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The Role of Hospital and Market Characteristics in Invasive Cardiac Service Diffusion

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Abstract Little is known about how the adoption and diffusion of medical innovation is related to and influenced by market characteristics such as competition. The particular complications that are involved in investigating these relationships in the health care sector may explain the dearth of research. We examine three invasive cardiac services: diagnostic angiography, percutaneous coronary interventions, and coronary artery bypass grafting. We document the relationship between the adoption by hospitals of these three invasive cardiac services and the characteristics of the hospitals, their markets, and the interactions among them, from 1997 to 2014. The results show that the probability of hospitals' adopting a new cardiac service depends on competition in two distinct ways: (1) hospitals are substantially more likely to adopt an invasive cardiac service if competitor hospitals also adopt new services; and (2) hospitals are less likely to adopt a new service if a larger fraction of the nearby population already has geographic access to the service at a nearby hospital. The first effect is stronger, leading to the net effect that hospitals duplicate rather than expand access to care. In addition, for-profit hospitals are considerably more likely to adopt these cardiac services than are either nonprofit or government-owned hospitals. Nonprofit hospitals in high-penetration, for-profit

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markets are also more likely to adopt them relative to other nonprofits. These results suggest that factors other than medical need—such as a medical arms race—partially explain technological adoption.

Keywords Analysis of health care markets · Cardiac treatment · Hospital competition · Access to care · For-profit hospital · Nonprofit hospital

1 Introduction

Innovation is often an important product of competition. Yet, although researchers have studied some causes of the adoption and diffusion of medical innovations, little is known about how that adoption is related to and influenced by market characteristics such as competition. The relationships between competition and technological innovation (Aghion et al. 2014) and the diffusion of innovation (Shapiro 2012) are difficult to specify, even in markets for ordinary goods. The particular complications that are involved in investigating these relationships in the health care sector may explain the dearth of research.

Because medical care is so different from ordinary market goods, it is even more difficult to characterize competitive medical markets and to predict or identify how competition affects innovation and diffusion of medical technology than in the case of other goods and services. Unlike other goods, in which the concentration of suppliers in populated areas helps consumers benefit from low prices, dispersion of medical suppliers is critical for patient access. In addition, medical care is often provided by hospitals, which are highly regulated, are organized as different types of legal entities, compete as local monopolies and oligopolies, receive payments from third parties instead of patients, and receive reimbursements based on government-regulated prices rather than market demand. Further, prices are not posted, and are typically unknown both to patients and medical staff. Unsurprisingly, there is no general theory of competition in such markets, much less a theory to explain the effects of such competition on technology development and diffusion. Despite these challenges, providing appropriate access to care, controlling costs, and insuring the quality of medicine all critically depend on understanding how and why medical providers adopt technology. Accordingly, we document important empirical regularities that provide evidence of the effects of hospital competition on the provision of care.

To investigate the connection between competition and medical technology diffusion, we study the relationship between the adoption of invasive cardiac services by hospitals and the characteristics of those hospitals, their markets, and the interactions among them. The bulk of payments for invasive cardiac services at hospitals come from government payers, which make it unlikely that differences in demand because of price explain our results. In addition, we include rich controls for market demographics that are strong predictors of the need for cardiac interventions.

We focus on the adoption of three invasive cardiac services from 1997 to 2014: diagnostic angiography; percutaneous coronary interventions (PCI); and coronary artery bypass grafting (CABG). These are particularly important services to study for several reasons. First, these services are meant to treat heart attacks (acute myocardial infarctions or AMIs), which are a leading cause of morbidity and mortality around the world and in the United States, making the interventions critical for a large part of the national and world populations. Second, AMI is one of the five most expensive inpatient conditions to treat; in 2013 AMI accounted for 602,000 hospitalizations and approximately $12 billion or 3.2% of national aggregate costs for all hospitalizations (Torio and Moore 2016). Understanding the diffusion of treatments would help develop interventions to control their costs. Third, there is evidence that for some patients, medical therapy alone is as effective as the far more expensive and invasive PCI. Finally, there is large variation in the treatment of cardiovascular disease by geographic area, and those differences are "predominantly driven by differences in local capacity and local medical decision making" (Wennberg et al. 1999, preface). These findings suggest that the diffusion and use of medical technology are driven, at least in part, by factors other than medical need. There is room for policy interventions that guide diffusion to increase the efficiency of medical care.

Previous research has demonstrated that by 2000, almost 80% of the U.S. population lived within 60 min of a hospital with PCI (Nallamothu et al. 2006). Given this coverage, there has been little room for new hospitals to increase geographic access to care. Previous research has shown that hospitals are most likely to introduce new invasive cardiac services when neighboring hospitals already offer such services, and this diffusion has not improved geographic access to care, but instead has duplicated existing services (Horwitz et al. 2013; Concannon et al. 2012). In fact, because hospitals are more likely to adopt a service if nearby hospitals already offer it, simulations suggest that more people would have had greater geographic access to care if—instead of allowing hospitals to decide whether to adopt a new service—new services had been randomly distributed to existing hospitals that did not already offer them (Horwitz et al. 2013). Strategic selection of hospitals to newly offer care would improve access more than random distribution, so the pattern of endogenous selection we find here is doubly inferior to the first best.

This paper builds on those findings in several important ways. First, unlike previous research that uses fixed distances, geopolitical designations, or hospital referral regions to define markets, we define hospital markets by travel time to the hospital based on medical recommendations of how quickly patients who are suffering the symptoms of a heart attack should be treated. Second, we consider hospital and market characteristics that are related to adoption of new technology. The latter include demographic characteristics of the population in each hospital's market, which are important to consider because these characteristics are associated with the probability that residents are insured, the type of insurance, and the costs and profit margins of medical treatment. The services that are studied here are both expensive to provide and, on average, profitable for hospitals, which makes the demographics of the patient population particularly significant for a hospital's bottom line. Third, we focus on the role of the legal ownership of hospitals: nonprofit, for-profit, and government. Here we consider the role of ownership in a hospital that adopts new services as well as the role of the market mix and the interaction between the two; these are factors that play important roles in the decisions of hospitals to offer medical services (Horwitz and Nichols, 2009). Finally, our study period, 1997–2014 (with 1996 data used as the base year from which to construct the pool for adoption), is lengthy.

We find that the probability of hospitals' adopting a new cardiac service depends on competition in two distinct ways. First, hospitals are substantially more likely to adopt an invasive cardiac service (defined as performing 11 or more such procedures per year) if competitor hospitals (defined as those within an hour drive of the observation hospital) also adopt new services. However, we also find that hospitals are less likely to adopt a new service if a larger fraction of the nearby population already has geographic access to the service at a nearby hospital (defined as residents who live within an hour drive of the observation hospital also live within an hour of another hospital that offers that service).

Although these two effects are offsetting, the response of hospitals' mimicking nearby adoption despite that hospital's patient market already having access to care has the net effect of duplicating access rather than substantially expanding access to care. For a hospital that has not yet adopted a particular invasive cardiac service, the adoption of the service by nearby hospitals increases the proportion of the population that has access, which modestly reduces the probability a given hospital adopts it; but the local increase in adoptions dominates, which leads to a net increase in its probability of adoption.

These results suggest that hospitals are engaging in a medical arms race rather than offering services that would increase geographic access to care.

Moreover, during the study period, for-profit hospitals are considerably more likely to adopt the three services that are studied here than either nonprofit or government-owned hospitals. Nonprofit hospitals also are more likely to adopt these cardiac services if they are in a high-penetration for-profit market, relative to nonprofit hospitals in a market with lower for-profit penetration, However, tests with regard to the relationship among the ownership of an individual hospital and whether competitors adopt a service yield few consistent or statistically significant results. In sum, the evidence is consistent with previous research on geographic variation in health care and suggest that factors other than medical need explain technological adoption.

2 Background

Technological progress in medicine has saved many lives. Cutler (2004), for example, has shown that technological innovation and associated spending has been, on average, well worth the costs. However, other researchers have questioned the value of rapid development and diffusion of medical technology. For example, Robinson and Luft (1985) characterized new service adoption as the result of a medical arms race—one that leads to inefficient investment in medical technology.

Scholars later found evidence that the acquisition of new medical technology was driven by, among other factors, a hospital's attempt to maintain or expand a local market (Hillman et al. 1987) and the importance that a hospital attaches to being a technological leader (Teplensky et al. 1995). Skinner and Staiger (2015, p. 3) made progress in reconciling these views—that technology adoption led to improvements in health and that technology adoption was caused by, at least in part, nonmedical reasons—in arguing that health care "improvements are largely associated with the adoption of effective treatments, rather than more factor inputs per se."

Indeed, researchers have found that expensive and profitable medical technology diffuses before there is a strong case for its widespread use. For example, Ladapo et al. (2009) found that 64-slice computed tomography was widely adopted by hospitals for its role in angiography for cardiac patients despite the lack of evidence with regard to its effectiveness for that purpose, which raises concerns about haphazard acquisition.

