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Interorganizational Relationships and Hospital Adoption of Surgical Robots

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ABSTRACT

The study investigates the relationship between interorganizational relationships (IORs) and hospital adoption of robotic surgery in the United States over a ten-year period. As a competitive strategy for hospitals, IORs should matter in a hospital's decision to adopt a surgical robot given associated costs and risks. While literature exists on IORs and technical innovation, there is a gap in the literature on IORs and hospital adoption of surgical robots. This study explores four types of IOR (i.e., networks, systems, contract management, and joint ventures), hospitals with more than one IOR, and hospitals with surgical robots. To evaluate the effect of IORs on hospital adoption of surgical robots over a ten-year period, the study employs generalized estimating equations to allow for analysis of repeated measurements of categorical response data. Data for this study was drawn from the American Hospital Association (AHA) Annual Survey of Hospitals, starting with the 2005 survey when AHA started collecting data on surgical robots. Over 27,625 observations from acute care hospitals are used in the study. Findings revealed hospitals engaged in certain types of IOR or in more than one IOR are more likely to adopt a surgical robot than hospitals not in such an arrangement. The findings will be of value to hospitals considering strategies to adopt surgical robots. They also afford opportunities to explore further IORs and hospitals having or adopting technology innovations.

Keyword: interorganizational relationship, hospital, adoption, robot, innovation

DEDICATION

This dissertation is dedicated to my children, Catherine (Cate) and Lauren. Your support and understanding during this journey to complete my doctorial work cannot be measured or overstated. Chase your dreams. Never give up. Trust that people will be there to help and support you along the way.

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CHAPTER 1

INTRODUCTION

Problem

Robotic surgery was performed at more than 2,200 hospitals in the United States (U.S.) in 2014 (*Intuitive Surgical, Inc*., 2014) (see Figure 1). Defined as the "use of

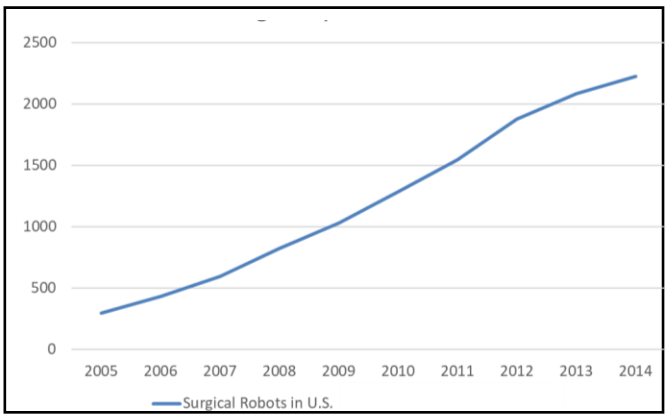

Figure 1. Adoption of surgical robots in the U.S. Data pulled from Intuitive Surgical, Inc. annual reports 2005-2014, retrieved from http://annualreports.com.

computer-guided imaging and manipulative devices to perform surgery without the surgeon's direct intervention" (AHA, 2015), the initial cost of a robot ranges from $1M to 2.5M (*Intuitive Surgical, Inc.,* 2013) with higher variable costs (van Dam et al., 2011). Robotic surgery can cost three times more than a non-robotic or traditional laparoscopic procedure with no evidence of higher quality patient outcomes or better cost data (Anger et al., 2014; CGPSGS, 2015; Ng & Tam, 2014; Paraiso, Jelovsek, Frick, Chen, & Barber, 2011; Paraiso et al., 2013; Sarlos, Kots, Stevanovic, Von Felten, & Schar, 2012; Schulz et al., 2007; Scott, 2015). While the number of robotic-assisted surgeries increases, the findings from several studies on robotic-assisted surgery do not support the rapid adoption of the technology (Cooper, Ibrahim, Lyu, & Makary, 2015; Neuner, See, Pezzin, Tarima, & Nattinger, 2012; Paraiso et al., 2011; Paraiso et al., 2013; Sarlos et al., 2012; Smith et al., 2010). Studies did not find evidence of higher quality outcomes, improved safety and/or cost savings when compared to a traditional laparoscopic approach (also referred to in studies and practice as conventional laparoscopic and minimally invasive surgery) (Alemzadeh, Iyer, Kalbarczyk, Leveson, & Raman, 2015; Alemzadeh, Raman, Leveson, & Iyer, 2013; Cevasco & Ashley, 2011; Paraiso et al., 2011; Venkat et al., 2012).

Traditional laparoscopic and robotic-assisted laparoscopic procedures are alternatives to open surgery, which requires an incision large enough to view the operative field and permit entry of a hand or instrument. Laparoscopic techniques produce equivalent results of open surgery while providing the advantages of minimal access, lower blood loss, less post-operative pain, fewer complications and deaths, and shorter length of stay and recovery time (Johar et al., 2013; Park, Choi, Lim, Jang, & Jun, 2011; Yu, Hevelone, Lipsitz, Kowalczyk, & Hu, 2012). However, given the higher costs and absence of evidence of superior performance, reasons for the high levels of adoption of surgical robots by U.S. hospitals are not completely clear and the sources for resources needed to establish such a program are not completely known (Neuner et al., 2012).

A review of literature found hundreds of studies on robotics at the procedural level but only a few at the hospital level pertaining to the adoption of surgical robots (Barbush et al., 2014; CGPSGS, 2015; Jin et al., 2011; Li et al., 2014; Makarov et al., 2013). Those studies show or suggest an association between hospitals adopting surgical robots and hospital environmental and structural factors (Barbush at al, 2014; CGPSGS, 2015; Jin et al., 2011; Li et al., 2014; Makarov et al., 2013). While there are studies on interorganizational collaboration and technology innovation, including a major study on interorganizational links and innovation in hospital services, no studies were found on the effects of interorganizational relationships (IORs) and hospital adoption of a robot to assist in laparoscopic surgery (Goes & Park, 1997; Jenssen & Nybakk, 2013; Pennington & Harianto, 1992).

Hospitals require access to resources, for example IORs, or means such as increased volume of robotic-assisted procedures to fund the adoption and implementation of a robotic surgical system. Robotic-assisted laparoscopic procedures require capital outlays and have higher operational and variable costs per procedure (e.g., cost of disposable equipment) (CGPSGS, 2015; Jin et al., 2011; Van Dam et al., 2011). The majority of leading payers, including the U.S. Centers for Medicare & Medicaid Services (CMS), reimburse all laparoscopic surgeries, whether they are a traditional laparoscopic or a robotic-assisted laparoscopic procedure, at the same rate (CMS, 2015; Murray, Mirza, Corona, Thrasher, & Duchene, 2014). Most payers consider robotic assistance a technique or incidental to the primary surgical procedure and not a separately reimbursed service (Barbash, Friedman, Glied, & Steiner, 2014; United Healthcare Community Plan, 2015). Hospitals have primarily justified or covered the additional costs associated with a surgical robot by increased volume of robotic-assisted laparoscopic procedures (CGPSGS, 2015; Jin et al., 2011).

IORs are considered a competitive strategy in health care (Goes & Park, 1997). They are defined as a long-term relationship or linkage among two or more organizations related by affiliation or exchange relations or any type of interorganizational relations for resources transactions (Kessler, 2013; Oliver, 1990; Oliver & Ebers, 1998). IORs include joint ventures, networks, strategic alliances, and other cooperative arrangements and collaborative agreements (Kessler, 2013; Provan, Fish, & Sydow, 2007). They provide a way to understand organizational behavior within the institutional environment (Goes & Park, 1997).

They may also provide access to resources needed to adopt surgical robots. Studies, including studies on large-scale longitudinal data on the effect of IORs at hospital level and innovation, have shown or suggested a relationship between IORs and innovation (Baum, Calabrese, & Silverman, 2000; Burns & Wholey, 1993; Deeds & Hill, 1996; Goes & Park, 1997; Najafian & Colabi, 2014). However, there are no studies found on IORs and hospitals' adoption of surgical robots.

Purpose of the Study

The purpose of this study is to investigate the relationship between IORs and hospital adoption of robotic surgery in the U.S. over a ten-year period. As a competitive strategy for hospitals, IORs can provide access to capital, information and technology (Goes & Parks, 1997; Pennings & Harianto, 1992). The strategy literature suggests interorganizational links could matter in a hospital's decision to adopt a surgical robot given the associated cost and risks (Dyer & Singh, 1998; Goes & Park, 1997; Powell, Koput, & Smith-Doerr, 1996). Based on initial findings, a study model was constructed to explore IORs and any associated effects on hospitals adopting or having surgical robots while controlling for environmental and organizational variables from other studies (see Figure 2). Literature exists on interorganizational networks and technical innovation but none on IORs and hospital adoption of surgical robots (Goes & Park, 1997; Jensen & Nybakk, 2013; Pennington & Harianto, 1992). This study explores the effect of IORs (i.e., contract management, systems, networks, and joint ventures) on hospitals' adoption of surgical robots.

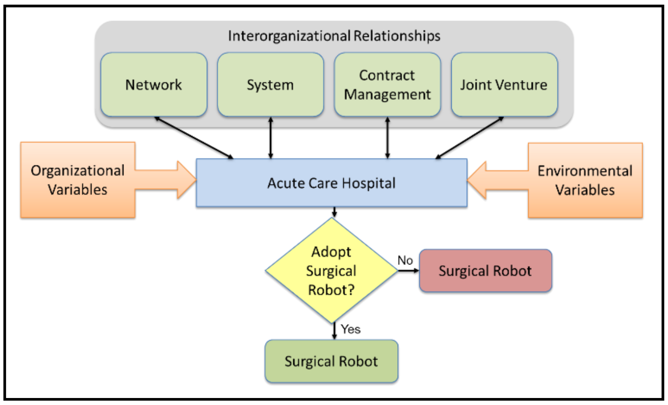

Figure 2. Conceptual model

Research Questions

While studies have examined IORs and technology innovation, studies on hospital adoption of surgical robots have not included the association of IORs with the adoption of such technology (Goes & Park, 1997; Thorgren, Wincent, & Örtqvist, 2009). Since the strategy literature suggests IORs might affect a hospital's decision to adopt a surgical robot, this study explores the relationship between IORs and hospital adoption of surgical robots. The study uses resource dependence theory as a conceptual framework. The primary study question was "Are hospitals that employ IORs as part of their strategy more likely to adopt robots for surgical procedures?" Secondary research questions that helped shape the study are:

1. Is there a relationship between the type of IOR and hospital adoption of a surgical robot?
2. Does the number of IORs associated with a hospital affect adoption of a surgical robot?

Significance of Study

Approximately 60 percent of all U.S. hospitals have not adopted robots for surgery (Barbash & Glied, 2010; *Intuitive Surgical, Inc.*, 2014). Knowing whether IORs matter in a hospital's decision to adopt a surgical robot should be of value to healthcare executives and policy makers involved in strategic planning, technology innovation and financial management. Since Goes and Park (1997) studied the relationship of select interorganizational links and technical innovation at the hospital level in one state more than two decades ago, there have been no additional studies on IORs and the adoption of technology in health care and no studies found on IORs and hospital adoption of surgical robots (Goes and Park, 1997). This study should provide an understanding of how IORs provide access to resources that allow hospitals to innovate. As medical technology innovations can account for more than half of a hospital's capital budget and a significant percentage of operating costs, findings should also provide decision makers a more complete understanding of variables affecting strategies and other decisions to adopt technology innovations that contribute to the growth in healthcare expenditures (Brody & Richards, 2014; Coye & Kell, 2006; Rye & Kimberly, 2007).

Study Plan

Given this study focuses on the relationship between IORs and hospital adoption of surgical robots, Chapter 2 provides a literature review of surgical robots, including studies associated with the decision to adopt robots and associated costs, outcomes and other findings. The review also looks at the IOR, types of IOR, and IORs and innovation in health care and other industries. It further explores the theory selected to frame the study of IORs and the adoption of surgical robots at the hospital level. Hypotheses derived from the literature review are presented and followed by methodology. Chapter 3 discusses data and methods to test the hypotheses. Chapter 4 presents the findings, and Chapter 5 discusses the findings and recommendations.

CHAPTER 2

LITERATURE REVIEW

The literature review focuses on studies associated with hospitals' decision to adopt robots, interorganizational links and adoption of technology, and interorganizational relationship (IOR) types and decision to adopt innovative technology. The review also incorporates a discussion on theory that frames the proposed study.

Robotic Surgery

The first surgical robot was introduced in the United Kingdom in 1983 to assist in orthopaedic procedures and was followed by other robotic systems used in both clinical trials and surgical procedures (Ng & Tam, 2014; Yates, Vaessen, & Roupret, 2011). The first surgical robot approved for use by the FDA in the United States was Robodoc® (Lanfranco, Castellanos, Desai, & Meyers, 2004). The robot consisted of a three-dimensional (3-D) workstation for preoperative surgical planning and a computer-controlled device for precision milling of a bone/joint to accept an implant. A major stimulus for continued development of surgical robots was laparoscopic surgery (Ng & Tam, 2014).

Literature on robotic-assisted surgery primarily pertains to the da Vinci Surgical System, which was the only manufacturer of robots used in laparoscopic surgeries in the U.S. during the proposed study period (Yates et al., 2011). Having only one manufacturer avoids issues with aggregating multiple technologies that could affect study results with heterogenous outcomes (Downs & Mohr, 1976; Goes & Park, 1997; Meyer & Goes, 1988). The FDA approved the da Vinci in 2000 as the first robotic system authorized for laparoscopic surgical procedures (*Intuitive Surgical, Inc.*, 2001; McNamee, 2014). The system consists of a patient side surgical cart, a vision system and a console where the surgeon sits and uses a stereoscopic viewer (depicts left-eye and right-eye views of the object as one 3-D image), hand manipulators and foot pedals to control a camera and robotic instruments. In 2004 fewer than 150 robots had been sold to less than three percent of hospitals in the U.S. (*Intuitive Surgical, Inc.,* 2004).

In 2005, the first year the American Hospital Association (AHA) documented surgical robots, U.S. hospitals adopted more than 150 surgical robots for a total of 303 robots (*Intuitive Surgical, Inc.*, 2005). Robots were being used in less than one percent of all U.S. operating rooms. By 2014, only eight percent of operating rooms and less than 40 percent of all hospitals had adopted surgical robots (*Intuitive Surgical, Inc.*, 2014).

