2015

# The Effect of Competition on Technology Diffusion and Treatment Choices in Healthcare Market

Yang Yu
*Lehigh University*

# The Effect of Competition on Technology Diffusion and Treatment Choices in Healthcare Market

by

Yang Yu

Presented to the Graduate and Research Committee

of Lehigh University

in Candidacy for the Degree of

Doctor of Philosophy

in

Business and Economics

Lehigh University

September 2015

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

Date

Dissertation Advisor

Committee Members:

Mary E. Deily, Committee Chair

Shin-Yi Chou

Muzhe Yang

Jason M. Hockenberry

# Acknowledgements

I would like to express my sincere gratitude to all the professors who teach and help me in my graduate life, and I would never have been able to finish my dissertation without the guidance of my committee members, support and help from my family and friends.

To my committee chair Dr.Mary E. Deily, I would like to gratefully and sincerely thank for her guidance, understanding, patience, and most importantly, her friendship during my graduate studies at Lehigh. She gave me the freedom to do whatever I wanted, at the same time continuing to contribute valuable feedback, advice, and encouragement.Her mentorship was paramount in providing a well rounded experience consistent my long-term career goals.

To my committee members Dr.Shin-Yi Chou, Dr.Muzhe Yang and Dr.Jason M. Hockenberry for their excellent guidance, thoughtful criticism on my research projects, I truly appreciate their effort and time.

To my professors for showing me through challenging coursework how to think, teach, and teach others to think: Dr.Judith A. McDonald and Dr.Chad D. Meyerhoefer.

To participants at Lehigh University Lunch Seminar Series for helpful comments.

To the department coordinator, Rene Hollinger for assisting me with all tasks necessary for completing my doctoral program, from organizing department lunch seminar to sending out letters for my job applications.

To my father, Zhongyuan Yu, who was also the first one introduced medical world to me. He provided me a lot of knowledge and information of the cardiovascular disease and medical background during my research period. His kindly help and support helped me to find out my interest topics and research field.

# Contents

# List of Tables

# List of Figures

# Abstract

This dissertation explores the effect of competition among physicians on the technology diffusion and treatment choices in health care market. In Chapter 2, I study the effect of competition among physicians on their use of a new technology for coronary heart disease in Pennsylvania from 2003-2008: drug-eluting stents in percutaneous coronary intervention (PCI) procedures. I use inpatient data from the Pennsylvania Health Care Cost Containment Council (PHC4), physician data from public websites, and hospital data from American Hospital Association (AHA) *Annual Survey of Hospitals*, and find that competition hastened diffusion of drug-eluting stents (DES) from 2003-2006, when physicians were quickly adopting the new technology, and hastened abandonment of DES after 2006, when new information came out revealing problems with DES. I also compare the competition effect among star physicians and non-star physicians, and find that the effect of competition is stronger on star physicians than on non-star physicians.

In Chapter 3, I examine the effect of relative strength of competition among providers on the treatment choices of procedures (coronary artery bypass surgery (CABG) and percutaneous coronary intervention (PCI)) and the appropriateness of care for coronary heart disease patients in Pennsylvania from 2000-2008. By using data Pennsylvania Health Care Cost Containment Council (PHC4) and hospital service areas (HSAs) from the *Dartmouth Alas of Health Care*, I find that in areas where competition among CABG surgeons is stronger than the competition among PCI physicians, patients are more likely to be treated by CABG surgery. I also find that as competition among CABG surgeons in an area increases, patients are more likely to be treated by CABG, with the result that the marginal patient receiving CABG is less clinically appropriate for CABG.

# Chapter 1

# Competition and Physician Behavior

One of the most important industries in the United States economy is health care, accounting for nearly two trillion dollars in expenditure annually (Smith et al., 2006). This industry is one in which competition is a real issue, given the controversy over the effect of competition on price and quality. Therefore, measuring the effects of competition is increasingly important for analysis of health care markets. This dissertation studies the effect of competition among physicians on the quality of the care they provide. In particular, we explore how physician competition affects diffusion of new technology, treatment choices, and appropriateness of treatment.

People supporting competition in health care argue that competitive health care markets lead to lower prices, premiums, out-of-pocket payments, and resource use, and to higher quality of care than do noncompetitive markets (Miller 1996; Baker 2001). In theory, competition aims to maximize social welfare with the optimal combination of price and quality (Baker 2001). The success of competitive strategies, however, depends on which insurers, hospital, physicians, and other participants in the health care system compete with each other and how (Gaynor and Vogt 2000; Luft, Robinson, Garnick, et al. 1986; Enthoven and Kronick 1989). Some studies attempt to determine whether health care markets with fewer competitors have higher prices, or whether competition among health care providers is more likely to occur through service quality or technological innovation. Other studies focus on evaluating the effects of growth in managed care on the degree of competition, or on the impact of regulations, antitrust efforts, and other policies on the amount and effects of competition.

Hospitals and physicians are the two primary providers of health care and their services comprise a large component of Gross Domestic Product (GDP). In 2009, hospital care accounted for 5.4 percent of GDP, and physician services 3.6 percent of GDP (Martin et al., 2011; Gaynor 2011). These two sectors have been undergoing significant structural shifts over the last several decades. Table 1.1 presents hospital structure trends from 1987 to 2006, which can indicate that U.S. hospital markets are highly concentrated and have become even more concentrated over time (Gaynor 2011). The rise of managed care is the principal factor driving this massive consolidation (Fuchs 1997): the rise of HMOs introduced aggressive price negotiations between hospitals and health plans, thereby giving hospitals a strong incentive to acquire bargaining power through consolidation.

In recent years, there has also been a dramatic increase in concentration in physician markets. Physicians are moving away from small, independent practices and into larger groups (Berenson et. al. 2010). From 1997 to 2005, the proportion of physicians in solo and two-physician practices fell from 40.7 percent to 32.5 percent (Liehaber and Grossman 2007). The fraction of doctors in groups of more than fifty increased from 30.9 percent in 2009 to 35.6 percent in 2011 (Welch et. al. 2013).

I study the effect of competition among physicians on quality, in particular on adoption of new technology and treatment choices, because when prices are regulated, as they are in most countries, health care providers need to compete on quality to attract patients. Gaynor (2006) lists reasons why quality in health care markets is so important. First, the effect of health care quality on an individual's well-being can be very great, and often will be more important than the quality of other goods or services. Second, due to the pervasive presence of insurance against health care expenditures, health care consumers are not exposed to the full expense associated with their health care decisions. Thus, in the presence of a reduced role for price, quality looms larger in consumer choice, and serves as an important rationing device. Especially in the case of beneficiaries of the U.S. Medicare program, price is irrelevant for choice. Medicare pays hospitals and doctors fixed prices for their services, thus a Medicare beneficiary pays the same amount regardless of where she obtains service.

We first review findings on the effects of competition among hospitals, because they have been the focus of most research on the effects of competition and provide evidence that quality may be affected by competition.

## Hospital Competition and Quality of Care

Before 1996, hospitals primarily competed on price through "wholesale" strategies (i.e., providing services attractive to managed care plans for large numbers of enrollees) because of Medicare's switch to prospective payment for inpatient services in 1983 and the development of the managed care plans (Devers et al. 2003). Evidence shows that high HMO penetration resulted in greater price competition and hospital price reduction (Bamezai et al. 1999). By 2001, with slower growing and less tightly managed HMOs, hospital competition based primarily on price was diminishing in importance, and the major concern in health care was becoming quality, and the effect of competition on quality (Devers et al 2003). Studies show that hospitals competed by duplicating costly equipments and services with better quality to attract physicians and patients, so it was no surprise to find health care costs to be positively correlated to the level of non-price competition (Dranove et al. 1986, Joskow et al, 1980, Wilson et al. 1982, Robinson et al. 1985)

Several studies provide evidence on whether competition among hospitals increases quality (Kessler and McClellan 1999, Growrisankaran and Town 2003; Kessler and Geppert 2005; Shortell and Hughes 1988; Held and Pauly 1983), particularly for Medicare patients. Kessler and McClellan (1999) study the impact of hospital market concentration on risk adjusted one-year mortality from acute myocardial infarction (AMI, i.e., a heart attack) for all non-rural Medicare beneficiaries with AMI during the period from 1985-1994. They find that risk-adjusted one year mortality on Medicare AMI patients is significantly higher in more concentrated markets. The results with regard to expenditures have a somewhat different pattern. Prior to 1991, expenditures were higher in less concentrated markets, while the reverse is true as of 1991.

In contrast to the Kessler and McClellan (1999) study, Gowrisankaran and Town (2003) estimate the effects of hospital market concentration on risk adjusted mortality rates for AMI and pneumonia, for both Medicare and HMO patients. Their approach is similar to that of Kessler and McClellan, but they define hospital markets using all patients (Medicare, HMO, Medicaid, indigent and self-pay, and indemnity patients). They find that mortality is worse for Medicare patients treated in hospitals with lower Medicare HHIs. The implication is that competition reduces quality for Medicare patients.

Kessler and Geppert (2005) extend the framework employed by Kessler and McClellan to consider the impact of concentration on differences in quality of care given patients with different degrees of illness severity. They examine outcomes (readmissions, mortality) and expense (expenditures, various measures of utilization) and expenditures for high-risk and low-risk Medicare heart attack patients in highly concentrated vs. unconcentrated markets. High-risk patients are those who were hospitalized with a heart attack in the previous year, whereas low-risk patients had no such hospitalization. They find that low-risk patients receive more intensive treatment in highly concentrated markets, but have no statistically significant difference in outcomes. High-risk patients, on the other hand, receive less intensive treatment in highly concentrated markets, and have significantly worse outcomes.

The results of these studies differ, even though they use similar methods to define market concentration, but they do not use identical areas, data, and strategies for selecting a sample. These the opposing results from the studies do not settle the debate over whether hospital competition truly improves quality or just increases the medical costs, but they do suggest quality may be affected.

## Hospital Competition and Technology Adoption

Factors driving adoption and utilization of new technology are poorly understood, but market forces may play a significant role. One way in which hospitals have competed for market share has been through the adoption of new technologies, a phenomenon called the medical arms race (Porter 2006). Hospitals increase market share by offering access to the best equipment and facilities to attract physicians. Thus, while technological innovation in medical technology has been a key driver improving life expectancy (Cutler and McClellan, 2001), it is also a significant driver of healthcare spending growth in the United States (Newhouse, 1992; Smith et al., 2009).

Most of the studies focus on variation of diffusion across hospitals (Chandra, Malenka and Skinner, 2014) with the majority studying hospital-level diffusion of high-cost procedures that are primarily imaging related, such as magnetic resonance imaging and computed tomography scanners (Fendrick et al., 1994; Bloom et al., 1991; Baker and Wheeler, 1998; Hillman et al., 1984). However, Sethi (2014) tests the hypothesis that hospitals existing in more competitive markets are more likely to adopt endovascular aneurysm repair (EVAR) for vascular surgery, and found that greater hospital competition is significantly associated with increased EVAR adoption at a time when diffusion of this technology passed its tipping point. These results suggested that adoption of a new technology is not solely driven by clinical indications, but may also be influenced by market forces.

## Physician Competition

Physicians play an important role in health care delivery, medical expenditure, technology adoption, and quality of care. In this dissertation, I focus on the relationship between physician competition and quality. To pursue better quality, physicians might change their adoption behavior and treatment decisions. Examining the effects of physicians' market power on their behavior may be an important step in assessing and controlling the health care market efficiency. The incentives of physicians to affect their own revenue by shifting services provided to patients is distinct from hospitals because hospitals are usually paid on a disease basis, and physicians are usually paid on a fee-for-service basis, earning additional revenue for every procedure performed. Therefore, the effect of competition among physicians might encourage physicians to make some decisions to attract more patients.

Measuring competition between physicians is much less well developed than for hospitals due to the fact that most physicians work in solo practices or in a practice with several physicians, and it is difficult to identify physician competition within practices or across practices. Existing work studies competition among clinics or small practices (Hamilton and McManus 2005, Gunning et al. 2013, Callaway 2010).

There is evidence that market power affects physician pricing behavior. Schneider et al. (2008) calculate county-specific competition indices for physician organizations and private insurers in California, and find that competition is significantly correlated with lower prices for physician services. Baker, Bundorf, and Royalty (2014) use Medicare claims data to create MSA level measures of competition and merge it to MSA level price data from Marketscan. They find that increased competition in physician markets is positively associated with lower prices, across all specialties. Dunn and Shapiro (2012) address the endogeneity of market structure by creating a fixed travel time competition index, and find that service prices are higher in less competitive markets.

The degree of competition in physician markets may also be important to patient health outcomes. The relationship between competition and quality however has remained unexplored in physician practice markets despite large increases in concentration. Larger practices have greater market share and greater opportunity for market power, and could lead to greater coordination of care between providers and, in turn improve patient outcomes (McWilliams et. al. 2013). However, Eisenberg (2014) studies data on cardiologists, referring physicians, and patient outcomes for Medicare beneficiaries who receive percutaneous coronary interventions (PCI), and finds a plausibly causal relationship between higher levels of concentration and mortality in the market for PCI patients. In this dissertation, I focus on three other aspects of health care quality: technology adoption, treatment choices, and appropriateness of care.

## The Effect of Competition among Physicians on Technology Diffusion

In most circumstances, physicians are the key agent in determining whether a patient is treated with a particular medical technology, suggesting that understanding the forces that affect physician technology adoption and use is critical to addressing the utilization of medical technology. Most of the research on physician adoption of new technologies has focused on the effect of physician characteristics such as age, urban versus rural location, and type of practice (solo/group) (Freiman, 1985; Hollingsworth et al., 2008). Other studies focus on the influence of star physicians (Burke, Fournier and Prasad 2007; Shinn 2012; Hamilton and McManus 2005), or on the link between peer effects and technology adoption (Coleman, Katz and Menzel 1966). Discussing a new technology with colleagues and relying on the experience of early adopters are often the most important sources for physicians to evaluate the benefits of the technology (Coleman et al.,1966; Escarce, 1996).

However, the literature on medical technology adoption and diffusion has largely ignored the role of physician competition. Callaway (2010) studied the adoption of health information technology (HIT), and found that the probability of adopting HIT increases with the number of physicians working at the clinic. However, he only focused on the effects of market size and economies of scale within clinics or practices, but not on the competition among physicians in a market setting.

## The Effect of Competition among Physicians on Treatment Decisions

The treatment decisions of physicians are of great interest in health care, because they determine health care appropriateness and physicians' own revenue. A review of published studies indicated that, on average, 50 percent of patients did not receive recommended preventive care; 30 percent did not receive needed care for acute medical conditions, and 40 percent went without necessary care for chronic conditions (Schuster, McGlynn, and Brook 1998). In United States, two patients in different locations with the same medical condition can receive drastically different treatments (Dartmouth Medical School 1999; Jencks et al. 2000), a phenomenon called geographic variation.

Two studies examined geographic variation in the intensity of treatment, and found that productivity spillovers might increase geographic variation in treatment (Chandra and Staiger, 2007; Skinner and Staiger, 2009), but do not explain how productivity differences developed. Another possible reason is differences in "social norms". A social norm is defined as a standard, customary, or ideal form of behavior to which individuals in a social group try to conform (Young 2007). If social norms are affected by competition conditions, then differences in competition may help explain geographic variations.

I study whether competition among physicians, or competition between two different types of physicians who can treat the same cohort of patients, affect treatment choices, possibly by influencing local norms. These treatment choices determine whether care is appropriate, where "appropriate" care refers to the right intervention for the right person at the right time and in the right setting (Enthoven et al., 2005). Therefore, studying competition among physicians is important, because the idea of appropriateness of care matches the original goal of research on competition, which is to determine its effects on the quality of care.

In Chapter 2, I study the effect of competition among physicians on their use of a new technology for coronary heart disease in Pennsylvania from 2003-2008: drug-eluting stents in percutaneous coronary intervention (PCI) procedures. I find that competition hastened diffusion of drug-eluting stents (DES) from 2003-2006, when physicians were quickly adopting the new technology, and hastened abandonment of DES after 2006, when new information came out revealing problems with DES. I also compare the competition effect among star physicians and non-star physicians, and find that the effect of competition is stronger on star physicians than on non-star physicians.

In Chapter 3, I examine the effect of relative strength of competition among providers on the treatment choices of procedures (Coronary artery bypass surgery (CABG) and percutaneous coronary intervention (PCI)) and the appropriateness of care for coronary heart disease patients in Pennsylvania from 2000-2008. I find that in areas where competition among CABG surgeons is stronger than the competition among PCI physicians, patients are more likely to be treated by CABG surgery. I also find that as competition among CABG surgeons in an area increases, patients are more likely to be treated by CABG, with the result that the marginal patient receiving CABG is less clinically appropriate for CABG.

Table 1.1: Hospital Market Concentration, U.S., 1987-2006[a]

| Year | Mean HHI[b] | Change[c] |
|---|---|---|
| 1987 | 2,340 | |
| 1992 | 2,440 | 100 |
| 1997 | 2,983 | 543 |
| 2002 | 3,236 | 253 |
| 2006 | 3,261 | 25 |

[a] Source: American Hospital Association. Data are for U.S. Metropolitan Statistical Areas with population$<$ 3 million.

[b] Herfindahl-Hirschmann Index. Means weighted by MSA population.

[c] Total change from the previous year in the table.

# Chapter 2

# Diffusion of Drug-Eluting Stents in PCI Procedures


## Abstract

Advances in medical technology are an important contributor to improvements in health care, but the diffusion of new procedures and technologies among physicians has not been widely studied. In this paper we study the effect of competition among physicians on their use of a new technology for coronary heart disease in Pennsylvania: drug-eluting stents in percutaneous coronary intervention (PCI) procedures. We find that competition hastened diffusion of drug-eluting stents (DES) from 2003-2006, when physicians were quickly adopting the new technology, and hastened abandonment of DES after 2006, when new information came out revealing problems with DES. We also compare the competition effect among star physicians and non-star physicians, and find that the effect of competition is stronger on star physicians than on non-star physicians.