The services we focus on here—diagnostic angiography, PCI, and CABG—provide apt examples of this phenomenon that is found in health care more generally. Diagnostic cardiac angiography is a procedure that involves: the placement of a catheter through veins or arteries and into the heart to inject a contrast agent; taking a picture with an x-ray machine; and evaluating whether the patient has a blockage in a coronary artery (Lange and Hillis, 2003). PCI—commonly called coronary angioplasty—is a procedure that opens coronary arteries that have been blocked by plaque. A doctor inflates a balloon at the tip of a catheter to open an artery and may place a stent to keep the artery open. CABG—which is commonly known as open heart surgery—is a surgery to allow blood to flow to the heart by using a healthy artery or vein from a patient and grafting it into a coronary artery so as to go around the blocked portion of the artery.

These services have provided great value for some patients, but not for all (Chandra and Skinner 2012). On the one hand, advances in the prevention and treatment of cardiovascular disease—including the services studied here—have led to striking improvements in morbidity and mortality. For example, from the mid-1970s through the early 2000s, age-adjusted death rates from coronary heart disease declined by more than 60% (Weisfeldt and Zieman 2007). Cutler and Kadiyala (2003) estimate that about one third of these reductions can be explained by invasive procedures. In another estimate, Cutler and McClellan (2001) conclude that approximately 70% of the survival improvement in cardiac mortality between 1984 and 1998 was attributable to technological change.

On the other hand, there is evidence of considerable geographic variation in treatment. Matlock et al. (2013) found that "the 2007 rate of coronary angiography varied nearly 6-fold from 6.8 per 1000 Medicare fee-for-service (FFS) beneficiaries in Honolulu, [Hawaii], to 39.8 per 1000 in Gulfport, [Mississippi]" (p. 3). In addition, in 2003, "[r]ates varied by a factor of five, from 1.9 per 1000 enrollees to 9.5." (Center for Evaluative Clinical Sciences 2005, p. 9).

There is also evidence of overuse. For example, a meta-analysis of randomized controlled trials that evaluated outcomes of treatment for stable coronary artery disease with PCI compared to medical therapy concluded, "Initial stent implantation for stable coronary artery disease shows no evidence of benefit compared with initial medical therapy for prevention of death, nonfatal myocardial infarction, unplanned revascularization, or angina" (Stergiopoulos and Brown 2012 at p. 312; Boden 2012; Stergiopoulos et al. 2014). Although PCI volume declined after the publication of these results, many patients continued to receive PCI for stable coronary artery disease (Howard and Shen 2014). In addition, findings that high spending is not well correlated with mortality and readmission outcomes in studies that control for population characteristics (Skinner et al. 2006) suggest that there is considerable room for reform to eliminate wasteful and unnecessary care. Notwithstanding this evidence of overuse, there is also evidence that higher spending hospitals perform more procedures in the first part of a hospital stay, which leads to higher cost and higher short-term mortality but dramatically lower long-term mortality (Doyle et al. 2015).

Service diffusion may also lead to reductions in the volume of procedures that are performed at individual hospitals and, consequently, lead to related reductions in quality. Professional guidelines recommend against the provision of cardiac interventions by low-volume physicians or at low-volume cardiac centers, although those guidelines recognize the complicated and potentially offsetting relationship among institutional and individual operators. (Levine et al. 2011). The positive—albeit, attenuating—association between volume and outcomes (Ross et al., 2010) suggests that diffusion that is concentrated within hospital markets may undermine the effectiveness of the treatments that are studied here. It may be optimal to perform a more limited number of interventions in a more restricted set of cases in a broad geographic area; but outcomes may be better as more interventions are performed at a specific location, which suggests that the concentration of procedures in a smaller number of hospitals is better for patients.

In fact, some researchers have found that lower volume occurs in markets where hospitals have begun performing CABGs, and that such low volume has led to increased mortality (Wilson et al. 2007). However, others have found that improvements in the quality of technology, the implementation of safeguards (such as checklists), and improved physician skill have led to decreased CABG mortality overall. (Finks et al. 2011). Similarly, Ho (2002) found that as hospitals developed staff capacity to provide percutaneous transluminal coronary angioplasty (PTCA), they achieved substantial reductions in inpatient mortality and emergency bypass surgery. Yet, hospital procedure volume was also associated with a small positive effect on outcomes. Ho concludes that centralizing PTCA by offering it at fewer hospitals could reduce costs, but may not have a strong effect on quality. Nonetheless, in an effort to improve quality, there have been calls for concentrating AMI treatment to a limited number high-quality, centralized providers that offer PCI treatment within a region (Chen et al. 2010).

Finally, these services are quite costly and, to the extent that they are unnecessary, a reduction in inappropriate provision could lead to large savings. Cardiovascular disease accounts for 17% of national health expenditures; given the aging of the U.S. population, the direct costs of treating cardiovascular disease are predicted to triple from $273 to $818 billion, in 2008 dollars, between 2010 and 2030 (Heidenreich et al. 2011).

3 Data and Market Definitions

3.1 Data and Descriptive Statistics

Data on hospital characteristics are from the American Hospital Association's Annual Surveys of Hospitals (AHA) 1996–2014. We include all non-federal, general medical and surgical hospitals and heart hospitals in the continental United States, including those in the District of Columbia. We exclude children's hospitals and hospitals for which driving times to nearby residential zip codes could not be computed (including several rural cases, and one hospital on an island). We identified the longitude and latitude of each hospital from the AHA or, if the AHA coordinates were missing or differed among years for the same address, we identified the coordinates using Google maps.

To determine whether a hospital treated any patients with AMI and whether a hospital provided any of the three services examined here, we rely on data from Medicare Provider Analysis and Review (MedPar) files for 100% of Medicare beneficiaries who received hospital inpatient services 1996–2014. The MedPar dataset included only fee-for-service beneficiaries who were eligible for both Medicare Part A and B and were also U.S. residents. Because of restrictions that forbid using federal data with values smaller than 11 in a cell, we coded a hospital as having treated patients with AMI if they treated at least 11 patients in a year with an International Classification of Diseases-9 (ICD-9) primary diagnosis code for AMI (ICD-9 Codes 410.00-410.92). We identified a hospital as providing a service in a given year if that hospital billed the Centers for Medicare and Medicaid Services for at least 11 procedures to Medicare beneficiaries, using the following ICD-9 codes: diagnostic angiography (37.21 through 37.23); PCI (depending on the year 36.01-.02; 00.66; 36.05-36.07); and CABG (36.1036.19).

Once a hospital is coded as providing a service, we assume that the hospital continues to provide the service for as long as it is in the sample; this is a reasonable assumption given the costs of starting new invasive cardiac services. We coded all other hospitals as not treating patients with an AMI diagnosis or as not providing one or more of the invasive cardiac services studied here. Adoption is defined as the first year after 1996 in which a service is offered.

We identified the centroid of every zip code tabulation area (ZCTA) using shape files that are available from the U.S. Census Bureau for the 2010 Census. Demographic data for each ZCTA are from the American Community Survey (2010–2014) and the U.S. Census (2000). We attributed the 2010–2014 ACS to 2012. We then interpolated and extrapolated from these data to all years in the sample with the use of a log or logit scale for demographic variables that were counts or percentages, respectively.

Driving distances are primarily from Google maps and, secondarily, from Open Source Road Mapping System (OSRM). We relied on OSRM to estimate approximate travel times and distances based on the closest road only when Google Maps did not estimate driving distance, such as when the centroid of a ZCTA lies in a rural area without roads, on an island, or in a body of water.

3.2 Market Definitions and Competitor Attributes

Our definition of geographic markets differs from others in health economics research. Previous researchers typically use political configurations such as counties or, more recently, hospital referral regions. The former do not track actual markets for care well (Wennberg et al. 1999). Although hospital referral regions are an improvement over using political areas to define health care markets, they define markets based on the actual use of medical services at hospitals and not the markets that would best serve patients. Because we are interested in how competition may or may not produce access to medically-indicated care in this project, which endogenously affects actual use patterns, we use a definition of market that is based on a potential patient's travel time to each hospital.

We identified each hospital's market to include all of the residents of ZCTAs, the centroid of which is 60 min or shorter driving time in a car to the hospital. We chose 60 min based on medical guidelines recommending the maximum amount of time from a patient's first contact with emergency medical personnel to treatment and the total amount of time from symptoms to treatment that produce the best medical outcomes.

More specifically, although medical authorities often refer to a "first golden hour" in which myocardial infarction can be treated with the best results (Boersma et al. 1996), therefore making the 60 min driving time too long for the best results, medical recommendation recognize the difficulty of such rapid treatment and tend to include longer times. For example, for primary PCI, some sources report that the "[b]est clinical outcomes…[are] achieved within 120 min after symptom onset." (Bates and Jacobs 2013, p. 890). Bates and Jacobs (2013) recommended a maximum "door-to-balloon" time of 90 min.

Meeting this standard has become the focus of national quality improvement initiatives as well as quality markers for CMS reimbursement (Menees et al. 2013). In 2008, median time between arrival at the hospital and treatment was 76 min for patients with acute ST-elevation myocardial infarction (STEMI) who are undergoing percutaneous coronary intervention (Flynn et al. 2010), which represented an improvement over past years. That implies that during our study period, fewer than half of patients with STEMI were treated within the time that is recommended by guidelines (Bradley et al. 2006). Moreover, mean symptom duration is two hours before first medical contact (Bates and Jacobs 2013). Patients are receiving treatment several hours after symptom onset in most cases, which leads to worse outcomes.