Costs

Findings suggest hospitals that adopt surgical robots are more likely to have access to resources or perform a high volume of surgeries to offset the costs associated with adopting a robotic surgical system (Barbash et al., 2014; Steinberg, Merguerian, Bihrle, & Seigne, 2008). With an initial cost of a robot ranging from $1M to $2.5M, establishment of a robotic program is a significant undertaking and a funding challenge for most hospitals, given the cost and the resources needed to purchase, train, set up, operate, and maintain a robot (Barbash & Glied, 2010; Cundy, Marcus, Hughes-Hallett, Khurana, & Darzi, 2015; Dirckx, 2011; Grover, Tan, Srivastava, Leung, & Tewari, 2010; Herron & Marohn, 2008; *Intuitive Surgical, Inc.*, 2013; Tsuda et al., 2015). The annual service contract ranges from $100K to $150K. Disposable equipment is estimated at $1.5K for each surgical procedure (Dirckx, 2011; Sutcliffe, Czoski-Murray, Chattle, Ayiku, & Parry, 2006). The search also found a wide variance in the cost of training, ranging from $50K to $555K (Dirckx, 2011; Mikhail et al., 2006; Steers, LeBeau, Cardella, & Fulmer, 2004; Steinberg et al., 2008). The cost of a robot-assisted laparoscopic surgery can be up to three times or more than a traditional laparoscopic procedure (CGPSGS, 2015; Cundy et al., 2015; Scott, 2015; Van Dam et al., 2011).

While there may be small benefits for the patient or surgeon that would warrant the cost to use a robot in some procedures (Antoniou, Antoniou, Koch, Pointner, & Granderath, 2012; Basto et al., 2015; Brody & Richards, 2014; Halabi et al., 2013; Heemskerk, Bouvy, & Baeten, 2014; Tsuda et al., 2015; Weissman & Zinner, 2013) (e.g., deep pelvic procedures), the high cost of acquiring, maintaining and operating the system exceeds any cost savings from shorter length of stays (Brody & Richards, 2014; Lotan, Cadeddu, & Gettman, 2004; Sutcliffe et al., 2006). More than 4,000 studies on robotic surgery did not find evidence of unequivocal superiority of robotic-assisted over traditional laparoscopic surgery in better quality of patient outcomes, safety, cost, or other measures to justify costs associated with adoption of a surgical robot (Anger et al., 2014; Basto et al., 2015; Cundy, Harling, Marcus, Athanasioub, & Darzi, 2014; Cundy et al., 2014; Cundy et al., 2015; Cundy et al., 2013; Ng & Tam, 2014; Paraiso et al., 2011; Paraiso et al., 2013; Sarlos et al., 2012; Schulz et al., 2007; Scott, 2015; Tsuda et al., 2015). Longitudinal studies on complications and adverse events found a significant amount of robot malfunctions and system downtimes, surgical site infections and underreporting of complications associated with surgical robots in FDA adverse event reports (Alemzadeh, Iyer, Kalbarczyk, Leveson, & Raman, 2015; Alemzadeh, Raman, Leveson, & Iyer, 2013; Cooper et al., 2015; Hermsen, Hinze, Sayles, Sholtz, & Rupp, 2010; Kaushik, High, Clark, & LaGrange, 2010).

Adoption of medical technologies requires hospitals to have access to resources (Coye & Kell, 2006). Competition for resources influences decisions on strategies to adopt technology such as the surgical robot (Barbash & Glied, 2010; Coye & Kell, 2006; Li et al., 2014; Teplensky, Pauly, Kimberly, Hillman, & Schwartz, 1995). While for-profit niche providers have better access to capital than community hospitals, access to resources can be a challenge for hospitals entering the "medical arms race" (Coye & Kell, 2006; Rothenberg, 2004). Without resources, the adoption of technology innovations by low-volume, low-margin hospitals are challenging and may require strategies to access resources (Coye & Kell, 2006; Cundy et al., 2015).

The literature review did not find any evidence that CMS and commercial payers encourage or provide economic incentives for hospitals to adopt surgical robots (Heemskerk et al., 2014; Straube, 2005). While some research suggests CMS and other payer decisions on reimbursement can drive technology adoption at the hospital level, the AHA suggests Medicare payment policies do not support hospital adoption of new technologies (AHA Policy Research, 2006; Coye & Kell, 2006; Rogers, 2003; Straube, 2005). The CMS and other insurers reimburse all laparoscopic surgeries, traditional or robotic-assisted, at the same rate (Blute & Prestipino, 2014; CMS.gov). The adoption of a surgical robot for a procedure is considered another tool a hospital elects to incorporate into its provision of patient care (Blute & Prestipino, 2014). Hospitals must look elsewhere for sources of capital, such as IORs or increased surgical volume, to finance the adoption of robotic surgery (Basto et al., 2015; Patel, 2006).

Hospitals may have access to resources or earnings from operations or surgical volume required to finance the adoption of a robotic surgical system and the additional fixed costs (Barbash et al., 2014; Coye & Kell, 2006; Lee, 2014). Studies suggest volume is associated with both the adoption of robots and an increase of robotic-assisted laparoscopic procedures needed to cover additional costs associated with a surgical robot (Basto et al., 2015; Barbash et al., 2014; CGPSGS, 2015; Cundy et al., 2013; Halm, Lee, & Chassin, 2002; Jin et al., 2011; Kent et al., 2014; Li et al., 2014; Makarov et al., 2013; Neuner et al., 2012; Steers et al., 2004; Tsui, Klein, & Garabrant, 2013). Cost models suggest robotic-assisted procedure costs are volume-dependent (Lotan et al., 2004; Scales, Jones, Eisenstein, Preminger, & Albala, 2005). Study findings show a breakeven volume ranging from 100-300 procedures annually for a five- to seven-year period (Basto et al., 2015; Lee, 2014). For most small hospitals, adopting a robot may be cost-prohibitive without the requisite surgical volume or access to resources (Cundy et al., 2015; Zender & Thell, 2010). Only 131 hospitals with 200 or fewer beds have robotic surgical systems (Lee, 2014).

The search also found hospitals' surgical volumes increased at hospitals that adopted a surgical robot. Barbush et al. (2014) found the number of robots and surgeon specialists in a market "were significant predictors of an increase in the volume of radical prostatectomies performed" (Barbash et al., 2014, p. 4). Findings from two large longitudinal studies also showed significant increases in surgical volume at hospitals that adopted a surgical robot and a decrease in volume at hospitals without robots (Makarov, Yu, Desai, Penson, & Gross, 2011; Neuner et al., 2012). Without significant volume or potential for increased volume, hospitals require other means to access resources to adopt a surgical robot.

Other Factors

While the search did not find any studies on the role of IORs in hospital adoption of surgical robots, it did find studies that showed an association between hospitals adopting surgical robots and environmental and structural factors (Barbush et al., 2014; Kessler & McClellan, 2000; Li et al., 2014; Makarov et al., 2013). The review found marketing, competition, patient, physician, and other hospital factors contributed to a hospital's decision to adopt a surgical robot (Barbush et al., 2014; CGPSGS, 2015; Jin et al., 2011; Li et al., 2014; Makarov et al., 2013; Steers et al., 2004). Hospitals that adopt surgical robots are more likely to be large, urban or teaching hospitals with high surgical volume (Barbash et al., 2014; Halabi et al., 2013; Li et al., 2014; Makarov et al., 2011; Makarov et al., 2013; Steers et al., 2004; Yamasato, Casey, Kaneshiro, & Hiraoka, 2014).

Evidence supports market competition, as measured by the number of competing hospitals in an area, as a determinant in a hospital's decision to adopt a surgical robot (Barbash et al., 2014; Barbash & Glied, 2010; CPSGS, 2015; Cundy et al., 2015; Jin et al., 2011; Li et al., 2014; Makarov et al., 2013; Schiavone et al., 2012; Steers et al., 2004). Hospitals adopting robots are "more likely located in areas with a higher proportion of other hospitals using robots" (Barbash et al., 2014, p. 3). There is a significant spatial and temporal association for hospitals that adopt robots (Li et al., 2014). Findings suggest the likelihood of a relationship between IORs and hospital adoption of surgical robots based on competition for resources.

Interorganizational Relationships

Long (1990) notes the success of healthcare organizations depends on the maintenance of effective interorganizational linkages or relationships with other organizations. Studies describe interorganizational linkages as partnerships, strategic alliances, coalitions, cooperative arrangements, collaborative agreements, or IORs and refer to networks or dyads (Cropper, Huxham, Ebers, & Smith Ring, 2008; Najafian & Colabi, 2014; Provan et al., 2007; Zajac, D'Aunno, & Burns, 2011). Network is defined as an IOR, an interorganizational collaboration or an interorganizational link among distinct but related organizations (Goes & Park, 1997; Najafian & Colabi, 2014). For this study, IOR is used and defined as interorganizational links, networks and collaborations.

Organizations use IORs as a strategy to improve the probability of survival when confronted with environmental uncertainties (Aiken & Hage, 1968; Goes & Park, 1997; Hearld & Carroll, 2015; Paulson, 1976; Proenca, Rosko, & Zinn, 2000; Provan, 1984; Schermerhorn & Shirland, 1981; Van de Ven & Walker, 1984). Because it is difficult for a healthcare organization to operate and manage effectively in isolation within a complex environment, IORs provide management processes, access to capital, technical information, and other resources from other members to reduce uncertainty and enhance market power (Danzon, Nicholson, & Pereira, 2005; Eisenhardt & Schoonhoven, 1996; Hanna & Walsh, 2002). Hospitals operate within a labyrinth of interdependencies or resources with other healthcare organizations that influence action taken to manage it

(Rossignoli & Ricciardi, 2015). Goes and Park (1997) suggest the technical complexity and environmental turbulence in health care result in hospitals establishing IORs earlier than most industries.

Entering an IOR to share resources can make fiscal and clinical sense for healthcare organizations (Friedman & Goes, 2000). Competition for resources can influence an organization's decision to remain autonomous or enter an IOR to access resources (Alexander & Morrisey, 1989; Morrissey & Alexander, 1987). A meta-analysis of 30 years of IOR literature suggests organizations enter IORs when advantages such as improved chance of survival outweigh potential loss of autonomy or right to allocate and use internal resources without regard to requests or expectations of other organizations within the IOR (Oliver, 1990; Provan 1984). Control is a major factor in the decision to join an IOR and is reflected in the type of IOR selected (Cropper et al., 2008; Hearld & Carroll, 2015; Zinn, Proenca, & Rosko, 1997).

Given hospitals with limited access to capital are faced with a widening gap in acquisition of medical technologies such as robotic surgical systems, research shows a hospital entering an IOR can be an effective strategy to gain access to new technology and reduce technology-driven health cost inflation (Friedman & Goes, 2000; Zajac et al., 2011). Organizations enter IORs to cooperate or collaborate with other organizations to leverage technology or obtain needed resources and capabilities (Hardy, Phillips, & Lawrence., 2003; Mascia & Di Vincenzo, 2011; Teece, 1986). IORs help organizations manage costs and risks among other members and access capital and other pooled resources required for innovation (Das & Teng, 2000; Eisenhardt & Schoonhoven, 1996; Zajac et al., 2011; Zinn et al., 1997).

Research suggests hospitals engaged in IORs have resource advantages over independent hospitals in raising capital (Ermann & Gabel, 1984; Flood & Scott, 1987). They share information, transfer technical knowledge, and acquire technology (Goes & Park, 1997; Pennington & Harianto, 1992; Nembhard, 2008). Given rationales to enter into a collaboration, including some combination of mutual gain/risk sharing, accessing technologies, pooling resources, and expanding competencies, it is reasonable to expect a hospital might enter IORs to gain access to capital for technology innovation such as surgical robots (Hardy et al., 2003; Powell et al., 1996).

Hospitals may need access to resources given the requirements and costs associated with a robotic surgical system, and IORs can offer increased access to resources to obtain new technology or technology innovations (Goes and Park 1997). Resource scarcity is repeatedly cited as a principal condition that facilitates the development of IORs (Levine & White, 1961; Paulson, 1976; Pfeffer & Salancik, 1978; Van de Ven & Walker, 1984). Studies find small, knowledge-intensive organizations enter an IOR in an environment of resource scarcity (Jenssen & Nybakk, 2013; Lind, Zmud, & Fischer, 1989). Building dependency relationships with other organizations provides a hospital access to a broader resource base, influence, expertise, knowledge, and information about innovations, new markets, new operational concepts, and capital resources that may be required of hospitals adopting surgical robots (Dyer & Singh, 1998; Hamel, Doz, & Prahalad, 1989; Oliver, 1990; Najafian & Colabi, 2014; Pfeiffer & Salancik, 1978; Powell et al., 1996).

IORs and Adoption of Innovation

While acquisition of new technology accounts for more than half of all hospital capital spending, the adoption of technology innovations within health care is a complex process affected by the environment and interaction with other organizations in the decision process (Coye & Kell, 2006; Fitzgerald, Ferlie, Wood, & Hawkins, 2002; Goes & Park, 1997; Teplensky et al., 1995). Technology such as the surgical robotic system, which can provide a competitive advantage within the market, requires considerable resources to successfully implement (Barbash et al., 2014; Cundy et al., 2015; Dirckx, 2011; Herron & Marohn, 2008; Jin et al., 2011; Makarov et al., 2013; Patel, 2006; Steers et al., 2004; Tsuda et al., 2015). Competition for resources to adopt costly innovations requires hospitals to make strategic choices on long-term investments and strategies such as IORs with the external environment (Greer, 1985). Studies on hospital adoption of technology innovations found adoption is related to hospital ownership and IORs (Goes & Park, 1997; McClellan & Kessler, 2002). The search also found financial or competitive factors, which provide an advantage over competitors, may be given equal or greater consideration to clinical needs for adopting an advanced technology (Teplensky et al., 1995). These findings could apply to the theoretical foundation of this study, suggesting hospitals in IORs may be more likely to adopt surgical robots.

