.4 outlines a simple model of free entry in a heterogeneous-product market to illustrate the importance of considering market expansion and hospital diversification. Section 1.5 presents the data and summary statistics. Section 1.6 describes the empirical models for identifying the presence of market expansion and business-stealing effects, and the impact of entrant share on patient surgical outcomes and costs, as well as on hospital differentiation. Section 1.7 presents the empirical results. Section 1.8 discusses the welfare impact of the CON repeal in Pennsylvania. Section 1.9

concludes.

1.2 Background

Federally mandated in 1974, the Certificate of Need program required individual states to review requests for the construction, expanding, and major medical equipment acquisition of health care facilities[1]. This regulation was originally implemented in an attempt to curb rising health care costs and promote quality of care by limiting unnecessary utilization of resources and excessive service provision. In the 1980s, critics pointed out that these state-sponsored programs did not meet the goal because they would reduce price competition among certified facilities, keeping the prices high and limiting the access to care. With the same concern, the federal government ended congressional funding for the CON program in 1987. In the decade that followed, 14 states discontinued their CON Programs. In Pennsylvania the state CON programs were discontinued in December of 1996, essentially allowing free entry into a broad range of hospital services.

Two features of the cardiac surgery market in Pennsylvania suit it well for the empirical study on the impacts of free entry. First, the cardiac care industry is characterized by high profit and high fixed costs. Cardiovascular disease is the largest single component of hospital expenditures in the country. Revenue from patients undergoing cardiac surgeries represents an extremely high proportion of total revenue for hospitals. Therefore, deregulation of the cardiac surgery market is likely to attract entry and at the same time, to incur nontrivial social costs in new facilities and equipment. It is

[1] Facilities and services regulated by CON majorly included hospitals, ambulatory surgical centers, nursing homes, and new surgical services such as open heart surgery, cardiac catheterization, neo-natal intensive care, and organ transplants.

documented that the setup cost of a CABG program was between $12 million and $14 million (Robinson, Nash et al. 2001; Huckman 2006). Yet very little is known about how much patient welfare these investments have turned into.

Second, cardiac surgery hospitals are highly differentiated in both specialty and geographic locations. In most homogeneous-product markets, competition leads to socially excessive entry,[2] but it may not be the case for the cardiac surgery market. Most cardiac surgery hospitals specialize in either or both treatments: coronary artery bypass graft surgery[3] (CABG) and percutaneous coronary interventions[4] (PCI). Patients who are more appropriate for CABG procedure tend to seek hospitals that specialize in CABG procedures, while those who are more appropriate for PCI procedures tend to receive treatments at hospitals that specialize in PCI procedures. Consequently, the cardiac surgery market has a potential for hospitals to specialize in different types of patients in terms of clinical indications and illness severity. Furthermore, previous studies consistently find that travel distance is one of the most important determinants of patients' hospital choice (Luft, Garnick et al. 1990; Tay 2003), suggesting that reduced travel distance, resulting from entry, improves patient welfare. Since these effects are not captured in a simple model for homogeneous-product markets, it is an empirical question whether free entry in the cardiac surgery market leads to increased or decreased social

[2] The critical insight of this literature is that because potential entrants ignore the negative externality on incumbent firms' revenues when making entry decisions, a free-entry industry may incur too many entry costs which offset incremental gains in consumer surplus generated through enhanced competition. See Chamberlin (1933), Spence (1976), Dixit and Stiglitz (1977), and Mankiw and Whinston (1986) for details.
[3] The CABG procedure involves surgically isolating a section of vein or artery and grafting it to create a bypass of blockage in the coronary artery. It was developed in the late 1960s and entered mainstream use in the United States during the 1970s, largely performed on patients whose indications represent a significant risk of heart attack.
[4] The PCI procedure involves only a small incision through which a balloon-tipped catheter is threaded and inflated within the coronary artery to improve the blood supply. The outcome of PCI was largely improved with the introduction of stent technology during the mid-1990s, making PCI more substitutable with CABG for patients with relatively severe CAD. PCI is less invasive compared to CABG, and thus more often performed on patients with relatively mild CAD.

welfare.

Figure 1-1 depicts the trend of new cardiac surgery program openings since Pennsylvania repealed its CON in the end of 1996.[5] Five programs entered immediately after the repeal, increasing the total number of providers from 43 to 48. By 2004 there were total of 28 post-CON entrants, accounting for 42% of all hospitals providing cardiac surgeries in Pennsylvania. The majority of entry occurred in urban or sub-urban areas. In contrast to the fact that all incumbent hospitals were performing both types of surgeries, new providers entered the market with differentiated preference on treatment. For example, among the six new entrants during 2003 and 2004, only one entrant was providing both procedures while the other five were providing only PCI procedures. Such trend is suggestive that the cardiac surgery markets in Pennsylvania may be evolving toward greater degree of specialization with the entry of new programs.

1.3 Previous Literature

A few empirical papers on entry efficiency focus on the cross-sectional market competitive responses to entry. Based on the entry model developed by Bresnahan and Reiss (BR)[6], Berry and Waldfogel (1999) examine the entry efficiency by employing data on market shares and prices in radio broadcasting markets. They conclude that due to the

[5] I infer participation in the cardiac surgery market by aggregating the discharge data to the hospital level, and observing the number of procedures done at each hospital. CABG and PCI procedures are treated as separate markets. A hospital is considered to be “in” the market for CABG (PCI) in any particular year if it performed at least 5 CABGs (PCIs) in that year. Such criteria are previously used in the study by Kessler, McClellan (2000) and Kessler, Geppert (2005).

[6] Bresnahan and Reiss (1990, 1991) model firms’ entry decision as the equilibrium outcome of a discrete game played between potential entrants. The general entry condition suggests that as intensified competition shrinks profit margin, entrants need a larger population to generate enough revenue to cover fixed entry costs. Thus examining the relationship between the number of firms and the market size allows the authors to determine whether additional firms generate additional revenue or just steal business from incumbent rival firms.

substitute pattern among radio stations, entry resulted in substantial business stealing, and that there was socially excessive entry into radio broadcasting. More recently, Abraham et al. (2007) analyze entry in the hospital industry with an extension of the BR framework[7]. They provide evidence that entry leads to a significant increase in competition, which in turn results in decreased hospital profits, expanded market demand, and increased quality. A limitation on this cross-sectional literature is that it does not offer evidence on market responses to entry overtime.

Two recent papers, Davis (2006) and Cutler et al. (2010), improve upon previous research using longitudinal data to learn about the welfare impact of entry. In examining the U.S. movie theater markets in the 1990's, Davis finds evidence for both business stealing and market expansion effects of entry. In particular, the magnitude of business stealing depends largely on the entrant theater's size and location relative to incumbents, highlighting the extent to which horizontal differentiation relaxes competition.

This paper is most similar to Cutler et al. (2010), who use PHC4 data to study the changes in patient volume of CABG surgeons in Pennsylvania during the post-CON period. The authors hypothesize that hospital entry will increase the demand of high-quality surgeons whose labor supply is relatively inelastic. The higher the entrant share, the high the volume will be shifted to those high-quality surgeons. This hypothesis assumes that patients first decide which hospital to visit and then choose their surgeons within the hospital. More commonly for CABG procedures, however, it is the surgeons that refer their patients to the admitting hospitals. This means that entrant hospitals should have the incentive to hire high-volume surgeons in order to increase their market

[7] The authors relaxed the assumption of "equal fixed costs" in the traditional BR model, and separately identify the changes in the toughness of competition from the changes in fixed costs due to entry.

shares. As a consequence, the entrant share may itself be an outcome, rather than a cause, of patient distribution across surgeons. Furthermore, given the fact that CABG and PCI both are major procedures performed at cardiac surgery centers, to provide a thorough welfare analysis of free entry in cardiac surgery market, both CABG and PCI markets need to be examined.

This paper contributes to the literature in several ways. First, by using an individual-level longitudinal dataset, I provide direct observation on the short-term and long-term demand responses to entry. Second, by estimating entrant market share with exogenous variations (i.e., distances between patients and hospitals), I circumvent the concern that market share is endogenously correlated with unobserved hospital and patient characteristics. Third, I exploit differences across hospitals in the dispersion of the patient population to see whether entry affects differentiation by hospitals. Furthermore, by conducting analysis on both CABG and PTCA procedures, this paper provides a more comprehensive evaluation on the welfare consequences of free entry in the cardiac surgery market. Lastly, by investigating the changes in patient health outcome and treatment costs, this paper also supplements the research on the effects of CON regulations on medical expenditures and quality of care.[8]

1.4 A Model for Free Entry

In this section I lay out the standard theory of entry based on the work by Mankiw

[8] Broadly speaking, this literature finds conflicting evidence on the effects of CON. For example, Robinson et al.'s (2001) study of the short-term impact of the termination of cardiac CON in Pennsylvania finds no evidence that the removal of CON affects the inpatient mortality rate of CABG. Ho et al.'s (2009) cross-states study finds evidence that the removal of CON regulations leads to lower CABG mortality. In contrast, the study by Vaughan-Sarrazin et al. (2002) finds that risk-adjusting in-hospital mortality was 22\% lower among CABG patients in states with continuous CON versus states with no CON.

and Whinston (1986). Consider a monopolistic competition market where the services provided by hospitals are imperfect substitutes for patients. Let the set-up costs for a new cardiac program be constant K, and the cost function be $c(q)$, where q denotes the number of procedures performed, and $c(0) = 0, c'(\cdot) > 0, c''(\cdot) \leq 0$ for all $q \geq 0$. Specify the total patients' utility to be of the form

$$u = G\left[\sum_{i=1}^{N} f(q_i)\right],$$

where q_i is the number of patients who receive surgery at hospital i, $f(q_i)$ is patients' utility generated by hospital i , and N is the total number of hospitals in the market. It is assumed that $f(0) = 0, f'(q) > 0$, and $f''(q) \leq 0$ for all $q \geq 0$ and that $G'(z) > 0$, and $G''(z) \leq 0$ for all $z \geq 0$. These concavity assumptions imply that the total utility increases when a given quantity patient flow is spread over more hospitals. That is, patients prefer variety.[9]

Assuming that the equilibrium is symmetric, the objective of the social planner in this market is therefore to solve

$$\max_{N}(N) = G[Nf(q_N)] - Nc(q_N) - NK,$$

where q_N is the equilibrium volume per hospital, given that N hospitals enter the market.

By differentiating the expression for social surplus, $W(N)$, with respect to the total number of hospitals N, we have

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[9] Proof: Since f is a concave function, $f(q_1) + f(q_2) = f\left(\frac{q_1}{(q_1+q_2)}(q_1 + q_2)\right) + f\left(\frac{q_2}{(q_1+q_2)}(q_1 + q_2)\right) \geq \frac{q_1}{(q_1+q_2)} f(q_1 + q_2) + \frac{q_2}{(q_1+q_2)} f(q_1 + q_2) = f(q_1 + q_2)$. Given that G is also a concave function, $G(f(q_1) + f(q_2)) \geq G(f(q_1 + q_2))$.

$$W'(N) = G'\left\{Nf'\frac{\partial q_N}{\partial N} + f\right\} - c(q_N) - Nc'(q_N)\frac{\partial q_N}{\partial N} - K.$$

Now consider the entrant's problem. Under free entry, hospitals enter until profits are driven to zero. Therefore, the market-equilibrium number of hospitals N meets the condition

$$\pi_N = 0$$

Note that when N hospitals have entered the market, the inverse demand function for all hospitals can be written as[10]

$$P(N) = G'[Nf(q_N)]f'(q_N).$$

Thus the equilibrium profits per hospital can be expressed as

$$\pi_N = G'[Nf(q_N)]f'(q_N)q_N - c(q_N) - K.$$

Rearranging terms and plugging π_N into the expression for $W'(N)$ yield

$$W'(N) = \pi_N + [G'f' - c']N\frac{\partial q_N}{\partial N} + G'[f - f'q_N].$$

When the market reaches a free-entry equilibrium (i.e., $\pi_N = 0$), whether social surplus is maximized is determined by the second and third term on the right-hand side. $[G'f' - c']$ in the second term represents hospitals' marginal profit when there are N hospitals, and is assume to be greater than zero. The second term thus illustrates the business-stealing effect: it is negative as long as the per-hospital volume declines in N (i.e., $\frac{\partial q_N}{\partial N} < 0$). The marginal entrant causes all existing hospitals to contract their volumes, resulting in a reduction in social surplus equal to $[G'f' - c']N\frac{\partial q_N}{\partial N}$. The third term represents the differentiation effect: it is positive because patients prefer variety[11]. It

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[10] Again, the assumption of symmetric equilibrium applies here.

[11] Proof: The first derivative of $f - f'q_N$ equals to $-f''q_N$, which is positive because $f'' < 0$. And because $f(0) = 0$, the term $f - f'q_N$ equals 0 when $q = 0$. Taken together, $f - f'q_N$ must be positive for all $q_N > 0$. Given that $G' > 0$, the third term is therefore positive.

demonstrates the fact that the marginal entrant increases the total patient surplus by $G'f$, but does not fully capture this increase in its revenue, $G'f'q_N$.

Since these two effects drive the free-entry equilibrium away from the social optimum in opposite directions, no clear theoretical prediction can be made on the overall welfare consequence of free-entry. That the entry of a new hospital creates negative externality on existing hospitals' profits suggests that free-entry leads to more hospitals than socially optimal. An extreme case of pure business stealing with no differentiation effect can be illustrated in Figure 1-2-A, where all hospitals produce homogeneous services and the market demand does not respond to entry. Therefore, the social surplus remains area *ABCD* following the entry. As demonstrated in Figure 1-2-B, the profits of the $(N + 1)$th hospital entirely comes from squeezing other hospitals' demand. Each hospital faces a downward-shifted demand and hence a reduction in profits equal to the area of rectangle *abcd*. Consequently, entry of the $(N + 1)$th hospital simply imposes a social cost equal to the N multiplied by the area of *abcd*.

Now consider an opposite extreme case of zero business-stealing in Figure 1-3. Figure 1-3-B demonstrates the situation where there is a sufficient rise in aggregate demand following the entry of hospitals, so that existing hospitals' volumes are not affected ($d_N = d_{N+1}$). Correspondingly in Figure 1-3-A, the original market demand curve is D_N, with total social surplus of area *ABCD.* Suppose that entry increases the total demand to D_{N+1}. If we also assume that price stays the same, then entry of the $(N + 1)$th hospital would produce additional social welfare benefits given by polygon *CBAFE*. The business-stealing effect vanishes and the variety-effect is positive, thus $W'(N) > \pi_N$, meaning that π_N is negative at social optimum. In this case, free-entry will provide fewer hospitals than the socially optimal number of hospitals. A social planner would have to subsidize entry in order to provide sufficient variety in the market.

The conclusions of this model can vary according to the change in the underlying assumptions of hospitals' behavior, and the functional forms of patients' utility and hospitals' profits. For example, Spence (1976) has shown that when there is some degree of freedom and all products compete equally with other products[12], product-variety is always stronger than business-stealing, which means that free entry results in insufficient entry. However, Koenker and Perry (1981) note that with the same patient utility and hospital production function in Spence (1976), post-entry collusion between hospitals may make room for excessive entry.

Despite the uncertainty in the conclusions of the theoretical model, we can still derive some empirical implications on free-entry policies in the hospital industry. First, as illustrated by the second example above, the repeal of the CON program, which is a move from entry-control to free-entry, can be welfare improving if entry results in demand expansion.

A second implication that follows immediately is that incumbent hospitals are likely to lose more healthy patients if hospital substitutability leads to a stronger business-stealing effect. It is reasonable to believe that for relatively healthy patients, hospitals are relatively more substitutable because these patients are usually on a non-emergency basis and thus have more time to seek for care among hospitals. Also, hospital reputation may be less important for healthy patients, as they usually need fewer high-intensity treatments which require highly specialized surgical teams affiliated with

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[12] In Spence (1976)'s setting, individual firm's demand function is $f = q^{\beta}$. The cross-price elasticity of demand is a constant $1/(1-\beta)$. In the case of substitutes, β ranges between 0 and 1, and each hospital treats the aggregate market volume as given (i.e., G' is exogenous of q).

existing hospitals. Although the impact of demand substitutability on the business-stealing effect is ambiguous in the theory model[13], it can be empirically tested by comparing the demand responses to entry between relatively healthier and relatively sicker patients.

Third, free entry may lead to hospital differentiation in various dimensions. Hospitals are horizontally differentiated according to geographic location. Previous studies consistently find that travel distance is one of the most important determinants of hospital choice (Tay 2003; Luft et al. 1990), especially when travel time increases risk of mortality and medical care is needed urgently.[14] Consequently, patients are expected to travel less to hospitals as new entrants introduce more hospital variety on the geographic dimension. Furthermore, since prices are either highly regulated or not fully observed by insured consumers, hospitals will resort to other aspects to attract patients. Thus free entry may lead to increased specialization as hospitals seek to dampen quality competition by making their services less substitutable. For example, hospitals need to decide whether they should specialize in care for relatively healthy patients or patients with more complications. They also need to consider, with the constraint of a limited budget, whether they should improve both CABG and PCI programs or specialize in a particular procedure. These decisions are likely not only to affect hospitals' costs, but also their patient mix. As some hospitals specialize in treating sicker patients and others specialize in treating healthier patients, the with-in hospital dispersion of patient severity and utilization is likely to decline following entry.

[13] Mankiw and Whinston (1986) notes that demand substitutability is neither a necessary nor a sufficient condition for the presence of a business-stealing effect.

[14] Although a large portion of CABG and PCI patients are admitted on a non-emergency basis (such as referred by a physician or transferred from another hospital), about 40 percent patients in Pennsylvania seek for treatment at their closest hospital performing cardiac surgeries.

Overall, we can conclude from this model that whether the free-entry policy is socially desirable depends crucially on how substitutable hospitals are to patients. Excessive entry is likely to rise when hospital differentiation is weak relative to business stealing. However, if patients care more about hospital differentiation, the loss of social welfare due to business stealing is likely to be offset by the social benefits from increased hospital differentiation.

1.5 Data and Descriptive Statistics

1.5.1 Data

The empirical analysis primarily uses detailed patient-level longitudinal data from the Pennsylvania Health Care Cost Containment Council (PHC4). Pennsylvania repealed its CON law in December, 1996. I use the inpatient records from 1997 to 2004– 8 years after the deregulation of the state's cardiac surgery market. The data set provides a wide range of patient information including age, race, and gender, diagnosis/procedure codes, admission source, and insurance type, zip code of residence, total in-hospital charges, and length of stay. In addition, the data set identifies the hospital associated with each admission record, with which I link the patient data with comprehensive hospital characteristics obtained from the American Hospital Association (AHA) *Annual Survey of Hospitals*. Hospital location, bed capacity, teaching status, ownership, and system member status variables are used in the analysis.