Further, for each observation hospital in our dataset, we identified another hospital as a competitor if that hospital is within a 60 min drive from the centroid of the observation hospital's zip code. However, as all nearby hospitals contribute to a weighted mean that also uses current admissions as a measure of size, small variations in measured distance from a focal hospital have minimal influence on measured adoption rates. The weighted mean is very robust to small errors in measurement of distance.

Thus, there are measures of: (1) the population that lives in the market area of each hospital, and characteristics of that population; (2) the fraction of that population that is within an hour of another hospital that provides the relevant cardiac service; and (3) nearby hospitals' service offerings. Note that when a nearby hospital adds a new service, it has two effects: Some nearby zip codes may newly have access to cardiac care (there is a drop in the population counted as having no access); but the fraction of nearby hospitals that offer the service jumps at other nearby hospitals that are capable of adding the service. These two changes are correlated but very imperfectly, both due to the sizes of affected areas and differences in the weighting (population weights across all nearby zip codes, or admission weights across all nearby hospitals). With these two imperfectly correlated variables used as separate predictors, we expect the standard errors to be larger; but to the extent that effects are large enough to be detectable, there is no bias that is introduced by modest collinearity.

4 Empirical Specification

In our main specifications, we investigate the extent to which the probability that each hospital adopts a new service (alternately diagnostic services, PCI, and CABG) in a given year depends upon: (1) the percentage of patients in the market that already have access to these services in the current year; and (2) the percentage of competing hospitals in the market that also adopt a service that same year. More specifically, we fit a discrete-time hazard model to annual data, on the assumption that the hazard of adoption (conditional probability of adoption of a given technology by the hospital, given no adoption to date) is proportional to a common baseline hazard that is specified flexibly over time. The continuous time Proportional Hazard (PH) model is of the form $\log(H_{it};\ X_{it}) = f(t) + X_{it}b$ or $H_{it} = \exp(f(t) + X_{it}b)$, where f(t) is an arbitrary function of time. The interval-censored PH model is of the form $\text{cloglog}(H_{ij};\ X_{ij}) = g(j) + X_{ij}b$, where t is continuous time, j is an index for ordered intervals—years—and g(j) is an arbitrary function estimated via year dummy variables. The cloglog regression for a discrete-time hazard model is fit via a generalized linear model

$$h_{ij} = f\left(Z_{ij}a + X_{ij}b + T_{ij}g\right) + e_{ij}$$

where the inverse cloglog function $f(x) = 1 - \exp(-\exp(x))$ and j indexes time to indicate that time is measured in discrete intervals. This model is similar to a logit for low-probability events (as is the case with the hazard of adoption in any given year), as demonstrated by the comparison of the inverse cloglog and inverse logit functions that are shown in Fig. 1. Hazards of 5% are − 2.94 on the logit curve and − 2.97 on the cloglog curve; hazards of 3% are − 3.48 on the logit curve and − 3.49 on the cloglog curve. At the rate of 1–2% for the baseline hazard of adoption of cardiac services in our data, the cloglog and logit models are essentially indistinguishable.

We use hazard models to estimate the probability of a hospital's offering a new cardiac service, alternately diagnostic angiography, PCI, and CABG. Generally, hospitals that offer PCI also offer diagnostic angiography, and those that offer

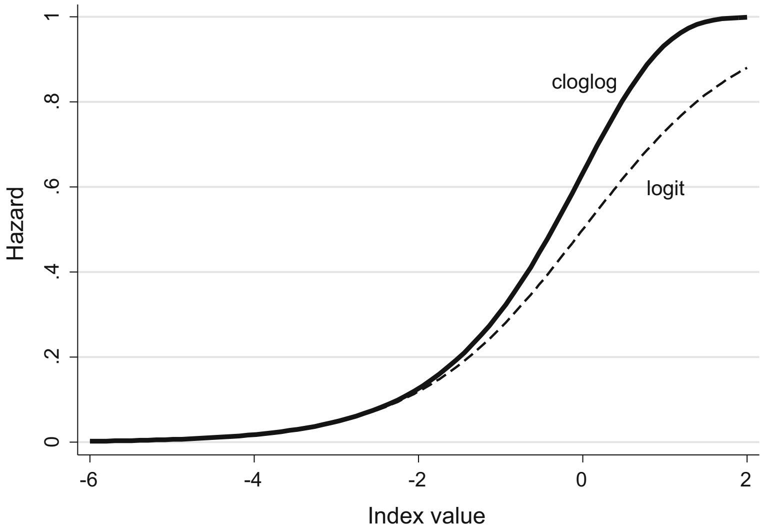

Fig. 1 Comparison of cloglog and logit link functions for hazard

CABG also offer diagnostic angiography and PCI (fewer than 12 hospitals per year (0.32%) offered a different mix of services). The primary independent variables measure the extent to which patients in each observation hospital's market already had access to that service and the rate at which the observation hospital's competitors adopted a new service. We estimate the following model:

$$E(\text{ServiceProvided})_{it} = f[\beta_0 + \beta_1 N_{it} + \beta_2 Y_t + \beta_3 D_{it} + \beta_4 H_{it}] \quad (1)$$

where N are the primary independent variables of interest, including: (1) the percentage of the population in each observation hospital's market that already has access to the service in question in the current year; and (2) the rate at which an observation hospital's competitors, which is defined as all hospitals that also lie within 60-min driving time of the observation hospital, adopt the service in question during the same year.

The percentage of the population in each hospital's market that already has access to a service at a hospital that they are likely to visit was determined by examining zip code tabulation areas within an hour's drive. For each of these nearby zip codes, we calculate whether hospitals (other than the observation hospital) located within a maximum of 60 min of the centroid of that ZCTA offered the service; we then computed the weighted average of that indicator by hospital size and distance to get the zip-code probability of coverage. We then averaged those zip-code probabilities of coverage, across all zip codes within an hour of the hospital in question, weighting by population size and distance, to get the percentage of the nearby population likely to already have access.

The rate at which an observation hospital's competitors adopted the service is an average of nearby hospitals' indicators, weighted by hospital size and distance. D is a vector of demographic variables for the hospital's patient market, again defined as all residents of ZCTAs, the centroids of which lie a maximum of 60 min driving time to the centroid of a ZCTA. The demographic variables are weighted by the size of the ZCTA's population and driving time from the observation hospital to the centroid of the ZCTA.

We include these demographic measures to account for differences by demographic status in the demand for invasive cardiac procedures. For example, men—especially older men—are more likely than women to suffer from cardiovascular disease (Cutler and Kadiyala 2003). Education, income, Caucasian race, and age are all positively correlated with having health insurance (Smith and Medalia 2015). Therefore, variation in these attributes likely is correlated with geographic differences in the demand for or profitability of these services.

For similar reasons, we include variables that measure: population size; age and sex (by percentage of the population in the market that is male or female and under 18, between 18 and 44, between 45 and 54, between 55 and 64, and equal to or older than 75); education (percentage of the population in the market with a high school degree or GED, some college, a college degree, with a graduate degree); percent income $\geq$ \$100K; the percentage of people on public assistance; and race (white, black, and other—which included native American, Asian and Pacific Islander, or mixed race; Hispanic).

Finally, we also measure whether the hospital is in an urban market, i.e., whether the population density is at least 500 people per square mile. According to the criteria published in the *Federal Register* on March 15, 2002 (67 FR 11663), an "urbanized area" consists of densely settled territory that contains 50,000 or more people, with the "densely settled" criterion referring to at least 500 residents per square mile. This last variable—an indicator of density of the population—also effectively adjusts for regional differences in the patient population's willingness to drive longer distances.

H is a vector of hospital and hospital market variables, including: the size of the hospital, which is measured by quintile of annual admissions; whether the hospital is a teaching hospital (measured by membership in either of two nonprofit organizations for teaching hospitals); and whether the hospital is part of a hospital network.

We also measure each observation hospital's Herfindahl–Hirschman index (HHI) to account for the concentration of hospitals in each hospital's observation market, defined as the sum of squared admission shares over all hospitals within 60 min driving time, unweighted by distance.

Y is a dummy variable for each year of data, to account for the baseline hazard of adoption in the most flexible nonparametric manner possible.

All standard errors (SE) are clustered at the hospital level. This clustering represents a conservative approach as to the nature of serial correlation within hospital, as the Maximum Likelihood Estimator of the discrete-time hazard model does not require a cluster-robust SE to account for multiple observations per unit of observation, but the cluster-robust SE is robust to any form of serial correlation.

We then estimate models of the form:

$$E(\text{ServiceProvided})_{it} = f[\beta_0 + \beta_1 N_{it} + \beta_2 Y_t + \beta_3 D_{it} + \beta_4 H_{it} + \beta_5 O_{it}] \quad (2)$$

Equation (2) is the same as Eq. (1) with the addition of a vector of variables O that includes indicator variables for nonprofit, for-profit, or government ownership of the observation hospital. We also interact ownership variables with the variable that measures the adoption rate of competitor hospitals in the observation hospital's market.