While studies suggest innovation is crucial for long-term growth and organizational survival, the definition of innovation varies (Meyer & Goes, 1988; Omachonu & Einspruch, 2010; Rogers, 2003; Rye & Kimberly, 2007; Van de Ven, 1986). Rogers (2003) defined innovation as an “idea, practice, or object that is perceived as new by an individual or other unit of adoption” (p. 12). The perception of newness or becoming aware of an innovation is considered specific to the organization and its adoption process (Rogers, 2003). Meyers and Goes (1988) defined medical innovation as "significant departures from previous techniques for diagnosis, treatment, or prevention, as determined by the collective judgments of experts in the field" (Meyer & Goes, 1988, p. 903). Goes and Park (1997) redefined medical or healthcare innovation as "a medical technology, structure, administrative system, or service that is relatively new to the overall industry and newly adopted by hospitals in a particular market area" (Goes & Park, 1997, p. 674). For this study, the definition of technology innovation combines elements of those of Goes and Park (1997) and Rogers (2003). Technology innovation is defined as a technology that is perceived as new by the hospital of adoption.

Review of the literature found inconsistent and sometimes anecdotal study findings and evidence of IOR influence on innovation adoption by organizations within and outside of health care (Baum, Calabrese, & Silverman, 2000; Deeds & Hill, 1996; Faems, Van Looy, & Debackere, 2005; Goes & Park, 1997; Jenssen & Nybakk, 2013; Kotabe & Swan, 1995; Najafian & Colabi, 2014; Pennington & Harianto, 1992;). Little research exists on IORs at the hospital level and technology innovation. While Rossignoli and Ricciardi (2015) suggest "technology innovations are the most important factor of change in power relations," there are only a few studies on IORs and technology innovation at the organizational level (Deeds & Hill, 1996; Faems et al, 2005; Jenssen & Nybakk, 2013; Kotabe & Swan, 1995; Najafian & Colabi, 2014; Pennington & Harianto, 1992; Pittaway, Robertson, Munir, Denyer, & Neely., 2004; Rossignoli & Ricciardi, 2015). There are even fewer studies based on large-scale longitudinal data on the effect of IORs at the hospital level and technology innovation (Goes & Park, 1997). None were found on IORs and hospital adoption of surgical robots. Other researchers found empirical evidence on IORs and innovation to be scarce, generally inconsistent and/or content-dependent (Faems et al., 2005; Goes & Park, 1997; Najafian & Colabi, 2014). A meta-analysis of the adoption of innovations by healthcare providers found only a few quantitative journal articles that measured the relationship of IORs and organization-level adoption outcomes (Rye & Kimberly, 2007). Literature search found only one longitudinal study measuring the relationship of IORs and hospital-level adoption of technology innovation that could serve as a point of departure for the proposed study (Goes & Park, 1997). A gap exists in research on the impact of IORs on technology innovations and associated theoretical and empirical evidence (Najafian & Colabi, 2014).

Given innovation often requires a collective effort and more resources than possessed by the organization initiating it, an IOR is a collective effort as well as a competitive strategy to enable innovation within organizations (Hanna & Walsh, 2002; Van de Ven, Polley, Garud, & Venkataraman, 1999). The adoption of technology innovation is facilitated by leveraging IORs. Innovation succeeds because IORs provide resources for greater bargaining power (Kaluzny, 1974). In an organizational-level study on hospital services, Goes and Park (1997) found a significant relationship between the level of resource exchange among hospitals within IORs and technology innovation. Hospitals engaged in IORs may be more likely to adopt technology innovations given IORs expand competencies and improve innovative capabilities of organizations (Faems et al., 2005; Goes & Park, 1997; Jenssen & Nybakk, 2013; Powell et al., 1996; Von Hippel, 1988).

Goes and Park (1997) found evidence of a relationship between selected IORs and technology innovations (i.e., laser surgery, ultrasound imaging, magnetic resonance imaging, fiberoptic endoscopy, cardiac catheterization, and computed axial tomography) (Goes & Park, 1997). As different types of IOR offer hospitals different levels or degrees of interdependence or autonomy, strategic purpose, and ownership arrangements in accessing resources, hospitals needing access and interorganizational exchange of resources to adopt technology innovations (Goes & Park, 1997) must determine which type or types of IOR to enter.

Goes and Parks (1997) found IORs were directly associated with technology innovation among hospitals. Other studies and meta-analyses on IORs and innovation also conclude IORs are a critical factor in implementing innovation within an organization, especially for organizations with limited resources (Hanna & Walsh, 2002; Jenssen & Nybakk, 2013; Najafian & Colabi, 2014; Pittaway et al., 2004). The few studies on IORs and innovation in health care either find or suggest a relationship between access to and/or exchange of resources among hospitals in IORs and innovation (Burns & Wholey, 1993; Goes & Park, 1997; Kaluzny, 1974; Milio, 1971). Sharing technology, reducing costs and obtaining access to innovation are important outcomes of IORs. Study findings on IORs and innovation suggest IORs can have a positive influence on an organization's technology innovation (Baum et al., 2000; Deeds & Hill, 1996; Faems et al., 2005; Fitzgerald et al., 2002; Goes & Park, 1997; Jenssen & Nybakk, 2013; Stuart, 2000).

Studies suggest IORs can provide hospitals access to reciprocal learning and collaborative knowledge, enhance organizational learning, and create new knowledge important to adopting technology innovations (Kale, Singh, & Perlmutter, 2000). Organizations within an IOR learn from others' successes and failures. This can be an invaluable resource when implementing technology innovations (Nembhard, 2008). Goes and Park (1997) found evidence that a greater volume of resource exchanges between hospitals leads to a greater transfer of information and technical competence, as well as an increase in the likelihood of technology innovation. As hospitals often rely on vendors and other external organizations for information to evaluate technology innovations, IORs provide a means for organizations to access information and expertise to learn faster at less cost and risks (Coye & Kell, 2006; Goes & Park, 1997; Powell et al., 1996). Without an IOR, a hospital may rely solely on the surgical robot manufacturer's marketing and sales organization as a major source of information (Barbash et al., 2014; CGPSGS, 2015; Jin et al., 2011; Li et al., 2014; Schiavone et al., 2012).

The search also found evidence or suggested a relationship between the number of IORs an organization engages and technology innovation. Studies find the level of technological sophistication of industries positively correlated with the number of IORs (Freeman, 1991; Hagedoorn, 1995). In a study of technology networking, which included joint ventures and contracts, and adoption of technology innovation over a ten-year period, Pennings and Harianto (1992) found the probability of innovation positively associated with the number of IORs (Pennington & Harianto, 1992). Other studies find or suggest organizations, including hospitals, engaged in multiple IORs tend to be more innovative or more likely to implement a technology innovation with other IOR members (Aiken & Hage, 1968; Goes & Park, 1997; Jenssen & Nybakk, 2013; Pennington & Harianto, 1992). Based on environmental factors and resource needs, hospitals generally enter into a number of multihospital systems and other IOR arrangements (Burns & Pauly, 2002; Shortell, 1988). These arrangements can involve a high degree of interdependence and provide access to resources required to adopt technology innovation (Cropper et al., 2008; Galaskiewicz, 1985; Longest, 1990; Luke, Begun, & Pointer, 1989; Provan, 1984). The numbers of IORs are positively associated with innovation up to a point of diminishing returns (Deeds & Hill, 1996). Given hospital affiliation with a system or network does not preclude it from participating in other IOR arrangements ("AHA," 2016), the study should expect to find hospitals that adopted surgical robots in multiple IOR arrangements.

The literature search found limitations in earlier research on IOR and technology innovation. Goes and Park (1997) suggest the effects of IORs on innovation could vary by innovation type and the need for additional research on the influence of IORs on specific innovations (Goes & Park, 1997). Earlier studies tend to look at one IOR or focus on product or technology innovation that present conflicting findings (Kotabe & Swan, 1995; Najafian & Colabi, 2014; Pennington & Harianto, 1992). Other than Goes and Park (1997), the search found studies pay little attention to the effect of IORs or the complexity of more than one IOR on innovation (Goes & Park, 1997). Sample sizes also are too small, and there are few analytical studies on innovation that use multiplex data and longitudinal research methods (Goes & Park, 1997; Najafian & Colabi, 2014; Rye & Kimberly, 2007). Further, earlier study findings may be suspect, given researchers used the total number of innovations as the primary dependent variable (Meyer & Goes, 1988). In taking an aggregated approach, researchers assumed the homogeneity of the various innovations (Downs & Mohr, 1976; Meyer & Goes, 1988). Goes and Park (1997) considered the practice of aggregating and treating innovations as a single effect as probably inappropriate and may have resulted in erroneous outcomes (Goes & Park, 1997; Meyer & Goes, 1988). This study focuses on the adoption of one specific technology innovation within health care using a large sample size and longitudinal and statistical research methods to avoid these weaknesses.

IOR Types and Innovation

An extensive review of IOR literature study suggests different types of IOR vary in terms of resource dependency, degree of autonomy, and performance required to accommodate hospitals and support adoption of technology innovation (Galaskiewicz, 1985). A major premise of resource dependence is the concept of IOR creating dependencies among organizations at a cost to an organization's autonomy (Provan, 1984). This reveals that IOR types have different degrees of autonomy and strategic purpose and may be associated with hospital adoption of surgical robots. Hospitals with more resources are more likely to be in IORs characterized by a high autonomy of member organizations (Zinn et al., 1997). Hospitals with fewer resources are likely to give up some autonomy within an IOR for resources such as contract management arrangements (Zinn et al., 1997). The IORs identified for this study (contract management, system affiliation, network, and joint ventures) are based on earlier studies and inclusion in the study data (Burns & Pauly, 2002; Goes & Park, 1997; Hearld & Carroll, 2015; Luke et al., 1989).

Contract Management

Contract management (CM) provides hospitals a strategy to own assets and maintain organizational autonomy while responding to resource scarcity, uncertainty and competition by engaging an external organization to manage daily operations for the hospital board of trustees (Alexander & Lewis, 1984; Alexander & Morrisey, 1989; Brown & Money, 1975; Carey & Dor, 2004). It can provide hospitals links to management expertise, resources and competencies to address complexities in resource acquisition needed for technology innovation (Alexander & Morrisey, 1989; Fottler, Schermerhorn, Wong, & Money, 1982; Goes & Park, 1997; Zinn et al., 1997). CM may provide a strategy for small hospitals wanting to adopt a surgical robot (Helseth, 2014; Lee, 2014; Zender & Thell, 2010). However, research on whether CM improves hospital financials and service offerings required for technology innovation varies (Biggs, Kralewski, & Brown, 1980; Carey & Dor, 2004; Hearld & Carroll, 2015; Kralewski, Dowd, Pitt, & Biggs, 1984)

Research findings are mixed on implications for technology innovation (Alexander & Morrisey, 1989; Carey & Dor, 2004; Dor, 1994; Goes & Park, 1997). While Alexander & Morrisey (1989) suggest CM could increase management capacity for innovation by bringing in outside experience, expertise, technology, and financial resources, later studies suggest CM does not have a significant, positive influence on technology innovation in healthcare services (Dor, 1994; Goes & Park, 1997). The CM hospital is less likely to have the medical specialties or resources to adopt innovative technology (Carey & Dor, 2004). This may account for the absence of studies on CM and the adoption of surgical robots. The implication for the study is hospitals in CM interorganizational relations may show less adoption of surgical robots.

System Affiliation

The findings on system affiliation are more favorable for adoption of technology innovation. System affiliations provide hospitals access to capital, product information, management and clinical expertise, economies of scales, marketing, and other opportunities that could enable a hospital to adopt a technology innovation (Burns & Pauly, 2002; Cuellar & Gertler, 2003; Fottler et al., 1982). System affiliation is an IOR where two or more "hospitals belong to a corporate body that owns and/or manages provider facilities, health-related subsidiaries, or even non-health-related facilities" (https://www.aha.org/system/files/2018-02/2018-aha-hospital-fast-facts.pdf; Morrissey & Alexander, 1987). It combines the strength of multiple organizations with the sharing of asymmetric competencies to overcome inefficiency in the adoption and implementation process (Goes & Park, 1997; Miles & Snow, 1986; Oliver, 1990). The system headquarters provides strategic and operational direction for affiliates (Alexander & Morrisey, 1989; Fottler et al., 1982).

While the literature and analyses on multihospital system performance generally found no evidence that a multihospital system strategy significantly improved hospital performance or reduced costs (Burns & Pauly, 2002; Dranove, Durkac, & Shanley, 1996; Shortell, 1988), the literature review did find evidence that there may be a positive relation between hospital systems affiliation and innovation (Goes & Park, 1997; McKinney, Kaluzny, & Zuckerman, 1991; Westphal, Gulati, & Shortell, 1997). Studies found multihospital systems provide a strategy to address “external uncertainties such as competition from other hospitals and changes in medical technology (Provan, 1984)” (Goes & Park, 1997, p. 677) and wider access to capital financing and other resources for expansion (Fottler et al., 1982). Study findings suggest system affiliation may stimulate technology innovation and help manage innovation costs by sharing information and other resources (Goes & Park, 1997). Unlike other IORs, system affiliations are likely to provide members information from other hospitals’ experiences in different markets (Proenca et al., 2000) and system-wide adoption of innovation (McKinney et al., 1991; Westphal et al., 1997). While the search found no studies on multisystem and hospital adoption of surgical robots, the literature search suggests that hospitals in systems are more likely to adopt surgical robots.

Network Membership

Studies show networks can influence technology adoption. Networks are strategic alliances with neighboring hospitals that form an IOR with many of the autonomy benefits of CM and easier to dissolve than a system (Bazzoli, Chan, Shortell, & D’Aunno, 2000; Bazzoli et al., 1999; Hearld & Carroll, 2015). Hospitals enter into a network or a relationship with “a group of hospitals, physicians, other providers, insurers, and/or community agencies that work together to coordinate and deliver a broad spectrum of services to their community” without a change in ownership (https://www.aha.org/system/files/2018-02/2018-aha-hospital-fast-facts.pdf; Hearld & Carroll, 2015). Hospitals use networks as a strategy to transfer funds, exchange ideas and technical knowledge, share expertise, or achieve another specific purpose without a long-term commitment of structural and administrative links (Casey, Wellever, & Moscovice, 1997; Goes & Park, 1997; Hearld & Carroll, 2015; Laumann, Galskeiwicz, & Mardsen, 1978; Moscovice & Stensland, 2002; Moscovice, Christianson, Johnson, Kralewski, & Manning, 1995).