As a proxy of each hospital's overall quality of cardiac care, in-hospital mortality ratings are collected from Pennsylvania Cardiac Surgery Reports[15]. In each period, hospitals are categorized into four groups according to whether a hospital has performed above 30 CABG surgeries, and if yes, whether the actual mortality rate was significantly higher, lower than, or equal to the risk-adjusted mortality rate.[16]

The patient sample includes individuals admitted to any hospital in Pennsylvania with a new diagnosis of CAD. Patients hospitalized for the same diagnosis in the previous three years are excluded. Also omitted are patients who reside outside of Pennsylvania, traveled farther than 80 miles for care, or for whom zip code information is not available.[17] These restrictions yield a final sample of 580,255 CAD patients.

The patient-level analysis centers on four outcomes: (i) whether an individual patient received CABG surgery or PCI within one quarter after admission for CAD;[18] (ii) all-cause mortality during the hospital stay for the surgery; (iii) Readmission for cardiac complication including heart failure, post surgical infection, and any other cardiac reasons[19] in the year following the surgery[20]; and (iv) the total costs of utilization during

[15] These reports are published by PHC4, including in-hospital or 30-day mortality rates, 7- or 30-day readmission rates, and post-surgical length of stay for hospitals and surgeons who performed CABG surgery on adult patients in a given period. Five reports were issued during the study period, and can be found on PHC4's Web site at www.phc4.org.

[16] New hospitals were usually not rated immediately. For example, a hospital that entered in the middle of 2001 would not appear in 2000's report. It might not appear in 2001's report either because of too few operations performed in 2001. In these cases the hospital will be categorized as "not rated".

[17] This accounts for 8% of the entire sample period.

[18] Procedure codes for CABG: ICD-9-CM 3610-3619. Procedure codes for PCI: ICD-9-CM 3601, 3602, 3605, 3606, 3607, and 3609. Diagnosis codes for CAD: ICD-9-CM 410x-414x.

[19] Heart failure (ICD-9-CM 428x) and post surgical infection (ICD-9-CM 9985) are the most common causes of readmissions following CABG procedure. Other cardiac reasons (ICD-9-CM 410x-413x) are included in order to capture all the potential adverse outcomes due to the surgeries.

[20] Measures of readmission are obtained by abstracting data on the principle diagnosis for all subsequent hospital visits, not counting transfers and readmissions within 3 months of the index admission.

hospital stay for the surgery[21].

1.5.2 Descriptive Statistics

Table 1-1 presents the descriptive statistics for patient outcomes and characteristics for the entire sample as well as for subsamples of CABG and PCI patients. The first column shows that 50% of hospitalized CAD patients in the study period received either CABG or PCI procedure within 3 month after admission. Over half of the CAD sample consists of Medicare patients, slightly less than half are admitted through an emergency department, and the majority live in urban counties. The next two columns show that CABG patients experience higher in-hospital mortality than PCI patients, while PCI patients are under greater risk of subsequent readmissions due to heart failure or ischemic heart diseases. CABG patients on average are more costly to treat, and stay in hospital for longer than PCI patients. The CABG patient sample consists of a larger share of elderly and severely ill (Charlson co-morbidity index ≥ 2) patients than the PCI population, and there are a higher proportion of CABG patients admitted with other fatal complications such as cardiogenic shock, hypertension, Congestive heart failure, diabetes, or renal failure. PCI patients are more likely to have received CABG or PCI procedure previously, although this group accounts for less than 2% of the PCI patient sample.

The hospital-level analysis uses outcome measures aggregated from the patient sample. For each CABG (PCI) hospital I calculate the average distances travelled by patients, the coefficient of variation (CV) of patient severity, and treatment intensity.

[21] Because the PHC4 data only records the total charge for each patient, a “listed price” rather than how much hospitals spend on patients, I calculate each patient’s costs by multiplying the patient’s total charges with the admitting hospital’s Medicare cost-to-charge ratio obtained from the Centers for Medicare & Medicaid Services (CMS).

Patient severity is measured by patient's Charlson co-morbidity index[22] and the patient's previous-year total in-hospital expenditures at admission. Treatment intensity is measured by the patient's total in-hospital expenditures during hospital stay. The CV serves as proxy of patient population heterogeneity; it is advantageous to standard deviation because it is free of the constant differences in patient severity and utilization among hospitals. The changes in these hospital-level statistics thus reflect the changes in hospital differentiation in geographic locations and specialization.

The descriptive statistics in Table 1-2 reflect some broad trends. The average distance between patients and admitting hospitals decreased by 12% (1.8 miles) during 1997 to 2004. The CV of in-hospital expenditures also decreased. Among hospitals, the average share of Medicare patients was increasing, while the shares of large, non-for-profit and teaching hospitals, and the share of hospitals that belonged to any health system were falling. Some of the newly opened cardiac programs with insufficient annual surgery volumes were not rated. The number of such facilities increased and then declined sharply, as the growing new programs finally reached the "gradable" threshold.

Figures 1-4 and 1-5 contrast the trends in 3-month rates of CABG and PCI procedure in Hospital Referral Regions (HRR) where entry occurred and where entry never occurred during 1997 to 2004. These rates are expressed as the number of procedures per 1,000 new CAD patients in the study sample. Figure 1-4 shows that despite the continuing entry of new surgery centers, CABG rates declined from about 20% in 1999 to 15% in 2004. The trends in regions that did and did not experience entry

[22] The Charlson co-morbidity Index contains 19 categories of co-morbidity, defined using ICD-9-CM diagnoses codes. Each category is assigned with a score ranging from 1 to 6; the higher the weight, the higher one-year mortality risk associated with the category (Charlson et al. 1987). A patient's Charlson index is the sum of these weights, reflecting the cumulative increased likelihood of dying during the follow-up year. In this paper, patient's Charlson index is calculated using STATA command "charlson".

almost overlapped with each other. However, CABG rates declined slightly slower in regions that experienced entry. Figure 1-5 shows a significantly and constantly higher rate of PCI in regions that experienced entry relative to in those that never experienced entry. It also shows a pronounced increase in the rate of PCI over time. The time-series is only suggestive, however, since it does not adjust for the time of entry and the number of entrants in different regions. The trends may as well be driven by underlying differences in medical practice patterns and population composition within each region.

1.6 Econometric Framework

1.6.1 Measure of Entrants' Market Share

The empirical strategy is to identify the impacts of entry using the variation in entrant hospitals' market share across markets and over time. Many previous studies calculate market share as the share of a hospital's total discharges over all discharges in the hospital's market (Krishnan 2001; Cutler 2010[23]). However, this measure may result in biased estimates of the impact of entry on market demand, costs, and health outcomes. First, it assumes that hospitals in the same geographic area are exposed to the same entrant share, which may lead to substantial measurement error. In fact, in urban areas many hospitals compete with only a few nearby entrants, while hospitals in rural areas with zero entrants are not necessarily unaffected by entry in other markets. Second, unobservable patient characteristics may be correlated with both entrant market share and

[23] For example, Cutler et al (2010) defines markets by the Hospital Referral Region (HRR). Each HRR comprises a group of zip codes within which people are referred for major cardiovascular surgical procedures and neurosurgery. There are 14 HRRs in the Pennsylvania, among which 5 had no cardiac surgery hospital by 2004.

surgery outcomes, causing bias in the estimated effects of entry on patient outcomes. For example, if unobservably sicker patients choose to go to better hospitals, which are usually located in urban areas with higher entrant share, the estimated impact of entry on patient outcome will be biased away from zero.

To address these potential sources of bias, I construct the predicted CABG and PCI entrant programs' share using a two-step method, analogous to the one developed in Kessler and McClellan (2000). I assign each patient with the entrant share at his/her zip code of residence. Thus each zip code area is a single market. CABG (PCI) entrant shares are calculated as the share of CABG (PCI) patients living in zip code area K who went to any new hospital for treatment.

First, I estimate patient-level hospital choice with a multinomial conditional logit model.[24] An individual patient's utility from going to a certain hospital is considered as a function of the individual's characteristics, the hospital's attributes, and relative distances between the hospital and the individual's closest alternatives in each attribute. These relative distances between hospitals capture the exogenous impact of travel costs on individual's hospital choice. The model is estimated by year for CABG and PCI patients separately, allowing the preferences over hospitals to vary over time and among patients seeking for different types of treatments. To address the problem that HMO/POS enrollees' hospital choices are constrained by their insurance plans, I estimate the model with a subsample including only Medicare enrollees, whose hospital choices are unrestricted. Estimated coefficients from the discrete-choice model are then applied to patients with all insurance types to predict the probability of patient i going to hospital j

[24] See the appendix for details of the conditional logit specification and the construction of predicted entrant share.

for CABG or PCI surgery. The assumption here is that Medicare patients have similar preference over hospitals with their HMO/POS counterparts conditional on diagnosis, home location, and other demographics. This assumption has been made several times in the existing literature.[25] Second, I estimate the patient flow from each zip code k to hospital j by summing up the predicted probabilities across hospitals and zip codes. Thus the entrant share in zip code k equals to the total predicted patient flow of all entrant hospitals divided by the total predicted patient flow in that zip code.

There are a couple of features about this method that address the potential concern of entrant market share. First, the method does not restrict individual's choice set within a discrete geographic area, and thus the expected entrant share captures not only the impact of entrants in one geographic area, but also the potential impact of entrants in nearby areas. Second, the hospital demand is predicted based only on observable, exogenous characteristics of patients, hospitals, and relative distances between alternative hospitals. Thus the predicted entrants' market share assigned to each patient is uncorrelated with unobservable attributes of individual patients and hospitals. Finally, measuring entrant share at the zip code level creates more variation in entrant share that facilities identification of entrants' impact.

1.6.2 Patient-level Analysis

The patient-level analysis compares changes in surgery incidence in markets where new entrants had a larger market share following the Pennsylvania CON deregulation to

[25] For example, Ho (2006) and Town and Vistnes (2001) use data on the hospital selection decisions of Medicare enrollees, assuming that the Medicare population's valuation of hospitals is a reasonable proxy for that of HMO/POS population.

markets where they had less market share. To test the market-expansion effect of new CABG hospitals (a similar analysis separately applies to PCI hospitals), I use the first-time CAD patient sample to estimate regressions of the form:

$$y_{ikt} = \alpha_k + \gamma_t + S_{kt}\beta + X'_{it}\eta + \epsilon_{ikt}, \quad (1)$$

where the dependent variable y_{ikt} equals to one if patient i from zip code k at time t received CABG (PCI) surgery within one quarter after admission to a hospital for CAD, α_k denotes zip-code fixed effects, γ_t denotes year fixed effects, and ϵ_{ikt} is an error term. To account for possible serial correlation over time within zip code areas, I allow for an arbitrary variance-covariance matrix in the error structure within each zip code area.

The key variables of interest are entrant share S_{kt}, a vector of indicators for whether the entrant share of CABG(PCI) procedures in zip code k at time t falls in either of the two categories: 10-25 percent or above 25 percent. The reference group is entrant share below 10 percent. The coefficient vector β thus identifies the differences in per-patient demand for surgery in areas where entry is more prevalent relative to areas where entry is rare. If $\beta's > 0$, then the entry of new hospitals expanded the market demand for CABG (PCI) surgery among CAD patients. If $\beta's$ are zero, then the entry is pure business stealing; the market demand for CABG (PCI) does not increase following the entry, leaving the hospitals in a stiffer competition for market share.

To mitigate the concerns that other factors might also have affected a patient likelihood of receiving any surgery, equation (1) also includes X'_{it}, a vector of patient characteristics including indicator variables for age (50-59, 60-69, 70-79, and 80 or older; omitted group is 49 or younger), race (White, Black, Asian; omitted group is other races), gender, urban residence, Charlson co-morbidity index (1, 2, 3, 4, 5, and ≥6; omitted group is 0), admission status (emergency admission and transferred admission), insurance type (Medicare, Medicaid, HMO, fee-for-service; omitted group is other insurance or uninsured) and major clinical indications at admission (cardiogenic shock, hypertension, dialysis, heart failure, renal failure, and acute myocardial infarction). Of particular concern is the potential confounding influence of health maintenance organizations (HMOs). Featured by utilization monitoring on high cost services, HMOs are less likely to encourage hospitalization and expensive surgical procedures. Therefore, high HMO penetration may reduce the overall demand for surgery. On the other hand, high HMO penetration may as well increase the overall demand for surgery if HMOs' selective contracting has successfully enhanced price competition among hospitals and lowered hospital prices, making high-cost surgeries like CABG more affordable (Town and Vistnes 2001; Miller and Luft 1997). I control for any impact of HMO penetration by including in X'_{it} a continuous variable for the percentage of HMO enrollees each year in the patient's county of residence.

Finally, the characteristics of the admitting hospital are not included in the patient-level specifications. There are two reasons for this. First, emergency patients are usually taken to the closest hospital for initial treatment and diagnosis. Depending on the risk for adverse outcomes, the patient may be discharged, transferred to a higher level of hospital, or receive surgical procedures immediately.[26] Thus, an emergency patient's likelihood of surgery does not necessarily relate to the characteristics of the initial admitting hospital. Second, for scheduled patients, the choice of admitting hospital may be endogenous of a patient's illness severity. Patients with mild conditions (thus a lower likelihood of surgery) may be referred to non-cardiac surgery hospitals, while patients with acute conditions

[26] See Braunwald et al. (1994) for details.

(thus a higher likelihood of surgery) are more likely to be referred to hospitals with cardiac-surgery hospitals.

New hospitals may have seized the market share from existing hospitals whether or not the total demand is expanded. To test the business-stealing effect between new and existing providers, I replace y_{ikt} in equation (1) with a binary variable that equals to one if the patient received CABG(PCI) surgery at any incumbent hospitals within one quarter of admission for CAD. It is worth noting that emergency patients were often stabilized at one hospital and then transferred to another hospital for surgical treatment, in which case the hospital of initial admission is not necessarily the same as the hospital that delivers the surgery. As such, a negative β indicates a decrease in per-patient demand of surgery at incumbent hospitals, rather than a decrease in the likelihood of surgery after patients being admitted to incumbent hospitals.

As previously discussed, the effect of entry may vary with the extent to which hospitals are substitutes to patients. If business-stealing effect increases with hospital substitutability, then incumbent hospitals are expected to lose more healthy patients as a result of entry (because hospitals are more substitutable for relatively healthier patients). To test this hypothesis, I estimate one variant of equation (1) to explore the nature of entry impact by comparing the heterogeneous demand response of high- versus low-risk patients. Specifically, I include in equation (1) the interactions of a patient's illness severity before treatment C_{ikt} and entrant share S_{kt}:

$$y_{ikt} = \alpha_k + \gamma_t + I(C_{ikt} = 1)S_{kt}\beta_1 + I(C_{ikt} = 0)S_{kt}\beta_2 + X'_{it}\eta + \epsilon_{ikt}, \qquad (2)$$

where C_{ikt} equals to 1 if the patient Charlson co-morbidity index is equal or greater than 2[27]. In the business-stealing analysis where the dependent variable indicates whether a patient receives treatment from any incumbent hospital, $\beta_1's$ and $\beta_2's$ are both expected to be negative, with $\beta_2's$ significantly larger in absolute value.

The above analysis has treated all hospitals that entered after 1997 CON-repeal as new hospitals. However, this assumption may not be appropriate if the impact of entry is only temporary. As robustness check, I alternatively define entrants as hospitals that were "in the market" for only three years or less. With this new definition, very few new entrants achieved 10 percent market share in a three-year period. I therefore use 1-10 percent and above 10 percent as the cut-offs for entrant share categories. The estimation results may be considered as the "short-term" impacts of entry as opposed to "cumulative" impacts derived from the main results.

To assess the effects of entry on surgery outcome and costs, I create two subsamples from the new-CAD patient sample, selecting those did undergo CABG or PCI procedures. For each subsample, I then reestimate equation (2) with y_{ikt} being a binary variable that equals one if the patient died during the hospital stay for surgery, or experienced cardiac complications during one year following the treatment. If $\beta's > 0$ then entry increases the probability of adverse outcomes. Similarly, I then let y_{ikt} be the log of total cost during the hospital stay and total in-hospital expenditures in three quarters following the surgery. If $\beta's > 0$ then entry increases the resource use on CABG (PCI) patients.

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[27] The ability of CCI to predict surgical risk was assessed in previous literature. See Charlson et al. (1987) and O'Connor et al. (1992) for details.

1.6.3 Hospital-level Analysis

An important limitation of the patient-level estimation is that it does not capture any hospital-differentiation effect, a potential source of welfare gain through free entry as previously pointed out. In this section I present a hospital-level analysis by examining the impacts of entrant share on differentiation by hospitals.

To test the hypothesis that hospital entry leads to improved geographic differentiation, I estimate the following equation:

$$V_{it} = \theta_j + \gamma_t + S_{jt}\beta + Z'_{jt}\varphi + \epsilon_{ikt}, \quad (3)$$

where V_{it} is the average distance from patients' zip code of residence to hospital j at time t; Z'_{jt} is a vector of hospital characteristics including bed capacity (200 beds to 400 beds and >400 beds; omitted group is <200 beds), teaching status[28], whether it is not-for-profit, whether it belongs to any health care system, its rating according to the Cardiac Surgery Report Cards (in-hospital mortality lower than expected, same as expected, and higher than expected; omitted group is unrated), and the share of Medicare admissions in total inpatient admissions. Hospital fixed effects θ_j is used to capture any time-invariant unobserved hospital characteristics.

Since hospitals attract patients from many zip code areas, the market share S_{jt} is constructed at the hospital level. S_{jt} equals the weighted average of entrant share in zip code areas where hospital j draws its patients, with weights being the relative likelihood that patients in each zip code area will be admitted to hospital j.[29] Thus the coefficient

[28] Two binary measures of teaching status are used, the first being whether the hospital has more than 20 full-time residents, and the second being whether the hospital is a member of Council of Teaching Hospitals and Health Systems (COTH).
[29] See appendix B for details of the construction of hospital-level entrant share.

vector β identifies the shift in patient distance to hospitals under larger impact of entrants relative to hospitals under smaller impact. Negative coefficients suggest that on average hospitals facing higher entrant share draw patients from a closer neighborhood. That is, higher entrant share is associated with greater geographic differentiation.

To explore whether entry leads to a smaller within-hospital dispersion of patient severity and utilization, I calculate the hospital-level CV of Charlson co-morbidity index, prior-year total hospital expenditures, and hospital expenditure for the CABG(PCI) surgery among patients receiving surgeries in each hospital. I reestimate equation (3), using these with-in hospital coefficients of variation as dependent variables. Again, coefficient vector $\beta's$ are expected to be negative.

1.7 Results

My empirical results suggest that both market-expansion effect and business-stealing effect are present in the CABG and PCI markets. Table 1-3 shows the demand responses to entry. The estimates in the table are the result of eight sets of regressions, with the top panel showing the effects of cumulative entrant shares and the lower panel showing the effects of 3-year entrant shares.