To investigate the influence of market penetration by organizational form, we estimate models of the form:

$$E(\text{ServiceProvided})_{it} = f[\beta_0 + \beta_1 N_{it} + \beta_2 Y_t + \beta_3 D_{it} + \beta_4 H_{it} + \beta_5 O_{it} + \beta_6 M_{it}] \quad (3)$$

Equation (3) is the same as Eq. (2) with the addition of M, a variable that measures the penetration of for-profit ownership in each market. The variable is an indicator variable that represents whether more than 10% of the hospitals in a market have for-profit ownership (the median for-profit penetration across all markets and years—1997–2014—is 5.7%, increasing from 6.3 in 1997 to 7.1% in 2014, and the mean is 13.1%, ranging from 12.3 in 1997 to 14.6 in 2014). The for-profit penetration variable is constructed as the average of a for-profit indicator over all hospitals that are within an hour drive of each zip code, weighted by distance, then weighted by population in that zip code and distance to the focal hospital. That is, market penetration is defined analogously to coverage in the population.

We also include interaction terms for the variable measuring high for-profit markets with the ownership of the observation hospitals and with the variable that measures the rate at which an observation hospital's competitors adopts each service:

$$E(\text{ServiceProvided})_{it} = f[\beta_o + \beta_1 N_{it} + \beta_2 Y_t + \beta_3 D_{it} + \beta_4 H_{it} + \beta_5 O_{it} + \beta_6 M_{it} + \beta_7 M_{it} O_{it} + \beta_8 M_{it} N_{it}] \quad (4)$$

5 Results and Limitations

5.1 Unadjusted Results

From 1997 to 2014, the proportion of hospitals that offered invasive cardiac services grew (1996 data are used only to construct the risk pool for adoption) (Table 1). As can be seen in Table 1, column 1, the proportion of hospitals not offering any invasive cardiac service declined; as can be seen in the remaining columns, a decreasing proportion of hospitals offered only diagnostic angiography over the study period (column 2); and an increasing percentage offered diagnostic and treatment services (columns 3 and 4).

The rate of new service adoption by hospitals varied by year and by service type, although the proportion of hospitals that newly adopted any of the services declined

Table 1 Proportion of hospitals offering cardiac services (1997–2014). *Source*: Authors' calculations based on Medicare Provider Analysis and Review (MedPar) files for 100% of Medicare beneficiaries (1997–2014)

Year	None (1)	Diagnostic angiography only (2)	Diagnostic angiography and PCI (3)	Diagnostic angiography, PCI and CABG (4)	Total number of hospitals (5)
1997	0.506	0.231	0.012	0.247	3566
1998	0.505	0.229	0.014	0.249	3713
1999	0.503	0.226	0.017	0.252	3774
2000	0.499	0.222	0.021	0.256	3784
2001	0.496	0.213	0.027	0.262	3799
2002	0.489	0.207	0.030	0.272	3807
2003	0.479	0.199	0.042	0.280	3813
2004	0.471	0.193	0.051	0.285	3798
2005	0.459	0.188	0.062	0.291	3804
2006	0.455	0.175	0.074	0.296	3803
2007	0.450	0.169	0.079	0.302	3793
2008	0.445	0.163	0.087	0.304	3795
2009	0.439	0.156	0.098	0.307	3789
2010	0.434	0.150	0.108	0.308	3773
2011	0.431	0.141	0.117	0.310	3764
2012	0.429	0.132	0.126	0.314	3753
2013	0.424	0.128	0.132	0.317	3728
2014	0.421	0.123	0.136	0.320	3709

Proportion offering a service is the fraction of hospitals that treated cardiac patients that offered a service divided by the total number of hospitals in the year. A hospital is considered as offering a service if it newly adopted a service in the observation year or any previous year in the sample. Columns 1–4 may not sum to one due to rounding and due to hospitals [fewer than 12 per year (0.32%)] that offer a different mix of services, such as diagnostic angiography and CABG but not PCI, or PCI and CABG but not diagnostic angiography

over the study period (Table 2), as the fraction that had not yet adopted fell. The percentage of hospitals that adopted diagnostic angiography in a year fell from 1997 to 2014, from 5.7 to 0.9% of hospitals that did not offer the service in the previous year (Table 2, Column 1). The percentage of hospitals that adopted PCI fell from 2.0 to 1.1% of hospitals that did not previously offer PCI in the previous year (Table 2, column 2). The percentage of hospitals that adopted CABG fell from 1.8 to 0.3% of hospitals that did not previously offer CABG (Table 2, column 3).

Descriptive statistics for all variables are reported in Table 3 for the samples at risk of adoption (including all years in the risk pool). That is, the samples differ across columns in Table 2 because the numbers of hospitals yet to adopt a service differ across service types. Still, we can see that adoption rates are roughly comparable across columns.

Table 2 Proportion of hospitals adopting cardiac services (1997–2014). Authors' calculations based on Medicare Provider Analysis and Review (MedPar) files for 100% of Medicare beneficiaries (1996–2014)

Year	Diagnostic angiography (1)	PCI (2)	CABG (3)
1997	0.057	0.020	0.018
1998	0.036	0.017	0.013
1999	0.028	0.019	0.013
2000	0.020	0.016	0.009
2001	0.023	0.022	0.014
2002	0.029	0.024	0.017
2003	0.027	0.030	0.012
2004	0.029	0.026	0.011
2005	0.030	0.027	0.010
2006	0.022	0.032	0.012
2007	0.019	0.019	0.011
2008	0.019	0.022	0.007
2009	0.020	0.025	0.006
2010	0.020	0.023	0.003
2011	0.010	0.022	0.006
2012	0.013	0.021	0.004
2013	0.015	0.015	0.004
2014	0.009	0.011	0.003

Proportion adopting a service is the number of hospitals that treat cardiac patients that newly adopted the service in that year divided by the number of hospitals that did not offer the service the previous year (the risk pool for adoption). A hospital may only adopt each service once. The denominator differs by service and includes only hospitals that were in both that year and the previous year (the risk pool must be observed in both years). For diagnostic angiography, the denominator equals the number of hospitals that did not offer any service in the previous year. For PCI, the dominator equals the number of hospitals that did not offer PCI in the previous year. For CABG, the denominator is the number of hospitals that did not offer CABG the previous year. A hospital is considered not to have offered a service in a year if it has not previously adopted the service, not adopted the service in that year, and did not offer the service in the base year (1996)

Note that even relatively low adoption rates in one year imply large gains over time in offering rates. One and a half percent of the risk pool adopting in each year (a 1.5% constant hazard) that is aggregated over 18 years would imply that nearly a quarter of the hospitals that did not offer a service in the first year would offer it by the last. Likewise, a small change in adoption rates can produce large changes over time, as hazard rates compound. For this reason, we compute changes in the expected rate of adoption and compare to baseline adoption rates.

Table 3 Covariate means for hospitals that offer each service and their markets (1997–2014). American Hospital Association's Annual Surveys of Hospitals (AHA) 1996–2014; U.S. Census (2000); American Community Survey (2010–2014); Medicare Provider Analysis and Review (MedPar) files for 100% of Medicare beneficiaries (1996–2014)

	(1) Dx angiography	(2) PCI	(3) CABG
For-profit hospital	0.121	00.140	00.146
Nonprofit hospital	0.596	00.617	00.619
Government hospital	0.283	00.243	00.234
High-FP market (> 10%)	0.374	00.380	00.381
% pop w/ DxAngio access	0.694	00.733	00.743
% pop w/ PCI access	0.541	00.566	00.582
% pop w/ CABG access	0.482	00.509	00.518
Adoption rate of competitors—DxAngio	0.040	00.047	00.048
Adoption rate of competitors—PCI	0.031	00.039	00.040
Adoption rate of competitors—CABG	0.017	00.019	00.019
Smallest hospitals (lowest fifth admit)	0.415	00.303	00.280
Small hospitals (20th–40th percentile admit)	0.351	00.291	00.275
Mid-size (40th–60th percentile admit)	0.166	00.231	00.241
Medium-large (60th–80th percentile admit)	0.054	00.131	00.150
Teaching hospital	0.040	00.078	00.090
Herfindahl–Hirschman Index (hosp ≤ 60 min)	0.249	00.220	00.214
Hospital is in a system	0.475	00.512	00.523
Population density ≥ 500 people/sq mile	0.248	00.342	00.366
Ln pop density	5.455	50.759	50.833
Ln pop nearby	9.740	90.847	90.876
% pop. male under 18	0.255	00.255	00.254
% pop. male 18–44	0.377	00.381	00.381
% pop. male 45–54	0.137	00.137	00.138
% pop. male 55–64	0.106	00.104	00.105
% pop. male 75 plus	0.053	00.052	00.051
% pop. female under 18	0.235	00.234	00.234
% pop. female 18–44	0.357	00.361	00.362
% pop. female 45–54	0.136	00.136	00.136
% pop. female 55–64	0.108	00.107	00.108
% pop. female 75 plus	0.083	00.081	00.080
% pop. high school graduate or GED	0.322	00.315	00.313
% pop. some college	0.211	00.209	00.209
% pop. college graduate	0.209	00.213	00.216
% pop. with graduate degree	0.076	00.081	00.083
% pop. Hispanic	0.093	00.097	00.099
% pop. White	0.814	00.798	00.794
% pop. Black	0.101	00.113	00.116
% pop. household income ≥ $100K	0.100	00.105	00.109
% pop. receiving public assist.	0.110	00.109	00.110