Networks can influence hospitals' adoption of innovation (Burns & Wholey, 1993; Granovetter, 1985; Thorgren et al., 2009). Based on a study of 1,375 hospitals over a 17-year period, Burns and Wholey (1993) found the adoption of innovation was influenced by the network. As in systems, networks provide hospitals an opportunity to learn from other members' experiences (Westphal et al., 1997). As interdependence and frequency of exchanges between hospitals increased within IORs, so does the exchange of financial resources, information and technical knowledge among organizations (Goes & Park, 1997; Proenca et al., 2000; Teece, 1992). Technical learning and competence gained from exchanges within networks support innovation (Granovetter, 1985). Goes and Park (1997) found strong evidence that "a greater volume of exchanges between hospitals increases the likelihood that innovations will spread between them" (Goes & Park, 1997, p. 691). While the literature search found no studies or analyses on network hospital adoption of surgical robots, the evidence suggests hospitals in networks are more likely to adopt technology innovations.

Joint Venture

Joint venture is a voluntary contractual arrangement "between two or more parties forming an unincorporated business" ("AHA Survey," 2012, p. 21) with the strategic purpose of "reciprocal exploitation of resources for specific mutual gain in presence of compatible strategic objectives" (Druckman, Singer & Van Cott, 1997, p. 130). Shaped by competitive pressures and focused on specific objectives, this type of IOR provides strategies to link hospitals with physicians and other organizations, allowing access to resources required to adopt technology innovations (Barringer & Harrison, 2000; Goes & Park, 1997). Joint venture arrangements with physicians or physician groups allow hospitals to exploit specific opportunities and clinical integration, pool resources and share risk, and enhance technological capabilities while lowering costs, improving efficiency and increasing volume (Cuellar & Gertler, 2006; Harrigan, 1985; Harrigan, 1988; Longest, 1990). Organizations remain independent and separate outside of the venture and avoid costs associated with opportunistic behavior and monitoring inherent in market transactions through ownership incentives and interests ("AHA Survey," 2012; Barringer & Harrison, 2000; Longest, 1990). Joint ventures can help an organization avoid the need to internalize an activity that may not align with its competencies or may be difficult and costly to manage (Barringer & Harrison, 2000; Harrigan, 1988).

While access to the latest technology is given as a reason for the increase in joint ventures, the literature review found studies on joint ventures but none on joint ventures and adoption of technology innovation or surgical robots ("AHA Data," 2011; Barringer & Harrison, 2000; Harrigan, 1985; Harrigan, 1988; Harrigan & Newman, 1990; Hennart, 1988; ; Kumar & Seth, 1998; Zajac et al., 2011). The funding entity within a joint venture controls both resources and direction for the adoption of technology (Cropper et al., 2008). Organizations, which are considered technology innovation leaders, do not readily transfer technological expertise to a joint venture unless necessary (Harrigan, 1988). Most joint ventures in industries such as health care focus on capturing economies of scale and scope or combining expertise and play only a modest role in process innovation and not technology innovation (Hennart, 1988; Robinson, 1997). The findings suggest hospitals in joint ventures are less likely to adopt technology innovation such as surgical robots. Technology such as the surgical robotic system requires considerable resources to successfully implement and can provide a source of competitive advantage within the market (Barbash et al., 2014; Cundy et al., 2015; Dirckx, 2011; Herron & Marohn, 2008; Jin et al., 2011; Makarov et al., 2013; Patel, 2006; Steers et al., 2004; Tsuda et al., 2015).

Based on the literature review, the study should show that hospitals dependent on other organizations for resource may be more likely to use an IOR or multiple IOR strategy to adopt technology innovations. Findings of one study found the relationship between innovation and type of IOR was significant (Kotabe & Swan, 1995). These findings suggest hospitals in certain types of IOR, i.e., network and system affiliation IORs, may be more likely to adopt surgical robots than hospitals in CM and joint ventures (Kotabe & Swan, 1995).

Theoretical Framework

Previous sections reviewed literature on surgical robots, including the cost to establish and operate a surgical robot program, IORs and technology innovation, as well as IOR types and the need for capital and other resources to adopt a surgical robot. Recognizing that access to resources is critical to adopt surgical robots and IORs provide a strategy to obtain resources for technology innovation, this section reviews the theoretical framework of the resource dependence theory (RDT).

The theoretical premise of RDT is environmental uncertainty and scarcity of resources that leads to hospitals seeking interdependencies to acquire resources for technology innovation and manage uncertainties while minimizing threats to organizational autonomy (Barringer & Harrison, 2000; Harrigan & Newman, 1990; Hillman, Withers, & Collins, 2009; Jenssen & Nybakk, 2013; Oliver, 1990; Pfeffer, 1987; Pfeffer & Salancik, 1978; Pfeffer & Salancik, 2003). The theory emphasizes the dynamic nature of the external environment and recognizes conflict between and among hospitals competing for resources required to adopt technology innovation (Barbash et al., 2014; Donias, Karamanoukian, Glick, Bergsland, & Karamanoukian., 2002). Hospitals must adjust to changes in technology and competition, constraints or pressures from stakeholders, and level of dependency on stakeholders for resources to survive (Pfeffer & Salancik, 1978; Proenca et al., 2000). These variables make hospitals more dependent on the task environments and other organizations to acquire resources to achieve organizational goals and objectives. To explore whether IORs matter in the adoption of surgical robots, RDT provides a reasonable framework given resource scarcity or competition and the high cost of surgical robot adoption.

As the principal rationale for IORs, RDT attributes the motive of gaining access to resources controlled by others and reducing competitive environmental uncertainty by entering into IORs (Galaskiewicz, 1985; Goes & Park, 1997; Hillman et al., 2009; Oliver, 1990; Provan, 1984). It presupposes organizations act rationally and deliberately to reduce uncertainty and dependence on others in an environment controlling scarce resources (Pfeffer & Salancik, 1978). For this study, RDT focuses on managing interdependencies and relationships needed to adopt surgical robots (Oliver, 1991).

The theory offers explanations for why hospitals join IORs based upon a set of relationships formed between an organization and its technical environment. The organization’s environment can be defined as a set of external “events in the world which have any effect on the activities or outcomes of the organization” (Pfeffer & Salancik, 1978, p. 12) or as a technical environment (Scott, 1998). The technical environment consists of activities related to patterns of interorganizational exchange and other factors that shape how hospitals compete with others for resources. Hospital survival is related to the degree of ability to adapt to environment changes in order to acquire resources (Gomes & Gomes, 2007). Pressure comes in the form of resource exchange. Within the RDT framework, stakeholders own the required resources (Frooman, 1999). Hospitals, as open systems, can establish relationships with others in the environment by looking for ways to exchange required resources (Oliver, 1991; Scott, 1998).

This study employs the RDT approach to frame IORs based on the roles of reciprocity or cooperation, negotiation, collaboration, and coordination among organizations in exchanging resources to achieve mutual goals or interests (Jacobs, 1974; Levine & White, 1961). The theory builds on dependency being reduced through strategies based on cooperation, i.e., IORs. Like other organizations, hospitals depend on the environment for resources, are constrained by interdependencies, and enter IORs to exchange or acquire resources for capital from the external environment to survive (Alexander & Morrissey, 1989; Rossignoli & Ricciardi, 2015). Proenca et al. (2000) used them to show the IOR facilitates adoption of innovation by providing hospitals information, knowledge and expertise. The type of IOR influences the information disseminated (Proenca et al., 2000).

The actual level of resource scarcity and uncertainty in the environment influences a hospital’s decision to remain autonomous or enter an IOR (Alexander &

Morrisey, 1989). Hospitals enter IORs in an attempt to control environmental uncertainty created by scarcity of resources, unforeseeable changes in the environment, functional specialization of diverse organization, and other organizations' attempts to gain control of critical resources (Pfeffer & Salancik, 2003; Rossignoli & Ricciardi, 2015). A hospital unable to generate necessary resources will surrender some autonomy and enter into a different type of IOR than a less dependent organization (Rossignoli & Ricciardi, 2015).

While RDT recognizes the influence and pressure of external factors on organizational behavior (Oliver, 1991), it is based on power residing with stakeholders such as IORs that control the resources. Nienhuser (2008) suggests the theoretical mechanism for RDT is power, which can translate into control over the flow of resources to an organization (Nienhüser, 2008; Pfeffer, 1982). Stakeholders external to the hospital, such as IORs, can control resources to adopt. Based on the various degrees of control and strategic objectives of the different IOR types, each hospital must decide how much control to cede to an IOR to access resources. The level of power is reflected in the type of IOR engaged by the hospital.

Although other theoretical perspectives are used to explain IORs, dependencies and the power of these relationships, RDT provides a practical framework (see Figure 3) to evaluate strategies for building links or dependency relationships with other organizations to access a broader resource base needed to respond to environmental pressures and adopt technology innovations (Barringer & Harrison, 2000; Hillman et al., 2009; Kessler, 2013; Oliver, 1991; Pfeiffer & Salancik, 1978). The theory helps to explain why the hospital with access to capital, information, and technical and operational expertise within IORs adopts surgical robots. Based on the above rationale, a hospital's dependence on external resources for a capital expenditure such as a surgical robot would influence its strategy and subsequent actions to enter into an IOR or multiple IORs. It also would influence the type of IOR engaged to overcome dependencies and

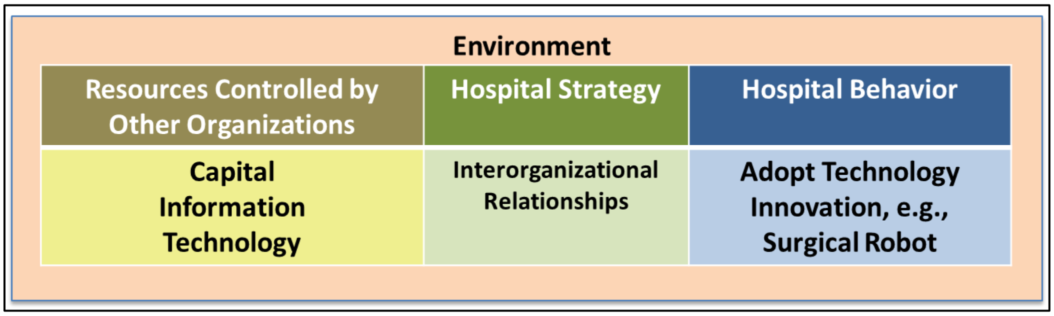

Figure 3. RDT framework: IOR provides resources for technology innovation

maintain or improve autonomy and legitimacy. Within the framework of RDT, IORs provide hospitals a strategy to influence the environment and maximize control of key resources through alliances and other means (Rossignoli & Ricciardi, 2015). An extensive review and analysis of the literature on IORs suggests RDT can be used to explain joint ventures, networks and other IOR types (Barringer & Harrison, 2000; Cook, 1977; Galaskiewicz, 1985; Hillman et al., 2009; Zaheer, Gözübüyük, & Mianov, 2010).

Hypotheses

Based on theoretical arguments presented and study findings in the literature review, the following hypotheses are tested to analyze the association between IORs and hospital adoption of a surgical robot.

Studies on adoption of technology innovation found an association with hospitals (McClellan & Kessler, 2002) and IORs (Goes & Park, 1997). The IORs provide organizations resources for bargaining power (Kaluzny, 1974) and are associated with implementing technology innovation within an organization, especially one with limited resources (Hanna & Walsh, 2002; Jenssen & Nybakk, 2013; Najafian & Colabi, 2014).

H_1. Hospitals engaged in IORs are more likely to adopt surgical robots than hospitals not engaged in an IOR.

As a major premise of resource dependence is the concept of IOR linkages creating dependencies among organizations at a cost to an organization's autonomy (Provan, 1984), certain types of IOR are more likely to be associated with hospital adoption of surgical robots. Hospitals with more resources are more likely to be in IORs characterized by high autonomy of its members (Zinn et al., 1997). Hospitals with access to fewer resources are more likely to cede some autonomy within an IOR such as contract management for resources (Zinn et al., 1997). Type of IOR should matter to hospital adoption of surgical robots, as some IORs are more likely to lead to adoption than other IOR types (Burns & Wholey, 1993; Thorgren et al., 2009).

H_2. The type of IOR is more likely to matter in hospital adoption of surgical robots than every IOR having the same effect on hospital adoption of surgical robots.

Networks can influence hospital adoption of innovation among their members (Burns & Wholey, 1993; Granovetter, 1985; Thorgren et al., 2009) by allowing for the exchange of ideas and innovations with other members (Goes & Park, 1997). As interdependence and frequency of exchanges between hospitals in the IOR increase so does the exchange of resources (Goes & Park, 1997; Proenca et al., 2000; Teece, 1992). Goes and Park (1997) found support for networks and hospital adoption of technology innovation (Goes & Park, 1997; Granovetter, 1985).

$H_{2.1}$. Hospitals engaged in a network are more likely to adopt a surgical robot than hospitals in other forms of IOR.

Goes and Park (1997) found a positive relationship between the structural links found in multihospital systems and innovation adoption (Goes & Park, 1997). This would suggest an association of system affiliation and hospital adoption of a surgical robot would be more likely. Research found system affiliation provides hospitals access to capital, information and other resources (Burns & Pauly, 2002; Cuellar & Gertler, 2003; Fottler et al., 1982) favorable for technology adoption. This study should find hospitals in a system affiliation IOR more likely to adopt a surgical robot.

$H_{2.2}$. Hospitals in a multihospital system are more likely to adopt a surgical robot than hospitals in other forms of IOR.

Goes and Park (1997) found a negative relationship between contract management and innovation adoption (Goes & Park, 1997). This would suggest an association of contract management and hospital adoption of a surgical robot to be less likely. Other study findings would support this as contract management did not have a significant, positive influence on technology innovation in healthcare services (Dor, 1994; Goes & Park, 1997). This study should find hospitals in contract management relationships are less likely to adopt a surgical robot.