Columns (1) and (2) in panel A of Table 1-3 suggest that higher entrant share was associated with a significant increase in the incidence of CABG and PCI. Given that the sample average of CABG rates in CAD patient sample was 18.8 percent, the estimates in the column (1) suggest that for an average CAD patient, entry resulting in 10 to 25 percent market share of CABG entrants led a 10.1 percent increase in the probability of undergoing CABG surgery within three months after being diagnosed as CAD. In markets with CABG entrant share above 25 percent, entry led to a 13.9 percent in the probability of undergoing CABG surgery. Similarly, patients were 2.9 percent (based on a 31.2 percent average PCI rate) more likely to receive PCI surgeries in markets with PCI entrant share between 10 and 25 percent market share, and were 10.9 percent more likely to receive PCI surgeries in markets where PCI entrant share above 25 percent. The magnitude of these effects is economically significant[30].

Columns (3) and (4) investigate the existence of business-stealing effect in the CABG and PCI markets. Results in column (3) indicate that increasing CABG entrant share up to 25 percent did not affect existing hospitals' demand. However, a further increase in the entrant share above 25 percent resulted in fewer patients receiving surgeries from incumbent CABG hospitals. Expressed as a percent change, the share of patients receiving CABG from any incumbent CABG hospital decreased by 11.7 percent (based on a 16.2 percent sample average). The business-stealing effect was stronger for the PCI market. Coefficients in column (4) suggest that increasing entrant market share beyond 10 up to 25 percent was associated with a drop of 1.5 percentage points in existing PCI hospitals' demand, and the drop was 5.8 percentage points as entrant market share grows beyond 25 percent. An average CAD patient had a 26 percent chance to receive PCI at an existing hospital. These business-stealing effects thus equal to a 5 percent decrease in existing hospitals' demand in markets with 10 to 25 percent entrant share and a 22 percent decrease in markets with above 25 percent entrant share. The relative sizes of business-stealing effects and entrant market share suggest that entrant hospitals gained market share not entirely by stealing patients from incumbent hospitals;

[30] It is also worth emphasizing that findings in this paper run counter to the cross-state study of Ho et al. (2009), which concludes that CON removal does not affect the statewide CABG and PCI volume. This is potentially to be attributed to the heterogeneous market responses across states that stopped CON programs.

part of their market share came from newly expanded total surgery demand.

The estimated market responses to new entrants in the most recent 3 years are reported in panel B, which shows that the findings in panel A are robust to an alternative definition of entrants. The 3-year entrant share is associated with increased market demand but reduced surgery demand for CABG and PCI at incumbent hospitals. Compared with panel A, these results further imply that market-expansion effects tend to have a smaller magnitude in the short run, whereas business-stealing effects are more pronounced in the first few years when new entrants start to build their business.

Table 1-4 investigates the extent to which hospitals expand market demand and compete for market share among low- and high-risk patients. Estimates from column (1) of panel A indicate that the market-expansion effect of entry was much more pronounced for high-risk patients than for low-risk patients. Increasing the entrant share to 10-25 percent and above 25 percent was associated with a substantial increase in CABG rates among high-risk patients by 2.7 and 4.1 percentage points, respectively; while the same rises in the entrant share only increased CABG rates by at most 1.5 percentage points among low-risk patients. This perhaps reflects that sicker CAD patients gain more benefits from obtaining more intensive treatments and thus have a stronger incentive to incur financial costs and other costs to do so. In contrast with the CABG markets, Column (2) shows a greater increase in the use of PCI procedure among low-risk patients as entrant share increases. This result is consistent with previous evidence that PCI has been increasingly used on low-severity CAD patients who would have otherwise received non-surgical treatment (Cutler and Huckman 2003).

Consistent with the second empirical implication in section IV, estimates in the next two columns of panel A indicate a stronger business stealing effect among relatively healthy CAD patients. Column (3) shows that in markets with CABG entrants holding above 25 percent market share, incumbent hospitals experienced significant decreases in the demand of low-risk patients. This result is not surprising given the findings in column (1) that entrant CABG hospitals were less able to generate new demand among low-risk CAD patients. In the meanwhile, 10 to 25 percent entrant share in fact had a slightly positive impact on incumbent hospitals' demand among high-risk patients, perhaps suggesting that the expanded demand of high-risk patients due to entry had a spillover effect on incumbent hospitals. Such a pattern may reflect increased access to surgery, increased the referral recommendations, and reduced barrier to care for sicker patients. Similarly, the magnitude of estimates in column (4) suggests that incumbent PCI hospitals also lost more low-risk patients, despite the substantial market-expansion effect among these patients. Overall, these distinct demand responses in low- and high-risk patient groups support the hypothesis that the business-stealing effect induced by free entry is stronger among low-risk patients, because new hospitals are more substitutable to existing hospitals for them than for high-risk patients.

The estimation results in panel B using the 3-year entrant share again suggest that in the short run, entry had a more immediate business-stealing effect rather than the demand-expansion effect. Consistent with panel A, the coefficients in columns (1) and (2) indicate a larger increase in CABG demands among relatively sicker patients, and a larger increase in PCI demands among relatively healthier patients. Also consistent with panel A, there was a stronger business-stealing effect in both CABG and PCI markets in the short run. For example, the average PCI rate is 20 percent for relatively sicker patients and 30 percent for relatively healthier patients. Increasing 3-year entrant share above 10 percent was associated with 18.5 percent loss of sicker patients and 29.7 percent loss of healthier patients in incumbent hospitals.

Table 1-5 presents estimates of the effects of CABG and PCI entrant share on in-hospital mortality, one-year readmission, log of length of stay, and log of costs during the hospital stay of new CAD patients who underwent CABG or PCI procedures. Panel A and B report the results for the CABG patient sample and the PCI patient sample, respectively. Panel A suggests that in general, sicker CABG patients were under greater risk of experiencing death and readmissions due to adverse CAD conditions and post-surgical infections, and were also more costly to treat than healthier patients. Compared with high-risk patients in markets with the least entrant share, patients from markets with 10 to 25 percent entrant share experienced 0.004 percentage points lower in-hospital mortality, which was marginally significant. Interpreted as a share of average in-hospital mortality among high-risk patients undergoing CABG, which is 2.58 percent, entry of new cardiac programs had the potential to improve CABG mortality by 15.5 percent. Patients' one-year readmission rates were not significantly affected by rises in entrant share, suggesting that the additional survivors were not in especially marginal health.

The next two columns in panel A show that patients in markets with higher CABG entrant share experienced statistically significant reduction in length of stay and surgery costs. In particular, raising entrant share above 25 percent is associated with a reduction of surgery costs by 5.7 percent for high-risk CABG patients and by 4.9 percent for low-risk CABG patients. Given that the average total costs of CABG surgery were about $25,000 and $21,000 for high- and low-risk patients, the above estimates suggest that entry resulting in above 25 percent market share led to about $1,000-$1,400 decrease in total costs per CABG surgery. It is important to notice that this result does not necessarily indicate cost-savings for patients since actually out-of-pocket payment is not observed; rather, it suggests improved efficiency of hospitals and surgeons performing surgeries.

Panel B shows that for patients undergoing PCI procedures, the in-hospital mortality and one-year readmission rates are not significantly affected by rises in entrant share. PCI patients in markets with higher entrant share experienced longer hospital stay and lower surgery costs. Since the average length of stay is only 4.2 and 2.7 days for high- and low-risk patients, the increase in length of stay was not economically substantial. Given that the average total costs of PCI surgery were about $15,000 and $12,000 for high- and low-risk patients, the results in column (4) suggest that entry resulting in above 25 percent market share led to about $420-$510 decrease in total costs per PCI surgery.

Overall, the patient-level analysis could be interpreted as broadly suggestive of an increase in the patient welfare. Entry of new cardiac surgery programs led to expanded market demand for surgery, improved quality of care, and reduced hospital utilization. Such efficiency gain may have resulted from improved specialization of hospitals, or shorter travelling distance as the number of hospitals increased. In addition, Table 1-5 finds little evidence of learning effect at the hospital-level for both cardiac procedures. Quality did not seem to decrease as patient flows were diluted with the entry of new hospitals.

Table 1-6 provides evidence on improved hospital differentiation as a consequence of entry, by comparing the impacts of entrant market share on various hospital outcomes. The unit of analysis for the regressions is the hospital-year. Coefficients in the panel A show that higher CABG entrant share is associated with shorter patient distance and lower dispersion in patients' hospital expenditures. Patient heterogeneity in terms of illness severity at admission and prior-year hospital expenditures was not significantly affected by entrant share. Panel B shows a similar pattern for PCI providers. In general, these findings provide evidence that free entry led hospitals to draw patients from closer locations and to treat patients with increasingly similar intensity, which resulted in less dispersed level of utilization. Such differentiation effect may provide an explanation to the efficiency gain suggested by results in Table 1-4.

1.8 Welfare Evaluation

The conventional way to evaluate welfare effect in health care is to compare the effect on total resources used to the effect on patients' health outcomes. Results in Table 1-4 suggest that in markets with 10 to 25 percent entrant share, high-risk CABG patients experienced 0.4 percentage point lower in-hospital mortality rate. Given a total of 7541 high-risk CABG patients in these markets, this estimate indicates entry is associated about 30 additional patients survived during the study period. Previous research estimates that an average CABG patient gain 6.58 quality-adjusted life-year (QALY) during the following 10 years (Hlatky et al. 2004), and that the value of a year of life in good health are between $100,000 and $250,000 (Culter 2004; Murphy and Topel 2006). Using these figures, the estimated monetary benefits associated with improved mortality were $20 to $50 million. These estimates are summarized in column (1) of Table 1-7.

The empirical results also suggest that CABG patients in markets with entrant share above 25% spend $1,000 to $1,400 less, and PCI patients in markets with entrant share above 25% spend $420 to $510 less than patients in other markets. Column (3) of Table 1-7 shows the estimated monetary value of cost savings. Given that about 22,800 CABG and 48,400 PCI procedures are performed in these markets, the estimated total cost-saving induced by entry was between $61 and $46 million (in 2000 dollars). Based on estimates by Robinson et al. (2001) and Huckman (2006), the average fixed costs per new program vary between $12 and $14 million. Thus the total internal costs associated with establishing new cardiac surgery programs was approximately between $280 and $320 million for the 23 new cardiac programs attributed to CON repeal. Combining these figures with the amount of cost savings, column (6) shows that the total costs associated with the CON repeal were estimated to be between $219 and $274 million, far greater than the upper-bound of benefit gains from improved patient mortality rate. Without considering the demand response, one would therefore conclude that free entry led to socially wasteful investments.

However, evaluating the overall welfare effects of entry also requires estimates of demand responses, as well as estimates of effects on differentiations and on enlarged patients' choice set. For the former, my analysis illustrates that there is substantial potential for entrant hospitals to increase market demand. The results in Table 1-4 show that on average CAD patients are 1.9-2.6 percentage points more likely to receive CABG and 0.9-3.4 percentage points more likely to receive PCI in markets with higher entrant share. These results yield an estimated increase of 960 CABG patients and 1909 PCI patients during 1997-2004.

According to estimates from Hlatky et al (2004), CABG and PCI patients on average gain 6.58 and 6.45 QALY, respectively, during the following 10 years. The life-time medical costs accrued after surgery are $123,000 for CABG patients and $120,750 (in 2000 dollars) for PCI patients. Again applying the estimates $100,000 to $250,000 per QALY, the estimated total monetary benefits are $535,000 to $1,522,000 for each additional CABG procedure and $524,250 to $1,491,750 for each additional PTCA procedure.

Assuming this applies to all patients[31], column (2) of Table 1-7 shows that the entry of new cardiac programs is estimated to have led to an increase of at least $1.5 billion (535,000*960+524,250*1909) in social welfare during this period. This estimate far exceeds the total social costs of entry by new surgery programs, leading to the conclusion that entry induced by CON deregulation is welfare improving. This finding underscores the importance of recognizing the demand responses to entry in economic evaluation of policies on hospital entry.

The above calculations do not include all aspects of the welfare effects of entry. I do not account for the welfare gains due to hospital differentiation and enlarged patient's choice set, because the literature does not provide the dollar values on them. I only account for quality improvements and cost-savings of patients who received CABG or PCI surgeries. Entry may yield gains for patients who received less intensive treatments such as catheterization and medication. Therefore, my calculation most likely underestimate welfare benefits associated with entry.

[31] The result in Table 1-5 that CABG patients did not experience adverse health outcomes guarantees that this estimate could be applied to the increased population of CABG and PCI patients.

1.9 Conclusion

Well-established economic theory predicts welfare loss on free entry to monopolistic competitive markets when firms provide homogenous products and entry incurs large fixed set-up costs. Theory also indicates that market expansion and additional welfare gains derived from product variety may alter this conclusion. However, we know remarkably little about the welfare consequences of free entry in heterogeneous-product industries.

In studying the Pennsylvania cardiac care market, this paper finds robust evidence that entry led to expanded demand of CABG and PCI procedures among CAD patients who are at risk of cardiac surgeries. For both procedures, the business stealing effect appears to be stronger among relatively healthy CAD patients, suggesting that the market responses to entry may be systematically different for patients with different medical needs. The empirical findings from outcome analysis further suggest that entry led to improved in-hospital mortality rates and reduced surgery cost. Finally, the results from hospital-level analysis provide some evidence that entry is associated with improved specialization of hospitals and reduced travelling distance by patients. Even without accounting for benefits from enhanced hospital differentiation, the welfare gains from free entry exceed the total fixed costs of entry by new surgery programs.

This paper does not address whether the increased surgery rate is associated with supply-induced demand or procedure overuse. This depends on whether these additional surgeries are performed on patients to whom the benefits from surgery exceed the associated risk and costs. To address this question, one would have to access more detailed patients' clinical data in order to determine the appropriateness of a certain procedure on each patient.[32] The evidence that increased entrant share was not associated with adverse health outcomes suggests that at least on the health dimension there were no substantial adverse welfare effects. However, whether entry in hospital industry leads to overuse of medical care remains an interesting question for further research.

The empirical results of this paper directly speak only to the impact of free entry policy in the hospital industry, and may not be generalized to other industries where the dimensions of product differentiation are limited. Nevertheless, the idea presented here should also apply to various surgery markets in other states, many of which repealed their CON laws in the 1990s. An investigation of the response of demand to hospital entry in other states is another interesting direction for future research and would be particularly useful for understanding the extent to which the results presented here generalize to nationwide.

[32] See Chandra and Staiger (2007) for details.

1.10 Appendix A: Estimating Patient Flow

I construct the predicted CABG and PCI entrant programs' market share using a two-step method, analogous to the one developed in Kessler and McClellan(2000). First, I estimate patient-level hospital choice models as a function of exogenous determinants of the hospital admission decision. The utility function is a composite of patient, physician, and insurer utility, all of which influence hospital choice. The choice set j for each individual i at year t is comprised of all non-federal hospitals offering at least 5 CABG (PCI) within 80-mile radius of her residence. This distance threshold captures over 99% of all patients. I model individual i's indirect expected utility from choosing hospital j as

$$U_{ij} = W(X_i; Z_j^1, \dots, Z_j^H) + V(D_{ij}^{1+}, \dots, D_{ij}^{H+}, D_{ij}^{1-}, \dots, D_{ij}^{H-}; Z_j^1, \dots, Z_j^H) + \epsilon_{ij}, \quad (4)$$

W is specified as a nonparametric function of the interaction between individual's characteristics X_i and hospital characteristics Z_j^h. V is specified as a nonparametric function of relative distances and hospital characteristics to flexibly capture the impact of travel costs and hospital characteristics on an individual's hospital choice. Specifically, hospital j is characterized by H binary characteristics $Z_j^1, \dots, Z_j^H$, and the utility of individual i from choosing j depends on the relative distances to its good substitutes (same-type) and the relative distances to its poor substitutes (different-type). Thus, there are $2 \times H$ relative distances that influence the utility of individual i from choosing j: D_{ij}^{h+} equals the distance from i to hospital j minus the distance from i to the closest hospital j' with $Z_{j'}^h = Z_j^h$, and D_{ij}^{h-} equals the distance from i to hospital j minus the distance from i to the closest hospital j' with $Z_{j'}^h \neq Z_j^h$. D_{ij}^{h+} and D_{ij}^{h-} will capture the impact of lower travel cost for a good/bad substitute at dimension Z^h on an individual's choice decision. To allow for any nonparametric relationship between distances and patient's choice, I categorize D_{ij}^{h+} and D_{ij}^{h-} into four quartile dummies based on the distribution of the respective relative distance. That is, $D_{ij}^{h+} = (DD1_{ij}^{h+}, \dots, DD4_{ij}^{h+})$ and $D_{ij}^{h-} = (DD1_{ij}^{h-}, \dots, DD4_{ij}^{h-})$.

If individual i receives treatment at hospital j, it is assumed that the utility associated with hospital j must exceed that of all other hospitals that i could have chosen. Denote $Y_{ij} = 1$ if individual i is treated at hospital j. As McFadden (1973) notes, the probability of individual i choosing hospital j equal to

$$\Pr(Y_{ij} = 1) = \frac{\exp\,(W_{ij} + V_{ij})}{\sum_{k\in J} \exp\,(W_{ik} + V_{ik})}. \tag{5}$$

I estimate equation (5) using maximum likelihood. The model is estimated by year for CABG and PCI patients separately, allowing the preference over hospital location and other characteristics to vary among different types of patients and over time. This method is not feasible with HMO/POS enrollees since their hospital choices are constrained and unobserved in the data. To address this problem I estimate equation (3)(5) with Medicare enrollees' sample whose hospital choices are unrestricted, assuming that Medicare patients have similar preference over hospitals with their HMO/POS counterparts conditional on diagnosis, home location, and other demographics. Estimated coefficients from equation (5) are then used to predict $\hat{d}_{jk}$, the expected demand for CABG(PCI) at hospital j from patients living in zip code k, for patients of all insurance types:

$$\hat{d}_{jk} = \sum_{i\in k} \hat{\pi}_{ij}, \tag{6}$$

where $\hat{\pi}_{ij}$ denotes the predicted probability of individual i receiving procedure CABG(PCI) at hospital j.

1.11 Appendix B: Constructing Entrant Market Share

Let S_k^{zip} be the entrants' share in zip code k. It simply equals the number of patients living in zip code k who go to new cardiac centers for surgery divided by the total number of patients in zip code k:

$$S_k^{zip} = \frac{\sum_{i \in Ent} \hat{d}_{jk}}{\sum_{j \in J} \hat{d}_{jk}}, \tag{7}$$

where Ent denotes the set of entrant hospitals, and J denotes the full set of hospitals providing CABG(PCI) procedure.

A given hospital j will form conjecture about the impact of entrants over those patients that it is likely to attract. Thus in the hospital-level analysis I weight S_k^{zip} for hospital j by the relative likelihood that patients in zip code k will be admitted to hospital j. That is,

$$S_j^{Hosp} = \sum_{k \in K} S_k^{zip} \cdot \hat{\alpha}_{km}, \tag{8}$$

where $\hat{\alpha}_{km}$ is the expected share of patients admitted to hospital j who live in zip code k and equals $(\sum_{i \in k} \hat{\pi}_{ij})/\hat{d}_{jk}$.