*JEL classification:* I10; I11; O33

## 2.1 Introduction

Technology diffusion is the process by which new technologies replace older ones. In healthcare, technology diffusion is important for improving the quality of medical care by improving health outcomes. Most studies on technology innovation in healthcare markets have focused on hospitals' adoption of specialized facilities or expensive equipment such as magnetic resonance imaging machines or intensive care units (Schmidt-Dengler 2006; Shinn 2012; Duffy 1992; Baker & Phibbs 2000; Russell 1979; Rapoport 1978). However, while in many circumstances physicians are the key agent in determining whether a patient receives a given medical technology, decisions by physicians to adopt new technologies have not been as widely studied. Existing work on physician use of new technology has focused on the effects of star physicians and of peers on physicians' adoption decisions (Shinn 2012; Burke, Fournier &Prasad 2007; Coleman, Katz & Menzel 1966; Amol & Guy 2009). In this paper, we study the effect of competition among physicians on their use of drug-eluting stents in Pennsylvania over the period 2003-2008.

Before 1980, most patients with severe coronary artery disease (CAD) would receive coronary artery bypass graft (CABG) surgery, an open-heart procedure that creates new routes around narrowed and blocked arteries enabling improved blood flow to the heart muscle (Cutler and Huckman 2003). However, the introduction of percutaneous coronary intervention (PCI) in the late 1970s provided a less invasive method for opening blocked arteries. With traditional PCI, which is performed by interventional cardiologists and interventional radiologists rather than surgeons, a catheter with a deflated balloon at its top is inserted into the blocked coronary artery. The balloon is inflated under high pressure to break down the blockage, which is known as a stenosis, and then removed. The advantage of PCI is that patients do not require general anesthesia and are not put on a heart-lung machine, and consequently recover more quickly[1]. The disadvantage is that blockage of the arteries may recur to the same or greater degree within three to six months, and may also result in greater residual angina than for CABG patients[2].

PCI was improved by the introduction of coronary stents in the mid-1990s. A bare metal stent (BMS) is a small metal coil that is inserted in the artery and pushes against the wall of the artery

[1] Michaels (2002) notes that CABG operations require general anesthesia and typically a stay of four to seven days in the hospital. It may take up to three months to fully recover from the surgery.

[2] Residual angina refers to pain or discomfort in the chest.

to keep it open. The stent is implanted during PCI: when the balloon is inflated, the stent is imbedded the sides of the artery. However, BMS patients must take medication to prevent blood clots and restenosis, and these medications, which affect the whole body, may cause some side effects.

In April 2003 the Food and Drug Administration (FDA) approved a new technology, Drug-Eluting Stents (DES), for general use by U.S. physicians. A DES is a normal metal stent that has been coated with a drug. The drug-eluting stent is placed into the diseased coronary artery and slowly releases the drug locally to prevent restenosis. DES is appropriate for all patients and has been extremely successful in reducing restenosis, as well as the side effects of PCI; Ullman (2012), for example, showed that drug-eluting stents were associated with lower adjusted mortality risk in patients aged 85 and older compared to bare-metal stents.

The new stents were adopted rapidly; they accounted for 55% of the coronary stent market by the end of 2003 (Epstein et al. 2012). However, in September 2006 the FDA issued a statement saying that there was a significant increase in the rates of death and of myocardial infarction (MI) as a result of using drug-eluting stents. Some research was also published to suggest that DES use was associated with higher long-term rates of thrombosis, myocardial infarction, death, and readmission compared to BMS (Pfisterer et al. 2006;Tung et al. 2006). Physicians responded to this news quickly: the use of DES rapidly decreased (Krone RJ et al. 2010; Epstein, 2011).

Inspection of the Pennsylvania data from 2003 to 2008 shows the effects of these events. Figure 2.1, which shows the diffusion rate of DES and BMS, suggests two episodes of diffusion, the first involving quick adoption of DES 2003-2006, and the second episode involving abandonment of DES[3]. The percentage use of DES started to decrease in the third quarter of 2006, continued to fall sharply through 2007 (reaching 60% at the end of 2007) until the first quarter of 2008. The partial recovery at that time is likely due to the availability of the first second-generation drug-eluting stents, which showed improved patient outcomes (Stone et al. 2010).

We study the two time periods of diffusion, from second quarter of 2003 to second quarter of 2006, and from third quarter of 2006 to fourth quarter of 2008, to see whether physician-level competition affected the diffusion of DES during either the adoption period or the abandonment

[3] Technological abandonment refers to instances where a technology is replaced by an older, preexisting treatment alternative or technology (Howard and Shen 2011).

period. We end our analysis at the end of 2008 because of the introduction of a second-generation DES at that time, and because after 2008 PCI procedures could be done on an outpatient basis in Pennsylvania, and we do not have outpatient data.

A challenge for the analysis is creating physician markets so as to measure their competitiveness. To measure competition among physicians, we first create hospital markets using the variable radius method (Elizinga and Hogarty 1978; Garnick et al. 1987). Then within each hospital market, we calculate a Herfindahl-Hirschman Index (HHI) based on physicians' shares of stent procedures performed in the hospitals in that market. We estimate a fixed-effects model using variations over time within each physician-market pair, because the fixed-effect model can address correlated unobservable and endogenous market formation problems (Yang et al. 2014).

We find that competition hastened the diffusion of DES in the first adoption period, and led to quicker abandonment in the second period when DES was shown to have poor long-term effects. We also compare the responsiveness of star and non-star physicians to competitive pressure, and find that competition affected star physicians more strongly than it did non-star physicians.

## 2.2 Literature Review

The decision to adopt a new technology depends on the benefits to be gained compared to the costs and risks involved: research shows that firms adopt new technologies faster if technologies have financial benefits, but that if adopting a new technology requires firms to incur costs, diffusion may be slower (Hall and Khan 2003). For example, Escarce (1996) found that hospitals with the greatest potential financial gains from a new innovation would be the ones to adopt it.

Competitive pressure may therefore provide a strong inducement to a firm to adopt new technology. Theoretical research suggests that competition encourages technology adoption because firms can copy their competitors' technology and products (Gotz 1999) and because competitive firms have a stronger incentive to adopt (Arrow 1962), and empirical work has generally found that competition encourages adoption of new technology (Levin 1987; Copeland et al. 2010). In health care, Hamilton and McManus (2005) examined the diffusion of intracytoplasmic sperm injection (ICSI) among U.S. fertility clinics, and found that clinics located in competitive markets were more likely to offer ICSI than clinics in monopolized markets, and that ICSI diffused faster within competitive markets. Callaway (2010) studied the diffusion of health information technology (HIT) among small physician practices, and found that the probability of adopting HIT increased with increased competition. Escarce et al. (1995) studied diffusion of laparoscopic cholecystectomy among practices, and found that more competitive practices were associated with earlier adoption and quicker diffusion.

Most studies of individual physicians' adoption of new technology have focused on the effect of physician characteristics such as age, location, and type of practice and in particular on the influence of star physicians (Burke, Fournier and Prasad 2007; Shinn 2012; Hamilton and McManus 2005; Freinman, 1985; Escarce et al. 1995). The presence of star physicians, who because of their training may be quicker to adopt new technologies, may simultaneously decrease the costs of learning about new technologies for other physicians, and spur them to adopt the new technologies to keep up with the competition. In these studies, star physicians, who are identified as those who attended the highest ranked medical schools, or who trained in best-rated hospitals, are found to influence other physicians' adoption rates. Other researchers have found that physicians with higher numbers of academic citations were quicker to use new technology, while its use by less-cited doctors (non-star physicians) depended significantly on whether or not they interacted with more prominent peers (star physicians) in the same hospital (Coleman, Katz, and Menzel 1966; Burke, Fournier and Prasad 2007; Shinn 2012).

However, little research exists on the effect of competition among individual physicians on their technology adoption decisions, and even fewer address technological abandonment either in health care or non-health care settings (Howard and Shen 2012)[4]. In this paper, we examine the effect of physician level market competition on diffusion and on abandonment of new technology while controlling for the effect of star physicians in each market. Further, we study the impact of competition on star physicians compared to non-star physicians during both the adoption phase, and the abandonment phase.

[4]Howard and Shen (2012) studied technology abandonment, and it was focused on the impact of comparative effectiveness research not competition.

## 2.3 Physicians' Use of New Technology

We model a physician's decision to use DES as depending on the benefit they receive compare to the cost of doing so. The benefit a physician receives is the increase in his utility, which we model as having both intrinsic and extrinsic values. The intrinsic benefit for adopting DES is the impact on the physician's reputation and on his altruistic desire to help his patients achieve better outcomes. The extrinsic benefit is the additional revenue the physician may receive from adopting the new technology. Physicians are reimbursed at the same rate for using DES as for BMS. However, the quantity of patient is likely to change from adopting DES: better outcomes will increase physician's reputation, and so attract more patients.

Using DES rather than BMS does not require physicians to learn to use new equipment. The most costly aspect of adoption is likely to be learning to evaluate whether a patients may be appropriately treated using DES instead of BMS. As found in the literature, star physicians or physicians with more experience may be quicker to learn the new technology because their better training and greater learning capability may lower their cost of learning. Their presence may reduce learning costs for other physicians as wells.

Competition may affect physicians' adoption decisions in two ways. First, the effect of new technologies is usually supported with evidence published in the medical literature. In more competitive areas, physicians might work harder to stay updated on the evidence about new technologies, for example, by going to medical conferences, reading medical papers, and attending study groups, and consequently being quicker to adjust their treatment strategies. Second, physicians may desire to achieve prestige through technology acquisition (Emanuel and Fuchs 2008; Teplensky et al. 1995). That is, physicians' use of new technology is affected by their desire to seem up to date and to have better outcomes for their patients. Having a better reputation and better outcomes should increase their income (as well as any "warm glow" from better outcomes) because they can maintain an advantage in getting referrals from other physician and thus treat more patients. In a more competitive market, both these incentives for physicians should be stronger: essentially, physicians may be more likely to engage in a "medical arms race" when confronted with competitors. Similarly, physicians in more competitive markets will have a greater incentive to abandon a technology associated with bad outcomes.

Star physicians might adopt new technology earlier than non-stars because, with their greater expertise and better training, they may be more confident sooner about the value of a new technology, and quicker at risk assessment than are non-star physicians. Star physicians may also adopt more rapidly to protect or enhance their reputation, and this effect may be more pronounced in markets where star physicians face tougher competition to attract patients. We compare the competition effect on star physicians to its effect on non-star physicians, and expect that the effect on star physicians will be stronger than on non-star physicians in both periods.

## 2.4 Data and Sample

We obtained inpatient data from the Pennsylvania Health Care Cost Containment Council (PHC4). An inpatient record includes a patient's age, gender, race, zip code of residence, insurance type (Medicare, Medicaid, Commercial, Blue Cross, or Government), the principal diagnosis code and secondary diagnoses codes, the principal procedure code and secondary procedure codes, as well as the license number of the operating physician, and a four-digit hospital identification number. We selected records for hospitalizations in which the patient has a primary or secondary procedure code indicating the insertion of BMS or DES (International Classification of Diseases, 9th Edition Clinical Modification, ICD-9 procedure codes 3606 and 3607, respectively). Our final sample is 229,346 patients, 163,824 treated with DES and 65,522 treated with BMS.

We also developed data on the set of physicians, who were either interventional cardiologists or interventional radiologists, who performed DES and BMS procedures for patients (aged 18 or older) in Pennsylvania from April 2003 through December 2008. The data we collected includes information on individual physicians for each market each quarter. Using public websites[5], we assembled data on each physician's license number, license issue date, license expiration date, specialties, first name, last name, years of practice, graduate medical school, and hospital of residency[6].

[5]Some of this information was kindly provided by Jason Hockenberry. Additional information was collected from various websites including http://www.licensepa.state.pa.us/;http://www.healthgrades.com/;http://www.castleconnolly.com/; http://www.beckersasc.com/news-analysis/50-best-hospitals-in-america.html;and http://worldranking.blogspot.com/2008/12/us-top-30-graduate-medical-school.html

[6]We also know each physicians gender, but do not use this information, because actually all of the physicians are male.

Our physician sample has 384 unique physicians: 324 physicians in the first period and 338 physicians in the second period. The lower bound of physicians case number in one quarter is one. The total sample has 4,969 observations in the first period, and 3,941 observations in the second period. Many physicians work in more than one market[7], we treat one physician in one market at each quarter as a separate observation. However, since a physician's adoption experience in one market might influence his adoption decision if he works in another market, we test our results using much larger markets based on the main hospital regions(Philadelphia and Pittsburgh) and hospital referral regions(HRR) to check robustness of the main result.

We matched the individual patient records to physicians using the physician ID contained in the inpatient record. Once patients were linked to physicians, we created variables to control for the average characteristics of the patients treated by each physician each quarter. We also used the hospital ID number and patients' zip codes to define physician markets.

The third source of data for the study is American Hospital Association (AHA) *Annual Survey of Hospitals*, which contains information on hospital bed size, and on whether the hospital is a teaching hospital[8]. We linked the AHA hospital identification number with the PHC4 hospital identifier using a link file, and merged AHA data with PHC4 data.

## 2.5 Empirical Approach

We first use our patient sample to estimate the effect of competition among physicians on patients' probability of receiving a drug-eluting stent. We estimate this specification first to generate a big picture of the effect of competition on the probability of being treated by DES from 2003-2008, and to show that these effects change after the evidence of bad outcomes was published. The individual patient sample enables us to explore indirectly the effect of technology diffusion as result of competition among physicians, that is, to examine how patients' probability of receiving DES was affected by competition among physicians. We then study why patients' probability of treated with DES changed more directly by examining the effect of competition on each physician's

[7]From 2003-2006, 60.6% of physicians practice in more than one market; from 2006-2008, 58.5% of physicians practice in more than one market.

[8]We also know whether a hospital is for-profit or private not-for-profit, but do not use these information, because almost all hospitals in Pennsylvania are private not-for-profit (96.6%).

use of the new technology during the two time periods, April 2003 - June 2006 and July 2006 December 2008.

### Competition and the Probability of DES for Individual Patients

We first estimate the following logistic model using patient-level data from the entire period, 2003-2008:

$$\begin{aligned} DES_{p,i,h,t} &= \alpha_1(Most\ competitive_{h,t} \times Post_1) + \alpha_2(Competitive_{h,t} \times Post_1) + \\ &\quad \beta_1(Most\ competitive_{h,t} \times Post_2) + \beta_2(Competitive_{h,t} \times Post_2) + \\ &\quad \theta_1 Patient_{p,h,t} + \theta_2 Phy_{p,h,t} + \theta_3 Hosp_{h,t} + \theta_4 Mkt_{h,t} + \\ &\quad \gamma_i + \mu_h + \delta_t + \epsilon_{p,i,h,t} \end{aligned} \tag{2.1}$$

where $p$ is patient, $i$ is physician, $h$ is hospital, and $t$ is quarter. $DES_{p,i,h,t}$ is a dummy variable that equals one if the patient was treated with DES; $Post_1$ equals one if the procedure occurred during the period April 2003 through September 2006; $Post_2$ equals one if the procedure occurred during the period September 2006 through December 2008. $Patient_{p,h,t}$ is a vector of patient characteristics; $Phy_{p,h,t}$, $Hosp_{h,t}$, and $Mkt_{h,t}$ are characteristics of the patient's physician, hospital, and physician market; and $\gamma_i$, $\mu_h$, and $\delta_t$ are physician, hospital, and quarter fixed effects.

$Most\ competitive_{h,t}$ and $Competitive_{h,t}$ are measures of competition among physicians. Ideally we would measure physician-level competition based on clinic or practice locations, because each physician only serves in one practice or clinic. Without this information, we must use other geographic bases to create markets, and we must assume that each individual physician competes with all others whether in or not in the same practice or clinic.

We first identify hospital markets using the variable radius method, which specifies a hospital's relevant geographic market as a circular area around the hospital that is the source of 75 percent of that hospital's patient flows, based on patients' zip codes; other hospitals within the hospital's circular area are considered to be relevant competitors (Elizinga and Hogarty 1978; Garnick et al. 1987). We then measure physician concentration within each hospital market based on a Herfindahl-Hirschman Index (HHI), which is calculated as the sum of squares of each physician's share of stent procedures performed at the hospitals in the market where the hospital that they use is located. That is, we identify competing physicians as those that perform PCIs at all the hospitals in the physician's hospital's market.

We convert our continuous measure of physician competition into dummy variables based on the distribution of physician HHIs in all years of the sample period. The least competitive markets are those where a physician's HHI falls within the first tercile of the distribution; a physician is located in a "competitive" market if his market's HHI falls within the second tercile of the HHI distribution, and in a "most competitive" market if the HHI falls within the third tercile of the distribution. We use the least competitive markets as the reference group.

The coefficient estimates $\alpha_1$, $\alpha_2$, $\beta_1$, and $\beta_2$ thus measure the effect of competition among physicians on a patient's probability of being treated with DES before and after 2006. Positive estimates of $\alpha_1$ and $\alpha_2$ imply that during the first period, patients in more competitive markets were more likely to be treated with DES than were patients in the least competitive markets. Negative estimates of $\beta_1$ and $\beta_2$ indicate that during the second period, patients in more competitive markets were less likely to be treated with DES than were patients in the least competitive markets.

$Patient_{p,h,t}$ is a vector of patient characteristics controlling age, gender, insurance type, and severity. We measure severity with two Charlson indices, a measure of the likelihood that a patient will die, for each patient. The first index uses a patient's diagnosis codes at admission. The second index uses codes for any hospital visits made by the patient in the four quarters prior to their admission for PCI, and these act as measures of general health, as they reflect a wider range of health issues, such as diabetes, while the Charlson index at admission controls for the severity of patient's heart problems at that time. Values for the Charlson index variable range from zero (the patient is in relatively good health) to 2 (the patient is very severely ill).

$Phy_{p,h,t}$ represents two variables: whether the patient's physician was a star, and the physician's years of experience. We follow the previous literature (Shinn 2012; Burke, Fournier and Frasad 2007) and define a physician as a star if he meets any of the following criteria: (i) graduated from a top 30 medical school (ii) completed residency training at one of the *U.S. News & World Report's*, or (iii) is included in *Castle* & *Connolly's Top Docs publications* during the period. We measure experience as the number of years since a physician graduated from medical school.