$H_{2.3}$. Hospitals are less likely to adopt a surgical robot when linked with other organizations by contract management than hospitals in other forms of IOR.

Access to the latest technology is given as a reason for the increase in joint ventures ("AHA Data," 2011), but the literature review did find support for joint ventures and adoption of technology innovation or surgical robots (Robinson, 1997). While joint venture IORs can improve access to resources and enhance technological capabilities, the interorganizational relationship incentives and interests may run counter to the adoption of a surgical robot (Barringer & Harrison, 2000; Longest, 1990). However, technology such as the surgical robotic system requires considerable resources to successfully implement and can provide a source of competitive advantage within the market (Barbash et al., 2014; Cundy et al., 2015; Dirckx, 2011; Herron & Marohn, 2008; Jin et al., 2011; Makarov et al., 2013; Patel, 2006; Steers et al., 2004; Tsuda et al., 2015). Organizations considered to be technology innovation leaders do not readily transfer technological expertise to a joint venture unless necessary (Harrigan, 1988). A joint venture adoption of a technology such as a surgical robot could undermine a hospital's ability to create a competitive advantage (Barringer & Harrison, 2000). The literature search suggests hospitals in joint ventures are less likely to adopt surgical robots.

$H_{2.4}$. Hospitals are less likely to adopt a surgical robot when linked by joint venture arrangements with physicians or physician groups than hospitals in other forms of IOR.

Findings support or suggest a positive correlation between number of IORs an organization engages and level of technology innovation (Freeman, 1991; Hagedoorn, 1995; Powell et al., 1996). Organizations engaged in multiple IORs have access to resources and tend to be more innovative (Aiken & Hage, 1968; Goes & Park, 1997; Jenssen & Nybakk, 2013) and likely to implement a technology innovation with other members (Pennington & Harianto, 1992).

H_3. Hospitals that engage in more than one IOR are more likely to adopt a surgical robot than hospitals engaged in only one IOR.

See Table 1 for summary of hypotheses.

Table 1

Study Hypotheses

	Hypotheses
$H_{1.0}$	Hospitals engaged in IORs are more likely to adopt surgical robots than hospitals not engaged in an IOR.
$H_{2.0}$	The type of IOR is more likely to matter in hospital adoption of surgical robots than every IOR having the same effect on hospital adoption of surgical robots.
$H_{2.1}$	Hospitals engaged in a network are more likely to adopt a surgical robot than hospitals in other forms of IOR.
$H_{2.2}$	Hospitals in a multihospital system are more likely to adopt a surgical robot than hospitals in other forms of IOR.
$H_{2.3}$	Hospitals are less likely to adopt a surgical robot when linked with other organizations by contract management than hospitals in other forms of IOR.
$H_{2.4}$	Hospitals are less likely to adopt a surgical robot when linked by joint venture arrangements with physicians or physician groups than hospitals in other forms of IOR.
$H_{3.0}$	Hospitals that engage in more than one IOR are more likely to adopt a surgical robot than hospitals engaged in only one IOR.

CHAPTER 3

METHODOLOGY

This chapter explains research design, data sources and variables used in the study. It describes statistical procedures for model estimation and methods to test the proposed hypotheses.

Study Sample

The unit of analysis was the acute care hospital. The sample consisted of all acute care hospitals in the United States that were members of the American Hospital Association (AHA) between and including 2005 and 2014. The period was selected to encompass the initial and subsequent years of AHA documentation of hospital member adoption of surgical robots. Before the start of 2005 less than 0.1 percent of the estimated 35,000 to 45,000 operating rooms in the United States (*Intuitive Surgical, Inc.,* 2004) had operational surgical robots in various stages of surgeon training, certification and employment in laparoscopic procedures. The intent was to show an association between IORs and hospital adoption of surgical robots. The study also accounted for organizational structure and environmental changes.

Data Sources

Data for this study was drawn from the AHA Annual Survey of Hospitals for 2005 to 2014. The surveys provided data on hospital organizational characteristics and had a response rate of more than 90 percent. In 2005 AHA started collecting data on surgical robots in hospitals.

The dataset had 61,061 observations in which acute care hospitals were included. After sorting to include only acute care hospitals, the dataset was reduced to 36,957 observations (see Figure 4). In examining hospital operating margins, several hospital

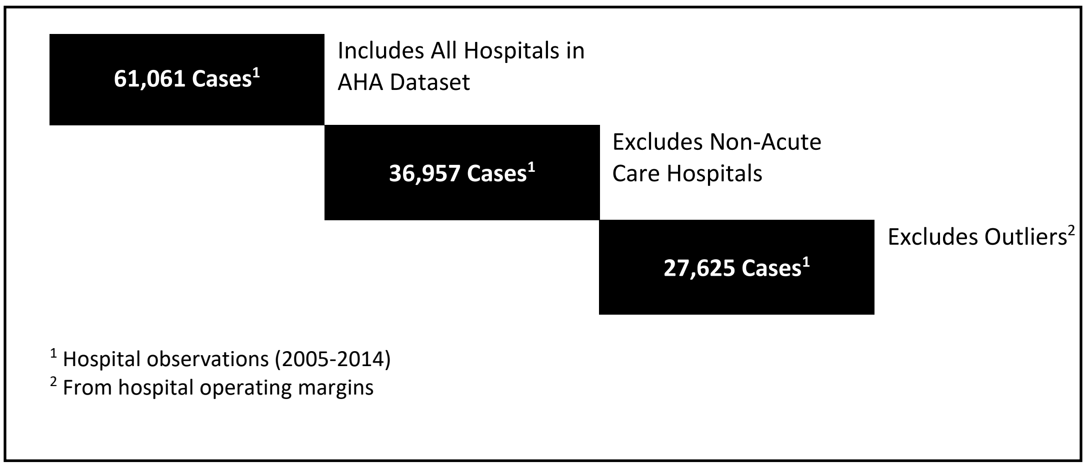

Figure 4. Inclusion / exclusion criteria

operating margins/data points were outside of the three standard deviations from the mean difference. Issues normally associated with extreme outliers (Iglewicz & Hoaglin, 1993) were considered before deciding to modify the dataset to normalize operating margins. The number of observations for the study was 27,625 for the ten-year period. The variables extracted from this data follow.

Measures

Dependent Variable

Hospital with Surgical Robot

Hospitals have either adopted or not adopted a surgical robot during the study period. As a binary variable it can only take two possible values. Hospitals that adopted a robot are coded as one, while those that have not adopted are coded as zero. See Table 2.

Table 2

Dependent, Independent and Control Variables

Variables	Measurement	Type of Variable	Data Source
Dependent Variable	Hospital with Surgical Robot (1=Yes, 0=No)	Dichotomous	AHA[a]
Independent Variables	Contract Management (1=Yes, 0=No)	Dichotomous	AHA
	System Affiliation (1=Yes, 0=No)	Dichotomous	AHA
	Network Membership (1=Yes, 0=No)	Dichotomous	AHA
	Physician Joint Venture (1=Yes, 0=No)	Dichotomous	AHA
	Hospital in More Than One IORs (1=Yes, 0=No)	Dichotomous	AHA
Control Variables			
Organization	Ownership Type ('government-nonfederal', 'non-government-not-for-profit', 'investor-owned, for profit')	Categorical	AHA
	Teaching Status (1=Yes, 0=No)	Dichotomous	AHA
	Number of Procedures (# of outpatient surgical operations + # of inpatient surgical operations)	Continuous	AHA
	Hospital Size (Total Beds)	Continuous	AHA
	Technology Level (Total # of Tech Innovations)	Continuous	AHA
	Financial Performance (Operating Margin)	Continuous	AHA
Environment	Market Competition (HHI[b])	Continuous	AHA
	Urban (1=Yes, 0=No)	Dichotomous	AHA

[a] AHA = American Hospital Association. [b] HHI = Hirschman-Herfindahl Index.

Independent Variables

Five variables represent the IORs in which data was available in the AHA Annual Survey. Consistent with other studies that examined IORs (Hearld & Carroll, 2015), the variables allowed for an analysis of the types of IOR in this study. All variables are dichotomous (0/1). Since IOR relationships are not mutually exclusive (hospital can engage in more than one IOR), a variable is used to indicate if a hospital had engaged in more than one IOR. The variables are contract management, system affiliation, network membership, joint venture, and more than one IOR.

Contract Management

Hospital day-to-day management is assumed by a separate contracting organization which reports to the board of trustees of the managed institution (Brown & Money, 1975) as a form of multi-institutional arrangement in health care (Alexander & Lewis, 1984). Hospitals that are contract managed are coded as one, while those that are not contract managed are coded as zero.

System Affiliation

Hospital belongs to a corporate body that owns and/or manages health provider facilities or health-related subsidiaries (or even non-health-related facilities) (AHA, 2015). A multihospital system is two or more hospitals owned, leased, sponsored, or contract managed by a central organization ("AHA," 2016). Hospitals with system affiliation are coded as one, while those not in a system are coded as zero.

Network Membership

Hospital is in a network or “a group of hospitals, physicians, other providers, insurers and/or community agencies that work together to coordinate and deliver a broad spectrum of services to their community” ("AHA," 2016, p. 1). Hospitals in a network are coded as one, while those that are not network members are coded as zero.

Joint Venture

Joint venture is a contractual arrangement between two or more parties forming an unincorporated business; participants in the arrangement remain independent and separate outside of the venture (AHA, 2016). Hospital participates in joint venture arrangement(s) with physicians or physician groups. Hospitals in joint ventures with physicians or physician groups are coded as one, while those not in such ventures are coded as zero.

More Than One IOR

The variable captures hospitals engaged in multiple IORs. Studies suggest a relationship between the number of IORs an organization engages and technology innovation up to a point of diminishing returns (Deeds & Hill, 1996; Freeman, 1991; Hagedoorn, 1995; Powell et al., 1996). Hospitals in more than one IOR are coded as one, while hospitals in one IOR or none are coded as zero.

Control Variables

Some studies of innovation (Fennell, 1980) argued that an organization adopts innovation contingent on the diffusion patterns of the innovation within its market. According to this view, hospitals often adopt an innovation to maintain prestige and status following adoption by competitors (Goes & Park, 1997, p. 683). Research shows that certain hospital characteristics and market characteristics matter to hospital adoption of technology innovation (Barbush at al, 2014; Dranove et al., 1992; Goes & Park, 1997; Kessler & McClellan, 2000; Li et al., 2014; Makarov et al., 2013). The study was designed to control or adjust for organizational and environmental variables.

Organizational Characteristics

Organizational characteristics from other studies on the adoption of surgical robots or other medical technical innovations include organization type, teaching status, volume or number of procedures, hospital size, and location (Barbush at al, 2014; Kessler & McClellan, 2000; Li et al., 2014; Makarov et al., 2013; Makarov, Li, Lepor, Gross, & Blustein, 2016). Therefore, the study accounts for these influential factors.

Ownership Type (Makarov et al., 2013). Organizational type defines responsibility for establishing policy for overall operation of a hospital. Hospitals that are owned by the government (nonfederal) are coded as zero (reference group), nongovernment, not-for-profit as one, investor-owned, for profit as two.

Teaching Hospital (Barbush at al, 2014; Makarov et al., 2013; Makarov et al., 2016). Studies show the use of robotics is becoming more common in teaching hospitals (Halabi et al., 2013; Yamasato et al., 2014). Hospitals affiliated with teaching institutions are coded as one, while those that are not affiliated with teaching institutions are coded as zero (the reference group).

Number of Procedures (Barbash et al., 2014; Makarov et al., 2013). Volume or number of procedures performed is associated with the adoption of robots (Barbash et al., 2014; Elixhauser Steiner, & Fraser, 2003; Halm et al., 2000; Makarov et al., 2013; Yu et al., 2012). A variable count is used to account for total number of outpatient surgical operations and inpatient surgical operations as noted in the AHA Annual Survey. The number of procedures is continuous and uses a summation score for each hospital. The hospitals that do not provide surgical care also are part of the control.

Hospital Size (Barbush at al., 2014). Hospital size, which reflects environmental demand and organizational response, has been studied in relationship to adoption of surgical robots (Barbash et al., 2014) and technology innovations (Goes & Park, 1997). Size is defined often by the number of beds. Most hospitals that adopt surgical robots have more than 200 beds (Lee, 2014). To control for this, total number of beds set up and staffed at the end of the reporting period was used. Number of beds is continuous.

Technology Level. As hospitals in IORs are more likely to adopt innovative technologies (Goes & Park, 1997), hospitals with a high level of technology may be more likely to adopt a surgical robot. To control for this, data from technology-related questions in the AHA Annual Survey are used to determine a hospital's technology level. Hospitals that employ a selected technology received a summation score to account for level of technology. Technologies identified in the AHA Annual Survey include robotic surgery, computer-assisted orthopedic surgery, robot-assisted walking therapy, single photon emission computerized tomography, multi-slice spiral computed tomography, image-guided radiation therapy, intensity modulated radiation therapy, proton beam therapy, electronic beam computed tomography, magnetoencephalography, simulated rehabilitation environment, and positron emission tomography – computed tomography.

Financial Performance. Findings suggest hospitals that adopt surgical robots are more likely to have access to resources or high volume of surgery (Barbash et al., 2014; Steinberg et al., 2008). The long-term financial health of a hospital can be assessed based on operating margin. Operating margin is calculated by dividing net operating income by total operating revenues, or:

$$\text{Operating Margin} = \frac{\text{Net Operating Income}}{\text{Operating Revenue}} \times 100 = \frac{\text{Operating Revenue - Operating Expense}}{\text{Operating Revenue}} \times 100$$

Generally accepted as a good measure of the sustainable profitability of a hospital, it focuses on business income as opposed to income from other sources (ACHE, n.d.). Hospitals' operating margins tend to be low. At the endline of the study period, nearly 25 percent of hospitals had negative operating margins with an aggregate operating margin of 6.4 percent based on an analysis of the 2014 AHA Annual Survey data for community hospitals (AHA, 2016). This study uses this measure to account for a hospital's financial performance. To control for this, data from the AHA Annual Survey was used to determine operating margins.

Environmental Variables

Environmental variables to control or adjust for are competition and urban location. Both variables are found in other studies on the adoption of surgical robots or other technology innovations.

