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Factors Associated With Hospital Decisions to Purchase Robotic Surgical Systems

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Background. Robotic surgical systems are expensive to own and operate, and the purchase of such technology is an important decision for hospital administrators. Most prior literature focuses on the comparison of clinical outcomes between robotic surgery and other laparoscopic or open surgery. There is a knowledge gap about what drives hospitals' decisions to purchase robotic systems. **Objective.** To identify factors associated with a hospital's acquisition of advanced surgical systems. **Method.** We used 2002 to 2011 data from the State of California Office of Statewide Health Planning and Development to examine robotic surgical system purchase decisions of 476 hospitals. We used a probit estimation allowing heteroscedasticity in the error term including a set of two equations: one binary response equation and one heteroscedasticity equation. **Results.** During the study timeframe, there were 78 robotic surgical systems purchased by hospitals in the sample. Controlling for hospital characteristics such as number of available beds, teaching status, nonprofit status, and patient mix, the probit estimation showed that market-level directly relevant surgery volume in the previous year (excluding the hospital's own volume) had the largest impact. More specifically, hospitals in high volume (>50,000 surgeries v. 0) markets were 12 percentage points more likely to purchase robotic systems. We also found that hospitals in less competitive markets (i.e., Herfindahl index above 2500) were 2 percentage points more likely to purchase robotic systems. **Limitations.** This study has limitations common to observational database studies. Certain characteristics such as cultural factors cannot be accurately quantified. **Conclusions.** Our findings imply that potential market demand is a strong driver for hospital purchase of robotic surgical systems. Market competition does not significantly increase the adoption of new expensive surgical technologies.

Keywords
health care market, hospital administration, robotic surgical system

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Introduction

Health care spending has been rising rapidly over the past 20 years. The national health spending in the United States is projected to reach $3.8 trillion in 2019 and continue to rise at an average annual growth rate of 5.7% from 2020 to 2027.[1] Researchers suggest that development and diffusion of new technologies contributes significantly to the growing costs. Some even argue that new technologies account for nearly half of the increase in health care spending.[2–4]

A robotic surgical system is an expensive new technology. Individual units are purchased at costs of nearly $2

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million dollars. Additional expenses include consumables, maintenance fees, and costs of training for both primary users and ancillary staff. In 2000, the Food and Drug Administration (FDA) approved the use of the da Vinci Surgical System for general laparoscopic surgery, which can be used to address gallbladder, gastroesophageal, and other intraabdominal disease. In 2001, the FDA approved use of the system for prostate surgery; the FDA subsequently approved its use for thoracoscopic surgery, cardiac procedures performed with adjunctive incisions, and gynecologic procedures. There are many articles in the literature concerning the high cost of robot-assisted procedures compared with conventional surgery and nonsurgical treatments.[5]

From a hospital perspective, the adoption of expensive new equipment is one of the most important decisions in hospital administration. On one hand, the adoption of equipment such as a robotic surgical system increases operational costs substantially; on the other hand, consumers (patients) often see the adoption of new technology as an indicator of high-quality care. Importantly, advanced technology acquisition may help hospitals recruit surgeons who are interested in using robotic surgical systems. There have been numerous studies on the use of robotic surgical systems and its impact on surgical outcomes.[6–11] However, there are only a few reports on the strategic decision making to build and maintain robotic surgical capabilities and programs.[12–14] Furthermore, most if not all of the current literature has focused on the choice of surgery type (i.e., robotic-assisted surgery v. other laparoscopic surgery and open surgery).

In this article, we focus on the acquisition decision and aim to identify factors that are significantly associated with the purchasing decision, and estimate the extent to which factors such as potential market demand/capacity and market competition affect such decisions after controlling for hospital and market characteristics (e.g., number of hospital beds, teaching status, nonprofit status, patient mix). We used panel data on hospitals in California from 2002 to 2011 to examine the association between the likelihood of acquiring robotic surgical systems and hospital purchase history, hospital characteristics, and market characteristics.

Theory

Assuming that the hospital administration is fully rational and informed, then the acquisition decision would probably depend on the cost of purchasing and implementing robotic surgery, and the expected benefit depending on the number of patient surgery cases and also other factors that affect payments such as the payer composition. There is potentially a threshold of robotic surgery volume for hospitals to consider acquisition of a robotic system as a volume too low will cause the robotic system to be underutilized and financially inadvisable.