$Hosp_{h,t}$ measures hospital characteristics: hospital total bed size, and the competitiveness of each hospital market. We include the measure of competitiveness of hospital market because drug-eluting stents are generally three to four times more expensive than bare-metal stents (Ryan and Cohen 2006), and therefore more expensive for hospitals to stock. Use of the new technology may thus be affected not just by physician competition but also by hospital competition. We calculate a second Herfindahl-Hirschman Index (HHI) as the sum of squares of each hospitals share of stent procedures within its market. We use the distribution of hospital HHIs over the entire sample period to create three categorical variables to identify the least competitive, competitive, and most competitive hospital markets.

$Mkt_{h,t}$ is a vector of market characteristics: the number of star physicians in each market, the number of non-star physicians in each market, HMO penetration, the number of AMI patients, and the amount of hospital competition. The presence of star physicians may hasten adoption by non-stars if star physician serve as leaders in the market, with other physicians influenced by their diffusion or abandonment decisions (Burke, Fournier and Prasad 2007).

Finally, greater penetration by HMOs may slow diffusion, because technological change can increase expenditures, and HMOs were designed to reduce high levels of utilization and spending (Newhouse1992)[9]. Since the Pennsylvania Department of Health reports HMO penetration by county rather than by zip code, we merge the county penetration rates to the physician market-level data by calculating the share of patients for each county in a hospital's market, and then calculating the HMO penetration rate for a hospital and therefore physician market as the weighted average of the county penetration rates.

We include fixed effects for the physician, for the admitting hospital, and for quarter. The use of physician fixed effects captures unobserved characteristics of physicians that may be cor-

[9]Evidence on the influence of HMOs on technology diffusion comes from studies of hospital decisions. Cutler and Sheiner (1998) studied a wide range of hospital-based technologies and found evidence that hospitals with higher HMO market shares had slower rates of diffusion of some technologies during the 1980s and 1990s. Baker & Phibbs (2002) and Baker & Afendulis (2006) found that hospitals located in areas with high HMO penetration were slower to adopt new technologies (mid-level neonatal intensive care units; percutaneous transluminal coronary angioplasty & coronary artery bypass graft surgery) than were hospitals in areas with low HMO penetration. But Baker and Phibbs (2002) also found that a larger HMO market share was associated with more high-level neonatal intensive care units, which they explain is because of the cost-effectiveness of these units.

related with their decision to use DES. For example, physicians with better reviews in Healthgrades[10] might be more likely to practice in more competitive markets, where they may have easier access to new medical evidence, and thus be quicker to use or abandon DES. Hospital fixed effects absorb all time-invariant differences among admitting hospitals that may affect the diffusion pattern. Quarter fixed effects control changes over time that may be affecting the diffusion pattern.

Table 2.1 presents descriptive statistics for physician, patient, market and hospital characteristics between 2003 and 2008. We distinguish between PCIs with DES and PCIs with BMS across the two study periods. Generally, we have similar characteristics across different procedure groups and time periods.

## 2.6 Competition and Physician Choice of Procedure

We use a fixed-effects linear regression to identify the effect of physician market competition on a physician's use of DES in the two sample periods. We estimate the following specification:

$$\begin{aligned} pdes_{i,m,t} &= \beta_1(comp_{m,t}) + \beta_2(\#\ of\ star_{m,t}) + \beta_3(\#\ of\ nonstar_{m,t}) + \beta_4 Exp_{i,m,t} + \\ &\quad \beta_5 Patient_{i,m,t} + \beta_6 Hosp_{i,t} + \beta_7 Mkt_{m,t} + \gamma_{i,m} + \delta_t + \epsilon_{i,m,t} \end{aligned} \tag{2.2}$$

where $i$ is physician, $m$ is market, and $t$ is quarter. We conduct our study at the level of a physician-market pair. Each physician working in each market at each quarter is called one physician-market pair, and is considered to be one separate observation. The dependent variable $pdes_{i,m,t}$ measures diffusion of DES among a physician's patients. The key variable $comp_{m,t}$ is the measure of competition among physicians. Control variables include $\#\ of\ star_{m,t}$, the number of star physicians in each market, and $\#of\ nonstar_{m,t}$, the number of non-star physicians in each market; $Exp_{i,m,t}$, a measure of physician $i$'s years of experience; $Patient_{i,m,t}$, a set of variables capturing the average characteristics of physician $i$'s patients; $Hosp_{i,t}$, the size of the hospital where the physician $i$ practices; $Mkt_{m,t}$, a vector of three market characteristics: HMO

[10] Healthgrades is a website that provides information about physicians, hospitals and healthcare providers.

penetration, hospital competition level, and number of AMI patients; and $\gamma_{i,m}$ and $\delta_t$, physician-market pair and quarter fixed effects.

The dependent variable $pdes_{i,m,t}$ measures the percentage of a physician's PCI patients that receive a drug-eluting stent in each market each quarter. We calculate this percentage each quarter and for each market in which a physician participates by dividing the number of a physician's DES cases by the total number of PCIs done by the physician in each market each quarter. We use this percentage to measure the diffusion rate because it captures whether the physician has adopted DES and also its diffusion among the physician's patients from quarter to quarter.

The variable $comp_{m,t}$ is the measure of competition among physicians. We convert the physician market HHI into three dummy variables: "Least competitive", "competitive", and "most competitive", using the terciles of the physician HHI distribution over the entire period. We expect that during the first period physicians in more competitive markets will be more likely to use DES, while during the second period competition will cause physicians to abandon DES faster than physicians in the least competitive markets.

The variables $\#\ of\ star_{m,t}$ and $\#\ of\ nonstar_{m,t}$ represent the number of star physicians and non-star physicians in each market each quarter. We expect that more star physicians in the market will promote quicker diffusion, because other physicians might either imitate star physicians or learn directly from them about using DES. For the same reasons, we expect that the presence of star physicians will hasten abandonment in the second period.

$Exp_{i,m,t}$ measures a physician's years of experience. More experienced physicians might adopt sooner than young physicians in the first period, but be quicker to abandon in the second period, because experienced physicians may be able to evaluate the effects of the new technology on their patients more rapidly than less experienced physicians. Furthermore, more experienced physicians may be more aware of the potential side effects of BMS on their patients and therefore quicker to adopt the new technology to solve these problems. We expect more experienced physicians to adopt DES faster in the first period, but to be quicker to abandon it in reaction to the negative information published in September 2006.

$Patient_{i,m,t}$ captures the average characteristics of a physician's patients in a quarter: the average age of patients, percentage of male patients, percentage of white, black or Asian patients, average severity level, and the percentage of patients with different types of insurance (Medicare, Medicaid, and uninsured, with privately insured as the reference group).

We include the variable $Hosp_{i,t}$,the bed size of the hospital where a physician practices. In our sample, over half of the physicians practice in more than one hospital in a market. We therefore create a weighted average of hospital size for a physician, using as weights the share of patients treated in each hospital, when a physician practices in more than one hospital in a market.

Although we are able to control numerous observable characteristics of physicians, patients, and markets, it is possible that there are some important determinants of the DES diffusion pattern that we do not observe and that are correlated with competition and with outcomes. For example, physicians may have different learning abilities which we cannot observe but that may affect their DES diffusion decision, because those physicians able to master the new technology more quickly will use the new technology sooner. Further, physicians with similar characteristics may choose to work in the same market or hospital and therefore bias the estimates. We control for time-invariant unobservable characteristics by including a fixed effect for each physician in each market, $\gamma_{i,m}$, in our model. We also control quarter fixed effects, $\delta_t$.

Table 2.2 shows the descriptive statistics for the physicians and for the characteristics of their patients and markets for the two periods. Overall, characteristics of physicians, physicians' patients, and markets are similar across the two time periods.

## 2.7 Effect of Competition on Star Physicians

Finally, we examine whether the influence of competition on adoption decisions differs for star physicians compared to that of non-star physicians by estimating equation (2.3) again for each of the two time periods:

$$\begin{aligned} pdes_{i,m,t} \;=\;& \theta_1(Most\ competitive_{m,t} \times Star_{i,m,t}) + \theta_2(Competitive_{m,t} \times Star_{i,m,t}) + \\ & \theta_3 Most\ competitive_{m,t} + \theta_4 Competitive_{m,t} + \theta_5(\#\ of\ star_{m,t}) + \\ & \theta_6(\#\ of\ nonstar_{m,t}) + \theta_7 Exp_{i,m,t} + \theta_8 Patient_{i,m,t} + \theta_9 Hosp_{i,t} + \\ & \theta_{10} Mkt_{m,t} + \gamma_{i,m} + \delta_t + \epsilon_{i,m,t} \qquad (2.3) \end{aligned}$$

$Star_{i,m,t}$ is a dummy variable that equals one if the physician is a star and zero if the physician is not. For the first period, positive values for $\theta_1$ and $\theta_2$ imply that competition promotes quicker use of DES by star physicians than by non-star physicians. For the second period, negative values for $\theta_1$ and $\theta_2$ imply that competition promotes quicker abandonment of DES by star physicians compared to non-star physicians.

As in specification (2.2), $Most\ competitive_{m,t}$ and $Competitive_{m,t}$ are competition category variables; $\#\ of\ star_{m,t}$ is the number of star physicians in market $m$ time $t$; $\#of\ nonstar_{m,t}$ is the number of non-star physicians in market $m$ time $t$; $Exp_{i,m,t}$ measures physician's years of experience; $Patient_{i,m,t}$ is the vector of physician's patients' average characteristics; $Hosp_{i,t}$ is the bed size of the hospital where a physician practices; $Mkt_{m,t}$ is a vector of three market characteristics: HMO penetration rate, hospital competition level, and the number of AMI patients; $\gamma_{i,m}$ is physician-market pair fixed effects; and $\delta_t$ is quarter fixed effects.

## 2.8 Results

Table 2.3 shows the results of estimating the probability of a PCI patient being treated with DES(Eq 2.1). The specification includes patient, physician, hospital and market characteristics, and hospital, physician and quarter fixed effects. Robust standard errors are clustered at the physician level. The estimates suggest that during the first period, patients are more likely to be treated with DES if their physician practices in a most competitive market, while after September 2006, patients in more competitive markets are less likely to be treated with DES. We can predict that competition among physicians promotes diffusion of the DES in the first period, and encourages quicker abandon of DES in the second period, and thus a patient's probability of receiving the treatment differs according to the competition among physicians in his area.

Figure 2.2 shows the raw data on trends in physician use of DES by the level of competition in physician markets. The figure indicates that physicians in the most competitive areas were quicker to adopt DES from second quarter of 2003 to second quarter of 2006, and quicker to abandon DES after second quarter of 2006, compared to physicians in less competitive areas.

Table 2.4 shows the results of estimating the physician-level specification (2.2), the specification of principal interest. Columns (1) and (2) show results for the first period, and columns

(3) and (4) show results for the second period. All specifications include quarter fixed effects (13 quarters in the first period, and 10 quarters in the second period). Robust standard errors are clustered at the physician market level. The key estimated coefficients for the two physician competition variables are reported in the first two lines; the reference group is the least competitive market.

Examining the results from 2003Q2-2006Q2, we find that physicians in the most competitive markets have a 0.0941 - 0.1094 percentage point higher diffusion rate compared to physicians in the least competitive markets. Compared to the mean diffusion rate, physicians in the most competitive markets are 12.4 percent to 14.4 percent[11]more likely to use DES. Further, the results in columns (3) and (4) indicate that physicians in the most competitive markets are 0.1075-0.1165 percentage point quicker to abandon DES compared to those in the least competitive markets, which compared to the mean diffusion rate, suggests they are 14.2 percent to 15.4 percent less likely to use DES[12].These results imply that competition among physicians hastened diffusion of DES during the first period, and made physicians more likely abandon it in the second period.

The other estimated coefficients show that physicians in markets with more star physicians were quicker to adopt DES during the first period and quicker to abandon DES during the second period, while more non-star physicians in a physician market lead to a significantly slower rate of diffusion in the first period, and slower rate of abandonment in the second period. These results confirm those of other researchers, who find that the presence of stars speeds diffusion for all physicians. Conversely, if the physician works in a market with more non-star physicians, he is slower to react to new information.

The estimated coefficient for the effect of a physician's experience shows that physicians with more experience are significantly quicker to adopt DES in the first period, and significantly quicker to abandon DES in the second period. The results confirm that experienced physicians are able to evaluate the effects of the new technology on their patients more rapidly than less experienced physicians.

The level of competition among hospitals, included in columns (2) and (4), has no influence on the main results. However, because there is a high correlation between the physician and hospital

[11]The mean diffusion rate is 0.758, $0.0941 \div 0.758 \times 100 = 12.4\%$ and $0.1094 \div 0.758 \times 100 = 14.4\%$.

[12]The mean diffusion rate is 0.758, $0.1075 \div 0.758 \times 100 = 14.2\%$ and $0.1165 \div 0.758 \times 100 = 15.4\%$.

market HHIs, we cannot conclude that hospital competition has no effect, that is, the insignificant result may be caused by multicollinearity[13].

Finally, we find that on average, higher HMO penetration is associated with a slower rate of diffusion in the first period, which is consistent with the literature (Baker & Phibbs, 2000; Baker & Afendulis 2006); the coefficient is not significant in the second period. As for insurance type, we find effects partially consistent with Epstein (2011): physicians with a large share of Medicaid patients are less likely to use DES in the second period than are physicians with private patients. However, we find no effects for other insurance types.

Table 2.5 shows the estimates of Eq.(2.3). The specification includes patient, physician, hospital and market characteristics, and hospital, physician and quarter fixed effects. Robust standard errors are clustered at the physician market level. The key estimated coefficients for the combined effect of competition and star physicians are reported in the first two rows.

We find that competition has a stronger effect on star physicians than on non-stars. The positive and significant results reported in column (1) show that that star physicians are 0.0488-0.695 percentage point more likely to adopt DES than non-star physicians in more competitive markets, indicating that competition promoted quicker adoption by star physicians than by non-star physicians from 2003Q2-2006Q2, while the results in column (2) show that star physicians are 0.0206-0.0534 percentage point less likely to use DES in more competitive markets, which indicate that competition resulted in quicker abandonment by star physicians than by non-star physicians during the period 2006Q3-2008.

## 2.9 Robustness Checks

We performed some additional estimations to test the robustness of our principal results. First, we consider that a physician's experience in one market of adopting DES might influence his use of DES in another market, if the physician work in more than one market. To test this hypothesis, we use three methods to identify larger physician markets, in an attempt to reduce physicians

[13]A cross-tabulation of physician competition levels and hospital competition levels shows that there is a strong correlation between the two measures. Of all the least competitive physician markets, 96.27% are also in the least competitive hospital market. Among most competitive physician markets, 81.33% are in the most competitive hospital markets.

appearing in multiple markets.

First, we use the hospital referral regions (HRR) identified in the Dartmouth Atlas of Health Care as the markets. The Dartmouth atlas divides Pennsylvania into 14 hospital referral regions, which is a collection of ZIP codes whose residents receive most of their hospitalizations from the hospitals in that area. In each HRR area, we measure market competition among PCI physicians using Herfindahl-Hirschman Indices (HHI) of concentration. We then convert this continuous measure of the relative competition into three dummy variables based on the distribution of HHI differences over the entire period 2003-2008. Although the HRR markets are larger than the original variable radius markets, we still find physicians in multiple markets from 2003-2006, the average percentage of physicians practicing in more than one market across one quarter is 50.4%, and from 2006-2008, the average percentage of physicians practicing in more than one market across one quarter is 49.7%.

Second, since Philadelphia and Pittsburgh areas are major hospital markets with the most advanced technologies and providers, we create larger markets using the Philadelphia (Southeast counties: Bucks, Chester, Delaware, Montgomery, and Philadelphia) and the Pittsburgh (Southwest counties: Allegheny, Armstrong, Beaver, Butler, Fayette, Green, Indiana, Lawrence, Washington, and Westmoreland) regions as two single markets, and use HRRs to identify the rest of the markets in the state. We still find that from 2003-2006, the average percentage of physicians practicing in more than one market across one quarter is 46.6%, and from 2006-2008, the percentage is 46.3%.

Third, because many physicians working in the Philadelphia region might also practice in Lehigh Valley area, merge counties in the Lehigh Valley (Lehigh counties: Adams, Berks, Cumberland, Dauphin, Lancaster, Lebanon, Lehigh, Northampton, Perry, and York) into the Philadelphia region to create a single market, keeping the Pittsburg region as another single market, and use HRRs to create the rest of the markets in the state. From 2003-2006, the average percentage of physicians working in more than one market across one quarter decreases to 29.6%, and from 2006-2008, the percentage decreases to 28.7%. The results in Table 2.6 continue to suggest that physicians in more competitive areas in the first period will be quicker to adopt the DES, are quicker to abandon DES in the second period.

The second way to check the results is to re-estimated specification (2.2) using a subsample of physicians with at least 15 years of experience (i.e., graduated from medical school more than 15 years ago). We exclude less experienced physicians because they may be low volume providers and low volume may be correlated with data errors, and because young physicians might take more risks. However, results in Table 2.7 are consistent with those in Table 2.4, indicating that excluding physicians with less experience does not affect the diffusion and abandonment trends on average.

Then, we examine whether the effect of competition that we find might instead be the effect of physicians' greater likelihood of practicing in more sophisticated hospitals if the physicians are located in more competitive markets. Physicians practicing in more sophisticated academic hospitals will have more opportunity to learn about new technologies and the latest medical research. Further, a physician may use the knowledge gained in an advanced hospital on his patients treated at other hospitals and in other markets. We create a new dummy variable to identify whether a physician had experience practicing in an academic hospital, where we identify an academic hospital as one that is affiliated with a medical school or university.

Finally, we replace the weighted measure of hospital size with the size of the largest hospital at which a physician practices. If a physician's adoption or abandonment decisions are affected by the resources available at a larger hospital, the physician's exposure to the technologies in a large hospital might spillover to his patients at other, smaller, hospitals in that market.