Competition. Competition can be measured by the number of competing hospitals in the market (Scott & Flood, 1987). The Herfindahl–Hirschman Index, or HHI, is used as an indicator of market concentration or amount of competition at the local level (Scherer, 1980). HHI values range from zero to one, using Health Service Area (HSA) and system level share of hospital inpatients days as the relevant market.

Urban. Hospitals that adopt surgical robots are more likely to be urban hospitals (Barbash et al., 2014; Halabi et al., 2013; Li et al., 2014; Makarov et al., 2011; Makarov et al., 2013; Steers et al., 2004; Yamasato et al., 2014). Hospitals in urban areas are coded as one, while hospitals in rural areas are coded as zero.

Analytic Strategy

Univariate Analysis

The univariate analysis was used to describe the IOR types and other categorical and continuous variables. Descriptive statistics included the dependent variable of hospital-provided robotic surgery and independent variables of IOR type, organizational factors and market factors. It also included descriptive statistics on the four provisional variables on how robotic surgery is provided. These variables controlled for how hospitals provide robotic surgery. Specifically, if a hospital answered yes to having a surgical robot, the next step was to determine if it was offered by the hospital, a system, a network, or a joint venture/contract as defined by the AHA dataset.

To account for ten years of survey data, the univariate analysis used crosstabs for categorical variables and compare means for numeric or quantitative variables. While the quantitative variables are continuous, most of the categorical variables are binary or Bernoulli variables. Only one of the categorical variables is a polytomous variable. The intent was to identify any patterns that exist and draw attention to the difference in hospitals that adopt surgical robots with regard to each hospital’s IOR strategy.

A bivariate analysis was used to determine relationships between the variables using the chi-square test of independence and the independent samples *t*-test. This also facilitated a more complete analysis. The chi-square test of independence was used to determine the statistical independence or association (dependence) between two categorical variables. The independent samples *t*-test was used to determine if there was a statistically significant difference between the means in two unrelated groups. Each variable within the study was compared with hospitals with robotic surgery for the endline or final year of the study period (2014). From the chi-square test the *p*-value of the Pearson chi-square was used to determine the statistical significance associated between hospitals with surgical robots and each categorical independent variable. From the independent samples *t*-test the *p*-value from the t test results of the Levene’s test was used to determine the statistical significance associated between hospitals with surgical robots and each continuous independent variable.

Generalized Estimating Equations

To evaluate the effect of IORs on hospital adoption of surgical robots over a ten-year period, the study employed the generalized estimating equations (GEE) method (Liang and Zeger, 1986 & Diggle, Liang and Zeger, 1994) to allow for analysis of repeated measurements of categorical response data. Like the binary logistics regression model, GEE is associated with generalized linear models. It extends the generalized linear model by relaxing "the assumption of normality for the error term and requires only that the dependent variable be linearly related to the predictors through a transformation or link function" (IBM Corporation, n.d.) and allows for an analysis of repeated measurements. The GEE method provides a method of inference for models when responses are correlated, i.e., logistic regression for binary outcomes. It also accounts for missing data in a longitudinal study, making assumptions about their relationships with available data. The GEE provides a semi-parametric approach to longitudinal analysis of categorical response.

For the study, the binary logistics option of the GEE model for binary responses was used. The dependent variable (hospital with surgical robot) and a number of the independent variables are categorical or nominal variables that can take on exactly two values (binary variable or dichotomous variable) with no intrinsic ordering to the categories. The conditional distribution $y \mid x$ is a Bernoulli distribution as the dependent variable is binary. The predicted values are probabilities and restricted to two categorical outcomes (0,1).

The binary logistics option specified binomial as the distribution and logit as the link function. The distribution and logit are appropriate as the dependent variable (hospital with surgical robot) and the predictor variables (i.e., type of IOR and more than one IOR) represent binary responses with a binomial distribution. The model assumed cases are dependent within subjects and independent between subjects, factors are categorial and covariates are scaled. In addition to the dependent variable, year was repeated within-subject variable and defined ordering of measurements within subjects.

The GEE provided a model from which predictions can be made about the likelihood that a type of IOR or more than one IOR will influence hospital adoption of a surgical robot. The outcome variable, Y, was the probability of having one outcome or another based on a nonlinear function of the best linear combination of predictor variables (Field, 2009). Quasi-likelihood estimation was used to estimate coefficients.

The first GEE analysis tested the first two hypotheses and examined all IOR types: network, system, contract management, and joint venture. Subsequent GEE analyses examined each IOR type independent of the others to test each sub-hypothesis of Hypothesis 2. More Than One IOR examined the third hypothesis.

The IBM SPSS (Statistical Package for the Social Sciences) statistics software was used to perform the analyses. It provided the required capabilities for the entire analytical process. For this study, two p-value interpretations are used: $p \leq 0.01$ as very strong evidence against H_0 and $p \leq 0.05$ as moderate evidence against H_0.

Odds Ratios and Probability

The GEE produces an odds ratio (OR) as a measure of association between an exposure and an outcome. For this study, the OR represented the odds that an outcome or hospital with surgical robot will occur given a particular exposure (i.e., type of IOR or more than one IOR), compared to the odds of the outcome occurring in the absence of the IOR. To calculate the change in odds that resulted from a unit change in the predictor, the model calculated the odds of a hospital with a surgical robot given it did not have the intervention or was not engaged in an IOR (Field, 2009). It then calculated the odds of a hospital with a surgical robot if it was engaged in an IOR. The last calculation to achieve the OR calculated the proportional change in the two previous odds. The exponential function of the regression coefficient or Exp(B) was the OR associated with a one-unit increase in the exposure.

For the study, an OR value greater than one indicated that as the predictor (the IOR) increases the odds of a hospital having or adopting a surgical robot increase. The converse was the OR value of less than one. A value equal to one indicated that the IOR does not affect the odds of the hospital having or adopting robotic surgery.

The GEE provided a *p*-value to determine a statistically significant difference between groups. Where the outcome was a *p*-value of < 0.05 or a greater than 5% significance level, there was a statistically significant difference between groups. Where the outcome of GEE analyses provided a *p*-value of < 0.01 or a greater than 1% significance level, there was very strong evidence against the null.

CHAPTER 4

RESULTS AND FINDINGS

The purpose of the study is to investigate the relationship between IORs and hospital adoption of robotic surgery in the U.S. over a ten-year period. This chapter presents results organized around the hypotheses. It provides the descriptive statistics of the hospitals, the IORs and the market, which includes the bivariate analysis. It also presents the results and findings of the GEE.

Data Description

For the purposes of hypothesis testing, there were approximately 27,625 observations of acute care hospitals available for analysis. Table 3 presents the means and standard deviations or the frequency and percentage of each variable for the baseline or the initial year of the study (2005) and the endline or the final year of the study (2014).

Table 3 shows the percentage of hospitals that provide robotic surgery increased from 10.6% in the baseline to 36.7% in the endline. With respect to how robotic surgery was offered by the hospital, frequency and percentage increased in all ways. Hospitals that provided robotic surgery by itself significantly increased from 8.0% to 35.6%. Hospitals that provided robotic surgery through an affiliation with a system increased from 4.3% to 14.2%. Hospitals that provided robotic surgery through its membership in a network or through a joint venture / managed contract also increased over the ten-year study period. All were statistically significant with a *p*-value less than 0.000.

Table 3

Descriptive Statistics of Variables (N=27,625 hospital observations)

	Baseline (2005) n = 2,799	Endline (2014) n = 2,463	
Variables	Mean (SD) or Frequency (%)		p^*
Hospital Provides Robotic Surgery			
No	2,503 (89.4)	1,558 (63.3)	0.000
Yes	296 (10.6)	905 (36.7)	
How Robotic Surgery Is Provided			
Hospital			
No	2,246 (92.0)	1,287 (64.3)	0.000
Yes	196 (8.0)	713 (35.6)	
System			
No	2,338 (95.7)	1,698 (84.9)	0.000
Yes	104 (4.3)	302 (14.2)	
Network			
No	2,411 (98.7)	2,157 (97.6)	0.001
Yes	31 (1.3)	52 (2.4)	
Joint Venture			
No	2,435 (99.7)	1,986 (99.3)	0.011
Yes	7 (0.3)	17 (0.8)	
IOR Type			
System Affiliation			
No	1,355 (48.4)	936 (38.0)	0.000
Yes	1,444 (51.6)	1,527 (62.0)	
Network Membership			
No	1,458 (62.4)	1,121 (57.0)	0.000
Yes	878 (37.6)	844 (43.0)	
Joint Venture			
No	1,618 (72.9)	1,193 (63.8)	0.000
Yes	601 (27.1)	678 (36.2)	
Contract Management			
No	2,104 (88.3)	1,775 (89.9)	0.000
Yes	278 (11.7)	200 (10.1)	
Multiple IORs			
No	1,947 (69.6)	1,511 (61.3)	0.000
Yes	852 (30.4)	952 (38.7)	
Organizational Factors			
Operating Margin	-.5616 (18.10)	-2.4911 (18.97)	0.000
Technology Level	2.08 (2.13)	3.57 (3.36)	0.000
Hospital Size	195.32 (190.40)	184.04 (194.59)	0.000
Number of Procedures	6827.70 (8344.73)	6191.20 (7862.97)	0.000
Teaching Hospital			
No	2,059 (73.6)	1,537 (62.4)	0.000
Yes	740 (26.4)	926 (37.6)	
Ownership Systems Type			
Nongovernment-Not-for-profit	1,887 (67.4)	1,604 (65.1)	
For Profit	320 (11.4)	386 (15.7)	0.000
Government-non-federal	592 (21.2)	473 (19.2)	
Market Factors			
Market Competition (HHI)[a]	.07354 (.04)	.07222 (.04)	0.519
Urban			
Rural	25 (1.1)	33 (1.6)	0.425
Urban	2,351 (98.9)	2,056 (98.4)	

	Baseline (2005) n = 2,799	Endline (2014) n = 2,463	
Variables	Mean (SD) or Frequency (%)		p^*
Per Capita Income	30,986.14 (9,704.97)	43,089.88 (12,767.47)	0.000
Percent Below Poverty Level	14.7705 (6.40)	16.3026 (6.73)	0.000
Percent < 65 without Insurance[b]	15.6247 (5.81)	13.0595 (5.09)	0.000
Unemployment Rate (over 16 years)	5.3209 (1.70)	6.2247 (2.06)	0.000
Persons 25+ Years with < HS[c]	42,592.79 (97281.93)	42,033.38 (95,711.20)	0.965
Population Estimate	422039.51 (837464.40)	455656.76 (885548.54)	0.739

Dataset Variables: Definitions and Descriptions

Independent Variable	
ID	AHA Identification Number
Year	Variable denoting study years: 2005-2014
Network	Binary variable: Is the hospital a participant in a network? 1=Yes, 0=No
System	Binary variable: Is the hospital part of a system? 1=Yes, 0=No
Mngt	Binary variable: Is the hospital contract-managed? 1=Yes, 0=No
Jntph	Binary variable: Does your hospital participate in any joint venture arrangements with physicians? 1=Yes, 0=No
multiple_IOR	Binary variable: Is the hospital involved in multiple IOR? 1=Yes, 0=No
Teaching	Binary variable: Is the hospital a teaching hospital? 1=Yes, 0=No
Ownership	Polytomous variable of hospital ownership: 1=non-government not for profit, 2=for profit, 3=governmental (not federal)
Urban	Binary variable: Is the hospital location urban? 1=Yes, 0=No
Opermar	Variable denoting operating margin.
sum tech	Variable denoting the hospital's sum total of technologies.
Suroptot	Variable denoting total surgical operations of the hospital.
Bdtot	Variable denoting total facility beds set up and staffed at the end of reporting period.
HHI	Variable denoting the Herfindahl Index of the Health Service Area.
Income	Variable denoting per capita income.
below_poverty lev	Variable denoting percent of persons below the poverty level.
uninsured	Variable denoting percentage of persons <65 without health insurance.
unemployment	Variable denoting the unemployment rate of persons 16 or older.
population	Variable denoting population estimate.
education	Variable denoting persons 25+ years with less than high school diploma.
Outcome Variable	
Robosurg	Binary variable demoting hospital with / without surgical robot. 1=hospital provides robotic surgery, 0=hospital does not

* p ≤ 0.05
[a] HHI = Hirschman-Herfindahl Index. [b] Less than 65 years old without health insurance. [c] HS = High school diploma.

Table 3 also shows changes in IOR type over the study period. The majority of hospitals were engaged in systems (62.0% at endline), followed by networks, joint ventures and contract management. Over the ten-year study period, the number of hospitals engaged in system affiliation, network membership and joint venture increased significantly with a *p*-value less than 0.000. However, the number of hospitals engaged in contract management decreased by 13.7% from baseline to endline. The analysis also shows a 27.3% increase in the number of hospitals engaged in multiple IORs, going from 30.4% to 38.7% over the ten-year study period. Both of these were statistically significant with a *p*-value less than 0.000.

The mean of the technology within the hospitals increased over the study period. Specifically, the average number of surveyed technologies resident in a hospital increased 61.8% from 2.08 in the baseline year to 3.36 in the endline year. The increase was statistically significant with a *p*-value less than 0.000. The mean for hospital operating margin, total number of procedures and hospital size all decreased over the ten-year period. All of these changes were statistically significant with a *p*-value less than 0.000.

Table 3 reflects frequency and percentage of organizational factors of categorical variables. The frequency for teaching hospitals increased over the ten-year period from 740 in the baseline year to 926 in the endline year. Within ownership type, only the frequency for for-profits increased from 320 in the baseline year to 386 in the endline year. The increases in teaching- and for-profit hospitals were statistically significant with a *p*-value less than 0.000.

In the market factors, the distribution of market competition, as measured by the Hirschman-Herfindahl Index, remained basically unchanged as the mean decreased by 1.8%. The decrease was not statistically significant with $p > 0.05$. More than 98.0% of the hospitals in the study were in urban areas over the ten-year period. The decrease was not statistically significant with a $p > 0.05$.