Table 3 continued

	(1) Dx angiography	(2) PCI	(3) CABG
Observations	31,787	43,851	47,572

% pop with service access and % pop with demographic characteristics are determined based on the percentage of the population in each hospital's market that is in a ZCTA with a centroid ≤ 60-min driving distance to a hospital with the service or with the characteristic. Adoption rate of competitors = distance and admission weighted percentage of competitors that adopt a service; hospital sizes based on annual admissions

5.2 Service Adoption, Geographic Access to Care, and Competitor Behavior

The probability of an observation hospital's adopting a new service depends upon competition through two paths. First, it depends on the degree to which the observation hospital's potential patient pool has access to services at another hospital. The potential patients are the residents of ZCTAs, the centroids of which fall a maximum of 60 min driving time from the observation hospital; and whether they have access at another hospital is determined by whether the centroids of the ZCTAs in which they reside are within 60 min of another hospital that offers that service. For economy of expression, we describe this variable as the hospital's market population already having access to care. Second, it depends on the degree to which an observation hospital's competitors also adopt the service in a given year. These two effects operate in different directions.

Controlling only for the year and demographic and hospital factors listed above, hospitals generally are more likely to adopt a new service if the populations in their markets already have access to that service at another hospital (Table 4, columns 1, 4, and 7, coefficients on the percent of the population with access to each service). To interpret the magnitude of the effects, we calculated the effect of a 10% increase in the percent of each hospital's market population who resided in a ZCTA, the centroid of which is a maximum of 60 min driving time from another hospital offering the service in question. More specifically, we add coefficients to the transformed[1] baseline hazard in the sample, then retransform to recover an estimated effect on the hazard for only that coefficient.

The probability of hospitals' adding diagnostic angioplasty increases by approximately 0.09 percentage points or slightly over a 4% increase in the probability that a hospital newly adopts diagnostic angioplasty that year (the mean adoption rate in the sample is 2.38% per year). The corresponding percentages for PCI are considerably higher: 0.63 percentage points, or a 29.0% increase over a base

[1] The cloglog transformation of baseline hazard h is $-\ln[\ln(1-h)]$, whereas the logit transformation is the log odds $\ln[(h)/(1-h)]$. If we add a coefficient c to the transformed hazard to get $y = c - \ln[\ln(1-h)]$, we retransform via $1 - \exp[-\exp(y)]$ for the new estimated hazard.

Table 4 Probability of adopting new service: existing population access and adoption by competitors (1997–2014). *Sources*: American Hospital Association's Annual Surveys of Hospitals (AHA) 1996–2014; U.S. Census (2000); American Community Survey (2010–2014); Medicare Provider Analysis and Review (MedPar) files for 100% of Medicare beneficiaries (1996–2014)

	(1) DxAngio	(2) DxAngio	(3) DxAngio	(4) PCI	(5) PCI	(6) PCI	(7) CABG	(8) CABG	(9) CABG
% pop w/ DxAngio access	0.408		− 4.749***	− 1.452***		0.340	− 1.183*		0.119
	(0.389)		(0.533)	(0.418)		(0.449)	(0.535)		(0.713)
% pop w/ PCI access	0.588		− 0.104	2.577***		− 9.175***	0.0489		0.110
	(0.536)		(0.858)	(0.454)		(0.869)	(0.785)		(0.751)
% pop w/ CABG access	− 0.625		2.925***	− 1.313***		6.947***	1.021		− 3.425***
	(0.512)		(0.855)	(0.332)		(0.807)	(0.717)		(0.723)
Smallest (lowest fifth admit)	− 5.324***	− 4.932***	− 4.721***	− 4.711***	− 4.909***	− 4.589***	− 4.573***	− 4.480***	− 4.166***
	(0.288)	(0.321)	(0.330)	(0.284)	(0.317)	(0.334)	(0.364)	(0.405)	(0.412)
Small (20–40th percentile admit)	− 3.681***	− 3.208***	− 3.046***	− 3.352***	− 3.540***	− 3.219***	− 3.972***	− 3.897***	− 3.643***
	(0.217)	(0.237)	(0.238)	(0.173)	(0.204)	(0.202)	(0.262)	(0.291)	(0.294)
Mid-size (40-60th percentile admit)	− 2.160***	− 1.743***	− 1.647***	− 1.699***	− 1.651***	− 1.463***	− 2.407***	− 1.954***	− 1.793***
	(0.192)	(0.213)	(0.212)	(0.127)	(0.139)	(0.137)	(0.171)	(0.177)	(0.185)
Medium-large (60–80th percentile admit)	− 1.380***	− 1.270***	− 1.177***	− 0.926***	− 1.072***	− 0.987***	− 1.175***	− 0.884***	− 0.754***
	(0.188)	(0.215)	(0.212)	(0.114)	(0.124)	(0.120)	(0.138)	(0.146)	(0.154)
HHI (hosp $\leq$ 60 min)	− 0.994*	− 2.753***	− 2.931***	− 0.238	− 3.184***	− 3.702***	− 0.430	− 6.103***	− 7.416***
	(0.409)	(0.563)	(0.636)	(0.345)	(0.601)	(0.691)	(0.512)	(0.897)	(1.070)
Hosp in system	0.203*	0.280**	0.245*	0.0775	0.111	0.129	0.136	0.183	0.229
	(0.0876)	(0.106)	(0.111)	(0.0744)	(0.0854)	(0.0846)	(0.106)	(0.123)	(0.126)
Adoption rate competitors—DxAngio		8.345***	9.320***		− 0.260	− 0.128		− 0.471	− 0.410
		(0.229)	(0.275)		(0.191)	(0.201)		(0.254)	(0.262)
Adoption rate of competitors—PCI		− 0.250	− 0.278		8.608***	10.81***		− 0.481	− 0.663
		(0.394)	(0.553)		(0.255)	(0.399)		(0.370)	(0.385)

Table 4 continued

	(1) DxAngio	(2) DxAngio	(3) DxAngio	(4) PCI	(5) PCI	(6) PCI	(7) CABG	(8) CABG	(9) CABG
Adoption rate of competitors—CABG		− 2.490***	− 3.387***		− 0.980***	− 2.622***		10.57***	11.73***
		(0.490)	(0.635)		(0.287)	(0.389)		(0.416)	(0.480)
Constant	− 1.501	− 9.744	− 9.974	15.82	17.13	41.84**	40.86*	70.34***	70.98**
	(12.57)	(16.11)	(17.65)	(11.23)	(13.58)	(14.89)	(16.81)	(21.19)	(22.42)
Observations	31,908	31,787	31,787	44,301	43,851	43,851	48,326	47,572	47,572
ymean	0.0238	0.0239	0.0239	0.0216	0.0213	0.0213	0.0096	0.0097	0.0097
N_clust	2579	2574	2574	3397	3380	3380	3425	3409	3409
Pseudo-R^2	0.094	0.531	0.551	0.052	0.391	0.436	0.034	0.352	0.375

Standard errors in parentheses, clustered at the hospital level. Control variables include hospital characteristics (population density of market, teaching status; network membership) and population characteristics (total population; % residents < 18, 18–44, 55–64, ≥ 75 by sex; % with high school degree, some college, college degree; grad. school; % Hispanic, white, black; median income; % median household income ≥ $100K, % on public assistance)

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

rate of 2.16% per year in the sample. For CABG the numbers fall in the middle: 0.10 percentage points, or about a 10.7% increase over a base adoption rate of 0.964% per year in the sample. However, only the results for PCI differ statistically from zero.

As can be seen in Table 4 for the coefficients on the adoption rates of competitors for each service (column 2, 5, 8), hospitals are also quite responsive to the behavior of their competitors in terms of adopting new services. Hospitals are more likely to adopt a new service if their competitors also adopt that service in a given year. The magnitudes of these effects are very large and the coefficients for all three services are significant at the 1% level. The magnitude of the probability of a hospital's adding diagnostic angioplasty increases by approximately 3.0 percentage points or about a 127% increase in the probability that a hospital newly adopts diagnostic angioplasty that year (the mean adoption rate is 2.39%). The corresponding percentages for PCI and CABG are even higher: for PCI, an increase of 2.83 percentage points, or a 133.1% increase over a base rate of 2.13%; for CABG, 1.79 percentage points, or about a 185% increase over a base adoption rate of 0.967%.

The two effects operate in opposite directions. Including both the percentage of residents in a hospital's market area with access to care at competing hospitals and also the adoption behavior of competitors is perhaps most telling. As can be seen in Table 4, columns 3, 6, and 9, when the adoption rate of competitors is included in the model, the coefficients on the percentage of the population with access to each service is large, negative, and significant at the 1% level. Hospitals are deterred from offering a new service if the market population already has access to that service elsewhere. However, the coefficients on adoption rates for each service by competitors of each observation hospital are larger in the regressions that adjust for the percentage of the population with access elsewhere, than in the regressions that do not control for that variable. These coefficients are also statistically significant at the 1% level.