Hospital market competition can play an important role as some argue that robotic system acquisition can strengthen the reputation of the hospital and attract both patients and surgeons and therefore benefit the hospital in the competition. The relationship between hospital market competition and acquisition of expensive medical equipment is complex. There is no consistent evidence in the literature examining this relationship. Some researchers believe that competition is associated with more rapid diffusion of novel expensive technologies.[15–17] Others argue that hospitals already having a larger share of the market have more resources and are therefore more likely to purchase expensive equipment based on the resource dependency theory.[18,19]

Methods

Data Source

The study examined the robotic surgical system purchase decisions of 476 hospitals in California during the years 2003 to 2011. Our analytical sample was compiled using data from the State of California Office of Statewide Health Planning & Development (OSHPD) 2002 to 2011. The 2002 data was used to construct certain look-back variables that involve characteristics in the previous year. California is the most populous state in the nation with more than 39 million people. The health care market in California is diverse covering both urban and rural areas. The OSHPD data cover all nonfederal hospitals operating in the state. The only major metro area on the state border is Las Vegas, which borders a rural area of California. The California health care market has considerable managed care penetration and Kaiser Permanente has a large presence.

We chose hospitals in California not only because of the diverse market but also because the OSHPD facility files offer unique data elements that enable us to determine the timing of robotic system acquisition. In response to Section §127285(3) of the Health and Safety Code, which stipulates that hospitals must report the acquisition of any diagnostic or therapeutic equipment valued in excess of $500,000, the OSHPD added a Major Capital Expenditures section to its Hospital Annual Utilization Data[20] and has required hospitals to include a text description of such equipment, its costs, and date of acquisition since 2002. Given that the price of a da Vinci system far exceeds $500,000, we used the above-mentioned variables to identify California hospitals that had purchased robotic surgical systems and the date of purchase. We cross-referenced the above information with the name and location of California hospitals listed on the Intuitive Surgical Inc. website to ensure the completeness of information. Because Intuitive Surgical Inc. manufactures all da Vinci Surgical Systems, a hospital listing posted on the company's website is a reliable source of verification. For hospitals identified only from the company website, we contacted these hospitals to determine the purchase date.

We then merged the above robotic acquisition data with OSHPD Annual Financial Data[20] via unique hospital identifiers. The OSHPD Annual Financial Data provide information on hospital characteristics, such as number of available beds, type of control (nonprofit or not), and teaching status. Next, we excluded short-term and long-term psychiatric hospitals and those without operating rooms, as these hospitals are not potential buyers of robotic surgical systems. To determine each hospital's market area, we mapped the address of each hospital to the corresponding Hospital Service Area (HSA) using the zip code–HSA crosswalk from the Dartmouth Atlas.[21] Finally, we linked the above facility-level data to the OSHPD Patient Discharge Data via unique hospital identifiers to obtain information about each hospital's surgery volume, patient demographics, and payer composition.

More specifically, hospital characteristics included number of available beds (more than 300, less than or equal to 300), control type (nonprofit, other), teaching status (yes, no), patient demographics (average age and proportion of females), payer composition (% covered by private payers), and the logarithm of hospital's directly relevant surgery volume in the previous year. Directly relevant procedures are defined as procedures that can potentially be performed as robot-assisted. We identified such procedures based on International Classification of Diseases, 9th Revision, procedure codes: prostatectomy (60.5), hysterectomy (68.31–68.9), cholecystectomy (51.21–51.24), colon and rectal procedures (48.62–48.63), partial nephrectomy (55.4), sacrocolpopexy (70.78–70.95), mitral valve repair (353.23–35.24), lobectomy (32.3–32.49), and transoral surgery (29.33, 25.1, 25.2). Market characteristics included the competitiveness of the market (i.e., the HSA) as measured by the Herfindahl index; whether there are existing robotic surgical systems owned by other hospitals in the same market area (yes, no); and the market-level surgery volume in the previous year, which serves as a proxy for potential market-level demand. We categorized Herfindahl-Hirschman index (HHI) into two groups: highly concentrated (HHI $>$ 2500) and not highly concentrated (HHI $\leq$ 2500). The HHI is a widely accepted measure of market concentration and competition for hospitals, and an HHI above 2500 usually indicates a highly concentrated and less competitive health care market.[22] In our study sample, 78% of the observations had highly concentrated market with HHI above 2500, while 22% had not highly concentrated markets at HHI 2500 or below. Similarly, we categorized the market-level surgical volume (excluding the hospital itself) in the previous year into three groups: zero, 1 to 50,000, and above 50,000. In our sample, 33% were in the zero group, 51% in the middle group, while 16% had above 50,000. The histograms of the HHI and surgical volume above zero are provided in Supplementary Figure 1. We also controlled for the time period of the observation (2003–2005, 2006–2008, 2009–2011) in our analyses. The final study sample included 3791 observations (hospital $\times$ years) from 2003 to 2011.