The demographic profile reflects an increase in per capita income, percent of the population below the poverty level, unemployment rate, and overall population during the study period. The increase for per capita income and poverty level was statistically significant with a *p*-value less than 0.000. The increase in population and the decrease in people over 25 with less than a high school diploma are not statistically significant ($p > 0.05$). The percent of people under 65 years of age without health insurance decreased from 5.81% in the baseline year to 5.09% in the endline year and was statistically significant with a *p*-value less than 0.000.

The analysis for the IOR type shows what percentage of each IOR type has hospitals with and without surgical robots in the final year of the study (Table 4). The overall observation is the majority of hospitals in some type of an IOR or in multiple IORs has a higher portion of hospitals with robotic surgery. The only exception to this was contract management where a lower portion of hospitals in contract management has robotic surgery (3.8%). With *p*-values less than 0.000, there was statistically significant association between hospitals with surgical robots and IOR types and numbers.

A higher proportion of hospitals with system affiliation have robotic surgery (77.0%) than hospitals in systems without surgical robots. With a *p*-value less than 0.000, there is a statistically significant association between hospitals with robotic surgery and system affiliation.

A slightly higher portion of hospitals with network membership have robotic surgery (52.4%) than hospitals in networks without surgical robots. With a *p*-value less than 0.000, there is a statistically significant association between hospitals with robotic surgery and network membership. There were about equal numbers and percentages of hospitals in networks and joint ventures with robotic surgery.

A much higher portion of hospitals with contract management do not have robotic surgery than hospitals with robotic surgery in contract management arrangements. With a *p*-value less than 0.000, there is statistically significant association with this finding.

A higher portion of hospitals with multiple IORs have robotic surgery (61.3%) than hospitals with robotic surgery not engaged in multiple IORs. With a *p*-value less than 0.000, there is statistically significant association between hospitals with robotic surgery and engaged in more than one IOR. A higher portion of hospitals without surgical robots were not engaged in multiple IORs (74.5%).

Table 4 shows the difference between hospital with and without robotic surgery. Hospitals with robotic surgery have adopted more technologies (mean of 7.40) than hospitals without surgical robots (1.55). With a *p*-value of 0.000, there is a statistically significant association between hospitals with surgical robots and a high number of technologies. Hospitals with robotic surgery have higher operating margins (mean of 0.8336) than hospitals without robotic surgery (mean of -4.4224). Hospitals with robotic surgery have a higher number or have more procedures (mean of 10,824.26) than hospitals without robotic surgery (mean of 3,499.98) and more beds (mean of 297.20) than hospitals without robotic surgery (mean of 118.30). These were all statistically significant with *p*-value less than 0.05. There was a statistical significantly higher number of hospitals with a teaching status with surgical robot capability (59.3%) compared to hospitals with teaching status without surgical robot capability (40.7%).

Table 4

Bivariate Analysis of Variables (2014) (N=2,463)

	Hospitals with No Robotic Surgery	Hospitals with Robotic Surgery	
Variables	Mean (SD) or Frequency (%)		*p**
IOR Type			
System Affiliation			
No	728 (46.7)	208 (23.0)	0.000
Yes	830 (53.3)	697 (77.0)	
Network Membership			
No	689 (64.0)	432 (48.6)	0.000
Yes	387 (36.0)	457 (51.4)	
Joint Venture			
No	792 (79.4)	401 (45.9)	0.000
Yes	206 (20.6)	472 (54.1)	
Contract Management			
No	915 (84.6)	860 (96.2)	0.000
Yes	166 (15.4)	34 (3.8)	
Multiple IORs			
No	1,161 (74.5)	350 (38.7)	0.000
Yes	397 (25.5)	555 (61.3)	
Organizational Factors			
Operating Margin	-4.4224 (19.42)	.8336 (17.70)	0.000
Technology Level	1.55 (1.89)	7.04 (2.35)	0.000
Hospital Size	118.30 (112.30)	297.20 (247.26)	0.000
Number of Procedures	3,499.98 (3,694.17)	10,824.26 (10,531.14)	0.000
Teaching Hospital			
No	1,169 (75.0)	368 (40.7)	0.000
Yes	389 (25.0)	537 (59.3)	
Ownership Systems Type			
Nongovernment-Not-for-profit	901 (57.8)	703 (77.7)	
For Profit	283 (18.2)	103 (11.4)	0.000
Government-non-federal	374 (24.0)	99 (10.9)	
Market Factors			
Market Competition (HHI)[a]	.08207 (.04)	.05527 (.04)	0.000
Rural / Urban			
Rural	31 (2.4)	2 (.3)	0.000
Urban	1,281 (97.6)	775 (99.7)	
Per Capita Income	40,810.95 (11,433.58)	46,852.62 (13,920.67)	0.000
Percent Below Poverty Level	16.8465 (7.29)	15.3870 (5.56)	0.000
Percent < 65 without Insurance[b]	13.3181 (5.09)	12.6324 (5.06)	0.003
Unemployment Rate (> 16 years)	6.3388 (2.33)	6.0327 (1.48)	0.001
Persons 25+ years with < HS[c]	27,878.13 (81,262.74)	65,862.30 (112,128.72)	0.000
Population Estimate	288,694.11 (751,146.54)	736,936.18 (1014,763.90)	0.000

* $p \leq 0.05$

[a] HHI = Hirschman-Herfindahl Index. [b] Less than 65 years old without health insurance. [c] HS = High school diploma.

Of the hospitals with robot surgery, the majority are urban (99.7%) (*p*-value = 0.000) and non-government, not-for-profit systems (77.7%). Of note, the average for market competition of hospitals with surgical robots (mean of 0.05527) was less than hospitals without robotic surgery (mean of 0.08207) with a *p*-value less than 0.000.

Hypothesis Testing

All IOR Types

Table 5 shows the odds ratios of a hospital with a surgical robot as the dependent variable and the four types of IOR. Based on the odds ratios, hospitals belonging to a network have approximately 1.4 times higher odds of having or adopting robotic surgery compared to hospitals not belonging to any network. The *p*-value equal to 0.000 indicates a statistically significant association. Hospitals belonging to a system have approximately 1.7 times higher odds of having or adopting robotic surgery compared to hospitals not belonging to a system. The *p*-value equal to 0.000 indicates a statistically significant difference between the groups. Hospitals in a contract management relationship have approximately 0.5 times lower odds of having or adopting robotic surgery compared to hospitals not in contract management. The *p*-value less than 0.005 indicates a statistically significant difference between the groups. Hospitals belonging to a joint venture have approximately 0.7 times lower odds of having or adopting robotic surgery compared to hospitals not in a joint venture. The *p*-value of 1.041 indicates a statistically insignificant difference between the groups.

For control variables, three are associated with higher odds of hospitals having or adopting a surgical robot. For-profit hospitals have approximately 1.8 times higher odds of having or adopting robotic surgery compared to government-non-federal hospitals. With increasing operating margins, hospitals have 1.01 higher odds of adopting robotic

Table 5

Generalized Estimating Equations Analysis of Hospital with Surgical Robot as Dependent Variable – System, Network, Joint Venture, and Contract Management

	Hospitals with Robotic Surgery (N=27,625)[a]	
Variables	Odds Rations	*p**
IOR Type		
Network Membership		
Yes	1.428	0.000
No	*Ref*	*Ref*
System Affiliation		
Yes	1.730	0.000
No	*Ref*	*Ref*
Contract Management		
Yes	0.471	0.005
No	*Ref*	*Ref*
Joint Venture		
Yes	0.696	1.041
No	*Ref*	*Ref*
Organizational Factors		
Operating Margin	1.005	0.038
Technology Level	2.406	0.000
Number of Procedures	1.000	0.004
Hospital Size	1.001	0.070
Teaching Hospital		
Yes	0.983	0.998
No	*Ref*	*Ref*
Ownership Systems Type		
Nongovernment-Not-for-profit	0.988	0.952
For Profit	1.817	0.002
Government-non-federal	*Ref*	*Ref*
Market Factors		
Market Competition (HHI)[b]	0.000	0.000
Urban		
Urban	0.115	0.028
Rural	*Ref*	*Ref*
Per Capita Income	1.000	0.321
Percent Below Poverty Level	0.974	0.073
Percent < 65 Years without Health Insurance	1.039	0.005
Unemployment Rate (over 16 years)	1.026	0.391
Persons 25+ Years with < High School Diploma	1.001	0.001
Population Estimate	1.000	0.000
Year		
2014	4.651	0.000
2013	3.798	0.000
2012	2.977	0.000
2011	2.155	0.000
2010	1.485	0.557
2009	1.092	0.610
2008	1.049	0.680
2007	1.106	0.273
2006	1.028	0.733
2005	*Ref*	*Ref*

* $p \leq 0.05$

[a] Hospital observations (2005-2014). [b] HHI = Hirschman-Herfindahl Index.

surgery. The *p*-value of 0.038 indicates a statistically significant association. And with an increasing number of technologies, hospitals have 2.4 higher odds of adopting robotic surgery. The *p*-value of less than 0.000 indicates statistically significant association.

For the other control variables of interest, only one (total surgical operations) indicated higher odds of adopting robotic surgery. However, with an odds ratio of 1.0, increasing number of procedures does not affect the odds of a hospital having or adopting robotic surgery. The *p*-value of 0.004 indicates statistically significant association. Teaching status had lower odds (0.98) but was not statistically significant (*p*-value of 0.952). Not-for-profit hospitals also had lower odds (0.99) and were not statistically significant (*p*-value of 0.998). Urban hospitals had lower odds (0.115) and were statistically significant (*p*=0.028). HHI had lower odds (0.000) and a *p*-value of 0.000 indicating statistically significant association.

Network

Table 6 shows the outcomes from the GEE analysis with a hospital with a surgical robot as the dependent variable and the network as the predictor variable over the ten-year period of study. Table 6 shows hospitals in a network have approximately 1.5 times higher odds of having or adopting robotic surgery compared to hospitals not in a network. The *p*-value less than 0.000 indicates a statistically significant difference between groups.

System

Table 7 shows the outcomes from the GEE analysis with a hospital with a surgical robot as the dependent variable and system as the predictor variables over the ten-year

Table 6

Generalized Estimating Equations Analysis of Hospital with Surgical Robot as Dependent Variable – Network

	Hospitals with Robotic Surgery (N=27,625)[a]	
Variables	Odds Rations	*p**
IOR Type		
Network Membership		
Yes	1.525	0.000
No	*Ref*	*Ref*
Organizational Factors		
Operating Margin	1.006	0.006
Technology Level	2.408	0.000
Number of Procedures	1.000	0.004
Hospital Size	1.001	0.057
Teaching Hospital		
Yes	0.995	0.966
No	*Ref*	*Ref*
Ownership Systems Type		
Nongovernment-Not-for-profit	0.793	0.216
For Profit	1.947	0.000
Government-non-federal	*Ref*	*Ref*
Market Factors		
Market Competition (HHI)[b]	0.000	0.000
Urban		
Urban	0.485	0.580
Rural	*Ref*	*Ref*
Per Capita Income	1.006	0.439
Percent Below Poverty Level	0.970	0.030
Percent < 65 Years without Health Insurance	1.043	0.001
Unemployment Rate (over 16 years)	1.032	0.285
Persons 25+ Years with < High School Diploma	1.000	0.000
Population Estimate	1.000	0.000
Year		
2014	4.973	0.000
2013	3.886	0.000
2012	2.998	0.000
2011	2.114	0.000
2010	1.596	0.015
2009	1.066	0.704
2008	1.074	0.519
2007	1.136	0.153
2006	1.035	0.650
2005	*Ref*	*Ref*

* $p \leq 0.05$
[a] Hospital observations (2005-2014). [b] HHI = Hirschman-Herfindahl Index.

period of the study. Based on the odds ratio, hospitals belonging to a system have approximately 1.8 times higher odds of having or adopting robotic surgery compared to

Table 7

Generalized Estimating Equations Analysis of Hospital with Surgical Robot as Dependent Variable – System

	Hospitals with Robotic Surgery (N=27,625)[a]	
Variables	Odds Rations	*p**
IOR Type		
System Affiliation		
Yes	1.839	0.000
No	*Ref*	*Ref*
Organizational Factors		
Operating Margin	1.005	0.033
Technology Level	2.429	0.000
Number of Procedures	1.000	0.003
Hospital Size	1.001	0.066
Teaching Hospital		
Yes	0.991	0.937
No	*Ref*	*Ref*
Ownership Systems Type		
Nongovernment-Not-for-profit	0.900	0.591
For Profit	1.484	0.031
Government-non-federal	*Ref*	*Ref*
Market Factors		
Market Competition (HHI)[b]	0.001	0.000
Urban		
Urban	0.397	0.422
Rural	*Ref*	*Ref*
Per Capita Income	1.000	0.305
Percent Below Poverty Level	0.971	0.040
Percent < 65 Years without Health Insurance	1.038	0.005
Unemployment Rate (over 16 years)	1.017	0.555
Persons 25+ Years with < High School Diploma	1.000	0.000
Population Estimate	1.000	0.001
Year		
2014	4.659	0.000
2013	3.841	0.000
2012	2.998	0.000
2011	2.109	0.000
2010	1.507	0.019
2009	1.111	0.525
2008	1.057	0.608
2007	1.110	0.236
2006	1.027	0.712
2005	*Ref*	*Ref*

* $p \leq 0.05$
[a] Hospital observations (2005-2014). [b] HHI = Hirschman-Herfindahl Index.

hospitals not belonging to any system. The *p*-value less than 0.000 indicates a statistically significant difference between the groups.

Contract Management

Table 8 shows the outcomes from the GEE analysis with a hospital with a surgical robot as the dependent variable and contract management as the predictor variables over the ten-year period of the study. Hospitals in a contract management relationship have approximately 0.6 times lower odds of having or adopting robotic surgery compared to hospitals not in contract management. The *p*-value of 0.032 indicates a statistically significant difference between the groups.

Joint Venture

Table 9 shows the outcomes from the GEE analysis with a hospital with a surgical robot as the dependent variable and joint venture as the predictor variables over the ten-year period of the study. Hospitals belonging to a joint venture have approximately 1.1 times higher odds of having or adopting robotic surgery compared to hospitals not being in a joint venture. The *p*-value of 0.506 indicates a statistically insignificant difference between the groups. The odds ratio is not statistically significant.