The results in Table 2.8 indicate that our results are unchanged by including these variables: we continue to find that physicians in the most competitive markets were quicker to adopt and to abandon. However, we find that after including these new variables, the number of star physicians in the market does not significantly promote quicker diffusion in the first period, nor quicker abandonment in the second period. This suggests that the presence of academic medical centers, not just the presence of star physicians, may influence physician decision-making.

## 2.10 Conclusion

This paper examines the role of competition among physicians in the diffusion and abandonment of drug-eluting stents. We use detailed patient level data that includes all PCI patients to create a unique physician-level dataset to analyze the effect of competition on physicians' use of new technology. The main contribution of this paper is to show that physician competition affects both technology diffusion and abandonment. We find that in more competitive areas, physicians are quicker to adopt new technologies and to abandon problematic technologies. The effects of competition among physicians on the abandonment of DES are stronger than the effects on the adoption, which suggests that physicians are more sensitive to using a new technology that may hurt their patients and their reputation. We also find that the effect of competition on star physicians is stronger than its effect on non-star physicians. Furthermore, our results also indicate that physicians with more experience are quicker to adopt DES, but quicker to abandon it after problems using it showed up.

There are several limitations to this study. First, we create physician competition markets based on the hospital market zip code, rather than physicians' practice zip code. It would be preferable to measure physician-level competition using physicians' practice locations to define physician markets. Second, our result is based on data from only one state, which might limit the implications for other states. Finally, beyond controlling for the presence of star and non-star physicians, we did not examine the possible impacts of peer effects among physicians. For example, physicians share information and experiences with their peers, and the individual's decision on adopting a new technology product might be impacted by the adoption decision of his relevant peer group.

Physician market structures are likely to change significantly under the Patient Protection and Affordability Act, because more physicians will be working as salaried employees of hospital or hospital- owned medical practices (Gottlieb 2012). By affecting competition among physicians, these changes in market structure may in turn affect diffusion decisions. A future area of research will be to study how competition among physicians changes under these new arrangements, and whether diffusion or abandonment rates are also affected.

Figure 2.1: Diffusion Trend of DES and BMS by Quarters in Pennsylvania, 2003Q2-2008Q4

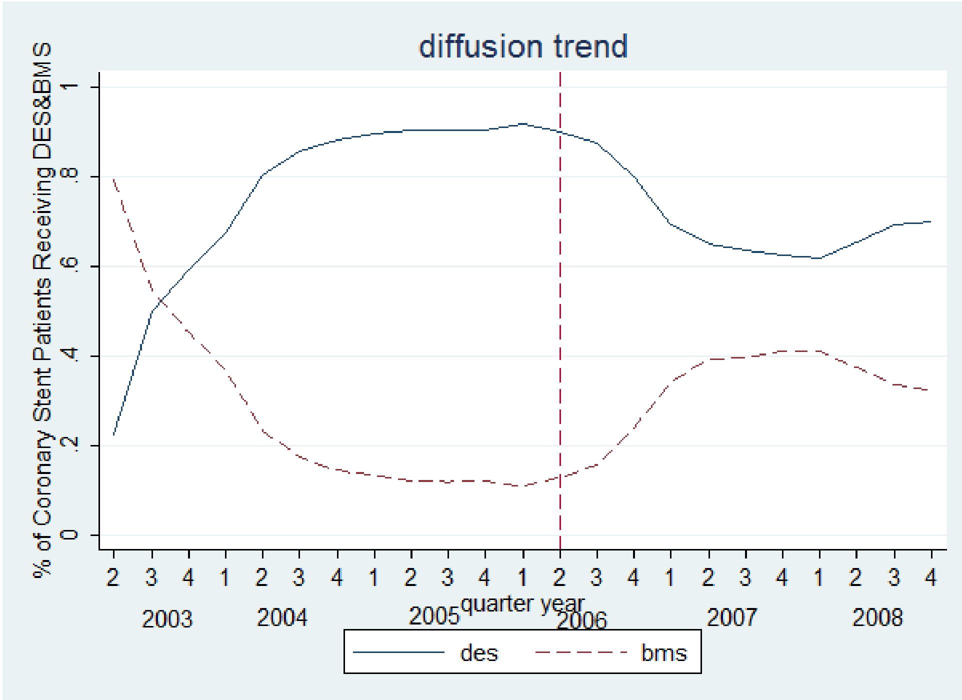

Figure 2.2: Diffusion Trends by Competition Levels in Physician Markets in Pennsylvania

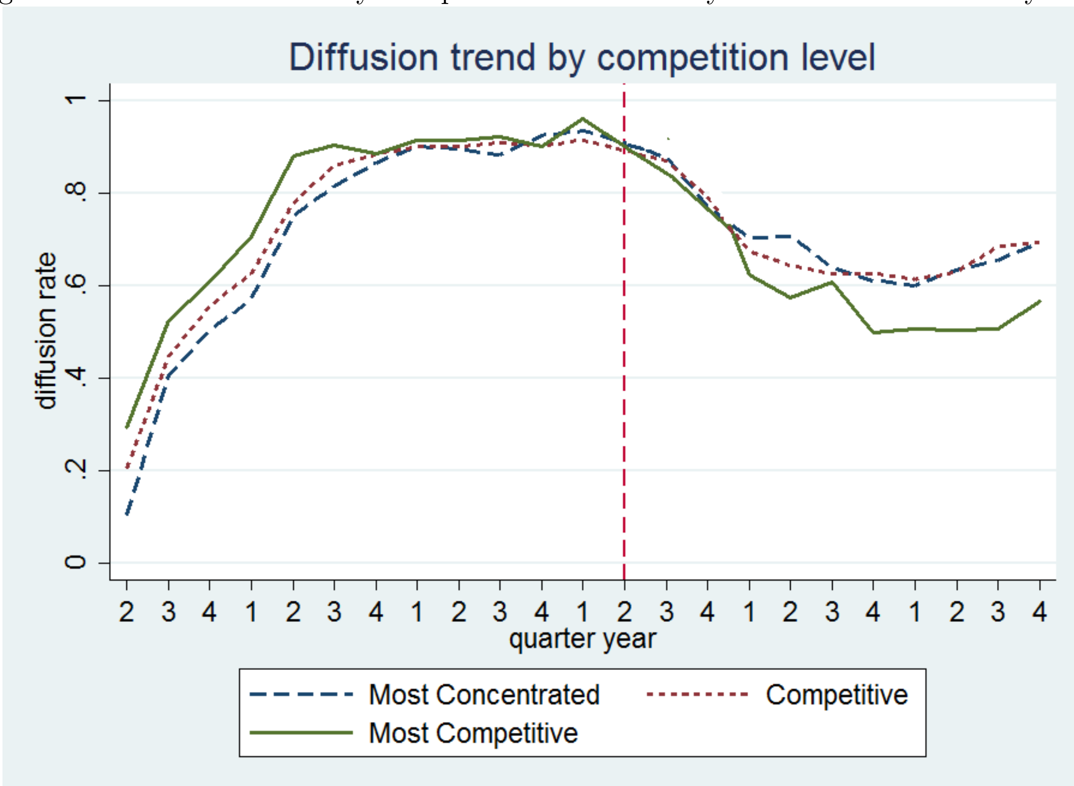

Table 2.1: Descriptive Statistics for PCI Patient Sample

| | 2003Q2-2006Q2 | | 2006Q3-2008Q4 | |
|---|---|---|---|---|
| | PCI with DES | PCI with BMS | PCI with DES | PCI with BMS |
| Patient treated with DES or BMS (%) | 76.46 | 23.51 | 69.57 | 30.43 |
| **Physician Market HHI** | | | | |
| First tercile (Least competitive) | 0.35 | 0.35 | 0.38 | 0.38 |
| Second tercile | 0.10 | 0.09 | 0.12 | 0.12 |
| Third tercile (Most competitive) | 0.02 | 0.02 | 0.03 | 0.03 |
| **Characteristics of patients (%)** | | | | |
| Emergency | 0.43 | 0.47 | 0.45 | 0.51 |
| Urgent | 0.27 | 0.29 | 0.24 | 0.26 |
| Elective | 0.30 | 0.23 | 0.31 | 0.23 |
| Uninsured | 0.01 | 0.01 | 0.01 | 0.02 |
| Medicare | 0.54 | 0.60 | 0.56 | 0.60 |
| Medicaid | 0.07 | 0.08 | 0.08 | 0.09 |
| Private Insured | 0.36 | 0.31 | 0.34 | 0.28 |
| Charlson Index=0 (before admission) | 0.66 | 0.65 | 0.64 | 0.65 |
| Charlson Index=1 (before admission) | 0.12 | 0.12 | 0.11 | 0.10 |
| Charlson Index=2 (before admission) | 0.22 | 0.23 | 0.25 | 0.25 |
| Charlson Index=0 (at admission) | 0.24 | 0.18 | 0.22 | 0.14 |
| Charlson Index=1 (at admission) | 0.39 | 0.39 | 0.36 | 0.36 |
| Charlson Index=2 (at admission) | 0.37 | 0.42 | 0.42 | 0.50 |
| Average age | 65.10 | 66.68 | 65.29 | 66.88 |
| Male | 0.62 | 0.63 | 0.62 | 0.64 |
| Female | 0.38 | 0.37 | 0.38 | 0.36 |
| White | 0.85 | 0.87 | 0.85 | 0.85 |
| Black | 0.09 | 0.08 | 0.09 | 0.09 |
| Asian | 0.00 | 0.00 | 0.00 | 0.00 |
| Other Race | 0.05 | 0.05 | 0.06 | 0.06 |
| **Characteristics of physician (%)** | | | | |
| Star (%) | 0.40 | 0.38 | 0.35 | 0.38 |
| Years of Practice | 21.17 | 20.24 | 22.52 | 21.89 |
| **Characteristics of hospital** | | | | |
| Bed size | 478.70 | 463.01 | 481.15 | 460.87 |
| Hospital HHI | 0.43 | 0.45 | 0.51 | 0.49 |
| **Characteristics of market** | | | | |
| HMO penetration | 0.44 | 0.43 | 0.34 | 0.34 |
| Number of star surgeons (mean) | 15.86 | 14.43 | 13.26 | 14.25 |
| **Sample Size** | | | | |
| Observations | 98,395 | 34,079 | 65,434 | 31,443 |

Table 2.2: Descriptive Statistics for Physician Sample

| | 2003Q2-2006Q2 | 2006Q3-2008Q4 |
|---|---|---|
| Diffusion rate (%) | 0.76 | 0.68 |
| Sample averages for independent variables | | |
| **Physician Market HHI** | | |
| First tercile (Least competitive) | 0.32 | 0.24 |
| Second tercile | 0.09 | 0.05 |
| Third tercile (Most competitive) | 0.02 | 0.02 |
| **Number of Stars and Non-stars in the Market** | | |
| Number of star physicians | 17.58 | 16.51 |
| Number of non-star physicians | 21.27 | 19.94 |
| **Characteristics of Physician** | | |
| Star (%) | 0.41 | 0.41 |
| Years of practice | 21.23 | 22.69 |
| Male (%) | 0.99 | 0.98 |
| **Average Characteristics of Physician's Patients** | | |
| Emergency (Percent) | 0.44 | 0.48 |
| Urgent (Percent) | 0.29 | 0.28 |
| Elective (Percent) | 0.27 | 0.24 |
| Uninsured (Percent) | 0.01 | 0.01 |
| Medicare (Percent) | 0.52 | 0.55 |
| Medicaid (Percent) | 0.07 | 0.08 |
| Private Insured (Percent) | 0.38 | 0.35 |
| Charlson Index=0 (before admission) | 0.67 | 0.69 |
| Charlson Index=1 (before admission) | 0.13 | 0.1 |
| Charlson Index=2 (before admission) | 0.2 | 0.21 |
| Charlson Index=0 (at admission) | 0.23 | 0.38 |
| Charlson Index=1 (at admission) | 0.4 | 0.42 |
| Charlson Index=2 (at admission) | 0.37 | 0.19 |
| Age | 64.8 | 65.44 |
| Male (Percent) | 0.64 | 0.63 |
| Female (Percent) | 0.36 | 0.37 |
| White (Percent) | 0.86 | 0.85 |
| Black (Percent) | 0.08 | 0.09 |
| Asian (Percent) | 0 | 0 |
| Other Race (Percent) | 0.05 | 0.06 |
| **Characteristics of hospital** | | |
| Bed size | 485.18 | 489.54 |
| **Characteristics of market** | | |
| Weighted avg percentage of HMO penetration | 0.44 | 0.36 |
| Hospital HHI | 0.42 | 0.46 |
| **Sample Size** | | |
| Number of physicians | 324 | 338 |
| Observations | 4,969 | 3,941 |

Table 2.3: Probability that a PCI Patient is Treated with DES, 2003Q2-2008Q4[a]

| | |
|---|---|
| Competitive * Post1 | 0.0995* |
| | [0.053] |
| Most competitive *Post1 | 0.3838* |
| (Omitted category=Most concentrated) | [0.205] |
| | |
| Competitive*Post2 | -0.1701* |
| | [0.087] |
| Most competitive*Post2 | -0.1480** |
| (Omitted category=Most concentrated) | [0.064] |
| Constant | 3.0866*** |
| | [0.749] |
| Observations | 186,081 |

[a] Post1 is from 2003Q2 through 2006Q2. Post2 is from 2006Q3 through 2008. Variables controlling for patient, physician, market, and hospital characteristics are included in the specifications, as are physician, hospital, and quarter fixed effects. Robust standard errors clustered by physician-level are in brackets. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2.4: Physicians' Use of DES [a]

| | 2003Q2-2006Q2 | | 2006Q3-2008Q4 | |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Physician market is competitive | 0.0336 | 0.0497 | -0.0599 | -0.0662* |
| | [0.037] | [0.035] | [0.039] | [0.040] |
| Physician market is most competitive | 0.0941* | 0.1094* | -0.1075** | -0.1165** |
| (Omitted category=Least competitive) | [0.056] | [0.060] | [0.048] | [0.048] |
| Number of star physicians in the mkt | 0.0029** | 0.0032** | -0.0105** | -0.0114** |
| | [0.001] | [0.001] | [0.005] | [0.005] |
| Number of non_star physicians in the mkt | -0.0016* | -0.0018* | 0.0061* | 0.0064* |
| | [0.001] | [0.001] | [0.003] | [0.004] |
| Years of experience | 0.2098*** | 0.2109*** | -0.0810*** | -0.0821*** |
| | [0.012] | [0.012] | [0.011] | [0.012] |
| Hospital market is competitive | | -0.0007 | | -0.0182 |
| | | [0.077] | | [0.040] |
| Hospital market is most competitive | | 0.0196 | | -0.0338 |
| | | [0.080] | | [0.047] |
| Weighted average HMO penetration | -0.0035** | -0.0032* | 0.0000 | 0.0002 |
| | [0.002] | [0.002] | [0.002] | [0.002] |
| # of AMI patients | -0.0000 | -0.0000 | -0.0000 | -0.0000 |
| | [0.000] | [0.000] | [0.000] | [0.000] |
| Percent of emergency patient | -0.0043 | -0.0043 | -0.0469 | -0.0473 |
| | [0.023] | [0.023] | [0.030] | [0.030] |
| Percent of urgent patient | -0.0122 | -0.0123 | 0.0128 | 0.0127 |
| | [0.024] | [0.024] | [0.038] | [0.038] |
| Percent of uninsured patient | 0.0379 | 0.0380 | -0.1124 | -0.1123 |
| | [0.084] | [0.084] | [0.111] | [0.111] |
| Percent of Medicare patient | 0.0160 | 0.0160 | -0.0474 | -0.0480 |
| | [0.025] | [0.025] | [0.031] | [0.031] |
| Percent of Medicaid patient | -0.0267 | -0.0269 | -0.0867* | -0.0867* |
| | [0.034] | [0.034] | [0.049] | [0.049] |
| Weighted average hospital bed size | -0.0000 | -0.0000 | -0.0000 | -0.0000 |
| | [0.000] | [0.000] | [0.000] | [0.000] |
| Constant | -3.6251*** | -3.6754*** | 3.0505*** | 3.1046*** |
| | [0.285] | [0.319] | [0.310] | [0.338] |
| Observations | 4,969 | 4,969 | 3,941 | 3,941 |
| R-squared | 0.320 | 0.320 | 0.144 | 0.144 |
| Adj. R-squared | 0.315 | 0.315 | 0.138 | 0.137 |

[a] All specifications include the average characteristics of the physician's patients (age, gender, admission type severity level at admission, severity level before admission, insurance type), as well as market characteristics (number of star physicians and non-star physicians), hospital size, and fixed effects for physician-market pair and quarter. Robust standard errors clustered by physician market level are in brackets.*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2.5: Effect of Competition on Use of DES by Star and Non-star Physicians[a]

| | 2003Q2-2006Q2 | 2006Q2-2008Q4 |
|---|---|---|
| | (1) | (2) |
| Competitive*Star | 0.0695* | -0.0206* |
| | [0.038] | [0.011] |
| Most competitive * Star | 0.0488* | -0.0534** |
| (Omitted category=Most concentrated) | [0.026] | [0.024] |
| Competitive | 0.0800 | -0.0589 |
| | [0.057] | [0.044] |
| Most competitive | 0.1290* | -0.0930** |
| (Omitted category=Most concentrated) | [0.069] | [0.042] |
| Number of star physicians in the mkt | 0.0031 | -0.0114** |
| | [0.003] | [0.005] |
| Number of non_star physicians in the mkt | -0.0020 | 0.0064* |
| | [0.004] | [0.004] |
| Year of experience | 0.2110*** | -0.0821*** |
| | [0.012] | [0.012] |
| Hospital competition level (Competitive) | -0.0091 | -0.0188 |
| | [0.081] | [0.040] |
| Hospital competition level (Most Competitive) | 0.0114 | -0.0353 |
| | [0.084] | [0.047] |
| Weighted average penetration rate | -0.0031* | 0.0003 |
| | [0.002] | [0.002] |
| # of AMI patients | -0.0000 | -0.0000 |
| | [0.000] | [0.000] |
| Percent of emergency patient | -0.0052 | -0.0476 |
| | [0.023] | [0.030] |
| Percent of urgent patient | -0.0127 | 0.0127 |
| | [0.024] | [0.038] |
| Percent of uninsured patient | 0.0375 | -0.1131 |
| | [0.084] | [0.111] |
| Percent of Medicare patient | 0.0159 | -0.0481 |
| | [0.025] | [0.031] |
| Percent of Medicaid patient | -0.0269 | -0.0875* |
| | [0.034] | [0.049] |
| Constant | -3.6710*** | 3.1030*** |
| | [0.321] | [0.337] |
| Observations | 4,969 | 3,941 |
| R-squared | 0.320 | 0.144 |
| Adj. R-squared | 0.315 | 0.137 |