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Table 1-1 Descriptive Statistics for CAD, CABG and PCI Patient Samples

	CAD Sample	CABG Sample	PCI Sample
1-quarter CABG rate	18.8%		
1-quarter PCI rate	31.2%		
1-quarter CABG rate at incumbent hospitals	16.2%		
1-quarter PCI rate at incumbent hospitals	26.0%		
In-hospital mortality		1.6%	0.7%
1-year Readmission		23.2%	31.5%
Total cost		22888	13223
[standard deviation]		[11128]	[7737]
Length of stay		8.270	3.109
[standard deviation]		[3.986]	[2.706]
Gender(1=male)	59.0%	70.8%	65.8%
Race Group			
White	84.0%	86.1%	83.8%
Black	10.0%	10.9%	11.5%
Asian	5.8%	2.8%	4.4%
Other races	0.2%	0.2%	0.2%
Age group			
Age<=49	9.5%	6.7%	13.1%
Age 50-59	17.5%	19.8%	23.2%
Age 60-69	23.6%	31.1%	26.7%
Age 70-79	29.7%	34.1%	27.0%
Age 80+	19.7%	8.3%	10.1%
Major indications at admission			
Cardiogenic shock	2.0%	1.5%	0.9%
Hypertension	55.1%	61.3%	56.6%
Dialysis	0.7%	0.5%	0.5%
Heart failure	19.2%	14.2%	8.6%
Diabetes	27.2%	30.2%	24.9%
Renal failure	4.4%	4.3%	1.7%
AMI	40.4%	27.9%	40.5%
Prior CABG	0.9%	0.1%	0.7%
Prior PCI	1.2%	0.6%	1.3%
Insurance type			
Medicare	58.2%	52.9%	47.5%
Medicaid	4.6%	3.5%	4.6%
HMO	13.9%	16.5%	18.0%
Fee-for-service	20.4%	24.5%	27.0%
Emergency room admission	46.9%	19.7%	29.7%
Transferred admission	16.0%	21.2%	22.6%
Urban residence	71.1%	75.9%	75.5%
HMO penetration rate at the county of residence	42.6%	42.3%	42.8%

Table 1-1 Descriptive Statistics for CAD, CABG and PCI Patient Samples (Cont'd)

Illness severity			
Charlson co-morbidity index (CCI)=0	23.6%	25.0%	26.7%
CCI=1	36.1%	37.1%	43.0%
CCI=2	23.4%	23.4%	20.6%
CCI=3	11.1%	10.2%	6.9%
CCI=4	3.7%	3.1%	1.9%
CCI=5	1.1%	0.8%	0.5%
CCI>=6	0.9%	0.4%	0.4%
# of patients	580,255	105,438	219,006

Notes: The CABG (PCI) samples are subsets of the CAD patient sample. It includes patients who are admitted to hospital with a new CAD diagnosis and underwent a CABG (PCI) procedure within 3 months after admission. In-hospital costs are in 1995 dollars.

Table 1-2 Descriptive Statistics on Cardiac Surgery Providers

	1997	2001	2004
Mean travel distance	13.96	12.819	12.202
[standard deviation]	[7.489]	[6.733]	[7.636]
CV of Charlson co-morbidity index	0.912	0.901	0.899
[standard deviation]	[0.071]	[0.084]	[0.082]
CV of log(prior-year hospital expenditures)	0.096	0.096	0.1
[standard deviation]	[0.01]	[0.013]	[0.013]
CV of log(in-hospital expenditures)	0.048	0.044	0.039
[standard deviation]	[0.008]	[0.008]	[0.007]
Not-for-profit	100%	98.3%	95.5%
Bed size <200	10.2%	13.3%	16.7%
Bed size 200-400	28.6%	45.0%	48.5%
Bed size>400	61.2%	41.7%	34.8%
Member of any health system	77.6%	73.3%	54.5%
Teaching	61.2%	46.7%	37.9%
COTH membership	40.8%	35.0%	27.3%
Medicare share	18.4%	43.7%	45.3%
No rating	8.2%	33.3%	10.6%
Low rating	67.3%	5.0%	10.6%
Medium rating	6.1%	56.7%	75.8%
High rating	6.1%	5.0%	3.0%
# of hospitals	48	59	66

Note: Distances are measured as the straight-line distance between the geographic centroid of the zip code of a patient's residence and the location of his or her admitting hospital. CV of Charlson co-morbidity index, prior-year expenditures, and in-hospital expenditures are aggregated from the patient samples. Not-for-profit status, bed size, health system membership, teaching status, and COTH membership are collected from the AHA annual survey data. Medicare share is calculated as the annual share of Medicare patients in all in-patient records. Hospital ratings are collected from Pennsylvania Cardiac Surgery Reports. Hospitals are matched to grades in the most recently published report. The study period includes five issues published in 1995, 2000, 2002, 2003, and 2004.

Table 1-3 Impact of Entry on Surgery Incidences

	CABG Surgery in 3 Months	PCI Surgery in 3 Months	CABG Surgery in 3 Months at Any Incumbent Hospitals	PCI Surgery in 3 Months at Any Incumbent Hospitals
	(1)	(2)	(3)	(4)
	A: Entrants defined as hospital in the market since 1997			
Effects of entrant share				
10-25%	0.019***	0.009***	0.002	-0.015***
	[0.003]	[0.003]	[0.003]	[0.004]
25%+	0.026***	0.034***	-0.019***	-0.058***
	[0.004]	[0.004]	[0.004]	[0.006]
Observations	580,255	580,255	580,255	580,255
R-squared	0.112	0.145	0.116	0.144
	B: Entrants defined as hospital in the market for 3 years or less			
Effects of entrant share				
1-10%	0.003	0.002	-0.002	-0.007**
	[0.003]	[0.002]	[0.003]	[0.003]
10%+	0.012***	0.009***	-0.032***	-0.076***
	[0.003]	[0.003]	[0.004]	[0.005]
Observations	580,255	580,255	580,255	580,255
R-squared	0.112	0.145	0.109	0.143

Notes: All specifications include a set of patient characteristics reported in Table1-1 as well as zip-code fixed effects and year fixed effects. Entrant shares are estimated for CABG and PCI markets separately. Standard errors, adjusted for correlation in residents in the same zip-code area over time, are reported in brackets. *** p<.01, **p<.05, *p<.10

Table 1-4 Impact of Entry on Surgery Incidences by Patient Illness Severity

	CABG Surgery in 3 Months	PCI Surgery in 3 Months	CABG Surgery in 3 Months at Any Incumbent Hospitals	PCI Surgery in 3 Months at Any Incumbent Hospitals
	(1)	(2)	(3)	(4)
	A: Entrants defined as hospital in the market since 1997			
High risk	0.029***	-0.059***	0.023***	-0.065***
	[0.002]	[0.002]	[0.002]	[0.002]
Effects of entrant share for high-risk patients				
10-25%	0.027***	0.001	0.012***	-0.011**
	[0.003]	[0.004]	[0.003]	[0.004]
25%+	0.041***	0.019***	-0.005	-0.031***
	[0.004]	[0.005]	[0.004]	[0.006]
Effects of entrant share for low-risk patients				
10-25%	0.014***	0.015***	-0.005	-0.018***
	[0.003]	[0.004]	[0.003]	[0.005]
25%+	0.015***	0.045***	-0.029***	-0.077***
	[0.004]	[0.005]	[0.004]	[0.007]
Observations	580,255	580,255	580,255	580,255
R-squared	0.110	0.144	0.114	0.143
	B: Entrants defined as hospital in the market for 3 years or less			
High risk	0.028***	-0.066***	0.025***	-0.069***
	[0.002]	[0.002]	[0.002]	[0.002]
Effects of entrant share for high-risk patients				
1-10%	0.012***	0.000	0.007*	-0.006**
	[0.003]	[0.003]	[0.004]	[0.003]
10%+	0.023***	0.005*	-0.019***	-0.057***
	[0.004]	[0.003]	[0.005]	[0.004]
Effects of entrant share for low-risk patients				
1-10%	-0.002	0.003	-0.007**	-0.007**
	[0.003]	[0.003]	[0.004]	[0.003]
10%+	0.005	0.011***	-0.040***	-0.089***
	[0.004]	[0.003]	[0.004]	[0.005]
Observations	580,255	580,255	580,255	580,255
R-squared	0.110	0.144	0.107	0.142

Notes: All specifications include a set of patient characteristics reported in Table1-1 as well as zip-code fixed effects and year fixed effects. Entrant shares are estimated for CABG and PCI markets separately. Sick patients, defined as those with Charlson co-morbidity equal to or greater than 2, accounts for 40% of the sample. Standard errors, adjusted for correlation in residents in the same zip-code area over time, are reported in brackets. *** p<.01, **p<.05, *p<.10

Table 1-5 Impact of Entry on Patient Surgery Outcomes

DEPENDENT VARIABLES	Death	Readmission	log(length of stay)	log (in-hospital costs)
	(1)	(2)	(3)	(4)
Panel A: CABG patients				
High risk	0.006***	0.095***	0.074***	0.046***
	[0.001]	[0.005]	[0.004]	[0.004]
Effects of entrant share for high-risk patients				
10-25%	-0.004*	-0.005	-0.018***	-0.019
	[0.002]	[0.007]	[0.007]	[0.012]
25%+	-0.004	-0.003	-0.033***	-0.057***
	[0.002]	[0.008]	[0.009]	[0.015]
Effects of entrant share for low-risk patients				
10-25%	0.001	-0.007	-0.003	-0.012
	[0.002]	[0.006]	[0.006]	[0.011]
25%+	-0.003	0.003	-0.010	-0.049***
	[0.002]	[0.007]	[0.007]	[0.014]
Observations	105,438	103,730	103,730	96,750
R-squared	0.099	0.067	0.311	0.366
Panel B: PCI patients				
High risk	0.002**	0.079***	0.052***	0.051***
	[0.001]	[0.004]	[0.005]	[0.004]
Effects of entrant share for high-risk patients				
10-25%	-0.001	0.002	0.040***	-0.016
	[0.001]	[0.006]	[0.010]	[0.012]
25%+	0.000	0.000	0.073***	-0.034**
	[0.001]	[0.007]	[0.013]	[0.015]
Effects of entrant share for low-risk patients				
10-25%	-0.000	-0.004	0.021***	-0.008
	[0.001]	[0.005]	[0.007]	[0.011]
25%+	0.000	0.003	0.053***	-0.035**
	[0.001]	[0.005]	[0.012]	[0.015]
Observations	174,600	173,381	173,381	161,976
R-squared	0.116	0.052	0.439	0.295

Notes: All specifications include a set of patient characteristics reported in Table1-1 as well as zip-code fixed effects, hospital fixed effects and year fixed effects. Sample sizes fall in readmission and length or stay regression due to exclusion of patients who died in hospital. Loss of observations in total costs regression is due to some hospitals having missing cost-to-charge ratio. Standard errors, adjusted for correlation in residents in the same zip-code area over time, are reported in brackets. *** p<.01, **p<.05, *p<.10

Table 1-6 Impact of Entry on Hospital Outcomes

DEPENDENT VARIABLES	Mean of patients' travelling distance	CV of patients' severity	CV of patients' prior-year in-hospital expenditures	CV of patients' in-hospital expenditures
	(1)	(2)	(3)	(4)
Panel A: CABG providers				
10-25%	-0.558	-0.018	0.003	-0.002***
	[0.445]	[0.013]	[0.002]	[0.001]
25%+	-1.603**	-0.024	-0.001	-0.003*
	[0.643]	[0.026]	[0.006]	[0.002]
Observations	456	455	447	456
R-squared	0.953	0.349	0.288	0.629
Panel B: PCI providers				
10-25%	-0.719*	-0.003	0.002	-0.002*
	[0.396]	[0.015]	[0.002]	[0.001]
25%+	-0.224	-0.005	0.003	-0.002
	[0.548]	[0.032]	[0.005]	[0.002]
Observations	467	467	464	467
R-squared	0.956	0.447	0.306	0.619

Notes: All specifications include a set of hospital characteristics reported in Table 1-2 as well as hospital fixed effects and year fixed effects. Standard errors, adjusted for correlation of the same hospital over time, are reported in brackets.
*** p<.01, **p<.05, *p<.10

Table 1-7 Monetary Value of Welfare Impacts from Free Entry

	Decrease in in-hospital mortality rate	Increase in surgery demand	Total benefits	Decrease in surgery costs	Fixed costs of entry	Total costs
	(1)	(2)	(3)	(4)	(5)	(6)
			No market-expansion effect			
Upper-Bound	\$50	0	50	\$61	\$280	\$219
Lower-Bound	\$20	0	20	\$46	\$320	\$274
			Consider market-expansion effect			
Upper-Bound	\$50	\$1,514	\$1,564	\$61	\$280	\$219
Lower-Bound	\$20	\$4,361	\$4,328	\$46	\$320	\$274

Notes: All values are in 2000 dollars and are in millions.