Estimating the magnitude of these effects together is somewhat complicated because an increase in the number of competitor hospitals that adopt a new service will also increase the percentage of the population that has geographic access to that service at another hospital. Nonetheless, to give a sense of the magnitude of the joint effect, we considered the case of a 50% increase in the number of competitors offering a new service. We assumed for the purposes of the simulation that this increase led to a 20% increase in the population with geographic access to the service, using the observed correlations of adoption and change in population coverage in our sample.[2] When we apply these assumptions, the probability of adopting cardiac angioplasty increases from 2.39 to 60.4%, for PCI from 2.13 to 51.3%, and for CABG from 0.97 to 81%.

[2] These are large changes in market structure, but not infeasible, as such large changes are observed in only 1–5% of cases in our data, but a typical positive adoption rate is 20% (median for diagnostic angiography, with a 30% mean; 13% median and 19% mean for PCI; and 9% median and 15% mean for CABG).

Table 5 Probability of adopting new service by hospital ownership: existing population access and adoption by competitors (1997–2014). *Sources*: American Hospital Association's Annual Surveys of Hospitals (AHA) 1996–2014; U.S. Census (2000); American Community Survey (2010–2014); Medicare Provider Analysis and Review (MedPar) files for 100% of Medicare beneficiaries (1996–2014)

	(1) DxAngio	(2) DxAngio	(3) PCI	(4) PCI	(5) CABG	(6) CABG
For-profit hospital	0.622***	0.881***	0.490***	0.704***	0.637***	1.222***
	(0.181)	(0.206)	(0.132)	(0.153)	(0.180)	(0.206)
Government hospital	− 0.527***	− 0.489*	− 0.508***	− 0.495*	− 0.929***	− 0.583*
	(0.160)	(0.233)	(0.134)	(0.197)	(0.233)	(0.285)
Adoption rate competitors—DxAngio	9.306***	9.444***	− 0.0815	− 0.296	− 0.396	− 0.398
	(0.277)	(0.315)	(0.201)	(0.249)	(0.258)	(0.309)
Adoption rate of competitors—PCI	− 0.257	0.0558	10.81***	10.90***	− 0.666	− 0.118
	(0.565)	(0.769)	(0.402)	(0.468)	(0.387)	(0.458)
Adoption rate of competitors—CABG	− 3.395***	− 3.682***	− 2.758***	− 2.157***	11.63***	12.05***
	(0.659)	(0.897)	(0.393)	(0.470)	(0.483)	(0.571)
% pop w/ DxAngio access	− 4.842***	− 4.930***	0.207	0.164	0.0322	0.0706
	(0.544)	(0.542)	(0.458)	(0.454)	(0.727)	(0.742)
% pop w/ PCI access	0.00807	0.107	− 9.061***	− 8.904***	0.322	0.182
	(0.854)	(0.862)	(0.880)	(0.862)	(0.738)	(0.756)
% pop w/ CABG access	2.770**	2.674**	6.945***	6.742***	− 3.602***	− 3.480***
	(0.849)	(0.848)	(0.814)	(0.796)	(0.701)	(0.711)
Smallest (lowest fifth admit)	− 4.669***	− 4.712***	− 4.522***	− 4.609***	− 3.974***	− 4.110***
	(0.341)	(0.337)	(0.335)	(0.338)	(0.400)	(0.433)
Small (20th–40th percentile admit)	− 3.089***	− 3.139***	− 3.273***	− 3.323***	− 3.781***	− 3.732***
	(0.246)	(0.243)	(0.201)	(0.201)	(0.295)	(0.289)
Mid-size (40th–60th percentile admit)	− 1.687***	− 1.744***	− 1.527***	− 1.563***	− 1.931***	− 1.951***
	(0.218)	(0.220)	(0.137)	(0.137)	(0.190)	(0.190)

Table 5 continued

	(1) DxAngio	(2) DxAngio	(3) PCI	(4) PCI	(5) CABG	(6) CABG
Medium-large (60th–80th percentile admit)	− 1.212***	− 1.263***	− 1.032***	− 1.069***	− 0.843***	− 0.855***
	(0.217)	(0.221)	(0.120)	(0.120)	(0.153)	(0.156)
HHI (hosp ≤ 60 min)	− 2.640***	− 2.724***	− 3.698***	− 3.743***	− 7.406***	− 7.213***
	(0.626)	(0.631)	(0.703)	(0.696)	(1.071)	(1.018)
FP*Competitors adopting DxAngio		− 0.900		1.090*		0.271
		(0.479)		(0.431)		(0.567)
FP*Competitors adopting PCI		0.0539		− 0.859		− 1.113
		(1.055)		(0.509)		(0.865)
FP*Competitors adopting CABG		1.021		− 1.205		− 1.403
		(1.272)		(0.710)		(0.750)
Gov*Competitors adopting DxAngio		0.590		− 0.875		− 0.541
		(0.510)		(0.587)		(0.989)
Gov*Competitors adopting PCI		− 1.697		0.886		− 1.600
		(1.038)		(0.526)		(1.348)
Gov*Competitors adopting CABG		− 0.669		− 1.466		0.466
		(1.400)		(0.813)		(0.955)
Constant	− 9.299	− 10.89	39.63**	41.73**	68.65**	66.53**
	(17.48)	(17.38)	(15.04)	(14.95)	(22.80)	(23.10)
Observations	31,787	31,787	43,851	43,851	47,572	47,572
ymean	0.0239	0.0239	0.0213	0.0213	0.0097	0.0097
N_clust	2574	2574	3380	3380	3409	3409

Table 5 continued

	(1) DxAngio	(2) DxAngio	(3) PCI	(4) PCI	(5) CABG	(6) CABG
Pseudo-R^2	0.556	0.557	0.438	0.441	0.386	0.388

Standard errors in parenthesis, clustered at the hospital level. Control variables include hospital characteristics (population density of market, teaching status; network membership) and population characteristics (total population; % residents < 18, 18–44, 55–64, ≥ 75 by sex; % with high school degree, some college, college degree; grad. school; % Hispanic, white, black; median income; % median household income ≥ $100K, % on public assistance)

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$

5.3 Hospital Ownership and Effects of Ownership Mix in Hospital Markets

Consistent with previous research (Horwitz and Nichols 2009), for-profit hospitals are more likely than nonprofit hospitals, which in turn are more likely than government hospitals, to adopt each of these three relatively profitable cardiac services, and the coefficients on ownership of the observation hospital are all statistically significant at the 1% level (Table 5, rows 1 and 2). Moreover, the magnitude of the effect of ownership of the observation hospital on the probability of adopting a new service is large.

Based on the coefficients that are reported in Table 5, column 1, for-profit hospitals are 2.02 percentage points more likely to adopt diagnostic angiography than are nonprofit hospitals; this represents an 84.3% increase in the probability of adoption on a base of 2.39%. The corresponding magnitudes for PCI are a difference of 1.32 percentage points, for an increase of 62.1 percent increase in the probability of adoption on a base of 2.13%, when we compare for-profit hospitals to nonprofits. For CABG, the difference is 0.85 percentage points, or an 88.3% increased hazard, on a base of 0.97%.

Government hospitals are less likely to adopt new services than are nonprofit hospitals. Government hospitals are 0.97 percentage points less likely to adopt diagnostic angiography than are nonprofit hospitals; this represents a 40.1% decrease in the probability of adoption on a base of 2.39%. The corresponding magnitudes for PCI are a − 0.84 percentage point differential, for a decrease of 39.6% in the probability of adoption on a base of 2.13%. For CABG, the difference is 0.58 percentage points, or a 60.1% decrease on a base of 0.97%.

Table 6 reports the probability of a hospital's adopting a new service taking into account the penetration of for-profit hospitals in the market. When controlling for ownership of observation hospitals, the coefficients on the variable that measures high for-profit market penetration are negative, but only the coefficients on CABG are statistically significant (Table 6, row 3).

Table 7 reports the results of interactions between an indicator variable for high for-profit penetration markets and: (1) the ownership of observation hospitals; and (2) the adoption rate of their competitors. The results are consistent with previous research that demonstrates that nonprofit hospitals are more likely to adopt profitable cardiac services in markets with high for-profit penetration than in markets with fewer for-profits (Horwitz and Nichols 2009); the nonprofit hospitals effectively behave more like for-profits in markets with more for-profit competitors.