[a] All specifications include the average characteristics of the physician's patients (age, gender, admission type severity level at admission, severity level before admission, insurance type), as well as market characteristics (number of star physicians and non-star physicians), hospital size, and fixed effects for physician-market pair and quarter. Robust standard errors clustered by physician market level are in brackets. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2.6: Physicians' Use of DES in HRR Market and Large Regions[a]

| | HRR market | | Philly, PGH and HRR | | Philly with LV, PGH and HRR | |
|---|---|---|---|---|---|---|
| | 2003Q2-2006Q2 | 2006Q2-2008 | 2003Q2-2006Q2 | 2006Q2-2008 | 2003Q2-2006Q2 | 2006Q2-2008 |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Physician market is competitive | 0.0162 | -0.0450 | 0.0325 | -0.0476 | 0.0240 | -0.0461 |
| | [0.022] | [0.037] | [0.029] | [0.029] | [0.042] | [0.057] |
| Physician market is most competitive | 0.0600** | -0.0849* | 0.0712** | -0.0706** | 0.0728** | -0.0783** |
| (Omitted category=Least competitive) | [0.029] | [0.044] | [0.031] | [0.036] | [0.036] | [0.038] |
| Number of star physicians in the mkt | 0.0001*** | -0.0001 | 0.0001*** | -0.0000 | 0.0000*** | -0.0000 |
| | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] |
| Number of non_star physicians in the mkt | -0.0001*** | 0.0001 | -0.0000 | 0.0001 | -0.0000* | 0.0001 |
| | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] | [0.000] |
| Years of experience | 0.2313*** | -0.1029*** | 0.2248*** | -0.1043*** | 0.2379*** | -0.0955*** |
| | [0.008] | [0.011] | [0.008] | [0.011] | [0.011] | [0.023] |
| Constant | -4.0254*** | 2.8849*** | -3.8984*** | 3.1495*** | -4.2002*** | 2.8384** |
| | [0.212] | [0.494] | [0.210] | [0.493] | [0.295] | [1.202] |
| % of physicians in more than one market | 50.4% | 49.7% | 46.6% | 46.3% | 29.6% | 28.7% |
| Observations | 6,492 | 5,137 | 6,323 | 5,021 | 5,029 | 4,018 |

[a] We use HRR and separate regions to create physician market, and measure competition. Philly is abbreviate of Philadelphia, PGH is abbreviate of Pittsburgh, and LV is abbreviate of Lehigh Valley. Columns (1) and (2) create market using HRR. Columns (3) and (4) generate Philadelphia and Pittsburgh regions, and use HRR to create the rest of the markets. Columns (5) and (6) generate Pittsburgh and Philadelphia regions, and merge Lehigh Valley region into Philadelphia, and use HRR to create the rest of the markets. All specifications include the average characteristics of the physician's patients (age, gender, admission type severity level at admission, severity level before admission, insurance type), as well as market characteristics (number of star physicians and non-star physicians), hospital size, and fixed effects for physician-market pair and quarter. Robust standard errors clustered by physician market level are in brackets. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2.7: Sample Restricted to Experienced Physicians ( Experience >15 years)[a]

| | 2003Q3-2006Q2 | 2006Q3-2008Q4 |
|---|---|---|
| | (1) | (2) |
| Physician market is competitive | 0.0284 | -0.0978** |
| | [0.038] | [0.042] |
| Physician market is most competitive | 0.1120* | -0.1329** |
| (Omitted category=Least competitive) | [0.059] | [0.054] |
| Number of star physicians in the mkt | 0.0032* | -0.0091** |
| | [0.001] | [0.004] |
| Number of non_star physicians in the mkt | -0.0033* | 0.0081* |
| | [0.001] | [0.004] |
| Years of experience | 0.2112*** | -0.0784*** |
| | [0.014] | [0.012] |
| Hospital market is competitive | 0.0055 | -0.0135 |
| | [0.058] | [0.037] |
| Hospital market is most competitive | 0.0157 | -0.0119 |
| | [0.063] | [0.045] |
| Weighted average HMO penetration | -0.0025 | 0.0008 |
| | [0.002] | [0.003] |
| # of AMI patients | -0.0000 | -0.0000 |
| | [0.000] | [0.000] |
| Percent of emergency patient | -0.0181 | -0.0377 |
| | [0.025] | [0.033] |
| Percent of urgent patient | -0.0264 | -0.0013 |
| | [0.027] | [0.043] |
| Percent of uninsured patient | 0.0288 | -0.2247* |
| | [0.089] | [0.126] |
| Percent of Medicare patient | 0.0000 | -0.0739** |
| | [0.027] | [0.035] |
| Percent of Medicaid patient | -0.0322 | -0.1061** |
| | [0.037] | [0.054] |
| Constant | -4.2412*** | 3.1472*** |
| | [0.393] | [0.366] |
| Observations | 3,965 | 3,167 |
| R-squared | 0.318 | 0.150 |
| Adj. R-squared | 0.312 | 0.141 |

[a] All specifications include the average characteristics of the physician's patients (age, gender, admission type severity level at admission, severity level before admission, insurance type), as well as market characteristics (number of star physicians and non-star physicians), hospital size, and fixed effects for physician-market pair and quarter. Robust standard errors clustered by physician market level are in brackets. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 2.8: Effect of Exposure to Academic Hospitals on the Rate of Diffusion[a]

| | 2003Q3-2006Q2 | 2006Q3-2008Q4 |
|---|---|---|
| | (1) | (2) |
| Physician market is competitive | 0.0562 | -0.0770** |
| | [0.035] | [0.037] |
| Physician market is most competitive | 0.1345** | -0.1416*** |
| (Omitted category=Least competitive) | [0.056] | [0.047] |
| Number of star physicians in the mkt | 0.0033 | -0.0068* |
| | [0.003] | [0.004] |
| Number of non_star physicians in the mkt | -0.0033 | 0.0066* |
| | [0.002] | [0.004] |
| Years of experience | 0.1352*** | -0.0645*** |
| | [0.010] | [0.012] |
| Hospital market is competitive | 0.0193 | -0.0022 |
| | [0.064] | [0.031] |
| Hospital market is most competitive | 0.0307 | -0.0098 |
| | [0.070] | [0.038] |
| Weighted average HMO penetration | -0.0025** | 0.0010 |
| | [0.001] | [0.002] |
| # of AMI patients | -0.0000 | -0.0000 |
| | [0.000] | [0.000] |
| Percent of uninsured patient | 0.0660 | -0.1095 |
| | [0.089] | [0.110] |
| Percent of Medicare patient | 0.0207 | -0.0487 |
| | [0.025] | [0.031] |
| Percent of Medicaid patient | 0.0073 | -0.0861* |
| | [0.033] | [0.049] |
| Academic hospital | 0.0234 | -0.0423* |
| | [0.037] | [0.022] |
| Teaching hospital | 0.0341 | -0.0445** |
| | [0.029] | [0.020] |
| Size of largest hospital | 0.0001** | 0.0000 |
| | [0.000] | [0.000] |
| Constant | -2.0759*** | 2.6009*** |
| | [0.298] | [0.319] |
| Observations | 3,822 | 3,941 |
| R-squared | 0.199 | 0.146 |
| Adj. R-squared | 0.192 | 0.138 |

[a] All specifications include the average characteristics of the physician's patients (age, gender, admission type severity level at admission, severity level before admission, insurance type), as well as market characteristics (number of star physicians and non-star physicians), hospital size, and fixed effects for physician-market pair and quarter. Robust standard errors clustered by physician market level are in brackets.*** p<0.01, ** p<0.05, * p<0.1

# Chapter 3

# Does Providers Competition Affect Treatment Choices?

## Evidence from Coronary Artery Bypass Graft and Percutaneous Coronary Intervention


### Abstract

Optimal revascularization strategy for cardiac patients has been, and remains, a topic of controversy. Evidence showed that patients with same medical condition can receive dramatically different treatments. Bu whether relative strength of competition among providers affects these treatment choices has not been widely studied. In this paper, our data on patients and hospitals characteristics are from the Pennsylvania Health Care Cost Containment Council (PHC4) and the American Hospital Association (AHA), and we collected data on physicians specialty from publicly available websites. We estimate the impact of relative strength of providers competition between two alternative procedures on the treatment choices, and the appropriateness of treatment. We find that patients are more likely to be treated by Coronary Artery Bypass Graft (CABG) if CABG surgeons are relative more competitive than Percutaneous Coronary Intervention (PCI) physicians. We also show that in the CABG surgeons relatively more competitive markets, CABG surgeons are more likely to treat patients even they are less appropriate for CABG surgery.

## 3.1 Introduction

In the United States, two patients with the same medical condition can receive drastically different treatments. Studies have found that geographic location exerts a strong influence on the choice of treatments and procedures (Burke et al. 2010, Chandra 2007). Yet most analyses of geographic variations and decisions of treatment choices do not investigate the effects of providers' competition on their decisions. In this paper, we investigate how competition among providers affects treatment choices and appropriateness of care.

There are wide and unexplained differences in costs and quality of care among providers and across geographic areas, a phenomenon called "small area variations"(Burke et al. 2009; Wennberg and Gittelsohn, 1973). The Dartmouth Atlas Report in 2012 states that locations matters for patients whose conditions can be treated with elective surgery, and a large body of research has documented significant geographic variation in the timing, intensity and appropriateness of care (Wennberg and Gittelsohn, 1973, 1982; Welch et al., 1993; O'Connor et al., 1999; Fisher et al., 2003; Weinstein et al., 2006; Deyo and Mirza, 2006). For example, Balcker, Buckles and Chandra (2006) explored the geographic variation in the appropriateness of use of Cesarean Delivery and found that areas with higher usage rates perform the intervention in medically less appropriate populations. Chassin et al. (1987) studied the relationship between geographic variation in the rates of using three procedures, and in the appropriateness of the treatments, and found significant levels of inappropriate use in high-use areas compared to low-use areas.

Several reasons have been proposed as explanations of the geographic variation. The Dartmouth Atlas Report (2012) reports that patients are more likely to receive a surgery if there are many patients with similar conditions in the area. Recently, several studies have proposed that specialization in more versus less intensive treatments and resulting productivity spillovers intensify geographic variation in treatment, particularly in the use of technologically intensive medical care (Chandra and Staiger, 2007; Skinner and Staiger, 2009). Finally, location-specific norms of behavior may also explain some of the variation. A social norm is defined as a standard, customary, or ideal form of behavior to which individuals in a social group try to conform (Young 2007). If norms for medical treatment differ, perhaps because of differences in competitive conditions, variation in norms could explain variation in care.

We study the role of competition in causing geographic variation in both treatment choices and appropriateness. We focus on cardiovascular disease in the paper. Cardiovascular disease occurs when the arteries supplying blood to heart become narrowed because of the buildup of cholesterol and plaque on the inner walls. Before 1980s, Coronary Artery Bypass Grafting (CABG) was an open-heart procedure that creates new routes around narrowed and blocked arteries, enabling improved blood flow to the heart muscle (Cutler and Huckman 2003). The introduction of percutaneous coronary intervention (PCI) in the late 1970s introduced an attraction alternative treatment for some patients. PCI is a minimally invasive surgery, a balloon or a metal coil is inserted in the artery and pushes against the wall of the artery to keep it open. These two procedures provided by different sets of doctors: CABG surgery is provided by cardiothoracic surgeons ("CABG surgeon"), and PCI procedure is provided by interventional cardiologists or interventional radiologists ("PCI physician").

Figure 3.1 shows the trends of CABG and PCI cases in Pennsylvania from 2000-2008. There is an increase in percutaneous coronary intervention (PCI) and a decrease in coronary artery bypass graft (CABG) surgery volumes in the treatment of coronary artery disease. The trend shows that PCI has been utilized increasingly and PCI-to -CABG ratio has still shifted significantly towards more PCI procedures.

In this paper, we study the effect of the relative strength of competition among providers on treatment choices for non-elective cardiac patients in Pennsylvania from 2000-2008. CABG is generally preferred for patients with left main coronary artery disease or severe triple-vessel disease with reduced left ventricular or diabetes, and PCI is generally preferred for patients with most forms of single-vessel disease when symptoms warrant coronary revascularization, in light of its lower procedural risk. The choice between PCI and CABG is most relevant for patients whose coronary artery disease (CAD) lies in between these extremes, namely patients with simple multi-vessel CAD with most forms of double-vessel CAD, less extensive forms of triple-vessel CAD, and without left main involvement and diabetes (Bravata et al 2007).

We therefore focus on treatment choices for Acute Myocardial Infarction (AMI) patients with simple multi-vessel coronary artery disease whose coronary disease is neither too limited nor too extensive, and either procedure (CABG or PCI) would be technically feasible. We use a logistic model to measure the impact of the relative strength of competition among two sets of providers, CABG surgeons and PCI physicians, on treatment choices for these patients.

We find that if competition among CABG surgeons is stronger than competition among PCI physicians in an area, patients are more likely to be treated by CABG surgery. We also investigate whether the relative strength of competition among providers affects clinical appropriateness for marginal patients, and find that marginal patients treated with CABG surgery are less appropriate for CABG in areas where competition among CABG surgeons is relatively stronger.

We think this is an interesting inquiry for three reasons. First, existing research studies the effect of hospital competition on health outcomes, but few study the effects of competition among physicians or surgeons and how it might affect local treatment norms. Second, most analyses of competition focus on its effects on the quality of care as measured by outcomes such as in hospital mortality, a low incidence event. We instead examine the effect of competition on choice of treatment and on the clinical appropriateness of the treatment choices for individual patients. Finally, our findings suggest that competition may not benefit all patients equally because of its effects on treatment selection, thereby potentially resulting in suboptimal care and increased health care expenditures (Head et al. 2013).

The paper proceeds as follows. Second 3.2 provides a general conceptual framework. Section 3.3 introduces the data and samples. Section 3.4 describes model of relative competition and the probability of CABG, and reports the estimation results, robustness checks, and falsification checks. Section 3.5 presents the model of relative competition and the appropriateness of care and reports the estimation results. Section 3.6 discussion.

## 3.2 Conceptual Framework

In many situations people rely on norms to guide their behavior, and norms are of particular relevance in environments where people interact with each other (Schram and Charness 2014). Norms can be formed by technology innovation, and social interactions may accelerate shifts in social norms over time initiated by technological change and other shocks (Burke et al. 2010). In healthcare, local norms are sometimes used to explain differences in treatment choices, and the norms are likely to be a consequence of local social interaction among physicians. Burke et al.

(2010) developed a formal model to explain how geographical variations in medical care arise, and found that the choices of a physician's nearby colleagues exert an influence on her own choices, either because of local increasing returns or because of pure conformity effects.

Until the development of PCI, coronary revascularization patients were treated either with medication or with CABG surgery. PCI provided a less invasive method for opening blocked arteries, and because of new published evidence, and updated guidelines, treatment norms changed, forcing PCI procedures for less severely ill and pushing the CABG markets toward treatment of more severely ill patients.

However, other factors might also contribute to the change of the social norms. In our paper, we consider that social norms may be affected by the relative strength of competition among providers. There is some evidence that physicians have a target income and they adjust their practice patterns accordingly (Wennberg 1984). Thus, in more competitive areas, providers are more likely to fight for more patients to preserve income. However, the number of patients that providers treat might not only be affected by competition with other providers of the same type. Competition among other types of doctors who can also treat the same patients might be another important factor. That is, providers facing more competition from physicians offering competing treatments may be more willing to treat marginal patients. This competition effect by slowing the change in local "norms" might slow the process substitution of PCI for CABG.

Figure 3.2 illustrates the idea that the strength of relative competition may affect the treatment choices for AMI patients. If competition among CABG surgeons is stronger than competition among PCI physicians, the local threshold might be pushed to the left. Furthermore, if the threshold varies because of the relative strength of competition, we should see differences in the clinical appropriateness of patients for these treatment. In particular, in areas where there is more competition among CABG surgeons than among PCI physicians, CABG surgeons may be more likely to regularly operate on patients who are as or more appropriate for PCI so as to maintain their incomes.

We ignore the demand side factors. First, health care consumers are not exposed to the full expense associated with their health care decisions (Chandra 2012; Gaynor 2006). Second, we limit our sample to non-elective (emergency and urgent) patients. We exclude elective patients because patients' choices may play a much more important role in selecting procedures if patients have more time to make decisions based on the risk and recovery period of the surgery. Further, they might also travel long distance to seek care. However, emergency patients must be treated without delay, and urgent patients can wait only one or two days, so we think their treatment choices will be more heavily influenced by providers. (Schuster et al.2009). That is, we expect that the local "norm", affected by relative strength of competition among providers, would be more likely to influence the treatment choices for these non-elective patients.

## 3.3 Data and Sample

To analyze the probability that a patient is treated with CABG, and the appropriateness of CABG as a treatment for those undergoing the surgery, we need data on individual patients, data on individual physicians, and data on individual hospitals. Inpatient data are from the Pennsylvania Health Care Cost Containment Council (PHC4). An inpatient record includes a patient's age, gender, race, zip code of residence, insurance type (Medicare, Medicaid, Commercial, Blue Cross, or Government), the principal diagnosis code and secondary diagnoses codes, the principal procedure code and secondary procedure codes, as well as the license number of the operating physician, and a four-digit hospital identification number.

Data on individual physicians and surgeons are from websites[1]. These data include each provider's license number and name; website searches on their names then allowed us to identify their specialty (cardiothoracic surgeon, interventional cardiologist or interventional radiologist physician).