Figure 1-1 Number of Entrant CABG and PCI Programs from 1997 to 2004

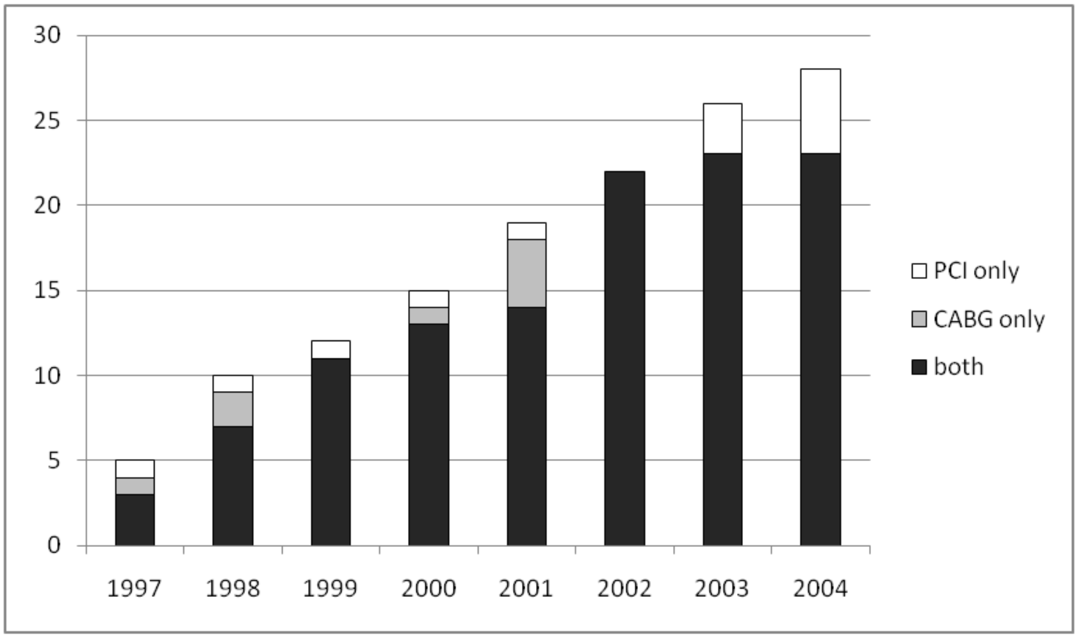


Figure 1-2 Graphical Illustration of Entry Model without Market-expansion

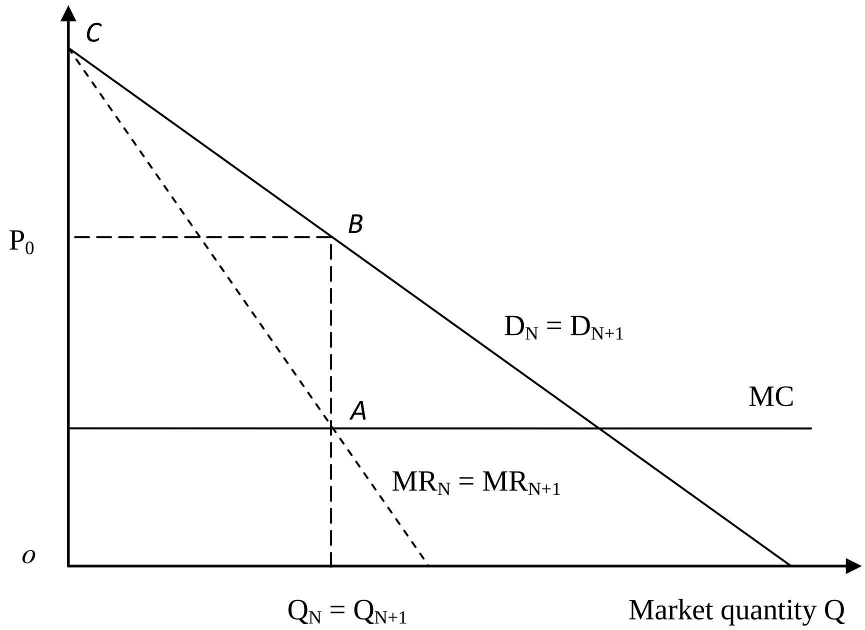


Figure 1-2-A

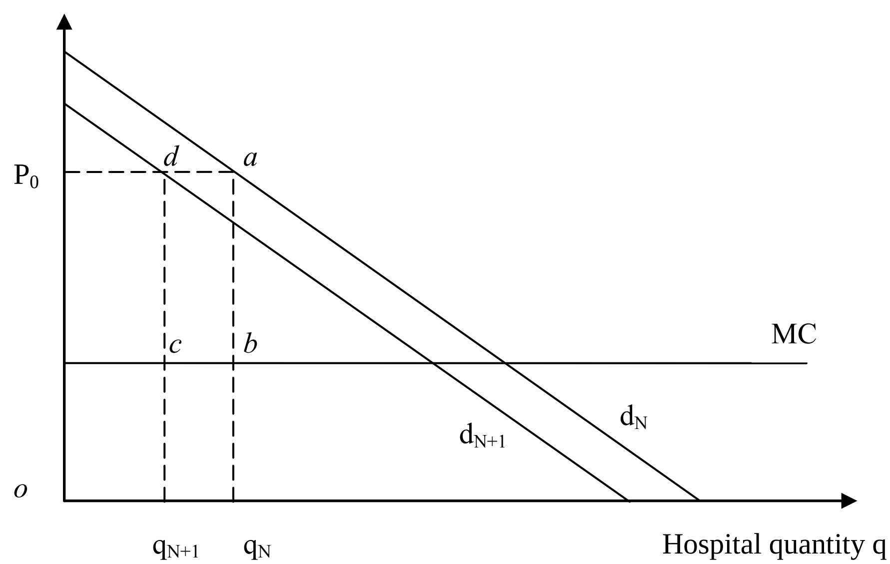


Figure 1-2-B

Figure 1-3 Graphical Illustration of Entry Model with Market-expansion

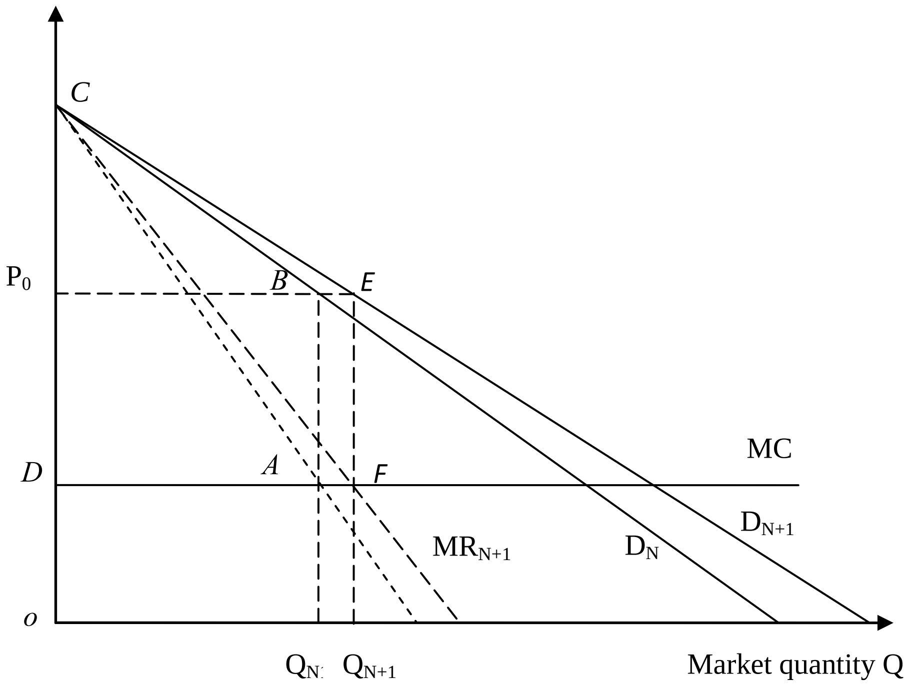


Figure 1-3-A

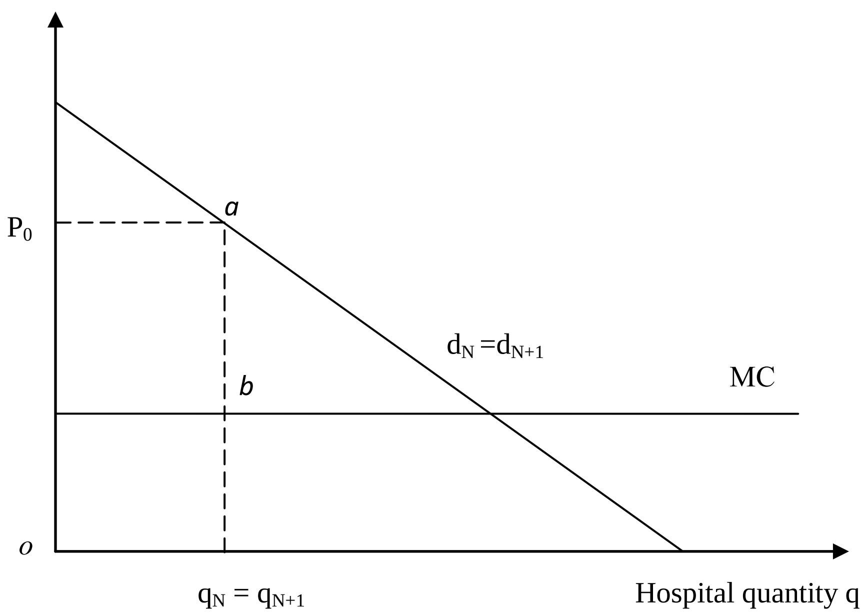


Figure 1-3-B

Figure 1-4 CABG Surgery Rate among New CAD Patients

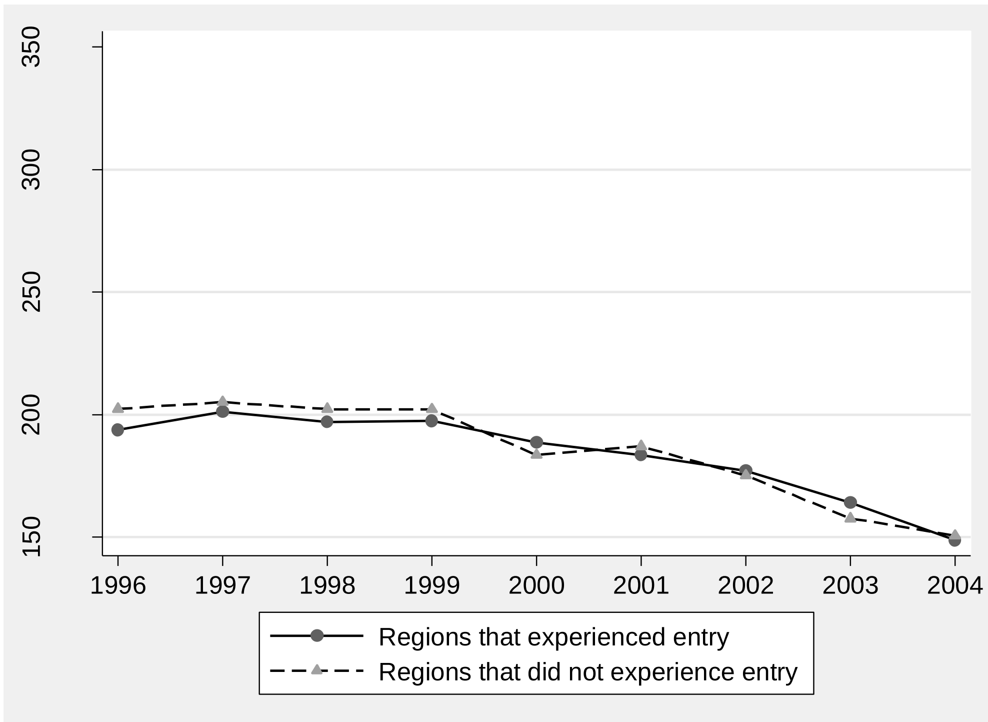
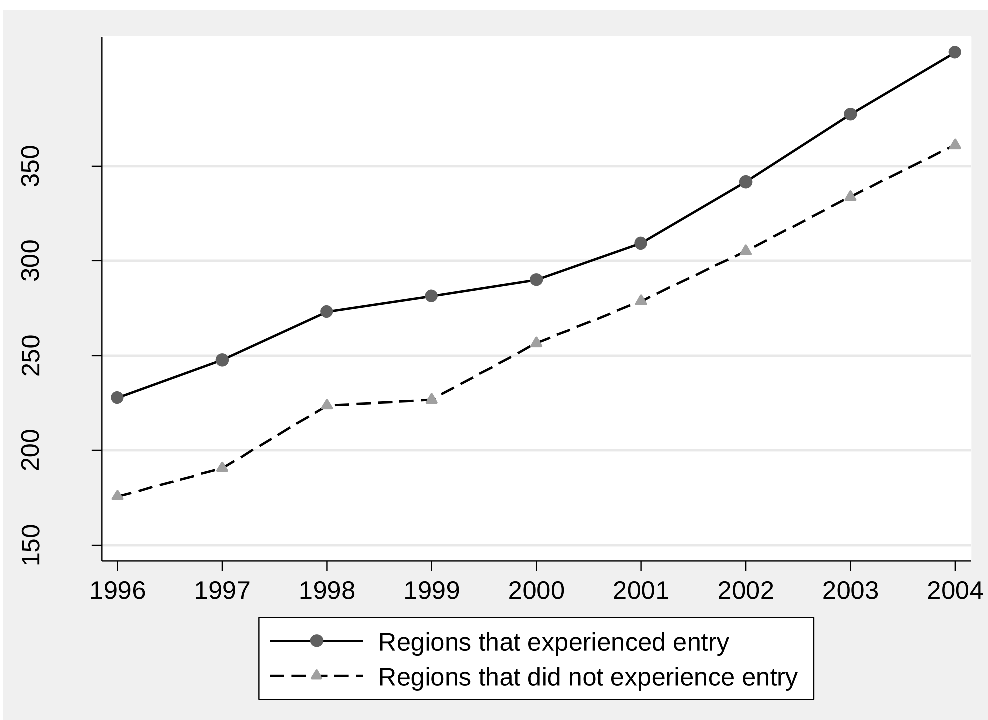


Figure 1-5 PCI Surgery Rate among New CAD Patients



2 Racial and Geographic Disparities in the Use of Revascularization among Acute Myocardial Infarction Patients

2.1 Background

There is an extensive literature documenting racial inequalities in the provision of cardiac procedures for patients with coronary artery disease.(Ayanian, Udvarhelyi, Gatsonis, Pashos, & Epstein, 1993; Barnato, Lucas, Staiger, Wennberg, & Chandra, 2005; Chen, Rathore, Radford, Wang, & Krumholz, 2001; Conigliaro, et al., 2000; Einbinder & Schulman, 2000; Ford & Cooper, 1995; Hannan, et al., 1999; Henry & the American College of Cardiology, 2008; Kressin & Petersen, 2001; Leape, Hilborne, Bell, Kamberg, & Brook, 1999; Peterson, et al., 1997; Schneider, et al., 2001; Sedlis, et al., 1997) These procedures include CABG, an intensive surgical intervention that involves isolating a section of vein or artery and grafting it to create a bypass of blockage in the coronary artery, and PCI, a less intensive procedure that involves a small incision through which a balloon is threaded and inflated to restore blood flow. While factors such as clinical presentations, income and insurance coverage play an important role, racial disparities still remain even when these factors are taken into account. For example, unequal treatments among minority Medicare beneficiaries are seen in all regions of the United States and have persisted over time. (Bertoni, et al., 2005)

An alternative explanation is that disparities may be attributable, in part, to where patients live: the surgery rates among minority patients are lower because they tend to cluster in geographic areas with lower surgery rates for all racial groups. Previous studies using national samples found evidence that a large proportion of the national-level racial differences in medical utilization and outcomes can be explained by the fact that minority populations are disproportionally distributed in the states that have lower use rate of procedures and more low-quality providers.(Baicker, Chandra, & Skinner, 2005; Skinner, Weinstein, Sporer, & Wennberg, 2003)

Despite the findings on the significant variations of surgery rates across states, few studies have examined the variations in surgery rates at the local geographic level, for example, by county. Even fewer have explored whether racial disparities in surgery rates vary across counties. An empirical investigation of racial disparities at the county level is important because the likelihood to undergo a discretionary surgical procedure, such as a coronary revascularization procedure, is often influenced by local medical practice norms and payment environment, which may vary drastically across adjacent counties. Given the substantial heterogeneity of racial composition in each county, the state-level racial disparities in surgery rates may be misleading because of the differences in overall surgery rates across counties. For example, it is possible that minority patients are less likely to undergo surgeries within each county; however, such local differences may be offset at the state level because minority patients tend to cluster in urban counties with higher overall surgery rates.

Geographic variation in medical utilization is commonly considered to reflect differences in local capacity of health care system and practice patterns of local health care providers. Previous research has shown that increased medical resource is associated with greater treatment intensity of chronic ill patients, particularly for end-of-life care.(Skinner & Wennberg, 2000; John E. Wennberg, 2004; J. E. Wennberg, Fisher, & Skinner, 2002) However, little is known about whether increased availability of medical resource is associated with narrower racial disparities in use of cardiac surgical procedures. Are minority patients additionally disadvantageous compared with their white counterparts in areas with lack of medical resources?

In this study, we offered an evaluation of the county-level variation in the relationship between race and surgery rates by analyzing the CABG and PCI surgery rates among Pennsylvania Medicare beneficiaries from 1995 to 2006. Specifically, we sought to address two questions: (1) To which extent can the state-level racial disparities in CABG and PCI surgery rates be explained by variations in surgery rates across counties? (2) Are the within-county racial disparities in surgery rates influence by local surgical capacity?

2.2 Data and Sample

This study performed a retrospective analysis using the administrative data from Pennsylvania Health Care Cost Containment Council (PHC4). The PHC4 collects detailed clinical and utilization information, such as diagnosis and procedure codes, diagnosis related groups (DRGs), and source of admission, for hospital discharges occurring in all Pennsylvania hospitals.

The sample for this analysis comprised Medicare beneficiaries (patients with Medicare listed as the primary expected payer) admitted with a new primary diagnosis of AMI, defined as the International Classification of Diseases, Ninth Revision, Clinical Modification code of 410.xx, between 1995 and 2006. We focused on the Medicare population in order to eliminate the substantial heterogeneity in health insurance coverage that affects the likelihood of receiving surgeries. Patients who were admitted with the same illness in the prior year or for subsequent episodes of care (ICD-9-CM 410.x2) were excluded. This analysis was limited to AMI patients who resided in Pennsylvania, and who were Black or White. Other racial groups including Asian or Pacific Islander, Hispanic American Indian or Eskimo, and other or unknown race were excluded due to low numbers of observations. Collectively, these patients accounted for 7.7% of all Pennsylvanian AMI patients.

Patients were linked overtime via unique patient ID, which enabled us to identify the procedure use following the first AMI admission. The outcomes were the individual-level use of CABG and PCI procedures within 3 months. Incidences of CAGB and PCI were analyzed as separate outcomes.

Patient sociodemographic characteristics included gender, age group (<65, 65-75 and >75), primary payer type (Medicare managed care plan, or others), secondary expected payer type (Medicaid, private insurance, or others), and log of median household income at the patient's zip code of residence, which was obtained by linking patient zip code to the 2000 US Census. To adjust for patient illness severity and preexisting conditions, we included the count of comorbid conditions according to AHRQ Elixhauser comorbidity diagnostic categories(Elixhauser, Steiner, Harris, & Coffey, 1998; Rosen, et al., 2005) and dummy variables of major clinical indications affecting the quality of CABG/PCI procedures (hypertension, heart failure, cardiogenic shock, cancer, renal failure, other coronary artery diseases, history of CABG/PCI procedure).(Council, 2008) We also considered the source of admission: whether the patient was admitted from emergency department, and whether the patient was transferred from another health care facility (hospital, skilled nursing facility, intermediate care facility, or assisted living facility); the reference group consisted of patients directly admitted to hospital.

2.3 Methodologies

The first hypothesis is that the observed disparities at the state level may be due to variation in surgery rates across the counties where patients live rather than the result of unequal treatment within local areas. We employed a two-level hierarchical model to test this hypothesis. The model can be described as follows:

$$I(\text{surgery}_{ijt}) = \alpha_{0j} + \alpha_{1j}\text{Black}_{ij} + X_{ij}\alpha_2 + \tau_t + \varepsilon_{ijt}$$

$$\alpha_{0j} = \gamma_{00} + \gamma_{01}C_j + \mu_{oj}$$

$$\alpha_{1j} = \gamma_{10} + \gamma_{11}C_j + \mu_{1j}$$

where $I(\text{surgery}_{ijt})$ is a binary variable indicating whether a patient i living in county j in year t received cardiac surgery within 3 months after his or her initial admission of AMI, α_{0j} is the county-specific intercept, Black_{ij} is an indicator for black patients, α_{1j} is the county-specific effect of race on the probability of receiving surgery, α_2 is a vector of coefficients for patient-level characteristics X_{ij}, τ_t is the year-specific effects, and ε_{ijt} is an independently, normally distributed error term.

To explore how racial differences in surgery rates may be explained by county-level factors, we modeled the intercept α_{0j} for each county j as a function of the state-level mean surgery rate γ_{00}, the county-level surgical capacity C_j, and a county-level random term μ_{oj}. The random intercept α_{0j} captures the between-county variation in surgery rate, and therefore enabled us to examine whether the observed racial differences were attributable to the underlying surgery rates of each county. Similarly, we allowed the within-county racial difference α_{1j} to vary by county-level surgical capacity C_j with a random term μ_{1j}. Identifying the coefficient γ_{11} allowed us to test the second hypothesis that the likelihood of receiving surgery is influenced by the local surgical capacity. The variance of μ_{1j} was used to assess the heterogeneity in racial disparities across counties.

We used the number of revascularization hospitals per 1000 AMI patients in each county as our main measure of local surgical capacity. We defined revascularization hospitals as those that performed at least 5 CABG or PCI procedures annually.(Cooke, Nallamothu, Kahn, Birkmeyer, & Iwashyna, 2011) Hospitals that performed PCI but did not perform CABG were also counted because such facilities represented for a nontrivial proportion of access to cardiac care services in nonurban areas.(Kutcher, et al., 2009) To detect any non-linear relationship between the surgical capacity and surgery rates, we coded the number of hospitals per capita into quintile categories. We then estimate a hierarchical model including a cross-level interaction between individual race group and the surgical capacity categorical variable. This specification allowed us to examine the extent to which black patients were better or worse off with the increase of local surgical capacity.

We first performed linear regressions of CABG and PCI rates on race group, using year dummies to control for state-level time trend. The coefficient for the race categorical variable therefore identified the "raw" differences in surgery rates between blacks and whites. The standard errors were adjusted for clustering of patients within counties. Next, we estimated a richer specification that adjusted for heterogeneity in above-mentioned patient socioedemographics and clinical characteristics. We then sequentially estimated two specifications of the above hierarchical model with and without the effects of county-level healthcare capacity. Likelihood ratio tests were used to compare the fit of the hierarchical model over the linear regression model.

2.4 Results

Our study sample included 195,043(94.7%) white and 10,887(5.3%) black Medicare enrollees, who were initially hospitalized for AMI in 67 counties and 234 hospitals between 1995 and 2006. Within three months of the admission, 9% of these patients underwent CABG procedure and 15.7% underwent PCI procedure (Table 2-1). The use rates of both CABG and PCI were lower among black patients. As compared with the proportion of white patients, a higher proportion of black patients were female, aged below 75, enrolled in Medicare managed care plans, and living in areas with lower median house household income. The black population represented a larger proportion of patients who were dual-eligible for Medicaid program, a finding that probably reflects a higher percentage of low-income Medicare enrollees among blacks. In regard to the admission source, black patients were more likely to be admitted through emergency department, while white patients were more likely to be transferred from other facilities. Despite the lower surgery rates, black patients were significantly sicker than white patients upon admission: they were more likely to have two or more comorbidities, and had higher rates of preexisting hypertension, congestive heart failure, diabetes, renal failure, and cancer.

Table 2-2 shows the use of CABG and PCI among blacks and whites in 10 counties with the highest black population densities in study sample. In 7 of the 10 counties, the rate of CABG within 3 months of initial AMI diagnosis was lower for blacks than for whites. In contrast, the rate of PCI within 3 months was not significantly different among blacks and whites in 7 of the 10 counties. In the remaining 3 counties, Philadelphia had PCI rate higher for blacks than for whites.