The interactions between hospital ownership and the adoption rates of competitors (FP/Gov * Comp. adopting DxAngio/PCI/CABG), adjusting for the ownership of observation hospitals and high for-profit penetration in their markets, yields inconclusive results (Table 7). The only consistent, statistically significant results suggest that for profit hospitals are more likely than nonprofit hospitals to increase the sophistication of their cardiac services as their competitors start

Table 6 Probability of adopting new service by ownership in market, controlling for the market penetration of for-profit hospitals: existing population access and adoption by competitors (1997–2014). *Sources*: American Hospital Association's Annual Surveys of Hospitals (AHA) 1996–2014; U.S. Census (2000); American Community Survey (2010–2014); Medicare Provider Analysis and Review (MedPar) files for 100% of Medicare beneficiaries (1996–2014)

	(1) DxAngio	(2) DxAngio	(3) PCI	(4) PCI	(5) CABG	(6) CABG
For-profit hospital	0.642***	0.912***	0.515***	0.720***	0.704***	1.309***
	(0.182)	(0.210)	(0.131)	(0.155)	(0.182)	(0.209)
Government hospital	− 0.522**	− 0.477*	− 0.501***	− 0.485*	− 0.912***	− 0.553
	(0.160)	(0.232)	(0.133)	(0.197)	(0.234)	(0.283)
High-FP market pen (over 10%)	− 0.109	− 0.113	− 0.127	− 0.108	− 0.422*	− 0.461*
	(0.146)	(0.150)	(0.134)	(0.132)	(0.188)	(0.193)
Adoption rate of competitors—DxAngio	9.306***	9.449***	− 0.0746	− 0.287	− 0.320	− 0.311
	(0.276)	(0.314)	(0.202)	(0.250)	(0.256)	(0.307)
Adoption rate of competitors—PCI	− 0.261	0.0605	10.81***	10.89***	− 0.705	− 0.178
	(0.565)	(0.769)	(0.401)	(0.467)	(0.390)	(0.463)
Adoption rate of competitors—CABG	− 3.374***	− 3.666***	− 2.730***	− 2.126***	11.69***	12.15***
	(0.660)	(0.895)	(0.388)	(0.464)	(0.486)	(0.576)
% pop w/ DxAngio access	− 4.815***	− 4.903***	0.232	0.186	0.0239	0.0488
	(0.545)	(0.543)	(0.456)	(0.453)	(0.716)	(0.729)
% pop w/ PCI access	− 0.00914	0.0940	− 9.077***	− 8.916***	0.268	0.144
	(0.854)	(0.863)	(0.879)	(0.863)	(0.732)	(0.747)
% pop w/ CABG access	2.789**	2.690**	6.939***	6.738***	− 3.538***	− 3.425***
	(0.848)	(0.848)	(0.809)	(0.794)	(0.690)	(0.698)
Smallest (lowest fifth admit)	− 4.663***	− 4.708***	− 4.516***	− 4.603***	− 3.968***	− 4.098***
	(0.340)	(0.337)	(0.335)	(0.339)	(0.399)	(0.431)
Small (20th–40th percentile admit)	− 3.086***	− 3.136***	− 3.263***	− 3.314***	− 3.750***	− 3.693***
	(0.245)	(0.243)	(0.199)	(0.199)	(0.288)	(0.283)

Table 6 continued

	(1) DxAngio	(2) DxAngio	(3) PCI	(4) PCI	(5) CABG	(6) CABG
Mid-size (40th–60th percentile admit)	− 1.686***	− 1.746***	− 1.527***	− 1.563***	− 1.929***	− 1.951***
	(0.217)	(0.220)	(0.138)	(0.137)	(0.189)	(0.189)
Medium-large (60th–80th percentile admit)	− 1.210***	− 1.262***	− 1.031***	− 1.067***	− 0.842***	− 0.854***
	(0.217)	(0.221)	(0.120)	(0.120)	(0.153)	(0.157)
HHI (hosp $\leq$ 60 min)	− 2.748***	− 2.838***	− 3.840***	− 3.859***	− 7.954***	− 7.755***
	(0.637)	(0.645)	(0.721)	(0.712)	(1.116)	(1.042)
FP*Competitors adopting DxAngio		− 0.918		1.076*		0.248
		(0.479)		(0.431)		(0.559)
FP*Competitors adopting PCI		0.0382		− 0.832		− 1.006
		(1.059)		(0.506)		(0.853)
FP*Competitors adopting CABG		1.021		− 1.219		− 1.528*
		(1.273)		(0.706)		(0.742)
Gov*Competitors adopting DxAngio		0.573		− 0.870		− 0.403
		(0.509)		(0.589)		(0.985)
Gov*Competitors adopting PCI		− 1.709		0.883		− 1.902
		(1.042)		(0.529)		(1.377)
Gov*Competitors adopting CABG		− 0.637		− 1.483		0.621
		(1.411)		(0.813)		(0.967)
Constant	− 8.038	− 9.579	42.19**	43.86**	74.88**	74.54**
	(17.59)	(17.49)	(15.18)	(15.18)	(22.88)	(23.25)
Observations	31,787	31,787	43,851	43,851	47,572	47,572
ymean	0.0239	0.0239	0.0213	0.0213	0.0097	0.0097
N_clust	2574	2574	3380	3380	3409	3409

Table 6 continued

	(1) DxAngio	(2) DxAngio	(3) PCI	(4) PCI	(5) CABG	(6) CABG
Pseudo-R^2	0.556	0.557	0.439	0.441	0.388	0.390

Standard errors in parentheses, clustered at the hospital level. Control variables include hospital characteristics (population density of market, teaching status; network membership) and population and market characteristics (total population; % residents < 18, 18–44, 55–64, ≥ 75 by sex; % with high school degree, some college, college degree; grad. school; % Hispanic, white, black; median income; % median household income $\geq$ \$100K, % on public assistance)

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

Table 7 Probability of adopting new service by market penetration of for-profit hospitals and competitor adoption (1997–2014). *Sources*: American Hospital Association's Annual Surveys of Hospitals (AHA) 1996–2014; U.S. Census (2000); American Community Survey (2010–2014); Medicare Provider Analysis and Review (MedPar) files for 100% of Medicare beneficiaries (1996–2014)

	(1) DxAngio	(2) DxAngio	(3) PCI	(4) PCI	(5) CABG	(6) CABG
For-profit hospital	1.277***	1.199***	1.043***	0.985***	1.905***	1.864***
	(0.262)	(0.279)	(0.190)	(0.196)	(0.233)	(0.241)
Government hospital	− 0.686*	− 0.748*	− 0.717**	− 0.758**	− 0.949*	− 1.047*
	(0.286)	(0.305)	(0.251)	(0.269)	(0.452)	(0.492)
High-FP market	0.333	0.649*	0.315	0.510	0.318	0.724
	(0.294)	(0.329)	(0.263)	(0.302)	(0.524)	(0.544)
FP*high-FP market	− 0.930*	− 0.981*	− 0.895**	− 0.886**	− 1.590**	− 1.671**
	(0.380)	(0.383)	(0.313)	(0.318)	(0.548)	(0.558)
Gov*high-FP market	− 0.387	− 0.376	− 0.352	− 0.324	− 0.534	− 0.517
	(0.324)	(0.321)	(0.275)	(0.284)	(0.529)	(0.535)
Adoption rate of competitors—DxAngio	9.455***	9.819***	− 0.307	− 0.0920	− 0.398	− 0.00408
	(0.315)	(0.348)	(0.251)	(0.293)	(0.310)	(0.346)
Adoption rate of competitors—PCI	0.0252	− 0.378	10.89***	10.98***	− 0.214	− 0.500
	(0.768)	(0.930)	(0.468)	(0.523)	(0.458)	(0.557)
Adoption rate of competitors—CABG	− 3.662***	− 3.283**	− 2.121***	− 1.684**	12.24***	12.93***
	(0.893)	(1.060)	(0.463)	(0.532)	(0.569)	(0.676)
% pop w/ DxAngio access	− 4.937***	− 5.115***	0.144	0.0747	− 0.107	− 0.300
	(0.549)	(0.560)	(0.451)	(0.457)	(0.727)	(0.749)
% pop w/ PCI access	0.199	0.271	− 8.856***	− 8.958***	0.397	0.557
	(0.871)	(0.893)	(0.862)	(0.866)	(0.746)	(0.764)
% pop w/ CABG access	2.610**	2.624**	6.668***	6.768***	− 3.639***	− 3.806***
	(0.850)	(0.889)	(0.794)	(0.801)	(0.702)	(0.713)