The third source of data is the American Hospital Association (AHA)*Annual Survey of Hospitals*, which contains information on hospital bed size and on whether the hospital is a teaching hospital[2]. We linked the AHA hospital identification number with the PHC4 hospital identifier using a link file, and merged the AHA data with the PHC4 data so that the characteristics of the relevant hospital are attached to each individual patient record.

[1]Some of these information were kindly provided by Jason Hockenberry. Additional information was collected from various websites including http://www.licensepa.state.pa.us/; http://www.healthgrades.com/;

[2]We also know whether the hospital is for-profit or not-for-profit, but do not use this information, because almost all hospitals in Pennsylvania are private not-for-profit (96.6%).

We use the medical markets identified in the *Dartmouth Atlas of Health Care* as our CABG surgeon and PCI provider markets. The Dartmouth atlas divides Pennsylvania into 128 hospital service areas (HSA), which is a collection of ZIP codes whose residents receive most of their hospitalizations from the hospitals in that area. Analysis at the HSA level is attractive because patients can be assigned to an HSA on the basis of their residence rather than the hospital at which they received treatment, which might be endogenous.

Our study sample includes non-elective AMI patients who have simple multi-vessel cardiovascular diseases and that were treated with either CABG or PCI between 2000 and 2008. We start with all multi-vessel coronary artery disease patients, and eliminate patients with left main coronary disease, diabetes, or severe multi-vessel disease[3], and patients who are not residents of Pennsylvania. We also exclude patients who are under 18, because treatment of children may be associated with an extremely severe situation, or need a separate category of care in a children's hospital.

During the sample period, a total of 35,071 patients were treated for simple multi-vessel cardiovascular disease, 13,896 patients with CABG, and 21,175 patients with PCI. Table 3.1 presents descriptive statistics for patients treated with CABG or PCI between 2000 and 2008. Generally, we have similar characteristics across different procedure groups and time periods.

## 3.4 Analysis of Relative Competition and the Probability of CABG

We hypothesize that CABG surgeons and PCI physicians might compete for patients, and that the relative strength of competition affects local treatment decisions. To test the hypothesis, we first estimate the probability that an AMI patient is treated with CABG in a HSA area as a function of the relative strength of competition among CABG surgeons and PCI physicians in that area:

$$CABG_{i,j,m,t} \quad = \quad \alpha_0 + \beta_1 COMP_{m,t} + \beta_2 PAT_{i,j,m,t} + \beta_3 HOSP_{j,t} + \gamma_m + \delta_t + \epsilon_{i,j,m,t}, \quad (3.1)$$

[3]Primary or secondary procedure code for multi-vessel CABG: International Classification of Diseases, 9th Edition Clinical Modification, ICD-9-CM 36.12,36.13, 36.14,.36.16; procedure code for multi-vessel PCI: ICD-9-CM 00.66, 00.41,00.42, 0043, 3605. Primary or secondary diagnosis ICD-9-CM for left main disease: 410.11 Primary or secondary diagnosis ICD-9-CM for diabetes: 250. We excluded patients undergoing concomitant ventricular reconstruction or pericardial or valve surgery (ICD-9: 35.xx, 37.31, 37.32, 37.35, 37.4, or 37.5).

The dependent variable $CABG_{i,j,m,t}$ equals one if patient $i$ from hospital $j$ in market $m$ in year $t$ is treated with CABG, and equals zero if the patient is treated with PCI. $\gamma_m$ and $\delta_t$ are HSA market and year fixed effects.

$COMP_{m,t}$ is the relative strength of providers' competition in HSA market $m$ at year $t$. In each HSA area, we measure market competition among CABG surgeons and among PCI physicians using Herfindahl-Hirschman Indices (HHI) of concentration. A provider's share of PCI (CABG) cases in an HSA is calculated as the number of his PCI (CABG) procedures in the HSA market in that year, divided by the total number of PCI (CABG) cases in that HSA market in the year. The HHI for PCI (CABG) in an HSA market is then calculated as the sum of the squares of providers' shares of PCI (CABG) cases in each HSA market in that year, where the summation is over all PCI (CABG) providers in an HSA market. $COMP_{m,t}$ is then calculated as the HHI for PCI physicians minus the HHI for CABG surgeons; therefore, a higher value for $COMP_{m,t}$ indicates that the CABG surgeon market is relatively less concentrated (more competitive) than the PCI physician market in that HSA that year.

We convert this continuous measure of the relative competition into three dummy variables based on the distribution of HHI differences over the entire period 2000-2008. The markets where concentration among CABG surgeons is relatively strongest are those where the HHI falls within the first tercile of the distribution. A CABG market is relatively "competitive" if the HHI difference falls within the second tercile of the HHI distribution, and a relatively "most competitive" CABG market is where the HHI difference falls within the third tercile of the distribution. We use the markets in the first tercile where concentration among CABG surgeons is relatively strong compared to PCI physicians as the reference group: we expect that if the CABG surgeon market is relatively less concentrated (more competitive) in an HSA, patients are more likely to be treated by CABG.

We also include a number of variables to control for characteristics of the patient and the patient's admitting hospital. $PAT_{i,j.m}$ is a vector of patient characteristics: age, gender, insurance type (Medicare, Medicaid, Private), severity level, clinical status at admission, and previous clinical status. We measure severity with two Charlson indices: a Charlson index is a measure of the likelihood that a patient will die, for each patient (Charlson et al., 1987). Values for the

Charlson index variable range from zero (the patient is in relatively good health) to 2 (the patient is very severely ill). The first index is based on a patient's diagnosis codes at admission controlling for the severity of a patient's heart problems at that time. The second index is based on codes recorded for any hospital visits made by the patient in the four quarters prior to the quarter of their admission. The second Charlson dummy acts as a measure of general health, as it reflects a wider range of health issues, such as diabetes.

We also include other information about the patient's clinical status at admission with dummy variables that indicate whether the patient has heart block, artrial fibrillation, hypertension, hypercholesterolemia, heart failure, lung disease, stable angina, angina pectoris, or glomerulonephritis at admission. Dummy variables are also included to control for whether the patient had any of the following clinical problems in the previous four quarters before the quarter of admission: stroke, heart failure, Myocardial Infarction (MI), unstable angina, peripheral vascular disease (PVD), diabetes, hypertension, angina pectoris, old MI, or chronic obstructive pulmonary disease (COPD).

Finally, $HOSP_{j,t}$ represents two characteristics of patient $i$'s admitting hospital $j$ at year $t$: the hospital's total bed size, and whether the hospital is a teaching hospital[4].

Although we are able to control various observable characteristics of patients and admitting hospitals, it is possible that there may be important determinants of the treatment choices related to markets that we do not observe and that are correlated with competition and with outcomes. For example, productivity spillovers across areas might affect treatment choices, or treatment choices may differ between rural areas and urban areas. We control for time-invariant market-related unobservable characteristics by including HSA fixed effects, $\gamma_m$, in our model. We also include year fixed effects, $\delta_t$, to control time trend effects. Column (3) of Table 3.1 shows the descriptive statistics for the variables used in regression (3.1). Overall, characteristics of patients treated with CABG and PCI are similar.

[4] Hospitals' teaching status did not vary over the period.

### Estimation Results

Table 3.2 reports the marginal effects of estimating logistic equation (3.1). Column (1) includes only patients' characteristics at admission. Column (2) adds the controls for patients' clinical status from four quarters before admission and at admission. Finally, we also ran the entire sample with the "age" variable interacted with all other patient characteristics to control for any interaction effects; these results are in column (3). Robust standard errors are clustered at the HSA market level.

The variable $COMP_{m,t}$ is positive and significant: the marginal effects are around 3.3 percentage points in all columns. After dividing by the mean probability of CABG, we find that providers in markets where competition among CABG surgeons is relatively stronger, patients are 8% more likely to be treated with CABG[5]. Thus, the results show that patients are more likely to be treated with CABG if they are in a market where competition among CABG providers is competitive or most competitive relative to competition among PCI physicians, compared to markets where competition among CABG providers is relatively less strong. We conclude that the treatment decisions for non-elective patients who have simple multi-vessel cardiovascular disease is affected by the pattern of provider competition in an area.

### Robustness Checks

To check the robustness of the effect of relative strength of competition on treatment choices, we re-estimated equation (3.1) using the continuous version of competition to measure relative competition interact with three time period dummies to address the effect of technology diffusion shocks. The three time dummy variables are: $Pre2003$, $MidPeriod$, and $Post2006$. $Pre2003$ is the dummy variable that includes years from 2000 to first quarter of 2003, $MidPeriod$ measures years from second quarter of 2003 to second quarter of 2006, and $Post2006$ measures years from third quarter of 2006 to 2008.

In late April 2003, the Food and Drug Administration (FDA) approved a new version of PCI, one using drug eluting stents (DES), which was considered a more effective treatment for patients with cardiovascular disease relative to traditional balloon PCI and bare metal stents (BMS). Thus

[5]The mean probability of treated with CABG is 0.4, and $0.033 \div 0.4 \times 100 = 8.2\%$

at this time PCI became even more attractive relative to CABG. However, after 2006, clinical trials indicated that DES was associated with higher long-term rates of thrombosis, myocardial infarction, death, and readmission, so that CABG was the treatment of choice for patients with severe coronary arterial disease (Serruys et al., 2009). Figure 3.1 shows the number of DES cases increases sharply after the 2nd quarter of 2003, and significantly decreases after the 2nd quarter of 2006.

Table 3.3 shows the results. We find that before 2003, if the competition among CABG surgeons is relatively stronger, patients are significantly more likely to be treated with CABG. During 2003 to 2006, when DES quickly diffused, the power of competition among CABG surgeons is weaker, and the competition coefficients are not significant, which indicates that the new technology DES is replacing CABG. However, after 2006, the competition among CABG surgeons affect the probability of CABG again, but with weaker effect compared to the period before 2003, which suggests that the information about problems with DES encouraged providers to treat patients with CABG, but with the creation of second generation of safer DES, the competition effect does lose strength.

### Falsification Checks

We use the entire sample of cardiovascular disease patients to do some falsification checks. First, we focus on those patients who do not have simple multi-vessel disease, and are therefore only appropriate for CABG surgery, to see whether the effect of relative strength of competition among providers will affect the treatment choice. Table 3.4 shows no significant effect for competition, which indicates that providers will compete for patients only if their patients are feasible for either CABG or PCI treatment.

Second, we re-estimate equation (3.1) including only elective patients, because elective patients might participate in treatment choice decision making, and thus relative competition strength among providers might not have effects on the treatment choices. As expected, Table 3.5 shows no significant relationship.

## 3.5 Analysis of Relative Competition and Appropriateness of Patients Treated with CABG

We next study whether CABG surgeons in relatively more competitive areas are more likely to treat patients who are less appropriate for this procedure. We first develop a measure of appropriateness for each patient by running a logistic regression model for the probability of receiving CABG based on patients' characteristics, clinical information, and time fixed effects (Chandra and Staiger 2007). Specially, we estimate:

$$CABG_{i,m,t} = G(\varphi_0 + \varphi_1 PAT_{i,m,t} + \delta_t) \tag{3.2}$$

Table 3.6 presents the results of this estimation procedure. The $p$ value of the Pearson $\chi^2$ goodness-of-fit test is 0.3567, so we can reject the hypothesis, and conclude that the estimation fits the model reasonably well. Fitted values from this regression are used as an empirical measure of clinical appropriateness for this procedure.

We use this measure of appropriateness of a patient for CABG to evaluate the effect of relative strength of providers' competition on the marginal patient's clinic appropriateness level in several ways. First, we examine a subsample of patients, those who have simple multi-vessel disease but who are slightly not appropriate for CABG, and to see whether these patients are more likely to be treated by CABG where competition among CABG surgeons is relatively stronger than competition among PCI providers. We split the fitted values from equation (3.2) at their median to yield two equally sized groups; those above the median are deemed appropriate for CABG surgery and those below are not; we then drop those patients with probability above the median from the sample. We then split the remaining sample again at its median, and take the upper half, that is the second quartile of the original sample, as a sample of patients that are slightly less appropriate for CABG.

We run equation (3.1) on this subsample to estimate the effect of the relative strength of competition among providers on these marginal patients' probability of being treated with CABG. We expect that marginal patients who are slightly less appropriate for CABG might nevertheless be more likely to receive CABG in areas where competition among CABG surgeons is relatively stronger than competition among PCI physicians.

Table 3.7 shows the results. We find that marginal patients who are slightly less appropriate for CABG are more likely to be treated with CABG if they are in an area where competition among CABG surgeons is relatively stronger. The result confirms our expectation that providers compete for patients, and that competition may affect treatment choices.

Second, we follow the approach used in Gruber, Levine and Staiger (1999) and Chandra and Staiger (2007) and estimate a specification explaining the average level of appropriateness of CABG patients for that procedure in an HSA area:

$$\begin{aligned} Appropriateness_{m,t} &= \mu_0 + \mu_1 \ln_( risk\ adjusted\ CABG\ rate)_m + \\ &\quad \mu_2 avg\_pa_{m,t} + \gamma_m + \delta_t + \epsilon_{m,t} \end{aligned} \tag{3.3}$$

The dependent variable is a measure of the average appropriateness for CABG surgery for patients receiving CABG in an HSA area, and is calculated by averaging the fitted values from equation (3.2) for all patients in an HSA. $avg\_pa_{m,t}$ is a vector of averages of the patient characteristics variables and patient clinical status variables in an HSA market. $\gamma_m$ and $\delta_t$ are HSA fixed effects and year fixed effects, respectively.

The explanatory variable of interest is the natural logarithm of the risk-adjusted area CABG rate. The coefficient $\mu_1$ measures the difference in mean appropriateness between the average and the marginal patient receiving CABG (Chandra and Staiger 2007). If average appropriateness among patients treated with CABG is declining as the CABG rate rises ($\mu_1 < 0$), we infer that the marginal patient treated with CABG was less appropriate than the average patient[6].

The results of equation (3.1) give us estimates of the probability that a patient is receiving CABG as a function of the competition level, patient's covariates, HSA fixed effects and year fixed effects. The coefficients on the HSA fixed effect variables from that estimation thus represent the predicted risk-adjusted CABG rate for each market after controlling for the effects of relative competition, patient characteristics, and year fixed effects.

The results of estimating equation (3.3) are reported in Table 3.8, with the standard errors

[6]When "average" is decreasing, "marginal" is less than "average"; when "average" is increasing, "marginal" is more than "average". For example, the relationship between marginal cost and average cost.

adjusted using bootstrap. The estimates in Column (1), which include the relative strength of competition effects to measure risk adjusted CABG rate, show that the marginal patient is significantly 2.58 percentage points less likely to be appropriate for CABG. The result suggests that in the markets where competition among CABG surgeons is relatively stronger than competition among PCI physicians, CABG surgeons are more likely to treat patients that are less appropriate, that is, if competition among CABG surgeons is stronger than among PCI physicians, the threshold in figure 3.2 will be pushed to the left.

Finally, we run another regression to estimate the effect of relative strength of providers' competition on the average appropriateness level in an HSA, that is, whether in areas with stronger relative competitor among CABG surgeons, the average patient receiving CABG would be less clinically appropriate for CABG. To test this insight we estimate:

$$Appropriateness_{m,t} = \mu_0 + \mu_1 COMP_{m,t} + \mu_2 avg\_pa_{m,t} + \gamma_m + \delta_t + \epsilon_{m,t} \tag{3.4}$$

The dependent variable measures the average appropriateness of patients treated with CABG in the market $m$ and year $t$. $COMP_{m,t}$ represents the two dummy variables measuring relative strength of competition. $avg\_pa_{m,t}$ is a vector controlling for patients' average characteristics in market $m$ and year $t$. $\gamma_m$ and $\delta_t$ are HSA and year fixed effects.

The results of estimating equation (3.4) are reported in Table 3.9. In areas where the competition among CABG surgeons is strongest compared to among PCI physicians, the average appropriateness for CABG decreases by 2.9 percent compared to areas where the difference in competition strength is smallest[7]. The result confirms that in areas where competition among CABG surgeons is relatively stronger than competition among PCI physicians, the average patients' appropriateness declines, and the marginal patients treated with CABG are less appropriate for this treatment.

[7] The mean appropriateness in the areas is 0.53, and $0.0153 \div 0.53 \times 100 = 2.9\%$

## 3.6 Discussion

Our results suggest that on average, treatment decisions for non-elective AMI patients are associated with relative strength of providers' competition, and these patients are more likely to be treated by CABG if competition among CABG providers is stronger than competition among PCI physicians. Because of the relative strength of competition, marginal patients who are slightly less appropriate for CABG might be still more likely to receiving CABG in areas where competition among CABG surgeons is relatively stronger than competition among PCI physicians.

Our results thus make a contribution to the debate on whether and how much competition is appropriate in health care. Compared to previous work, our study focuses on a different type of competition. Instead of analyzing hospital competition, we focus on the effect of the relative strength of providers' competition on treatment choices. While we find that treatment decisions are affected, we also find that providers' decision-making is also affected by the trends in technology innovation, that is, we find that competition among CABG surgeons has no effect on treatment choices from 2003 and 2006, which suggests that DES is a leading treatment choice for coronary artery disease in innovation period, while competition among CABG surgeons has weaker effect after 2006 when DES was showed to have some bad outcomes.

There are several limitations to this study. First, our result is based on data from only one state, which might limit the implications for other states. Second, we only study CABG and PCI treatments, and the relative strength of competition among CABG surgeons and PCI physicians. The effect of competition might not be the same for other alternative providers and other diseases (For example, carotid endarterectomy or carotid stenting surgery are alternative treatments for carotid artery disease). Third, we focus on the relative strength of competition among different types of providers, but did not examine the possible impacts of competition among the same type of providers, or peer effects among providers.