Table 2-3 reports adjusted racial disparities in the use of CABG. Adjusted for year trend, the likelihood to undergo CABG was, on average, 3.2 percentage points (95% confidence interval (CI): -0.038 - -0.027), lower for blacks than for whites. Given that the time-adjusted average use rate of CABG was 9.1% among whites, this estimate means that blacks were 35.2% less likely to undergo CABG. Adjusting for patient characteristics significantly reduced such racial difference to 2.4 percentage points (95% CI: -0.034 - -0.014), which amounts to 26.4% based on the risk-adjusted rate for whites. Men on average had higher CABG rate than women. Elderly Medicare patients were more likely to undergo CABG than those under 65. On the other hand, those who were above 75 had significant lower rate. Having Medicaid listed as the secondary expected payer was associated with lower CABG rate, possibly reflecting the fact that low-income senior patients who were dually eligible for Medicare and Medicaid had limited access to care.(Grabowski, 2007) Patients transferred from other facilities were more likely to receive CABG, while patients admitted through emergency department were less likely to. Conditional on patient sociodemographic presentation, most of the clinical indications were significantly associated with the likelihood of surgery. Adjusting for county random effects further reduced the magnitude of disparity to 0.019 percentage points (95% CI: -0.027 - -0.011), suggesting that blacks and whites in the same county were treated more similarly than would have been assumed based on state-level risk-adjusted difference.

The improvement in fit compared to the linear model was significant ($\chi2 = 613.54$, $p < .0001$). This set of results indicates that black patients, on average, live in counties with lower CABG rates among both blacks and whites.

In contrast, Table 2-4 shows that although the state-level racial disparity in PCI rates was almost fully explained by individual characteristics (-0.019 (-0.028 - -0.01) vs. 0.002 (-0.01 - 0.014)), further adjusting for the county-level variation increases the magnitude of racial disparity in PCI rates among AMI patients. Again, the likelihood ratio test indicates a better model fitting using county-specific random effects ($\chi2 = 1702.15$, $p < .0001$). These results suggest that, on average, blacks were less likely to undergo PCI than whites within the same county, but such difference was offset by the fact that blacks cluster in counties with relatively higher PCI rates among both blacks and whites.

As shown in Table 2-5, local surgical capacity contributed to higher surgery rates for both racial groups and slightly reduced the gap between whites and blacks. Counties were stratified into five quintiles according to the surgical capacity, which is defined as the number of revascularization hospitals per 1000 AMI patients. Although the confidence interval for each of these categorical variables overlapped with each other, we focus on comparing the magnitudes of the coefficients in interpreting the results. Conditional on patient clinical and sociodemographic factors, those living in counties with the larger surgical capacity were more likely to undergo CABG and PCI. The coefficients on the interaction terms suggest that the effect of county-level surgical capacity on racial disparity was not linear; however, overall, increased surgical capacity was associated with lessened within-county racial difference in CABG and PCI rates.

For instance, all else being equal, black patients living in counties of the lowest surgical capacity (the first quintile) were 0.039 percentage points (95% CI: -0.065 - -0.013) less likely to undergo CABG and 0.042 percentage points (95% CI: -0.074 - -0.010) less likely to undergo CABG than their white counterparts, while blacks living in counties of the largest surgical capacity (the fifth quintile) were 0.023 percentage points (95% CI: -0.034 - -0.011) less likely to undergo CABG and had equal PCI rates with white patients (point estimate: 0.009, 95% CI: -0.003 - 0.022).

2.5 Sensitivity Analysis

We performed sensitivity analyses to examine the robustness of the findings. First, a small proportion (3% of all hospital-years) of revascularization facilities performed PCI but did not perform CABG. To reconcile the fact that these facilities did not actually provide meaningful capacity for potential CABG recipients, we repeated our cross-level analysis using an alternative definition of local surgical capacity that excluded these non-CABG facilities. The results were consistent with the results obtained from our linear model.

Second, we considered the number of hospitals treating AMI patients in each county as broader measure of healthcare capacity. Again, we stratified the data into five quintiles according to the number of AMI hospitals (treating at least 5 AMI cases during a year) per 1000 AMI patients. As shown in Table 2-6, increased number of AMI hospitals per capita was not associated with significantly greater likelihood to undergo CABG, nor was it associated with narrowed racial difference in CABG rates (i.e., the magnitudes of cross-level interaction effects did not show a decreasing trend across quintile groups). Regarding the likelihood of undergoing PCI, counties in the lowest AMI hospital capacity had significantly lower PCI rates and larger racial difference between whites and blacks. Overall, these results suggest that the use of PCI procedure was more likely to be influenced by the availability of hospitals treating AMI patients.

2.6 Discussion

Persistent racial disparities are well recognized by policy makers and clinicians as a serious health system problem in need of correction. (Boler M, 2001; Geiger, 1996; John E. Wennberg, 2004) Using inpatient claims data of Medicare beneficiaries in from 1995 to 2006, we show that because black and white populations tended to cluster in counties of distinct underlying treatment patterns, geographic variation may play an important role in the differential surgery use among black and white AMI patients. We also find positive association between greater surgical capacity and narrower racial disparities in CABG and PCI rates.

Our findings that the state-level racial disparity in CABG procedure decreased, and in PCI procedure increased, with county adjustment indicate that blacks were more likely to live in counties with lower CABG rates and higher PCI rates for both black and white populations. These results are in agreement with earlier studies on the use of coronary interventions and other procedures such as knee arthroplasty and hip replacement, which documented wide variability of procedure use among racial groups both within and between regions.(Baicker, et al., 2005; Baicker, Chandra, Skinner, & Wennberg, 2004; Skinner, et al., 2003) More importantly, our study advances this literature by highlighting the importance to control for variation at smaller geographic units such as counties. Most studies using national samples found that blacks tend to live in parts of the country that have higher share of low-quality providers or lower use rates, leading to the conclusion that minority groups are actually treated more similarly(Baicker, et al., 2005; Skinner, et al., 2003) within regions. Conversely, we demonstrate that black patients were on average less likely to undergo PCI procedures within counties, but such disparity was mitigated by the fact that blacks were more likely to cluster in urban areas of higher average rates of PCI. These results are consistent with Barnato et al., which shows that black patients tend to seek for care in hospitals with higher rates of cardiac surgical procedures.

While racial differences in cardiac revascularization rates have been discussed in previous studies,(Baicker, et al., 2004; Barnato, et al., 2005; Rothenberg, Pearson, Zwanziger, & Mukamel, 2004; Schneider, et al., 2001) there has been little documentation of how local medical resources may influence these disparities. In this paper, we show that greater county-level surgical capacity contributes to narrowed local racial gaps in surgery rates, suggesting that consequences of inadequate medical resources may be particularly exacerbated for blacks, compared with whites. There are several potential explanations for such finding. On the demand side, black patients living in counties with lower surgical capacity may not have sufficient knowledge about how to access the best care, or may be more reluctant to undergo intensive surgical procedures due to unfamiliarity to these procedures. (Ayanian, et al., 1993; Sedlis, et al., 1997) On the supply side, local surgical capacity may influence physician practice patterns in a way that race bias in physician referral (Schneider, et al., 2001; Schulman, et al., 1999) is more pronounced in counties with lower surgical capacity. Thus, the implication to health policy is that more efforts may be needed to strengthen referral services and to ensure effective communication between patient and providers so that well-informed patients better participate in treatment decisions.

Another implication of this analysis is that for discretionary surgical procedures, policy should not simply target on equalizing black rates with white rates. Instead, the objective depends critically on whether the racial gap stems from underuse among minorities or overuse among whites.(Hannan, et al., 1999; Peterson, et al., 1997; Schneider, et al., 2001) In this analysis, we find a positive association between greater local surgical capacity and higher surgery rates, which raises the concern of overutilization issues in areas with larger numbers of providers. Despite the American College of Cardiologists' well-developed appropriateness classifications of CABG and PCI surgery, numerous studies have found inappropriate use of both CABG and PCI. (Hannan, et al., 1999; Schneider, et al., 2001) Particularly, Schneider, et al. shows that overuse is more likely among white population. These finding suggest that even with clinical decision-support guidelines, it is difficult to effectively reduce the overuse of cardiac surgical procedures without associated financial incentives. Therefore, current reform of payment system could strengthen the link between payment and effectiveness measures in order to ensure that inefficiencies in the treatment are reduced and appropriate care is provided.

An important limitation of this analysis is our focus on Medicare beneficiaries. Although this approach greatly eliminates heterogeneity in health coverage among non-Medicare patients, we are unable to ascertain the effects of geography on racial disparities among other populations. Others have suggested that patients with private insurance or under Medicaid program may face different levels of disparities in care.(Hargraves & Hadley, 2003; Wenneker, Weissman, & Epstein, 1990) As well our findings can be generalized only to populations that are similar in their characteristics to those in Pennsylvania. Future research is needed to examine the replicatability our findings in other states or at the national level.

The second limitation is that the inpatient claims data used for this analysis are collected primarily for billing purposes, and thus clinical detail and outcome measures are limited. While we attempt to control for patient comorbidities, our specification lacks measures of detailed medical history and laboratory results, which are used by physicians in making treatment decisions. Regarding health outcomes, we only observe in-hospital death, which accounts for a small proportion of short-term mortality of AMI patients. As a result we are not able to address larger issues about whether differential treatment is associated with adverse health outcomes among black patients.

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Table 2-1 Descriptive Statistics by Race[a]

	Total (n = 207,570)	Whites (n = 195,043)	Blacks (n = 10,887)	*P* Value[b]
Dependent Variable				
CABG within 3 months	9.0	9.1	5.8	< 0.0001
PCI within 3 months	15.6	15.7	14.2	< 0.0001
Patient demographics and clinical history				
Male	48.3	48.6	42.6	< 0.0001
Age 64-	8.1	7.6	16.9	< 0.0001
Age 65 - 74	34.1	33.9	38.3	< 0.0001
Age 75+	57.8	58.5	44.8	< 0.0001
Primary payer: Medicare managed care	16.2	15.8	23.2	< 0.0001
Second payer: Medicaid	5.5	4.8	18.1	< 0.0001
Second payer: private insurance	41.9	42.9	25.1	< 0.0001
Mean log of household income[c] (SE)	10.6 (0.30)	10.6 (0.29)	10.3 (0.36)	< 0.0001
Transferred admission	14.1	14.4	7.7	< 0.0001
Emergency admission	72.1	71.7	80.5	< 0.0001
Hypertension	43.8	43.1	55.4	< 0.0001
Congestive heart failure	0.6	0.6	1.0	< 0.0001
diabetes	26.6	26.2	34.4	< 0.0001
Renal failure	5.8	5.4	11.9	< 0.0001
cancer	2.6	2.6	3.4	< 0.0001
Cardiogenic shock	4.7	4.8	3.7	< 0.0001
Other coronary artery diseases	61.0	61.2	55.9	< 0.0001
CABG	3.2	3.2	2.4	< 0.0001
PTCA	4.5	4.5	3.8	< 0.0001
Elixhauser 0	19.4	19.8	12.3	< 0.0001
Elixhauser 1	33.6	33.8	29.5	< 0.0001
Elihauser 2	28.1	28.0	30.9	< 0.0001
Elihauser 3+	18.8	18.4	27.3	< 0.0001
Number of revascularization hospitals/1000 AMI patients				
First quintile: 0 - 0.84	25.9	27.1	4.1	< 0.0001
Second quintile: 0.85 - 2.03	14.2	14.6	6.3	< 0.0001
Third quintile: 2.04 - 2.96	20.0	20.0	20.6	0.16
Fourth quintile: 2.97 - 3.89	20.1	19.1	38.7	< 0.0001
Fifth quintile: 3.90+	19.8	19.2	30.3	< 0.0001

Abbreviations: CABG, coronary artery bypass graft; PCI, percutaneous coronary intervention; SE, standard error.

[a] Data are presented as percentages unless otherwise indicated.

[b] *t* Tests.

[c] Household income is abstracted at level of zip code.

Table 2-2 Use of CABG and PCI in Selected Counties, By Race

	CABG within 3 months (%)			PCI within 3 months (%)		
County	White	Black	Difference	White	Black	Difference
Philadelphia	7.0	5.6	1.4[a]	12.3	13.4	-1.2[b]
Dauphin	10.0	8.4	1.6	20.0	19.9	0.1
Delaware	8.5	5.2	3.3[a]	13.3	11.2	2.1[c]
Allegheny	9.3	6.2	3.1[a]	17.1	15.1	2.1[b]
Chester	7.9	4.3	3.6[b]	15.9	16.2	-0.3
Beaver	9.5	5.3	4.3[b]	22.0	16.3	5.7[b]
Monroe	7.8	4.2	3.5[a]	15.1	13.6	1.5
Erie	12.0	2.5	9.4[a]	17.2	16.9	0.3
Mercer	7.1	6.4	0.7	15.7	15.4	0.3
Washington	11.1	10.2	0.9	20.9	18.5	2.4

[a] $p < 0.10$; [b] $p < 0.05$; [c] $p < 0.01$ (two-tailed tests).

Table 2-3 Factors Associated With CABG Use Within 3 Months Among Newly Diagnose AMI patients

	Year Adjusted*		+ Patient Characteristics*		+ County Random Effects	
	Coefficient	95% CI	Coefficient	95% CI	Coefficient	95% CI
Black	-0.032[c]	(-0.038 - -0.027)	-0.024[c]	(-0.034 - -0.014)	-0.019[c]	(-0.027 - -0.011)
Male			0.029[c]	(0.025 - 0.032)	0.029[c]	(0.027 - 0.032)
Age 65 - 74			0.018[c]	(0.011 - 0.024)	0.018[c]	(0.013 - 0.022)
Age 75+			-0.043[c]	(-0.050 - -0.036)	-0.042[c]	(-0.047 - -0.037)
Primary payer: Medicare managed care			0.002	(-0.004 - 0.008)	0.004[b]	(0.000 - 0.008)
Second payer: Medicaid			-0.024[c]	(-0.033 - -0.014)	-0.022[c]	(-0.028 - -0.017)
Second payer: private insurance			-0.002	(-0.011 - 0.008)	-0.002	(-0.004 - 0.001)
Log household income (zip code level)			0.006	(-0.005 - 0.018)	0.005[a]	(-0.000 - 0.011)
Transferred admission			0.060[c]	(0.051 - 0.070)	0.061[c]	(0.057 - 0.066)
Emergency admission			-0.036[c]	(-0.045 - -0.028)	-0.040[c]	(-0.044 - -0.037)
Hypertension			0.019[c]	(0.014 - 0.024)	0.019[c]	(0.016 - 0.022)
Congestive heart failure			-0.019	(-0.042 - 0.004)	-0.021[b]	(-0.037 - -0.005)
Diabetes			-0.000	(-0.005 - 0.004)	-0.000	(-0.003 - 0.003)
Renal failure			-0.015[c]	(-0.021 - -0.008)	-0.016[c]	(-0.021 - -0.010)
Cancer			-0.038[c]	(-0.046 - -0.029)	-0.037[c]	(-0.045 - -0.029)
Cardiogenic shock			0.012[b]	(0.002 - 0.022)	0.010[c]	(0.005 - 0.016)
Other coronary artery diseases			0.056[c]	(0.050 - 0.063)	0.055[c]	(0.052 - 0.057)
Prior CABG			-0.083[c]	(-0.090 - -0.077)	-0.084[c]	(-0.091 - -0.078)
Prior PTCA			-0.043[c]	(-0.049 - -0.038)	-0.044[c]	(-0.050 - -0.038)
Elixhauser 1			-0.000	(-0.004 - 0.004)	-0.001	(-0.004 - 0.003)
Elixhauser 2			0.000	(-0.006 - 0.007)	-0.001	(-0.005 - 0.004)
Elixhauser 3+			-0.007	(-0.015 - 0.002)	-0.008[c]	(-0.013 - -0.003)
White, mean CABG use rate	0.091	(0.086 - 0.097)	0.091	(0.085 - 0.096)	0.084	(0.079 - 0.089)

*Standard errors in the linear regression models are adjusted for correlation in patients living in the same county.

[a]$p < 0.10$; [b]$p < 0.05$; [c]$p < 0.01$ (two-tailed tests).

Table 2-4 Factors Associated With PCI Use Within 3 Months Among Newly Diagnose AMI patients

	Year Adjusted*		+ Patient Characteristics*		+ County Random Effects	
	Coefficient	95% CI	Coefficient	95% CI	Coefficient	95% CI
Black	-0.019[c]	(-0.028 - -0.010)	0.002	(-0.010 - 0.014)	-0.011[a]	(-0.023 - 0.001)
Male			0.003[a]	(-0.000 - 0.007)	0.004[b]	(0.001 - 0.007)
Age 65 - 74			-0.027[c]	(-0.034 - -0.020)	-0.029[c]	(-0.034 - -0.023)
Age 75+			-0.115[c]	(-0.124 - -0.106)	-0.116[c]	(-0.122 - -0.111)
Primary payer: Medicare managed care			0.007	(-0.011 - 0.025)	0.009[c]	(0.005 - 0.014)
Second payer: Medicaid			-0.030[c]	(-0.044 - -0.016)	-0.024[c]	(-0.030 - -0.017)
Second payer: private insurance			0.004	(-0.012 - 0.020)	0.011[c]	(0.007 - 0.014)
Log household income (zip code level)			0.032[c]	(0.011 - 0.053)	0.013[c]	(0.006 - 0.020)
Transferred admission			0.069[c]	(0.052 - 0.085)	0.073[c]	(0.067 - 0.079)
Emergency admission			-0.046[c]	(-0.063 - -0.029)	-0.051[c]	(-0.055 - -0.046)
Hypertension			0.056[c]	(0.051 - 0.061)	0.055[c]	(0.052 - 0.059)
Congestive heart failure			-0.063[c]	(-0.076 - -0.051)	-0.067[c]	(-0.086 - -0.047)
Diabetes			-0.001	(-0.005 - 0.003)	0.000	(-0.004 - 0.004)
Renal failure			-0.058[c]	(-0.064 - -0.051)	-0.061[c]	(-0.067 - -0.054)
Cancer			-0.018[c]	(-0.026 - -0.011)	-0.017[c]	(-0.026 - -0.007)
Cardiogenic shock			-0.040[c]	(-0.053 - -0.028)	-0.044[c]	(-0.051 - -0.037)
Other coronary artery diseases			0.103[c]	(0.093 - 0.113)	0.097[c]	(0.094 - 0.101)
Prior CABG			-0.029[c]	(-0.037 - -0.020)	-0.030[c]	(-0.038 - -0.021)
Prior PTCA			0.065[c]	(0.052 - 0.077)	0.059[c]	(0.052 - 0.066)
Elixhauser 1			-0.051[c]	(-0.057 - -0.045)	-0.052[c]	(-0.057 - -0.048)
Elixhauser 2			-0.085[c]	(-0.093 - -0.077)	-0.087[c]	(-0.092 - -0.082)
Elixhauser 3+			-0.115[c]	(-0.125 - -0.105)	-0.117[c]	(-0.123 - -0.110)
White, mean PTCA use rate	0.157	(0.145 - 0.168)	0.156	(0.146 - 0.166)	0.140	(0.131 - 0.150)

*Standard errors in the linear regression models are adjusted for correlation in patients living in the same county.

[a]p < 0.10; [b]p < 0.05; [c]p < 0.01 (two-tailed tests).