Model and Estimation

We employed a binary response model to examine the relationship between a hospital's robotic system acquisition decision and the characteristics of the hospital and market. The model has the following structure:

$$Y_{it} = \begin{cases} 1 & X_{it}\theta + c > u_{it} \\ 0 & \text{Otherwise} \end{cases}$$

The Y_{it} is the binary variable that captures hospital i's decision in year t to purchase or not purchase a machine with 1 denoting yes, 0 denoting no. The X_{it} captures the corresponding hospital and market characteristics, an indicator of whether the hospital had purchased robotic surgical systems before was also included to capture the dynamics of purchasing decisions. The c denotes a constant term.

We used a probit estimation to examine the relationship between the probability of acquiring a robotic system and hospital and market characteristics. The estimation strategy we adopted allows for heteroscedasticity in the error term. Hospitals can differ in many dimensions, and the distribution of the error term may not be identical for different hospitals. If heteroscedasticity is present and ignored, the estimates can be very far from the true parameter values (i.e., inconsistent).[23,24] Therefore, it is important to account for heteroscedasticity if it is present. We captured heteroscedasticity with the following general form: $u_{it} = S_{it}\varepsilon_{it}$, where $S_{it} = \exp(X_{it}\delta)$, which is widely used in the literature and available in STATA.[23–25] Furthermore, we conducted a Wald test for the presence of heteroscedasticity in the model by testing whether $\delta = 0$.[26] We also considered the clustering by hospitals in our statistical inference so as to obtain appropriate standard errors. Analysis was conducted using Stata 14 (Stata Corp., College Station, TX).

Sensitivity Analyses

We conducted two sensitivity analyses. First, because California hospital market has considerable managed care penetration, we conducted a sensitivity analysis including Medicare county-level managed care penetration rate[27] into our analysis. In this sensitivity analysis, the sample size decreased to 3706 due to 9 facilities with unknown managed care penetration rate. Second, as mentioned in the theory section of the introduction, it is possible that there is a surgery volume threshold that makes robotic surgical system acquisition not worth considering. In our main analysis, we have excluded short-term and long-term psychiatric hospitals and hospitals without operating rooms. In this sensitivity analysis, we further excluded hospitals in markets where the total surgery volume is less than 1000 in the previous year. By doing this, we excluded around 10% of the sample resulting in 3422 observations for 433 hospitals.

Results

We provide the sample description in Table 1. During 2003 to 2011, there were 78 robotic surgical system purchases by California hospitals in the sample. The table also provides group comparisons by purchase decision. We found significant group differences by previous purchase of a robotic surgical system, number of beds, control type, teaching status, proportion of patients covered by private payers, and directly relevant surgery volume in the previous year. More specifically, hospitals with more beds ($>$300 v. $\leq$ 300), nonprofit hospitals, teaching hospitals, hospitals with more patients covered by private payers, and hospitals with a higher directly relevant surgery volume in the previous year were much more likely to purchase a robotic surgical system (all $P < 0.001$). More robotic surgical system purchases happened in the later years of the sample (e.g., 42 purchases in 2009–2011 compared with 13 purchases in 2003–2005).

We provide the estimation results for the binary response model of robotic surgical system acquisition decision in Supplementary Table 1. Importantly, we found very strong evidence for heteroscedasticity as we reject the null hypothesis of constant variance (the usual probit model) at all conventional significance levels ($P < 0.0001$). Therefore, it is indeed important to model the heteroscedasticity in this analysis. Since we took into account potential heteroscedasticity by flexibly modeling it, we have two sets of parameter estimation results: one set is on the main equation for acquisition decision, while the other set is on the heteroscedasticity model. We found that many explanatory variables are significant in one of the equations and not in the other, which makes it crucial to consider both equations in estimating the overall impact.