This study of treatment decisions and clinical appropriateness has been of great interest. Empirically, the treatment decision is determined by many factors, potentially resulting in sub-optimal care and increased health care expenditures. The best way to deliver care is in a way that promotes communication amongst physicians and other caregivers around the patient in a timely manner. That is the most appealing to the patients, it is most efficient for the caregivers, and it delivers the highest quality care, possibly because of concern about questionable treatment choices. The concept of a “Heart Team” has become the subject of increasing interest in treating cardiovascular disease. A Heart-Team includes a consultation and decision-making forum by a multidisciplinary team (e.g. interventional cardiologist and a cardiac surgeon and other specialists as needed) (Head SJ et al. 2012). Our results on treatment choices confirm the important role of heart team concept. In future study, I plan to explore the effect of Heart Teams on health outcomes for patients, and health expenditures for hospitals and insurance companies. I will further explore whether the “Heart Team” concept makes any change to the effect of healthcare market structures.

Figure 3.1: Treatment Choices between CABG and PCI

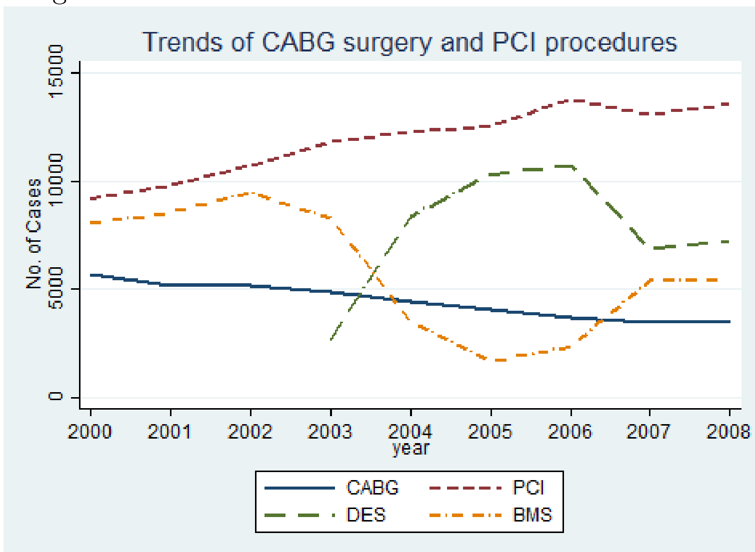

Figure 3.2: Trends of CABG Surgery and PCI Procedures

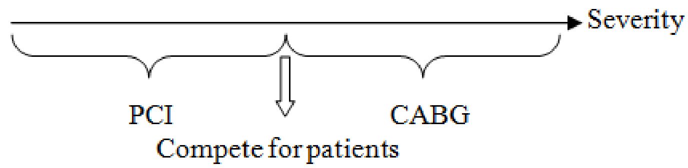

Table 3.1: Descriptive statistics for Non-elective Patients

| Variable | CABG | PCI | CABG and PCI |
|---|---|---|---|
| | (1) | (2) | (3) |
| | N=13,896 | N=21,175 | N=35,071 |
| **Dependent Variable** | | | 0.40 |
| CABG=1 | | | |
| **Independent Variable** | | | |
| **Relative Strength of Competition** | | | |
| First tercile (Least competitive) | | | 0.43 |
| Second tercile | | | 0.09 |
| Third tercile (Most competitive) | | | 0.16 |
| **Patient characteristics** | | | |
| Emergency | 0.76 | 0.80 | 0.78 |
| Urgent | 0.24 | 0.20 | 0.22 |
| Age (years) | 69.33 | 66.23 | 67.46 |
| Male | 0.65 | 0.61 | 0.63 |
| White | 0.86 | 0.85 | 0.85 |
| Black | 0.07 | 0.10 | 0.09 |
| Asian | 0.00 | 0.00 | 0.00 |
| Medicare | 0.66 | 0.55 | 0.59 |
| Medicaid | 0.06 | 0.09 | 0.08 |
| Private | 0.27 | 0.35 | 0.32 |
| Charlson Index=0 (at admission) | 0.22 | 0.20 | 0.2 |
| Charlson Index=1 (at admission) | 0.42 | 0.56 | 0.51 |
| Charlson Index=2 (at admission) | 0.36 | 0.24 | 0.29 |
| Charlson Index=0 (previous year) | 0.79 | 0.77 | 0.78 |
| Charlson Index=1 (previous year) | 0.07 | 0.08 | 0.07 |
| Charlson Index=2 (previous year) | 0.13 | 0.16 | 0.15 |
| heart block | 0.00 | 0.00 | 0.00 |
| Atrial fibrillation on admission | 0.21 | 0.11 | 0.15 |
| hypertensive on admission | 0.48 | 0.54 | 0.52 |
| Hypercholesterolemia | 0.29 | 0.44 | 0.38 |
| Heart failure | 0.35 | 0.23 | 0.28 |
| lung problem | 0.00 | 0.01 | 0.00 |
| Stable Angina | 0.01 | 0.01 | 0.01 |
| Angina pectoris | 0.02 | 0.01 | 0.01 |
| glomerulonephritis | 0.00 | 0.00 | 0.00 |
| Stroke history | 0.02 | 0.02 | 0.02 |
| Heart failure history | 0.08 | 0.12 | 0.10 |
| MI history | 0.04 | 0.04 | 0.04 |
| Unstable angina history | 0.04 | 0.05 | 0.04 |
| PVD history | 0.05 | 0.05 | 0.05 |
| Diabetes history | 0.10 | 0.10 | 0.10 |
| Hypertension history | 0.31 | 0.35 | 0.33 |
| Angina pectoris history | 0.02 | 0.03 | 0.03 |
| Old MI history | 0.07 | 0.08 | 0.08 |
| Diabetes history | 0.00 | 0.00 | 0.10 |
| COPD history | 0.10 | 0.14 | 0.12 |
| **Hospital Characteristics** | | | |
| Hospital bed size | | | 465.242 |
| Teaching Hospital | | | 0.38 |

Table 3.2: Probability of Patients Treated with CABG[a]

| | Probability of patients treated with CABG | | |
|---|---|---|---|
| | (1) | (2) | (3) |
| VARIABLES | Marginal Effect | Marginal Effect | Marginal Effect |
| CABG Competitive | 0.0334*** | 0.0332*** | 0.0317*** |
| | (0.00953) | (0.00947) | (0.00946) |
| Most Competitive | 0.0335*** | 0.0337*** | 0.0328*** |
| (Omitted category=Most concentrated) | (0.00946) | (0.00943) | (0.00944) |
| Patients' history clinical characteristics | N | Y | Y |
| Intersection terms | N | N | Y |
| Observations | 34,097 | 34,097 | 34,097 |

[a] Results are from logistic estimate of equation (1). All regressions include year dummy variables, HSA area dummy variables, and an intercept. We include patients severity level at admission and four quarters before admission measured by Charlson Index. We also include patients historical clinical status, and clinical status at admission, and all other patients characteristics. The dummies for clinic characteristics of the patients: heart block, atrial fibrillation on admission, hypertensive on admission, hypercholesterolemia on admission, heart failure on admission, lung problem on admission, stable angina on admission, angina pectoris on admission, historical heart failure, historical MI, historical unstable angina, historical PVD, historical diabetes, historical hypertension, historical angina pectoris, historical old MI, historical COPD. Complete results can be provided upon request. The standard errors in parenthesis are clustered at the HSA regional level.*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3.3: Competition Effects with Time Trend[a]

| | Marginal Effect |
|---|---|
| Relative strength of competition*Pre2003 | 0.173*** |
| | (0.0415) |
| Relative strength of competition*Mid Period | 0.0865 |
| | (0.0685) |
| Relative strength of competition*Post2006 | 0.00892*** |
| | (0.00282) |
| Pre2003 | 0.0541*** |
| | (0.0190) |
| Mid Period | 0.0226** |
| | (0.0112) |
| Observations | 34,097 |

[a] Results are from logistic estimate of equation (1). Relative strength of competition is continuous value of the different between HHI of PCI physicians and HHI of CABG surgeons. Pre2003 equals to 1 if from 2000-2003. Post2003 equals to 1 if from 2003-2006. Post2006 equals to 2 if after 2006. All regressions include year dummy variables, HSA area dummy variables, and an intercept. We include patients severity level at admission and four quarters before admission measured by Charlson Index. We also include patients historical clinical status, and clinical status at admission, and all other patients characteristics, such as: age, gender, race, insurance type. Complete results can be provided upon request. The standard errors in parenthesis are clustered at the HSA regional level.*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3.4: Probability of Patients Treated with CABG (Only Appropriate for CABG)[a]

| VARIABLES | Marginal Effect<br>CABG |
|---|---|
| CABG Competitive | -0.0150 |
| | (0.00955) |
| Most Competitive | 0.00728 |
| (Omitted category=Most concentrated) | (0.0121) |
| Observations | 28,018 |

[a] Results are from logistic regression. Sample includes patients who only appropriate for CABG. All regressions include year dummy variables, HSA area dummy variables, and an intercept. We include patients severity level at admission and four quarters before admission measured by Charlson Index. We also include patients historical clinical status, and clinical status at admission, and all other patients characteristics, such as: age, gender, race, insurance type. The standard errors in parenthesis are clustered at the HSA regional level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3.5: Probability of Elective Patients Treated with CABG[a]

| VARIABLES | Marginal Effect CABG |
|---|---|
| CABG Competitive | 0.0861 |
| | (0.0593) |
| Most Competitive | 0.0681 |
| (Omitted category=Most concentrated) | (0.0568) |
| | |
| Observations | 3,769 |

[a] Results are from logistic estimate of equation (1). Sample includes elective patients. All regressions include year dummy variables, HSA area dummy variables, and an intercept. We include patients severity level at admission and four quarters before admission measured by Charlson Index. We also include patients historical clinical status, and clinical status at admission, and all other patients characteristics, such as: age, gender, race, insurance type. The standard errors in parenthesis are clustered at the HSA regional level. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 3.6: Estimation of Appropriateness[a]

| VARIABLES | Coefficient | Standard Errors |
|---|---|---|
| Gender | -0.3308*** | [0.029] |
| Age | 0.0062*** | [0.002] |
| White | 0.0443 | [0.061] |
| Black | -0.0133 | [0.075] |
| Asian | 0.4821*** | [0.185] |
| Medicare | 0.1859 | [0.141] |
| Medicaid | 0.1585 | [0.149] |
| Private | 0.0292 | [0.142] |
| Less severe at admission ((Charson Index=1) | -0.6701*** | [0.040] |
| Most severe at admission((Charson Index=2, omitted category=Charson Index=0) | -0.0800** | [0.039] |
| Less severe previous years(Charson Index=1) | -0.0179 | [0.053] |
| Most severe previous years(Charson Index=2, omitted category=Charson Index=0) | -0.2270*** | [0.048] |
| Admitting hospital teaching | -0.0003*** | [0.000] |
| Admitting hospital total bed size | 0.0841* | [0.044] |
| Constant | 0.7746*** | [0.227] |
| Patients' clinical characteristics | Y | |
| Observations | 34,092 | |

[a] The specification includes patients characteristics, clinical information and time fixed effects so as to estimate appropriateness for CABG. Clinical characteristics are: heart block, atrial fibrillation on admission, hypertensive on admission, hypercholesterolemia on admission, heart failure on admission, lung problem on admission, stable angina on admission, angina pectoris on admission, historical heart failure, historical MI, historical unstable angina, historical PVD, historical diabetes, historical hypertension, historical angina pectoris, historical old MI, historical COPD. The standard errors in brackets are clustered at the HSA regional level. *** p<0.01, ** p<0.05, * p<0.1

Table 3.7: Probability of Marginal Patients' Treated with CABG[a]

| | (1) |
|---|---|
| VARIABLES | Marginal effect |
| Competitive | 0.0413* |
| | (0.0234) |
| Most Competitive | 0.0401* |
| | (0.0240) |
| Observations | 8,367 |

[a] Results are from logistic estimate for marginal patients slightly less appropriate for CABG. We get the subsample from the 2nd quartile of total sample by appropriateness. All regressions include year dummy variables, HSA area dummy variables, and an intercept. We include patient's severity level at admission and four quarters before admission measured by Charlson Index. We also include patient's historical clinical status, and clinical status at admission, and all other patients' characteristics. The standard errors in parenthesis are clustered at the HSA regional level. *** p<0.01, ** p<0.05, * p<0.1

Table 3.8: Marginal Patient's Appropriateness for CABG[a]

| | (1) |
|---|---|
| VARIABLES | Area's Appropriateness |
| | Competition effects |
| ln(CABG rate) | -0.0258** |
| | [0.013] |
| Observations | 275 |

[a] Estimation results for patients only receive CABG. All regressions include year dummy variables, HSA area dummy variables, and an intercept. We include average patients characteristics and the share of patients clinical status in each HSA market. The standard errors in brackets are adjusted using bootstrap. *** p<0.01, ** p<0.05, * p<0.1

Table 3.9: Area's Average Appropriateness for CABG[a]

| | (1) |
|---|---|
| VARIABLES | Area's Mean Appropriateness |
| Competitive | -0.0056 |
| | [0.008] |
| Most Competitive | -0.0153* |
| (Omitted category=Most concentrated) | [0.009] |
| Observations | 275 |

[a] Estimation results for patients only receive CABG. All regressions include year dummy variables, HSA area dummy variables, and an intercept. We include average patients characteristics and the share of patients clinical status in each HSA market. The standard errors in brackets are clustered at the HSA regional level. *** p<0.01, ** p<0.05, * p<0.1

# Conclusion

This dissertation studies the effect of competition among physicians on physicians' technology use and treatment decision. In chapter 2, we study the impact of competition among physicians on the diffusion of the drug eluting stents. By using inpatient data in Pennsylvania who performed PCI from 2003-2008, we find that competition among physicians will promote quicker diffusion of DES from 2003-2006, and encourage quicker abandon of DES from 2006-2008. We also compare the competition effect among star physicians and non-star physicians, and find that the effect of competition is stronger on star physicians than on non-star physicians. In chapter 3, we estimate the impact of relative strength of provider's competition between two alternative procedures on the treatment choices, and the appropriateness of treatment. We find that patients' are more likely to be treated by Coronary Artery Bypass Graft (CABG) if CABG surgeons are relative more competitive than Percutaneous Coronary Intervention (PCI) physicians. We also show that in the CABG surgeons relatively more competitive markets, CABG surgeons are more likely to treat patients even though they are less appropriate for CABG surgery.

Compare to the existing research about physician competition and quality of care, this dissertation has several contributions. First, I do not directly study the relationship between competition and quality (i.e. 30-day mortality), but using technology diffusion and treatment choices behavior to measure quality of care. Second, except for studying competition among the same type of physicians, in chapter 3 I study relative strength of competition among two types of providers who can treat the same patients. Third, I study patients with all insurance types (Medicare, Medicaid, and Private).

There are several limitations of this dissertation. First, we create physician competition markets based on the hospital market zip code, rather than physicians' practice zip code. The variable radius method that used to create market is based on the actual patient flows, which may be correlated with unobservable hospital quality, if patients are willing to travel further for high-quality care. Second, our result is based on data from only one state, which might limit the implications for other states. Third, I only study CABG and PCI treatments, and the effect of competition might not be the same for other alternative providers and other diseases.

Physician markets are likely to change significantly under the Patient Protection and Affordable Care Act. Instead of being self-employed, American physicians are becoming directly employed by hospitals or hospital-owned medical practices. Examining the competition and social interactions among physicians owned by the same or different hospital systems will be of great interest. Furthermore, I plan to examine the effects of whether this new market structure is cost effective by evaluating the impact on the out-of pocket price and health outcomes for patients, the actual charges paid by insurance companies, and on hospital expenditures and revenues.

# Bibliography


[1] The dartmouth atlas of health care in the united states. *chicago:American Hospital Publishing.* (1996).

[2] Arrow, K. Economic welfare and the allocation of resources for invention. In *The rate and direction of inventive activity: Economic and social factors.* Princeton University Press, 1962, pp. 609–626.

[3] Baicker, K., Buckles, K. S., and Chandra, A. Geographic variation in the appropriate use of cesarean delivery. *Health Affairs 25*, 5 (2006), w355–w367.

[4] Baker, L. C. Measuring competition in health care markets. *Health Services Research 36*, 1 Pt 2 (2001), 223.

[5] Baker, L. C., and Afendulis, C. Managed care, adoption of cardiac care technologies, and health of ami patients.

[6] Baker, L. C., Bundorf, M. K., Royalty, A. B., and Levin, Z. Physician practice competition and prices paid by private insurers for office visits. *JAMA 312*, 16 (2014), 1653–1662.

[7] Baker, L. C., and Phibbs, C. S. Managed care, technology adoption, and health care: the adoption of neonatal intensive care. Tech. rep., National Bureau of Economic Research, 2000.

[8] Baker, L. C., and Wheeler, S. K. Managed care and technology diffusion: the case of mri. *Health Affairs 17*, 5 (1998), 195–207.

[9] Bamezai, A., Zwanziger, J., Melnick, G. A., and Mann, J. M. Price competition and hospital cost growth in the united states (1989-1994). *Health Economics 8*, 3 (1999), 233–243.

[10] Berenson, R. A., Ginsburg, P. B., and Kemper, N. Unchecked provider clout in california foreshadows challenges to health reform. *Health Affairs* (2010), 10–1377.

[11] Bloom, B. S., Hillman, A. L., and Schwartz, J. S. Abruptly changing patterns of diffusion and use of extracorporeal shock-wave renal lithotripsy. *American journal of kidney diseases 18*, 1 (1991), 103–107.

[12] Bravata, D. M., McDonald, K. M., Gienger, A. L., Sundaram, V., Perez, M. V., Varghese, R., Kapoor, J. R., Ardehali, R., McKinnon, M. C., Stave, C. D., et al. Comparative effectiveness of percutaneous coronary interventions and coronary artery bypass grafting for coronary artery disease.

[13] Burke, M. A., Fournier, G. M., and Prasad, K. The diffusion of a medical innovation: is success in the stars? *Southern Economic Journal* (2007), 588–603.

[14] Burke, M. A., Fournier, G. M., and Prasad, K. Geographic variations in a model of physician treatment choice with social interactions. *Journal of Economic Behavior & Organization 73*, 3 (2010), 418–432.

[15] Callaway, B. *THE DIFFUSION OF HEALTH INFORMATION TECHNOLOGY IN SMALL PHYSICIAN PRACTICES: PRACTICE CHARACTERISTICS AND COMPETITION AS DRIVERS OF ADOPTION*. PhD thesis, Georgia Institute of Technology, 2010.