Table 2-5 Differences in CABG and PCI Use in Association With County-level Surgical Capacity

	CABG Within 3 Months		PCI Within 3 Months	
	Coefficient	95% CI	Coefficient	95% CI
Revascularization Hospitals Per Capita				
First quintile	--	--	--	--
Second quintile	0.011[c]	(0.003 - 0.019)	0.026[c]	(0.016 - 0.036)
Third quintile	0.013[c]	(0.006 - 0.019)	0.029[c]	(0.021 - 0.038)
Fourth quintile	0.015[c]	(0.009 - 0.022)	0.037[c]	(0.028 - 0.045)
Fifth quintile	0.019[c]	(0.013 - 0.026)	0.038[c]	(0.030 - 0.047)
Interaction Effect				
Black, first quintile	-0.039[c]	(-0.065 - -0.013)	-0.042[c]	(-0.074 - -0.010)
Black, second quintile	-0.026[b]	(-0.048 - -0.004)	-0.018	(-0.044 - 0.009)
Black, third quintile	-0.031[c]	(-0.044 - -0.018)	-0.013[a]	(-0.028 - 0.002)
Black, fourth quintile	-0.024[c]	(-0.035 - -0.014)	0.005	(-0.007 - 0.016)
Black, fifth quintile	-0.023[c]	(-0.034 - -0.011)	0.009	(-0.003 - 0.022)

[a]$p < 0.10$; [b]$p < 0.05$; [c]$p < 0.01$ (two-tailed tests).

Table 2-6 Sensitivity Analysis of County-level Surgical Capacity Using AMI Hospitals

	CABG Within 3 Months		PCI Within 3 Months	
	Coefficient	95% CI	Coefficient	95% CI
AMI Hospitals Per Capita				
First quintile	--	--	--	--
Second quintile	0.001	(-0.003 - 0.006)	0.011[a]	(0.005 - 0.017)
Third quintile	0.010[a]	(0.005 - 0.015)	0.011[a]	(0.005 - 0.018)
Fourth quintile	0.004	(-0.002 - 0.010)	0.017[a]	(0.010 - 0.024)
Fifth quintile	0.004	(-0.003 - 0.011)	0.012[b]	(0.003 - 0.020)
Interaction Effect				
Black, first quintile	-0.018[b]	(-0.037 - 0.000)	-0.027[b]	(-0.050 - -0.003)
Black, second quintile	-0.023[a]	(-0.037 - -0.010)	-0.01	(-0.029 - 0.008)
Black, third quintile	-0.020[a]	(-0.032 - -0.008)	-0.013	(-0.030 - 0.003)
Black, fourth quintile	-0.019[b]	(-0.034 - -0.004)	0.001	(-0.019 - 0.021)
Black, fifth quintile	-0.024[a]	(-0.039 - -0.010)	-0.006	(-0.025 - 0.013)

[a]$p < 0.10$; [b]$p < 0.05$; [c]$p < 0.01$ (two-tailed tests).

3 The Relative Impacts of Hospital Volume and Surgeon Volume on Coronary Artery Bypass Graft Procedure

3.1 Introduction

Many studies have demonstrated the empirical evidence that higher hospital volume is associated with better patient outcomes for a wide range of procedures, including coronary angioplasty, coronary artery bypass surgery (CABG), carotid endarterectomy, and cancer surgeries (Birkmeyer, et al., 2002; Halm, Lee, & Chassin, 2002; Shahian & Normand, 2003). These findings have promoted several policy initiatives that encourage patients needing certain procedures to seek care at hospitals performing a larger volume of similar procedures. For example, the Leapfrog Group, a large coalition of private and public purchasers, has used hospital volume as a proxy of quality and as the basis for evidence-based hospital referral for several high-risk procedures (esophagectomy, pancreatectomy, coronary artery bypass graft, percutaneous coronary intervention, and abdominal aortic aneurysm repair). (Birkmeyer, Finlayson, & Birkmeyer, 2001)

Despite the considerable body of literature, however, little is known about the mechanisms underlying the observed association between hospital volume and surgical outcomes. Because high-volume hospitals tend to be much larger facilities, they may have a broader range of specialist and technology-based services, better-staffed intensive care units, and other resources that are not available at smaller centers. As a consequence, high-volume hospitals may be better equipped to deliver complex high-risk surgical procedures. On the other hand, the outcome of a surgical procedure may also depend on how well the operation itself is performed. Thus an alternative explanation for the observed relation between the hospital volume and the outcome is that high-volume hospitals tend to hire surgeons who are more experienced with specific procedures. Numerous studies have explored the associations between surgeon volume and mortality for various high-risk surgical procedures (Hannan, Siu, Kumar, Kilburn, & Chassin, 1995; Huckman & Pisano, 2006; Ramanarayanan, 2008). While these analyses have examined the role of surgeon volume in surgical quality, relatively few studies have simultaneously characterized the relative influence of hospital-level and surgeon-level volume with sufficient precision.

The purpose of this study is to investigate the extent to which the observed effects of hospital volume on outcomes can be explained by the experience of the operating surgeon of CABG procedure. CABG surgery was developed in the late 1960s and entered mainstream use in the United States during the 1970s. It is a risky and invasive procedure that involves surgically isolating a section of vein or artery and grafting it to create a bypass of blockage in the coronary artery.

CABG surgery is selected for this analysis for several reasons. First, the procedure is frequently the focus of debate concerning the regionalization of health care services. The Leapfrog Group has recommended that payers contract with hospitals with an annual volume of CABG surgery procedures of at least 500. The American College of Cardiology recommends that hospitals with annual volumes of <100 be closely monitored (Eagle, et al., 1999). Given the considerable attention on the CABG surgery volume threshold, it is important to explore the factors which lead high-volume hospitals to provide better performance. Second, the past decades have witnessed a national trend of decreased case volume of CABG surgery, accompanied by an increase in the number of hospitals providing CABG surgery (Epstein, Polsky, Yang, Yang, & Groeneveld, 2011). Combined, these trends caused increasingly more patients to receive CABG surgery at hospitals with relatively low volumes of this procedure. Therefore, a revisit to the volume-outcome relationship for CABG helps to understand the potential adverse effects of decreasing hospital volume on surgical quality. Third, the extensive studies on this procedure have established a commonly accepted quality measure- in-hospital mortality, which is observed in the hospital administrative data used for this analysis.

Using comprehensive inpatient claims data from the Pennsylvania Health Care Cost Containment Council (PHC4), I find that patients treated at high-volume hospitals, on average, had lower in-hospital mortality than those treated at low-volume hospitals. However, such positive volume-outcome relationship can be fully explained by surgeon volume. That is, patients treated by high-volume surgeons have lower risk-adjusted mortality than those treated by low-volume surgeons, regardless of the volume of admission hospital. These results imply that the effects of hospital volume on surgical outcomes tend to be confounded by variation across surgeons. The policy implication of this study is that targeting on the CABG volume of operating surgeons could be an effective policy strategy to ensure surgical quality in low-volume CABG hospital. An implication beyond the CABG procedure is that for high-risk procedures, which require high technical skills and extensive use of specific intra-surgical processes, the experience of the operating surgeon rather than the admitting hospital could serve as a better predictor of the risk of death.

The rest of the paper has the following structure. The next section discusses the data used in the analysis. Section 3.3 presents the empirical framework. Section 3.4

presents the findings. Section 3.5 discusses the study's implications and limitations.

3.2 Data and Descriptive Statistics

The PHC4 data set identifies hospitals associated with each admission record, along with a wide range of patient-level information including age, race, gender, admission year and quarter, diagnosis/procedure codes, admission source, insurance type, zip code of residence, and discharge status. All patients admitted to Pennsylvania hospitals from 1995 to 2004 with a primary procedure of coronary artery bypass (ICD-9 procedure codes 36.10-36.19) are initially included in the study sample. Through unique hospital identifier, the patient sample is linked with comprehensive hospital characteristics obtained from American Hospital Association (AHA) annual survey, which provides information such as hospital location, bed capacity, teaching status, ownership, and system member status.

The study sample covers 163,462 CABG procedures performed by 845 surgeons at 67 hospitals between 1995 and 2004. To characterize volume, I aggregate the discharge data to hospital- and surgeon- level, observing the total number of procedures that each hospital and each surgeon performed in each quarter during 1995 to 2004. Overall, approximately 50 percent of CABG surgeons operated at more than one hospital.

In analyzing the surgery outcomes I exclude patients admitted to federal hospitals, osteopathic hospitals and long term hospitals because the patient mix and process of care in such facilities are usually different from those in general hospitals. In addition, I exclude CABG patients with hospital stays longer than 30 days and those who had a valve replaced simultaneously. These restrictions are intended to exclude small subgroups of patients who had a much higher level of risk at base line and thus to minimize confounding. After losses due to these exclusions and incomplete information, there are 150,042 observations.

Table 3-1 presents descriptive statistics of the key variables used in the analysis. The mean of dependent variable, patient mortality, is higher in high-volume hospitals (2.1%) than in low- and medium-volume hospitals (1.8%). This difference may be driven by the fact that high-volume hospitals attract a larger population of sick patients. As is shown in the table, high-volume hospitals treat relatively fewer patients with a Charlson co-morbidity index below 2 and more patients with a Charlson co-morbidity index greater than or equal to 2. There are negligible differences in gender, race and age between patients who received care from low-volume hospitals and those who received care from high-volume hospitals. The percentage of patients who are admitted through emergency department in low-volume hospitals is almost double of the percentage in high-volume hospitals, while the proportion of patients transferred from other facilities is significantly higher in high-volume hospitals. These patterns are suggestive of physician referring more patients to high-volume hospitals.

Summary statistics for hospital characteristics are reported in Table 3-2, which shows that high-volume hospitals are much more likely than low-volume hospitals to be equipped with large bed capacity, more likely to be a member of some health system, and be identified as a teaching hospital.

3.3 Empirical Setting

3.3.1 Calculation of the Risk-Adjusted Mortality Rate

A commonly accepted measure of outcomes for CABG procedure is in-hospital mortality. However, observed mortality rates across hospitals and surgeons represent potentially-biased measures of the surgical quality, due to the heterogeneity in patients' pre-surgical conditions. Specifically, high-quality hospitals and surgeons may attract patients with more severe forms of coronary disease, and these individuals are more likely to die in the hospital independent of provider quality.

To adjust the binary mortality outcome for patient severity, I estimate logistic regression on the in-hospital mortality, controlling for several patient characteristics and existing clinical conditions (e.g., age, gender, complicated hypertension, heart failure, heart attack, kidney failure, cardiogenic shock, and others[33]) that could affect a patient's underlying probability of dying in the hospital. The dependent variable in this regression, $Mort_{ish}$, is an indicator equal to one if patient i, who received CABG from surgeon s at hospital h- died in the hospital, and zero otherwise. The form of this logistic regression is as following:

$$ln(\frac{Mort_{ish}}{1 - Mort_{ish}}) = \alpha_0 + X_i'\alpha_1 + \mu_{ish}, \quad (9)$$

where X_i' is a vector of patient-level characteristics and clinical indications. I calculate the expected probability of death for each patient as the fitted value for that individual obtained from the logistic regression. That is,

[33] The selection of potential predictors for mortality follows the suggestions in the technical notes of Pennsylvania' Guide to Coronary Artery Bypass Graft Surgery reports published by PHC4. The corresponding ICD-9 diagnosis and procedure codes for each indication can be found in these publications as well.

$$EMR_{ish} = \frac{exp\ (\hat{\alpha}_0 + X_i'\hat{\alpha}_1)}{1 + exp\ (\hat{\alpha}_0 + X_i'\hat{\alpha}_1)}.$$

I estimate the expected mortality rate (EMR_{ish}) for each hospital h during a given quarter, by averaging the EMR_{ish} across all patients at the same hospital. The risk-adjusted mortality rate for a given hospital ($RAMR_{ht}$) is then calculated as follows:

$$RAMR_{ht} = \frac{EMR_{ht}}{OMR_{ht}} \times OMR_t.$$

where OMR_{ht}, the observed mortality rate the hospital, is the share of patients who died in the hospital based on the total number of patient undergoing CABG procedures; and OMR_t is the average observed mortality rate for the entire state of Pennsylvania during that quarter. By multiplying OMR_t, the ratio of observed-to-expected mortality is normalized to the statewide average of CABG mortality. The risk-adjusted mortality rates at surgeon-level are calculated in the same method.

3.3.2 The Relative Impacts of Surgeon and Hospital Volume

Prior to test the relative influence of surgeon volume and hospital volume on patient's in-hospital mortality, I first establish the baseline relation between outcome and volume at hospital and surgeon levels separately. The basic logistic regression of patient mortality on hospital-level volume takes the following form:

$$ln(\frac{Mort_{isht}}{1 - Mort_{isht}}) = \beta_0 + Vol_{ht}'\beta_1 + \beta_2 RAMR_{h,t-1} + \beta_3 RAMR_{s,t-1} + X_t'\beta_4 + Z_{h,t}'\beta_5 + \theta_t + \mu_{isht}. \quad (10)$$

Again, the unit of analysis is patient and the dependent variable is an indicator for in-hospital death of patient *i* treated by surgeon *s* in hospital *h* at quarter *t* (*t* = 1, …, 40).

Vol'_{ht} is a vector of categorical variables that rank hospitals in order of increasing volume. I select cutoff points that most closely sort patients into three evenly sized groups with low, medium, and high hospital volume. X'_t is a vector of patient-level characteristics and clinical indications. To capture the impact of hospital's capacity- and technology-based resource on surgical outcome, I include $Z'_{h,t}$, a vector of hospital characteristics such as the number of staffed beds, teaching status, whether it is not-for-profit, and whether it belongs to any health care system[34]. To control for the fact that surgeons and hospitals have different underlying levels of quality independent of procedure volume, I include two additional variables: the risk-adjusted mortality rate of hospital and the risk-adjusted mortality rate of surgeon in the prior quarter ($RAMR_{h,t-1}$ and $RAMR_{s,t-1}$). Quarter fixed effects are included to capture the fact that the statewide CABG mortality declined during the sample period. To account for possible serial correlation over time within hospital, I allow for an arbitrary variance-covariance matrix in the error structure within each hospital.

Consistent with the findings of prior studies, the coefficient vector β_1 is expected to be negative: an increase in a hospital's procedure volume reduces its patient mortality, conditional on patient illness severity and hospital characteristics. Further, coefficients β_2 and β_3 are expected to be positive: hospitals that performed better in the previous quarter should also perform better in the current period. In assessing the impact of surgeon volume on mortality, I reestimate model (10), replacing Vol'_{ht} with Vol'_{st}, a vector of categorical variables indicating the group of low-, medium- and high-volume surgeons.

[34] Bed capacity is coded as two categorical variables: 200 to 400 beds and $>$400 beds; omitted group is $<$200 beds. Two binary measures of teaching status are used, one being whether the hospital has more than 20 full-time residents, and the other being whether the hospital is a member of Council of Teaching Hospitals and Health Systems (COTH).

Next, I test the hypothesis that some portion of the impact of hospital volume is attributable to surgeon's experience. Specifically, I estimate a variant of model (10) in which the influence of surgeon volume is taken into account and the impact of hospital volume is examined within each surgeon-volume cluster:

$$ln\left(\frac{Mort_{isht}}{1 - Mort_{isht}}\right) = \gamma_0 + \sum_{k=1}^{3} I(Vol_{st} = k) \cdot Vol'_{ht}\gamma_{1k} + Vol'_{st}\gamma_2 + \gamma_3 RAMR_{h,t-1} + \gamma_4 RAMR_{s,t-1} + X'_t\gamma_5 + Z'_{h,t}\gamma_6 + \theta_t + \mu_{isht}. \quad (11)$$

According to the hypothesis that the negative relation between hospital volume and mortality is confounded by the experience of operating surgeon, the coefficients on hospital-volume categories within each surgeon-volume category(γ_{11}, γ_{12}, and γ_{13}) would be expected to be smaller in absolute magnitude than coefficients $\beta's$ in model (10), or insignificantly different from zero. Analogous to the predictions with respect to model (10), the coefficient vector on surgeon volume, γ_2, is expected to be negative.

3.4 Results

Figure 3-1 presents the relationship between volume and outcome in terms of patients' mortality rates, adjusted for individual demographics, medical history and clinical indications. Surprisingly, the risk-adjusted mortality rates were higher in all three surgeon groups who operated in hospitals with the largest CABG quarterly volume (>149) than those who operated in hospitals with the lowest volume (<81), although the differences are not statistically significant (t-statistics between low-volume-hospital group and the other two groups are -0.9 and 1.37, respectively). Meanwhile, the risk-adjusted mortality rates were significantly higher among surgeons performing less than

27 cases per quarter in each hospital volume category. Even within the high-volume hospital group, patients who received their surgery from low-volume surgeons have considerably higher mortality rates than those who received care from high-volume surgeons (2.82% vs. 2.15%).

Table 3-3 reports the logistic regression results for the effects of hospital volume on the odds of death in hospital. Column 1 and 2 contain results from specification (10) which considers the overall impact of hospital volume without taking surgeon volume into account. The results suggest that an increase in a hospital's quarterly CABG volume was associated with a reduction in risk-adjusted mortality. Adjusting for patient demographics and medical history, those being treated in hospitals with medium CABG volume (81-149 cases per quarter) were 12.4% less likely to die in hospital than those being treated in hospitals with low CABG volume (below 81 cases per quarter). However, there was not a significant difference in mortality rate between hospitals with low and high CABG volume (odds ratio=0.956, *p*-value = 0.682). The significance and magnitude of the coefficients remain after hospital fixed effects are included, suggesting that the negative coefficient was not driven by constant differences across hospitals. It is not surprising that in column 1 the coefficients for surgeon quality and hospital quality in the prior period are significantly positive, as surgeons and hospitals with worse outcomes in the prior quarter would be expected to have worse outcomes in the current period. On the other hand, once hospital fixed effects are included (column 2), hospital quality was negatively associated with in-hospital mortality (odds ratio = 0.169, p-value < 0.1), indicating a mean-reversion pattern at hospital-level. In particular, a hospital whose performance was under its own average in past quarter tended to improve its quality in the current quarter.

Columns 3 and 4 of Table 3-3 present results from specification (11) which considers the impact of hospital volume on mortality while controlling for potentially confounding influence of surgeon volume. Again, the addition of hospital fixed effects does not substantially affect the estimation results. Both columns suggest that the impact of hospital volume drop in magnitude and significance once surgeon volume is controlled for. In fact, the coefficients of hospital-volume categories are insignificant in all three surgeon-volume clusters. These results are consistent with hypothesis that high-volume hospitals achieve better surgical outcomes not through hospital-level experience but by hiring more experienced surgeons.

Applying the same analysis to surgeons, Table 3-4 shows the impact of surgeon volume without and with adjustment for hospital volume. Table 3-4 confirms that patient mortality rate significantly improves as the surgeon volume increases, and such effect exists across hospitals with varying volumes. Specifically, coefficients in column 3 and 4 suggest that hospital volume along does not significantly influence mortality, while higher surgeon volume is strongly correlated with lower mortality within each hospital cluster. Overall, it is concluded that surgeon volume is a more important predictor for surgical mortality than hospital volume for CABG procedure.