Table 7 continued

	(1) DxAngio	(2) DxAngio	(3) PCI	(4) PCI	(5) CABG	(6) CABG
FP*Competitors adopting DxAngio	− 0.842	− 0.493	1.175**	1.249**	0.498	0.708
	(0.473)	(0.498)	(0.425)	(0.434)	(0.539)	(0.548)
FP*Competitors adopting PCI	− 0.00190	− 0.237	− 0.662	− 0.659	− 0.967	− 1.142
	(1.079)	(1.089)	(0.516)	(0.520)	(0.826)	(0.820)
FP*Competitors adopting CABG	1.093	1.224	− 1.301	− 0.863	− 1.491*	− 1.127
	(1.282)	(1.281)	(0.692)	(0.692)	(0.723)	(0.731)
Gov*Competitors adopting DxAngio	0.631	0.708	− 0.927	− 0.934	− 0.751	− 0.579
	(0.516)	(0.518)	(0.571)	(0.565)	(1.058)	(1.036)
Gov*Competitors adopting PCI	− 1.541	− 1.498	1.019	1.070*	− 1.149	− 1.645
	(1.032)	(1.065)	(0.526)	(0.524)	(1.469)	(1.509)
Gov*Competitors adopting CABG	− 0.964	− 0.873	− 1.532	− 1.349	0.350	0.978
	(1.420)	(1.422)	(0.812)	(0.794)	(0.945)	(0.996)
FPMarket*Competitors adopting DxAngio		− 0.866*		− 0.293		− 0.753
		(0.411)		(0.379)		(0.511)
FPMarket*Competitors adopting PCI		0.804		− 0.142		0.788
		(1.055)		(0.476)		(0.789)
FPMarket*Competitors adopting CABG		− 0.732		− 1.133		− 1.561*
		(1.237)		(0.607)		(0.749)
Constant	− 8.733	− 11.46	43.13**	44.34**	70.60**	73.31***
	(17.34)	(17.43)	(15.10)	(15.00)	(22.67)	(22.23)
Observations	31,787	31,787	43,851	43,851	47,572	47,572
ymean	0.0239	0.0239	0.0213	0.0213	0.0097	0.0097
N_clust	2574	2574	3380	3380	3409	3409

Table 7 continued

	(1) DxAngio	(2) DxAngio	(3) PCI	(4) PCI	(5) CABG	(6) CABG
Pseudo-R^2	0.558	0.559	0.442	0.443	0.395	0.398

Standard errors in parentheses, clustered at the hospital level. Control variables include hospital characteristics (population density of market, teaching status; network membership; size quintiles by admissions) and population and market characteristics (total population; % residents < 18, 18–44, 55–64, ≥ 75 by sex; % with high school degree, some college, college degree; grad. school; % Hispanic, white, black; median income; % median household income $\geq$ \$100K, % on public assistance; HHI). High FP penetration = markets $\geq 10\%$ FP hospital penetration

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$

offering invasive cardiac services in the form of diagnostic angiography.[3] This can be seen in columns 3 and 4 (FP*Comp. adopting dxAngio). For-profit hospitals are 4.6 percentage points more likely than are nonprofits to adopt PCI if their competitors adopt diagnostic angiography; this represents a 216% increase in the probability of adoption on a base of 2.13%. The magnitude of the effect increases when we adjust for the interaction between the adoption rates of competitors and being in a high for-profit market.

5.4 Limitations

There are several limitations to our study. First, there may be some measurement error in the service adoption variables. We identify hospitals as offering a service based on whether a hospital bills (or has billed) for 11 or more procedures on Medicare fee-for-service beneficiaries. It is possible that a hospital newly offers a service in a given year and provides fewer than 11 procedures or provides more procedures on patients who are not insured under the Medicare fee-for-service program. However, patients who receive the services that are studied here tend to be old enough to qualify for Medicare. Medicare was the primary expected payer for 51.1% of hospital stays that involved a cardiac stent insertion procedure in 2009 (Auerbach et al. 2012). Over 60% of CABG patients are 65 or older (Epstein et al. 2011 Table 2) and therefore are old enough to qualify for Medicare. Younger cardiac patients may also be covered by Medicare. In fact, in 2012, approximately 17% of Medicare beneficiaries who were under 65 had Ischemic Heart Disease (Center for Medicare & Medicaid Services 2015).

Nonetheless, hospitals may perform these services on patients who are insured under the Medicare Advantage program instead of, or in addition to, those covered by Medicare fee-for-service. However, even those regions with the highest levels of Medicare Advantage enrollment also have high levels of fee-for-service enrollment. At the end of the study period, in 2014, 30% of Medicare beneficiaries were enrolled in Medicare advantage plans; and by 2016 the rate was at least 40% in five states (Jacobson et al. 2016). Therefore, even in these high enrollment states, 60% of all enrollees were in fee-for-service plans.

Second, as with any study that uses observational data, it is not possible completely to rule out bias due to endogeneity. Our results are consistent with hospitals' simultaneously adopting new services in response to changes in an unobserved common factor that increases the demand for cardiac services in their markets, rather than in reaction to each other's decisions. However, because government reimbursement through Medicare payments accounts for the bulk of cardiac spending, it is unlikely that differences in market prices account for the differences in technology diffusion that we find here. Moreover, our inclusion of extensive demographic and hospital control variables—most importantly, variables that control for population growth and changes in the age distribution in the

[3] Compared to nonprofit hospitals, for profit hospitals are less likely to adopt CABG if their competitors do (column 8; fp*adoption rate of competitors-CABG), but this is no longer statistically significant after adjusting for being in a for-profit market (column 9).

markets—suggest that simultaneous response to demand shocks does not explain our results.

Following Oster (2017), as an additional robustness test we exclude groups of controls, alternately excluding: (1) education and income covariates; and (2) race covariates; we then rerun all the analyses described above. The coefficients and proportions of variance explained remain stable across analyses, with the coefficients in these alternate specifications remaining within the range of a single standard deviation of the specifications reported here. This exercise supports the notion that results are robust to the inclusion of multiple varieties of control variables.

Nonetheless, it is possible that we have not measured, yet hospitals observe, changes in the population of a hospital's geographic market or other local shocks that explain the results we have found. For example, if the adoption of catheterization labs is promoted by a third party (such as a stent manufacturer) in an area, or a conference is held in the area that promotes such adoption, all hospitals would be exposed to a common shock. In this case, adoptions could be correlated for that reason and not because hospitals are competing against each other. Even if that type of hypothetical common shock were the cause, however, the pattern of adoption we document is of direct policy concern, since it results in duplicative services more than increased access, and can lower welfare relative to a situation where some adoptions of new services are moved from a service-rich area to a service-poor area.

Third, it may be that hospitals simultaneously adopted new services, not in response to information that a competitor hospital planned to adopt, but rather in response to changes in the costs of supplying the service such as a decrease in input prices of the equipment or the physicians. It is unlikely that such decreases explain the patterns we observe. Over the study period, the percentage and number of hospitals that adopted a new service decreased. And the patterns of adoption were clustered within markets as defined in this analysis (relatively small areas based on 60-min driving distances) and were not consistent across the country, whereas markets for technology or talent are much larger—if not national.

6 Discussion

From 1997 to 2014, hospitals have continued to adopt new invasive cardiac services, although the rate of adoption slowed over the study period. Larger hospitals are more likely to adopt new services than are smaller hospitals. For-profit hospitals are more likely to adopt new services than are nonprofit hospitals, which, in turn, are more likely than government hospitals to adopt new services. On average, hospitals appear to make decisions with regard to the adoption of new services based on the behavior of competitors in the markets in which they operate, controlling for population size and other characteristics.

The welfare effects of our findings with regard to cardiac technology diffusion are uncertain. Although the spread of technology is generally good for social welfare, this has not always been the case with health care technology. Large geographic differences in the provision of care and in spending on care cannot be explained by differences in the population treated and have not led to differences in health outcomes, which suggests that there is a great deal of waste. Cardiac treatments are typically quite profitable services for hospitals (Horwitz 2005), and oversupply is a particular worry for the provision of services that tend to be profitable for providers. In fact, at the extreme, there have been distressing cases of hospitals and physician providing services—particularly profitable services, such as cardiac treatments—to patients who did not need the intervention (Eisler and Hansen 2013; Vrana and White 2003).

Although our study does not measure social welfare directly, the results suggest that current patterns of cardiac technology diffusion can either increase or decrease social welfare, depending on conditions of a health care market. Social welfare is enhanced if hospitals base their decisions to adopt on the existence of unmet medical need in their markets. There is some evidence that they are doing so. They are less likely to adopt a new service if the patients in their markets already have geographic access to a service at another hospital.

However, previous research that finds little increase in geographic access to care suggests that adoption decisions are in fact driven by a competitor's decision to adopt (Horwitz et al. 2013). Our results strongly support this finding. Although hospitals respond to the needs of potential patients to be within 60-min driving time of an invasive cardiac service, they also respond to the behavior of their competitors and adopt even if doing so duplicates existing services, thereby failing to increase geographic access.

Nonetheless, even if competition has led to inefficient diffusion, there may well be offsetting benefits to hospital competition. Recent studies have identified benefits to hospital competition in terms of reducing excess capacity (Santerre and Adams 2002), prices (Town and Vistnes 2001), and adverse outcomes (Kessler and McClellan 2000). The link between hospital-level volume and improved patient outcomes implies that such effects are unlikely for the cardiac services in this study, but such effects are outside the scope of this study. Future research should investigate the relationship among adoption, the role of hospital competition for patients and services, and outcomes such as health status and spending.

In addition to identifying two mechanisms that may explain a hospital's decision to adopt a new service, we find that for-profit hospitals are considerably more likely than are nonprofits to adopt new services. However, this study does not find many differences in the relationship between ownership and responsiveness to the adoption decisions of competitors.

Despite improvements in treatments, cardiovascular disease is the leading cause of death in the United States and has been for many decades, though whether cancer or cardiovascular disease is the leading cause has recently begun to vary by race and socioeconomic status (Heron and Anderson 2016). Understanding the continued diffusion of treatments in markets that already have geographic access may help in addressing this persistent health problem.

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