[16] Chandra, A., Cutler, D., and Song, Z. Who ordered that? the economics of treatment choices in medical care. *Handbook of health economics 2* (2012), 397–432.

[17] Chandra, A., Malenka, D., and Skinner, J. The diffusion of new medical technology. *Discoveries in the Economics of Aging* (2014), 389.

[18] Chandra, A., and Staiger, D. O. Productivity spillovers in healthcare: evidence from the treatment of heart attacks. *The journal of political economy 115* (2007), 103.

[19] Charlson, M. E., Pompei, P., Ales, K. L., and MacKenzie, C. R. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. *Journal of chronic diseases 40*, 5 (1987), 373–383.

[20] Chassin, M. R., Kosecoff, J., Park, R. E., Winslow, C. M., Kahn, K. L., Merrick, N. J., Keesey, J., Fink, A., Solomon, D. H., and Brook, R. H. Does inappropriate use explain geographic variations in the use of health care services?: A study of three procedures. *Jama 258*, 18 (1987), 2533–2537.

[21] Coleman, J. S., Katz, E., Menzel, H., et al. *Medical innovation: A diffusion study.* Bobbs-Merrill Company Indianapolis, 1966.

[22] Copeland, A., and Shapiro, A. H. The impact of competition on technology adoption: an apples-to-pcs analysis. Tech. rep., Staff Report, Federal Reserve Bank of New York, 2010.

[23] Cutler, D. M., and Huckman, R. S. Technological development and medical productivity: the diffusion of angioplasty in new york state. *Journal of Health Economics 22*, 2 (2003), 187–217.

[24] Cutler, D. M., and McClellan, M. Is technological change in medicine worth it? *Health affairs 20*, 5 (2001), 11–29.

[25] Cutler, D. M., and Sheiner, L. Managed care and the growth of medical expenditures. In *Forum for Health Economics & Policy* (1998), vol. 1.

[26] Devers, K. J., Brewster, L. R., and Casalino, L. P. Changes in hospital competitive strategy: a new medical arms race? *Health services research 38*, 1p2 (2003), 447–469.

[27] Deyo, R. A., and Mirza, S. K. Trends and variations in the use of spine surgery. *Clinical orthopaedics and related research 443* (2006), 139–146.

[28] Dranove, D., Satterthwaite, M., and Sindelar, J. The effect of injecting price competition into the hospital market: the case of preferred provider organizations. *Inquiry* (1986), 419–431.

[29] Duffy, S. Q. Do competitive hospitals really adopt technology faster? an analysis of the influence of alternative relevant market definitions. *Eastern Economic Journal* (1992), 187–208.

[30] Dunn, A., Shapiro, A. H., et al. *Physician market power and medical-care expenditures.* BiblioGov, 2013.

[31] Eisenberg, M. D. The impact of competition on quality in physician markets: The case of cardiologists.

[32] Elzinga, K. G., and Hogarty, T. F. Problem of geographic market delineation revisited: The case of coal, the. *Antitrust Bull. 23* (1978), 1.

[33] Emanuel, E. J., and Fuchs, V. R. The perfect storm of overutilization. *Jama 299*, 23 (2008), 2789–2791.

[34] Enthoven, A., and Kronick, R. A consumer-choice health plan for the 1990s. universal health insurance in a system designed to promote quality and economy (1). *The New England Journal of Medicine 320*, 1 (1989), 29–37.

[35] Enthoven, A. C., and Tollen, L. A. Competition in health care: it takes systems to pursue quality and efficiency. *HEALTH AFFAIRS-MILLWOOD VA THEN BETHESDA MA- 24*, 5 (2005), 1383.

[36] Epstein, A. J., Ketcham, J. D., Rathore, S. S., and Groeneveld, P. W. Variations in the use of an innovative technology by payer: the case of drug-eluting stents. *Medical care 50*, 1 (2012), 1.

[37] Epstein, A. J., Polsky, D., Yang, F., Yang, L., and Groeneveld, P. W. Coronary revascularization trends in the united states, 2001-2008. *Jama 305*, 17 (2011), 1769–1776.

[38] Escarce, J. Externalities in hospitals and physician adoption of a new surgical technology: an exploratory analysis. *Journal of health economics 15*, 6 (1996), 715–734.

[39] Escarce, J. J., Bloom, B. S., Hillman, A. L., Shea, J. A., and Schwartz, J. S. Diffusion of laparoscopic cholecystectomy among general surgeons in the united states. *Medical care 33*, 3 (1995), 256–271.

[40] Fendrick, A. M., Escarce, J. J., McLane, C., Shea, J. A., and Schwartz, J. S. Hospital adoption of laparoscopic cholecystectomy. *Medical Care 32*, 10 (1994), 1058–1063.

[41] Fisher, E. S., and Wennberg, J. E. Health care quality, geographic variations, and the challenge of supply-sensitive care. *Perspectives in biology and medicine 46*, 1 (2003), 69–79.

[42] Freiman, M. P. The rate of adoption of new procedures among physicians: the impact of specialty and practice characteristics. *Medical care* (1985), 939–945.

[43] Fuchs, V. R. Managed care and merger mania. *JAMA 277*, 11 (1997), 920–921.

[44] Garnick, D. W., Luft, H. S., Robinson, J. C., and Tetreault, J. Appropriate measures of hospital market areas. *Health services research 22*, 1 (1987), 69.

[45] Gaynor, M. What do we know about competition and quality in health care markets? Tech. rep., National Bureau of Economic Research, 2006.

[46] Gaynor, M., and Town, R. J. Competition in health care markets. Tech. rep., National Bureau of Economic Research, 2011.

[47] Gaynor, M., and Vogt, W. B. Antitrust and competition in health care markets. *Handbook of health economics 1* (2000), 1405–1487.

[48] Gottlieb, S. Health care consolidation and competition after ppaca. Tech. rep., American Enterprise Institute, 2012.

[49] Götz, G. Monopolistic competition and the diffusion of new technology. *The rand journal of economics* (1999), 679–693.

[50] Gowrisankaran, G., and Town, R. J. Competition, payers, and hospital quality1. *Health services research 38*, 6p1 (2003), 1403–1422.

[51] Gruber, J., Levine, P., and Staiger, D. Abortion legalization and child living circumstances: who is the" marginal child?". Tech. rep., National Bureau of Economic Research, 1997.

[52] Gunning, T. S., and Sickles, R. C. Competition and market power in physician private practices. *Empirical Economics 44*, 2 (2013), 1005–1029.

[53] Hall, B., and Khan, B. New economy handbook, 2003.

[54] Hamilton, B. H., and McManus, B. Technology diffusion and market structure: Evidence from infertility treatment markets. *Available at SSRN 813826* (2005).

[55] Head, S. J., Kaul, S., Mack, M. J., Serruys, P. W., Taggart, D. P., Holmes, D. R., Leon, M. B., Marco, J., Bogers, A. J., and Kappetein, A. P. The rationale for heart team decision-making for patients with stable complex coronary artery disease. *European heart journal* (2013), eht059.

[56] Held, P. J., and Pauly, M. V. Competition and efficiency in the end stage renal disease program. *Journal of Health Economics 2*, 2 (1983), 95–118.

[57] Hillman, A. L., and Schwartz, J. S. The adoption and diffusion of ct and mri in the united states: a comparative analysis. *Medical care 23*, 11 (1985), 1283–1294.

[58] Hollingsworth, J. M., Krein, S. L., Dunn, R. L., Wolf Jr, J. S., and Hollenbeck, B. K. Understanding variation in the adoption of a new technology in surgery. *Medical care 46*, 4 (2008), 366–371.

[59] Howard, D. H., and Shen, Y.-C. Comparative effectiveness research, technological abandonment, and health care spending. *Advances in health economics and health services research 23* (2012), 103–121.

[60] Jencks, S. F., Cuerdon, T., Burwen, D. R., Fleming, B., Houck, P. M., Kussmaul, A. E., Nilasena, D. S., Ordin, D. L., and Arday, D. R. Quality of medical care delivered to medicare beneficiaries: a profile at state and national levels. *Jama 284*, 13 (2000), 1670–1676.

[61] Joskow, P. L. The effects of competition and regulation on hospital bed supply and the reservation quality of the hospital. *The Bell Journal of Economics* (1980), 421–447.

[62] Kessler, D. P., and Geppert, J. J. The effects of competition on variation in the quality and cost of medical care. *Journal of Economics & Management Strategy 14*, 3 (2005), 575–589.

[63] Kessler, D. P., and McClellan, M. B. Is hospital competition socially wasteful? Tech. rep., National bureau of economic research, 1999.

[64] Krone, R. J., Rao, S. V., Dai, D., Anderson, H. V., Peterson, E. D., Brown, M. A., Brindis, R. G., Klein, L. W., Shaw, R. E., and Weintraub, W. S. Acceptance, panic, and partial recovery: the pattern of usage of drug-eluting stents after introduction in the us (a report from the american college of cardiology/national cardiovascular data registry). *JACC: Cardiovascular Interventions 3*, 9 (2010), 902–910.

[65] Levin, S. G., Levin, S. L., and Meisel, J. B. A dynamic analysis of the adoption of a new technology: the case of optical scanners. *The Review of Economics and Statistics* (1987), 12–17.

[66] Liebhaber, A., and Grossman, J. M. Physicians moving to mid-sized, single-specialty practices. *Tracking report/Center for Studying Health System Change*, 18 (2007), 1–5.

[67] Luft, H. S., Robinson, J. C., Garnick, D. W., Maerki, S. C., and McPhee, S. J. The role of specialized clinical services in competition among hospitals. *Inquiry* (1986), 83–94.

[68] Martin, A., Lassman, D., Whittle, L., Catlin, A., et al. Recession contributes to slowest annual rate of increase in health spending in five decades. *Health Affairs 30*, 1 (2011), 11–22.

[69] McWilliams, J. M., Chernew, M. E., Zaslavsky, A. M., Hamed, P., and Landon, B. E. Delivery system integration and health care spending and quality for medicare beneficiaries. *JAMA internal medicine 173*, 15 (2013), 1447–1456.

[70] Michaels, A. D., and Chatterjee, K. Angioplasty versus bypass surgery for coronary artery disease. *Circulation, Journal of the American Heart Association 106* (2002), 187–190.

[71] Miller, R. H. Competition in the health system: good news and bad news. *Health Affairs 15*, 2 (1996), 107–120.

[72] Navathe, A., and David, G. The formation of peer reputation among physicians and its effect on technology adoption. *Journal of Human Capital 3*, 4 (2009), 289–322.

[73] Newhouse, J. P. Medical care costs: how much welfare loss? *The Journal of Economic Perspectives* (1992), 3–21.

[74] O'Connor, G. T., Quinton, H. B., Traven, N. D., Ramunno, L. D., Dodds, T. A., Marciniak, T. A., and Wennberg, J. E. Geographic variation in the treatment of acute myocardial infarction: the cooperative cardiovascular project. *Jama 281*, 7 (1999), 627–633.

[75] Pfisterer, M., Brunner-La Rocca, H. P., Buser, P. T., Rickenbacher, P., Hunziker, P., Mueller, C., Jeger, R., Bader, F., Osswald, S., and Kaiser, C. Late clinical events after clopidogrel discontinuation may limit the benefit of drug-eluting stentsan observational study of drug-eluting versus bare-metal stents. *Journal of the American College of Cardiology 48*, 12 (2006), 2584–2591.

[76] Porter, C. E., and Donthu, N. Using the technology acceptance model to explain how attitudes determine internet usage: The role of perceived access barriers and demographics. *Journal of business research 59*, 9 (2006), 999–1007.

[77] Rapoport, J. Diffusion of technological innovation among nonprofit firms: a case study of radioisotopes in us hospitals. *Journal of economics and business 30*, 2 (1978), 108.

[78] Robinson, J. C., and Luft, H. S. The impact of hospital market structure on patient volume, average length of stay, and the cost of care. *Journal of Health Economics 4*, 4 (1985), 333–356.

[79] Russell, L. B. Regulating the diffusion of hospital technologies. *Law and contemporary problems* (1979), 26–42.

[80] Ryan, J., and Cohen, D. J. Are drug-eluting stents cost-effective? it depends on whom you ask. *Circulation 114*, 16 (2006), 1736–1744.

[81] Schmidt-Dengler, P. The timing of new technology adoption: The case of mri. *Manuscript, London School of Economics* (2006).

[82] Schneider, J. E., Li, P., Klepser, D. G., Peterson, N. A., Brown, T. T., and Scheffler, R. M. The effect of physician and health plan market concentration on prices in commercial health insurance markets. *International journal of health care finance and economics 8*, 1 (2008), 13–26.

[83] Schram, A., and Charness, G. Inducing social norms in laboratory allocation choices.

[84] Schuster, M. A., McGlynn, E. A., and Brook, R. H. How good is the quality of health care in the united states? *Milbank Quarterly 76*, 4 (1998), 517–563.

[85] Schwartz, L. M., Woloshin, S., Wasson, J. H., Renfrew, R. A., and Welch, H. G. Setting the revisit interval in primary care. *Journal of General Internal Medicine 14*, 4 (1999), 230–235.

[86] Serruys, P. W., Morice, M.-C., Kappetein, A. P., Colombo, A., Holmes, D. R., Mack, M. J., Ståhle, E., Feldman, T. E., van den Brand, M., Bass, E. J., et al. Percutaneous coronary intervention versus coronary-artery bypass grafting for severe coronary artery disease. *New England Journal of Medicine 360*, 10 (2009), 961–972.

[87] Sethi, R. K. V. Technology adoption in the united states: The impact of hospital market competition.

[88] Shinn, L. T. The impact of star physicians on diffusion of a medical technology: The case of laparoscopic gastric bypass surgery. *Available at SSRN 2058434* (2012).

[89] Shortell, S. M., and Hughes, E. F. The effects of regulation, competition, and ownership on mortality rates among hospital inpatients. *The New England Journal of Medicine 318*, 17 (1988), 1100–1107.

[90] Skinner, J., and Staiger, D. Technology adoption from hybrid corn to beta blockers. Tech. rep., National Bureau of Economic Research, 2005.

[91] Skinner, J., and Staiger, D. Technology diffusion and productivity growth in health care. Tech. rep., National Bureau of Economic Research, 2009.

[92] Smith, C., Cowan, C., Heffler, S., Catlin, A., et al. National health spending in 2004: recent slowdown led by prescription drug spending. *Health Affairs 25*, 1 (2006), 186–196.

[93] Smith, S., Newhouse, J. P., and Freeland, M. S. Income, insurance, and technology: why does health spending outpace economic growth? *Health Affairs 28*, 5 (2009), 1276–1284.

[94] Stone, G. W., Rizvi, A., Newman, W., Mastali, K., Wang, J. C., Caputo, R., Doostzadeh, J., Cao, S., Simonton, C. A., Sudhir, K., et al. Everolimus-eluting versus paclitaxel-eluting stents in coronary artery disease. *New England Journal of Medicine 362*, 18 (2010), 1663–1674.

[95] Teplensky, J. D., Pauly, M. V., Kimberly, J. R., Hillman, A. L., and Schwartz, J. S. Hospital adoption of medical technology: an empirical test of alternative models. *Health services research 30*, 3 (1995), 437.

[96] Tung, R., Kaul, S., Diamond, G. A., and Shah, P. K. Narrative review: drug-eluting stents for the management of restenosis: a critical appraisal of the evidence. *Annals of internal medicine 144*, 12 (2006), 913–919.

[97] Ullman, K. Drug-eluting stents lower event rates in oldest patients. Tech. rep., Medpage Today, 2012.

[98] Weinstein, J. N., Lurie, J. D., Olson, P., Bronner, K. K., Fisher, E. S., and Morgan, M. T. S. United states trends and regional variations in lumbar spine surgery: 1992–2003. *Spine 31*, 23 (2006), 2707.

[99] Welch, W. P., Cuellar, A. E., Stearns, S. C., and Bindman, A. B. Proportion of physicians in large group practices continued to grow in 2009–11. *Health Affairs 32*, 9 (2013), 1659–1666.

[100] Welch, W. P., Miller, M. E., Welch, H. G., Fisher, E. S., and Wennberg, J. E. Geographic variation in expenditures for physicians' services in the united states. *New England journal of medicine 328*, 9 (1993), 621–627.

[101] Wennberg, J., and Gittelsohn, A. Small area variations in health care delivery a population-based health information system can guide planning and regulatory decision-making. *Science 182*, 4117 (1973), 1102–1108.

[102] Wennberg, J. E., McPherson, K., and Caper, P. Will payment based on diagnosis-related groups control hospital costs? *The New England journal of medicine 311*, 5 (1984), 295–300.

[103] Wilson, G. W., and Jadlow, J. M. Competition, profit incentives, and technical efficiency in the provision of nuclear medicine services. *The Bell Journal of Economics* (1982), 472–482.

[104] Yang, M., Lien, H.-M., and CHOU, S.-Y. Is there a physician peer effect? evidence from new drug prescriptions. *Economic Inquiry 52*, 1 (2014), 116–137.

[105] Young, H. P. Social norms.

# Biography

Yang Yu from Xiamen, P.R. China. She earned her Bachelor of Science in International Economics and Trade from Renmin University of China in June of 2009. She received her Master of Science in Economics in May 2011 from Lehigh University. In 2011, she joined the doctoral program in Economics at Lehigh University.

Yang Yu was admitted into the Economics Ph.D. Program in the College of Business and Economics at Lehigh University, where she took courses, passed microeconomics and macroeconomics comprehensive exams as well as health economics field exam. She presented her third year paper in the spring semester of 2013. Her research interests lied in the fields of Health Economics, Industrial Organization and Applied Microeconometrics.

The doctoral program at Lehigh University had provided she with the opportunities to both teach as an independent instructor and serve as a teaching assistant. She taught recitation for Principles of Economics, Money, Banking, and Financial Markets. She also taught summer course Principles of Economics independently in the summer of 2014.

Yang Yu presented her work at various conference, including American Society for Health Economist Conference, Eastern Economics Association Annual Meeting, and Chinese Economics Society Annual Meeting.