3.5 Conclusion

The objective of this study is to determine the relative impact of hospital and surgeon CABG volume on in-hospital mortality. Using comprehensive inpatient claims data from PHC4, this analysis shows that patients treated by high-volume surgeons have lower risk-adjusted mortality than those treated by low-volume surgeons, regardless of the volume of admission hospital.

While an association between hospital volume of CABG procedure and mortality has been found in numerous studies, it remains questionable whether hospital volume can be used as one of the quality indicators to be considered during the referral process. The results of this paper imply that surgeon volume play a more important role in risk of death for CABG procedure than hospital volume. Under the national trend of decreasing hospital CABG volumes, more attention should be paid on building the volume of operating surgeons with the goal of ensuring surgical quality in low-volume CABG hospital.

Another implication beyond the CABG procedure is that for high-risk procedures, which require high technical skills and extensive use of specific intra-surgical processes, the experience of the operating surgeon rather than the admitting hospital could serve as a better predictor of the risk of death. This implication cautions against policies that attempt to regionalize procedures to a smaller number of hospitals (Ho, Town, & Heslin, 2007; Plomondon, et al., 2006). Not only these policies may not achieve desired volume effects on outcomes, they are also likely to negatively affect outcomes by causing travel constraints and disrupt physician continuity of care.

The study has several limitations. First, the outcome measure, in-hospital mortality, is defined as death before hospital discharge. However, since a large proportion of deaths occur after patients are discharged from hospital, in-hospital mortality along would not adequately reflect the true quality of surgery. Second, the RAMR is not a statistically robust measure for surgeons and hospitals with very low volume (fewer than 5 cases).

For example, there is a higher likelihood for a surgeon who performed only one case to receive a low RAMR (0%) than for a surgeon who performed more than fifty cases. However, that is not enough to suggest that the former is of better quality than the latter. Third, the study at this stage only identifies the correlation, rather than causal relationship between surgeon volume and surgical outcome. However, as discussed extensively in the health care literature, the positive correlation between health outcomes and provider volume may be due to a referral system that directs more patients to high quality providers.

In line with this research I will look for approaches that measure surgeons' and hospitals' quality more precisely, especially for providers with extremely low caseload. Another direction is to find some exogenous shock to providers' volume and use that as an instrumental variable to identify the causal relationship between volume and outcome. Finally, it is interesting to expand this study to other aspects of surgical quality such as the 3-month readmission and the length of stay, since hospital-based service (e.g. intensive care, pain management, respiratory care, and nursing care) may be beneficial in terms of relatively longer-term health outcome.

3.6 References

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Table 3-1 Characteristics of Patients, According to Hospital Volume

	Low-Volume Hospitals	Medium-Volume Hospitals	High-Volume Hospitals
In-hospital mortality	1.8%	1.8%	2.1%
	(0.13)	(0.13)	(0.14)
Gender(1=male)	70.3%	69.7%	69.4%
Race Group			
White	10.9%	11.4%	9.0%
Black	84.7%	86.4%	87.8%
Asian	4.0%	2.1%	3.0%
Other races	0.3%	0.2%	0.2%
Age group			
Age<=49	7.1%	7.8%	7.3%
Age 50-59	20.2%	19.9%	18.8%
Age 60-69	30.8%	31.3%	32.3%
Age 70-79	33.4%	33.4%	34.2%
Age 80+	8.6%	7.6%	7.4%
Cardiogenic Shock	1.3%	1.4%	1.9%
Hypertension	61.7%	58.3%	57.5%
Dialysis	0.5%	0.6%	0.7%
Heart failure	15.2%	13.8%	16.2%
Diabetes	31.2%	29.6%	29.3%
Renal failure	4.3%	4.2%	4.0%
AMI	26.8%	28.7%	27.5%
Concurrent Valve	0.9%	1.1%	1.4%
Insurance type			
Medicare	51.5%	52.8%	54.2%
Medicaid	4.4%	3.6%	3.0%
HMO	14.8%	14.9%	12.9%
Fee-for-service	25.8%	24.9%	25.9%
Emergency room admission	24.8%	18.3%	12.3%
Transferred admission	16.4%	25.1%	29.0%
Urban residence	71.7%	73.6%	80.1%
Healthiness Index			
Charlson co-morbidity index(CCI)=0	21.5%	21.1%	20.3%
CCI=1	33.0%	33.4%	32.7%
CCI=2	23.0%	23.4%	23.7%
CCI=3	12.9%	12.4%	12.8%
CCI=4	5.4%	5.5%	5.9%
CCI=5	2.3%	2.4%	2.5%
CCI>=6	1.9%	1.8%	2.2%
Number of observations	52759	52189	52016

Table 3-2 Characteristics of Hospitals, According to Hospital Volume

	Low-Volume Hospitals	**Medium-Volume Hospitals**	**High-Volume Hospitals**
Non-for-profit	98%	100%	100%
Bed size <200	18%	6%	0%
Bed size 200-400	51%	32%	9%
Bed size>400	31%	62%	91%
Member of any health system	40%	58%	87%
Teaching	28%	40%	70%
COTH membership	68%	83%	89%
Medicare share	42%	40%	41%
(standard deviation)	(0.10)	(0.07)	(0.08)
Number of observations	1333	506	294

Table 3-3 Association Between Hospital Volume and In-hospital Mortality[a]

Overall impact of hospital volume				
Medium Hospital volume	0.876*	0.857*		
	[0.062]	[0.078]		
High Hospital volume	0.956	0.948		
	[0.089]	[0.100]		
Overall Impact of surgeon volume				
Medium surgeon volume			0.769***	0.754***
			[0.072]	[0.062]
High Hospital volume			0.760*	0.800*
			[0.126]	[0.095]
Impact of hospital volume among low-volume surgeons				
Medium Hospital volume			0.874	0.879
			[0.079]	[0.110]
High Hospital volume			1.049	1.034
			[0.117]	[0.143]
Impact of hospital volume among medium-volume surgeons				
Medium Hospital volume			0.938	0.940
			[0.118]	[0.106]
High Hospital volume			1.052	1.088
			[0.157]	[0.172]
Impact of hospital volume among high-volume surgeons				
Medium Hospital volume			0.981	0.878
			[0.164]	[0.122]
High Hospital volume			0.986	0.968
			[0.173]	[0.141]
Hospital RAMR, prior quarter	13.982**	0.169*	11.119**	0.170*
	[15.194]	[0.170]	[11.608]	[0.170]
Surgeon RAMR, prior quarter	2.123***	1.917**	2.004***	1.850**
	[0.603]	[0.567]	[0.536]	[0.520]
Quarter Fixed Effects	Y	Y	Y	Y
Hospital fixed effects	N	Y	N	Y
Standard errors clustered by hospital	N	Y	N	Y
Observations	150042	150042	150042	150042

[a] Coefficients are report as odds ratio.

* p < 0.10; ** p < 0.05; *** p< 0.01.

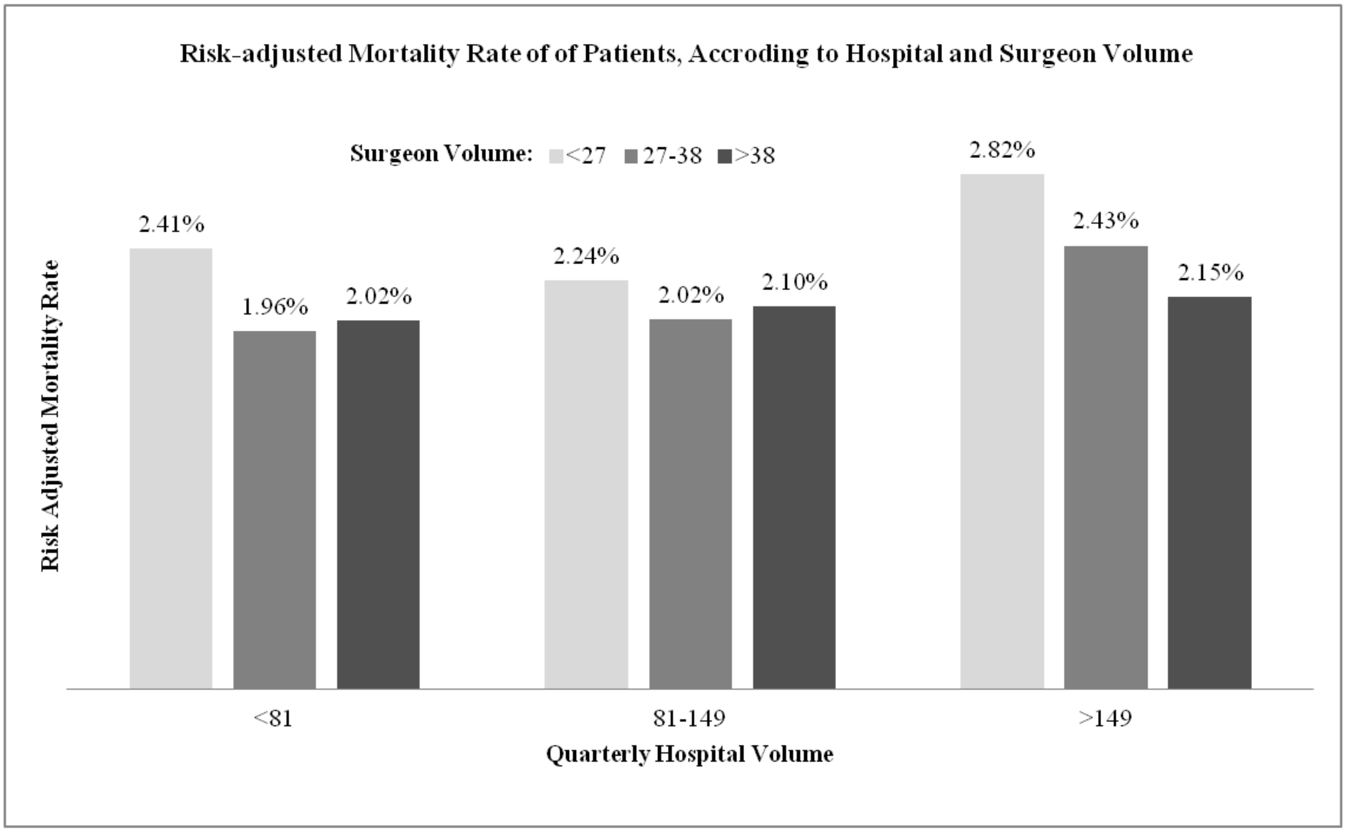
Table 3-4 Association Between Surgeon Volume and In-hospital Mortality[a]

Overall impact of Surgeon volume				
Medium Surgeon volume	0.780***	0.782***		
	[0.044]	[0.043]		
High Surgeon volume	0.764***	0.772***		
	[0.045]	[0.048]		
Overall Impact of hospital volume				
Medium hospital volume			0.874	0.879
			[0.079]	[0.110]
High Hospital volume			1.049	1.034
			[0.117]	[0.143]
Impact of surgeon volume in low-volume hospitals				
Medium Surgeon volume			0.769***	0.754***
			[0.072]	[0.062]
High Surgeon volume			0.760*	0.800*
			[0.126]	[0.095]
Impact of hospital volume in medium-volume hospitals				
Medium Surgeon volume			0.825**	0.806**
			[0.069]	[0.073]
High Surgeon volume			0.853	0.800*
			[0.085]	[0.091]
Impact of hospital volume in high-volume hospitals				
Medium Surgeon volume			0.771**	0.793*
			[0.093]	[0.096]
High Surgeon volume			0.714***	0.749***
			[0.054]	[0.063]
Hospital RAMR, prior quarter	12.647**	0.187*	11.119**	0.170*
	[13.746]	[0.188]	[11.608]	[0.170]
Surgeon RAMR, prior quarter	2.024***	1.851**	2.004***	1.850**
	[0.544]	[0.521]	[0.536]	[0.520]
Quarter Fixed Effects	Y	Y	Y	Y
Hospital fixed effects	N	Y	N	Y
Standard errors clustered by hospital	N	Y	N	Y
Observations	150042	150042	150042	150042

[a] Coefficients are report as odds ratio

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Figure 3-1 Patient Risk-adjusted Mortality Rates by Hospital and Surgeon Volume Category



Suhui Li

Contact Information

101 W. Main Street, Apt. 37
Clinton, NJ 08809
Personal Website: http://www.lehigh.edu/~sul207
Phone: (484) 707-4858
Fax: (610)758-4677
Email: sul207@lehigh.edu

Education

2012 (expected) Ph.D., Economics, Lehigh University
Thesis: Essays on Entry, Volume and Outcomes in Hospital Markets
Advisor: Shin-Yi Chou
Dissertation Committee: James A. Dearden, Mary E. Deily, Yang Wang
Expected Completion: May 2012.

2007 B.S., Management, Dalian University of Technology, P.R. China.

Honors and Awards

Summer Fellowship, Mathematica Policy Research, Summer 2011
Best Teaching Assistant of the Year, Lehigh University, Fall 2010
Warren York Dissertation Fellowship, Lehigh University, Spring 2010
Research Assistantship, Lehigh University, 2008-2009
Teaching Assistantship, Lehigh University, 2007-2008, 2010-2011
School of Management Scholarship, Dalian University of Technology, 2004-2006

Research Fields

Primary Fields: Health Economics, Industrial Organization
Secondary Fields: Labor Economics, Applied Microeconometrics
Research Interests: Healthcare Market, Labor Market, Social Welfare, Game Theory

Research

Research Papers

1. Suhui Li "The Welfare Effects of Free Entry: Evidence from the Pennsylvania Cardiac Care Market" (job market paper)

Theory predicts that free entry in a homogeneous-products market is socially wasteful due to substantial business-stealing. In hospital markets where hospitals differentiate in location and quality of care, however, free entry may be welfare improving if entry increases aggregate demand and improves hospital differentiation. This paper studies the consequences of hospital entry by examining the Pennsylvania cardiac surgery market, which experienced substantial entry after the Certificate of Need (CON) state regulation was repealed in 1996. I find that hospital entry was associated with both increased demand for surgeries and improved hospital specialization. I also find that entry led to significant cost-savings and slightly improved patient outcomes. The welfare benefits from free entry exceeded the fixed costs of new hospital facilities, suggesting that free entry in the Pennsylvania cardiac surgery market was welfare improving.

2. James Dearden, Suhui Li, Chad Meyerhoefer "Demonstrated Interest: Signaling Behavior in College Admissions"

3. Shin-Yi Chou, Mary E. Deily and Suhui Li “Regionalization and Health Outcomes for Scheduled Surgery”

4. Shin-Yi Chou, Mary E. Deily, Suhui Li and Yi Lu “Quality Information and Quality Competition: Evidence from the Pennsylvania CABG Market”

5. Suhui Li “Racial and Geographic Disparity in the Use of Revascularization among Acute Myocardial Infarction Patients”

6. Suhui Li “The Relative Impacts of Hospital Volume and Surgeon Volume for Coronary Artery Bypass Graft Procedure”

Work in Progress

1. “How Exogenous the Market Competition Measures Should Be? Evidence from the CABG Hospital Market”, with Yi Lu (Lehigh University).

Professional Activities

Referee for: Contemporary Economic Policy, Eastern Economic Journal

Conference Presentations

1. Eastern Economic Association Annual Meeting, “The Welfare Effects of Free Entry: Evidence from Pennsylvania Cardiac Care Market”, Boston, MA, March 2012.
2. Eastern Economic Association Annual Meeting, “The Welfare Impact of Free Entry: Evidence from Pennsylvania Cardiac Care Market”, New York, NY, February 2011.
3. Eastern Economic Association Annual Meeting, “Quality Information and Quality Competition: Evidence from the Pennsylvania CABG Market”, New York, NY, February 2011.
4. Third American Society of Health Economists Conference: “Quality Information and Quality Competition: Evidence from the Pennsylvania CABG Market”, Ithaca, NY, June 2010.
5. Eastern Economic Association Annual Meeting: “Demonstrated Interest: Signaling Behavior in College Admissions”, Philadelphia, PA, February 2010.
6. Seventh International Health Economics Association Conference: “Hospital Report Cards, Patients’ Travel Distance, and Health Outcome”, Beijing, P.R. China, July 2009.
7. Eastern Economic Association Annual Meeting: “Hospital Report Cards, Patients’ Travel Distance, and Health Outcome”, New York, NY, February 2009.

Other Professional Activities

1. Eastern Economic Association Annual Meeting, Discussant, MA, Boston, March 2012.
2. Eastern Economic Association Annual Meeting, Session Chair & Discussant, New York, February 2011.
3. Twenty First Annual Health Economics Conference, Correspondent, Bethlehem, PA, October 2010.
4. Third American Society of Health Economists Conference, Discussant, Ithaca, New York, NY, June 2010.

5. Eastern Economic Association Annual Meeting, Session Chair & Discussant, Philadelphia, PA, February 2010.
6. Department Seminars, Department of Economics, Lehigh University, Presenter, Bethlehem, PA, November 2009, September 2010.
7. National Bureau of Economic Research Summer Institute, Attendee (Invited), Cambridge, MA, July 2009, July 2010, July 2011
8. Lehigh University Academic Symposium, Presenter, Bethlehem, PA, April 2009.
9. Eastern Economic Association Annual Meeting, Discussant, New York, NY, February 2009.

Teaching Experience

Instructor

Principle of Economics (Online Course): Summer 2010, Summer 2011
Statistics: Fall 2011, Spring 2011 (scheduled)

Teaching Assistant

Principle of Economics: Fall 2007, Spring 2007
Applied Microeconomic Analysis: Summer 2008, Summer 2009
Money, Banking and Financial Markets: Spring 2010, Fall 2010, Spring 2011
Statistics: Summer 2010, Fall 2010, Spring 2011

Skills and Other Information

Computer Skills: STATA, SAS(earned Certification of Base Programmer for SAS 9), LATEX, Maple, Matlab, R, SPSS, ArcGIS

Languages: English and Chinese

Reference

Shin-Yi Chou, Professor of Economics, Lehigh University,
Research Associate, National Bureau of Economic Research.
621 Taylor Street, Bethlehem, PA 18015
syc2@lehigh.edu, (610)758-3444

James A. Dearden, Professor of Economics, Lehigh University.
621 Taylor Street, Bethlehem, PA 18015
jad8@lehigh.edu, (610)758-5129

Mary E. Deily, Professor of Economics, Lehigh University.
621 Taylor Street, Bethlehem, PA 18015
med4@lehigh.edu, (610)758-4951

Yang Wang, Assistant Professor of Economics, Lafayette College.
Quad Drive, Easton, PA 18042
wangy@lafayette.edu, (610)-330-5297

Anthony P. O’Brien, Professor of Economics, Lehigh University.
621 Taylor Street, Bethlehem, PA 18015
anthony.obrien@lehigh.edu, (610)758-3411