To examine the overall average marginal effect, which is the estimated impact on the probability to acquire robotic systems, we combined the coefficient estimates from both equations; results on average marginal effects are presented in Table 2. We found that the largest impact comes from the market-level surgery volume (excluding the hospital's own volume). Compared with hospitals that are the sole surgery provider in the market, hospitals in high volume ($>$50,000) market areas are 12.20 percentage points more likely to purchase robotic surgical systems. We also found that hospitals in highly concentrated markets (i.e., Herfindahl index above 2500) were 1.98 percentage points more likely to purchase robotic systems. There was also a significant upward time trend, with higher likelihood of robotic system purchase during later years. Higher number of beds and hospital's directly relevant surgery volume in the previous year were also positively associated with around 1 percentage point increase in the probability to acquire robotic systems.

The sensitivity analysis including managed care penetration rate showed that the impact of managed care penetration rate was relatively small with a marginal effect of 0.03 percentage point on the probability of acquiring robotic systems and a P value of 0.336. The sensitivity analysis excluding hospitals in markets where the total surgery volume is less than 1000 showed similar results. The estimated marginal effect of market-level surgery volume above 50,000 compared with zero was 13.07 percentage points ($P = 0.044$), which was very close to the 12.20 percentage points ($P = 0.043$). The marginal effect of market competition (highly concentrated market with HHI $>$ 2500 compared with HHI $\leq$ 2500) was 2.18 percentage points ($P < 0.001$), which was also close to the original result of 1.98 percentage points ($P < 0.001$). The Wald test for heteroscedasticity still showed $P < 0.0001$ in this sensitivity analysis. Therefore, it shows that our results are relatively robust. Detailed results are provided in Supplementary Tables 2 and 3.

Table 1 Sample Description

	Total	Purchase of Robotic Surgical Systems		*P* Value
		Yes	No	
Overall	3791 (100%)	78 (2.06%)	3713 (97.94%)	
Purchase of robotic surgical system before				<0.001
Yes	250 (6.59%)	20 (8.00%)	230 (92.00%)	
No	3541 (93.41%)	58 (1.64%)	3483 (98.36%)	
Number of beds				<0.001
>300	876 (23.11%)	52 (5.94%)	824 (94.06%)	
≤300	2915 (76.89%)	26 (0.89%)	2889 (99.11%)	
Control type				<0.001
Nonprofit	2044 (53.92%)	66 (3.23%)	1978 (96.77%)	
Other control type	1747 (46.08%)	12 (0.69%)	1735 (99.31%)	
Teaching hospital				<0.001
Yes	213 (5.62%)	14 (6.57%)	199 (93.43%)	
No	3578 (94.38)	64 (1.70%)	3514 (98.21%)	
Patients' average age				0.140
Mean (SD)		45.08 (13.68)	47.91 (16.91)	
Proportion of females (%)				0.850
Mean (SD)		58.47 (6.07)	58.26 (10.11)	
Proportion covered by private payers (%)				<0.001
Mean (SD)		39.54 (15.22)	29.72 (20.22)	
The hospital's directly relevant surgery volume in the previous year				<0.001
Mean (SD)		627 (359.67)	222.52 (263.23)	
Herfindahl index				0.985
>2500 (highly concentrated market)	2968 (78.29%)	61 (2.06%)	2907 (97.94%)	
≤2500 (not highly concentrated market)	823 (21.71%)	17 (2.07%)	806 (97.93%)	
Existing robotic surgical systems (excluding the hospital's own) in the same market area				0.139
Yes	995 (26.25%)	26 (2.61%)	969 (97.39%)	
No	2796 (73.75%)	52 (1.86%)	2744 (98.14%)	
The market-level surgery volume (excluding the hospital's own) in the previous year				0.247
>50,000 (high volume)	607 (16.01%)	12 (1.98 %)	595 (98.02%)	
1–50,000 (not high volume)	1954 (51.54%)	47 (2.41%)	1907 (97.59%)	
0	1230 (32.45%)	19 (1.54%)	1211 (98.46%)	
Year				<0.001
2003–2005	1261 (33.26%)	13 (1.03%)	1248 (98.97%)	
2006–2008	1257 (33.16%)	23 (1.83%)	1234 (98.17%)	
2009–2011	1273 (33.58%)	42 (3.30%)	1231 (96.70%)	

Discussion

In this study, we examined hospital- and market-related factors associated with a hospital's decision to purchase robotic surgical systems. We showed that market-level surgery volume and market competition level have significant impact on a hospital's decision to acquire such systems. The largest impact came from market-level relevant surgery volume in the previous year, with the discovery that higher market-level surgery volume was associated with approximately a 12 percentage point increase in the probability of acquiring robotic surgical systems. In comparison, the impact from market competition was much smaller. A highly concentrated market with a Herfindahl index above 2500 is associated with a 2 percentage point increase in the probability of acquiring robotic surgical systems. In other words, less market competition is actually positively associated with the probability of acquiring robotic systems in our analysis. Therefore, a hospital's decision to acquire robotic systems appears to be more influenced by the potential market demand/capacity (market surgery volume in the previous year) than competition.

Our findings suggest that hospital decisions to purchase robotic machines are mainly driven by market demand and also depend on the resources available. More competitive (i.e., less concentrated) markets do not predict more adoption of expensive new technologies. These results imply that there is less evidence for concerns

Table 2 Estimated Marginal Effect on Acquisition Decision

	Average Marginal Effect (Percentage Points)	95% Confidence Interval	*P* Value
Purchase of robotic surgical system before			
Yes	−0.325	[−1.62, 0.970]	0.623
No (Ref)			
Number of beds			
>300	1.377	[0.259, 2.494]	0.016
≤300 (Ref)			
Control type			
Nonprofit	0.882	[−0.048, 1.81]	0.063
Other control type (Ref)			
Teaching hospital			
Yes	−0.229	[−1.491, 1.032]	0.722
No (Ref)			
Patients' average age	−0.035	[−0.072, 0.002]	0.064
Proportion of females (%)	−0.170	[−0.252, −0.087]	<0.001
Proportion covered by private payers (%)	0.020	[−0.005, 0.046]	0.112
The hospital's directly relevant surgery volume in the previous year (log base 2)	1.178	[0.69, 1.666]	<0.001
Herfindahl index			
>2500 (highly concentrated market)	1.976	[1.000, 2.952]	<0.001
≤2500 (not highly concentrated market) (Ref)			
Existing robotic surgical systems (excluding the hospital's own) in the same market area			
Yes	−0.012	[−2.915, 0.607]	0.199
No (Ref)			
The market-level surgery volume (excluding the hospital's own) in the previous year			
>50,000 (high volume)	12.201	[0.388, 24.014]	0.043
1–50,000 (not high volume)	0.508	[−0.349, 1.365]	0.245
0 (Ref)			
Year			
2009–2011	1.749	[0.605, 2.892]	0.003
2006–2008	0.422	[−0.478, 1.322]	0.358
2003–2005 (Ref)			

about market competition driving the costly acquisition of robotic systems and leading to wasteful health care spending.

Decisions on large capital expenditures such as robotic surgical system purchases are important for the financial health of hospitals. The acquisition of a robotic system can cost up to $2 million, and there are additional consumables and annual maintenance fees that contribute to ongoing costs. It is largely unknown how acquisitions of robotic surgical systems affect the market share of hospitals. Future studies to further examine the relationship between the acquisitions of a robotic system and the financial health and performance of hospitals are warranted.

The years of data used in this study span the great recession of 2008. Our categorization of time period of observation (2003–2005, 2006–2008, 2009–2011) partly deals with this issue. Studies examining the impact of 2008 recession (i.e., the great recession of 2008) on hospitals usually use 2008 as the cutoff year.[28,29] For example, Dranove and colleagues[29] used an indicator variable for year >2008 to capture the impact of the financial crisis on hospitals. Our categorical variable also captures this timing information as the last time period (2009–2011) is essentially post-crisis.[28] There is a scarce literature on the impact of the 2018 recession on hospital capital investment. One study in the literature showed that hospital capital investment declined from 2008 to 2010. Our study did not show decline in the acquisition of robotic surgical systems, with more acquisitions in the later years (2009–2011). It is possible that there could be even more acquisition if there were no financial crisis. However, we need to note that robotic system acquisition is only one type of capital investment and does not represent the full landscape of hospital capital investment.

This study has limitations common to observational database studies. Certain characteristics such as cultural factors, size of the residence program, and leadership styles are not available in the database used for the analysis. Focus group discussions or surveys among hospital administrators could be an interesting future research direction to determine critical determinants of purchasing decision. Furthermore, this study is based on one state's experience, although California has diverse geographic and socioeconomic characteristics and wide coverage of market areas with varying levels of hospital density. To the best of our knowledge, this is the first large observational study focusing on the impact of surgery market characteristics on robotic system purchase decisions, and we found that a hospital's decision to purchase robotic systems is mainly driven by potential market demand.

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Supplemental Material

Supplementary material for this article is available on the *Medical Decision Making Policy & Practice* website at https://journals.sagepub.com/home/mpp.

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