More Than One IOR

Table 10 shows the outcomes from the GEE analysis with a hospital with a surgical robot as the dependent variable and more than one IOR as the predictor variables over the ten-year period of the study. Hospitals belonging to more than one IOR having robotic surgery have approximately 1.4 times higher odds of having or adopting robotic surgery compared to hospitals not belonging to more than one IOR. At a *p*-value of 0.001

Table 8

Generalized Estimating Equations Analysis of Hospital with Surgical Robot as Dependent Variable – Contract Management

	Hospitals with Robotic Surgery (N=27,625)[a]	
Variables	Odds Rations	*p**
IOR Type		
Contract Management		
Yes	0.561	0.032
No	*Ref*	*Ref*
Organizational Factors		
Operating Margin	1.006	0.008
Technology Level	2.421	0.000
Number of Procedures	1.000	0.008
Hospital Size	1.001	0.075
Teaching Hospital		
Yes	0.961	0.732
No	*Ref*	*Ref*
Ownership Systems Type		
Nongovernment-Not-for-profit	0.748	0.128
For Profit	1.848	0.001
Government-non-federal	*Ref*	*Ref*
Market Factors		
Market Competition (HHI)[b]	0.000	0.000
Urban		
Urban	0.546	0.642
Rural	*Ref*	*Ref*
Per Capita Income	1.000	0.226
Percent Below Poverty Level	0.974	0.060
Percent < 65 Years without Health Insurance	1.043	0.001
Unemployment Rate (over 16 years)	1.029	0.335
Persons 25+ Years with < High School Diploma	1.000	0.000
Population Estimate	1.000	0.000
Year		
2014	4.761	0.000
2013	3.711	0.000
2012	2.824	0.000
2011	1.989	0.000
2010	1.028	0.945
2009	1.035	0.835
2008	1.030	0.792
2007	1.096	0.296
2006	1.035	0.638
2005	*Ref*	*Ref*

* $p \leq 0.05$
[a] Hospital observations (2005-2014). [b] HHI = Hirschman-Herfindahl Index.

the result was statistically significant. The predictor variable or more than one IOR increases as does the odd of the hospital having a surgical robot.

Table 9

Generalized Estimating Equations Analysis of Hospital with Surgical Robot as Dependent Variable – Joint Venture

	Hospitals with Robotic Surgery (N=27,625)[a]	
Variables	Odds Rations	*p**
IOR Type		
Joint Venture		
Yes	1.070	0.506
No	*Ref*	*Ref*
Organizational Factors		
Operating Margin	1.006	0.007
Technology Level	2.408	0.000
Number of Procedures	1.000	0.009
Hospital Size	1.001	0.052
Teaching Hospital		
Yes	0.991	0.942
No	*Ref*	*Ref*
Ownership Systems Type		
Nongovernment-Not-for-profit	0.724	0.088
For Profit	1.807	0.002
Government-non-federal	*Ref*	*Ref*
Market Factors		
Market Competition (HHI)[b]	0.000	0.000
Urban		
Urban	0.215	0.107
Rural	*Ref*	*Ref*
Per Capita Income	1.000	0.387
Percent Below Poverty Level	0.975	0.074
Percent < 65 Years without Health Insurance	1.041	0.003
Unemployment Rate (over 16 years)	1.031	0.301
Persons 25+ Years with < High School Diploma	1.000	0.000
Population Estimate	1.000	0.000
Year		
2014	4.562	0.000
2013	3.650	0.000
2012	2.790	0.000
2011	1.964	0.000
2010	1.355	0.085
2009	1.022	0.895
2008	1.020	0.860
2007	1.100	0.282
2006	1.039	0.609
2005	*Ref*	*Ref*

* $p \leq 0.05$

[a] Hospital observations (2005-2014). [b] HHI = Hirschman-Herfindahl Index.

Table 10

Generalized Estimating Equations Analysis of Hospital with Surgical Robot as Dependent Variable – More Than One IOR

	Hospitals with Robotic Surgery (N=27,625)[a]	
Variables	Odds Rations	*p**
IOR Type		
More Than One IOR		
Yes	1.358	0.001
No	*Ref*	*Ref*
Organizational Factors		
Operating Margin	1.006	0.008
Technology Level	2.438	0.000
Number of Procedures	1.000	0.005
Hospital Size	1.001	0.075
Teaching Hospital		
Yes	0.983	0.885
No	*Ref*	*Ref*
Ownership Systems Type		
Nongovernment-Not-for-profit	0.777	0.177
For Profit	1.729	0.003
Government-non-federal	*Ref*	*Ref*
Market Factors		
Market Competition (HHI)[b]	0.000	0.000
Urban		
Urban	0.589	0.653
Rural	*Ref*	*Ref*
Per Capita Income	1.000	0.305
Percent Below Poverty Level	0.973	0.058
Percent < 65 Years without Health Insurance	1.041	0.002
Unemployment Rate (over 16 years)	1.022	0.451
Persons 25+ Years with < High School Diploma	1.000	0.001
Population Estimate	1.000	0.000
Year		
2014	4.652	0.000
2013	3.777	0.000
2012	2.887	0.000
2011	2.015	0.000
2010	1.646	0.005
2009	1.061	0.716
2008	1.061	0.754
2007	1.034	0.326
2006	1.019	0.797
2005	*Ref*	*Ref*

* $p \leq 0.05$
[a] Hospital observations (2005-2014). [b] HHI = Hirschman-Herfindahl Index.

Control Variables

Three variables (not-for-profit ownership, operating margin and technology) are associated with higher odds of outcome occurring for network, system, contract management, joint venture, and more than one IOR. The odds ratio and *p*-values are close to those found in the first GEE analysis. The most notable odds ratio is that of a hospital with other technologies having robotic surgery. The odds were more than two times higher than those of a hospital without other technologies.

Summary of Findings

Findings can be summarized as those supported, partially supported or not supported by the GEE analysis. Table 11 presents hypotheses, sub-hypotheses and analysis findings. Hypothesis 1 (hospitals engaged in IORs more likely to adopt surgical robots than hospitals not engaged in an IOR) was partially supported, as was Hypothesis 2 (type of IOR being more likely to matter in hospital adoption of a surgical robot).

Table 11

Support for Hypotheses and Sub-hypotheses

Hypothesis / Sub-hypothesis		Finding
$H_{1.0}$	Hospitals engaged in IORs are more likely to adopt surgical robots than hospitals not engaged in an IOR.	Partially Supported
$H_{2.0}$	Type of IOR is more likely to matter in hospital adoption of surgical robot than every IOR having the same effect on hospital adoption of surgical robots.	Partially Supported
$H_{2.1}$	Hospitals engaged in a network are more likely to adopt a surgical robot than hospitals in other forms of IOR.	Supported
$H_{2.2}$	Hospitals in a multihospital system are more likely to adopt a surgical robot than hospitals in other forms of IOR.	Supported
$H_{2.3}$	Hospitals are less likely to adopt a surgical robot when linked with other organizations by contract management than hospitals in other forms of IOR.	Supported
$H_{2.4}$	Hospitals are less likely to adopt a surgical robot when linked by joint venture arrangements with physicians or physician groups than hospitals in other forms of IOR.	Not Supported
$H_{3.0}$	Hospitals that engage in more than one IOR are more likely to adopt a surgical robot than hospitals engaged in just one IOR.	Supported

Hospitals engaged in a network (Hypothesis 2.1), a system (Hypothesis 2.2) or more than one IOR (Hypothesis 3) are more likely to adopt a surgical robot than hospitals not in such an arrangement ($p < 0.001$, $p < 0.001$ and $p < .01$, respectively). There is strong support for these hypotheses and for these three IOR predictors, which lead to the partial support of Hypotheses 1 and 2. These findings were statistically significant and confirm that hospitals engaged in certain types or multiple IORs are more likely to adopt a surgical robot than hospitals not in such an arrangement. Hospitals engaged in a contract management relationship are less likely to adopt a surgical robot than hospitals not in such an arrangement ($p < 0.05$), lending support to Hypotheses 2 and 2.3. The above findings are an important contribution to the understanding of the effects of certain IORs on hospital adoption of technology innovation. Of the four types of IOR studied, only joint ventures (Hypothesis 2.4) did not have statistical significance. While the hypothesis that hospitals engaged in joint ventures being less likely to adopt a surgical robot was not supported (odds ratio of 1.070 and p-value was not significant at 0.506 ($p > 0.05$)), it does not detract from the other findings but offers insight. The default position was that there is no relationship between two measured phenomena. All but one sub-hypothesis are supported or partially supported by the findings, answering the research questions.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The purpose of this study was to determine the effect of IORs on hospital adoption of surgical robots. While research on IORs and the adoption of technology in health care has been limited in scope or focused on just one population of healthcare organizations (Goes & Park, 1997), this study allowed for an analysis of repeated measurements – 27,625 hospital yearly observations – over a ten-year period to explore the relationship of IORs and hospital adoption of surgical robots. To evaluate this longitudinal study, the GEE method (Liang & Zeger, 1986; Diggle, Liang & Zeger, 1994) was employed. This allowed for analysis of repeated measurements of categorical response data to analyze the relationship between IOR types and numbers and hospital adoption of surgical robots. This chapter discusses the findings and their meaning and significance as they relate to research study questions and hypotheses, implications of the findings, recommendations, and conclusions.

Discussion of Findings

The study tested the hypotheses based on responses to the AHA Annual Survey that were analyzed using the GEE method. The overarching proposition was hospitals engaged in IORs in general, specific types of IOR and more than one IOR will be more likely to adopt surgical robots. The overarching hypothesis focused on the effect of IORs on a hospital with surgical robots. Each hypothesis was based on a hospital engaged in a type or number of IOR being likely to adopt a surgical robot than hospitals not in such an arrangement. Table 12 summarizes outcomes from the GEE analyses with hospital with surgical robot as the dependent variable and network, system, contract management, joint venture, and more than one IOR as predictor variables over the study period.

Table 12

Generalized Estimating Equations Analysis of Hospital with Surgical Robot as Dependent Variable – System, Network, Joint Venture, Contract Management, and More Than One IOR

	Hospitals with Robotic Surgery (N=27,625)[a]			
			Wald Confidence Interval for Exp(B)	
Variables	Odds Ratio	*p**	Lower	Upper
IOR Type				
Network Membership				
Yes	1.525	0.000	1.257	1.852
No	*Ref*	*Ref*		
System Affiliation				
Yes	1.839	0.000	1.470	2.299
No	*Ref*	*Ref*		
Contract Management				
Yes	0.561	0.032	0.331	0.951
No	*Ref*	*Ref*		
Joint Venture				
Yes	1.070	0.506	0.876	1.307
No	*Ref*	*Ref*		
Number of IORs				
More Than One IOR				
Yes	1.358	0.001	1.125	1.638
No	*Ref*	*Ref*		

* $p \leq 0.05$
[a] Hospital observations (2005-2014).

Network

Hospitals enter into a network relationship as a strategy to access resources without a long-term commitment of structural and administrative links (Casey, Wellever, & Moscovice, 1997; Goes & Park, 1997; Laumann et al., 1978; Moscovice & Stensland, 2002; Moscovice et al., 1995). The study finding showed strong support for the hypothesis and for networks as a predictor of a hospital being more likely to adopt a surgical robot than hospitals not in such an arrangement ($p < 0.001$). It also supports earlier research findings that networks can influence the adoption of technology innovation of hospitals within a network (Granovetter, 1985; Thorgren et al., 2009). The finding is consistent with studies that showed an increase in interdependence and frequency of exchange between hospitals in networks was associated with an increase in exchange of resources and the likelihood that innovations will increase among members (Goes & Park, 1997; Proenca et al., 2000; Teece, 1992). Findings of this study on network hospital adoption of surgical robots and earlier research studies further strengthen the evidence of hospitals that employ network strategies are more likely to increase the odds of having or adopting a surgical robot or other technology innovations.

System

Of interest in this study was the influence of system affiliation on hospital adoption of surgical robots. Hospitals enter into a system affiliation to access capital, product information and other resources that can enable a hospital to adopt a technology innovation (Burns & Pauly, 2002; Cuellar & Gertler, 2003; Fottler et al., 1982). Findings of this study show strong support for hospitals engaged in a system (Hypothesis 2.2) being more likely to adopt a surgical robot than hospitals not in such an arrangement ($p < 0.001$). The positive relationship between system interorganizational relationships and hospital adoption of surgical robots is consistent with earlier studies that found a positive relationship between the structural links found in multihospital systems and innovation adoption (Goes & Park, 1997; McKinney et al., 1991; Westphal et al., 1997). The finding is also consistent with earlier study findings of systems providing a strategy to address external uncertainties such as changes in medical technology and to gain wider access to resources (Fottler et al., 1982; Goes & Park, 1997; Provan, 1984). It is likely that a hospital being in a system compared to not being in one increases the odds of a hospital having a surgical robot. This would suggest hospitals in systems have access to resources favorable to the adoption of technology innovation and are more likely to be adopters of such technology. The first two findings are important in showing support for Hypothesis 1 that hospitals in an IOR are more likely to adopt surgical robots.

Contract Management

Hospitals enter into this interorganizational relationship to gain access to resources and competencies to address complexities in resource acquisition needed to respond to resource scarcity, uncertainty and competition without surrendering organizational autonomy (Alexander & Morrisey, 1989; Fottler et al., 1982; Goes & Park, 1997; Zinn et al., 1997). However, a finding of this study shows support for hospitals engaged in a contract management relationship being less likely to adopt a surgical robot than hospitals not in such an arrangement ($p < 0.05$). While contract management allows hospitals to gain access to resources and competencies, this does not necessarily transition to the adoption of technology innovation. In fact, as the predictor variable increases, the odds of a hospital with a surgical robot decrease. The finding lends support to Hypothesis 2.3 and is consistent with studies that suggest contract management does not have a significant, positive influence on technology innovation in healthcare services

(Alexander & Morrisey, 1989; Dor, 1994; Goes & Park, 1997). The finding is also consistent with an earlier study that suggested a contract-managed hospital is less likely to have the specialties or resources to adopt innovative technology (Carey & Dor, 2004). The outcome, along with the outcomes of networks and systems, lends support to Hypothesis 2 that posits type of IOR is important to hospital adoption of surgical robots.

Joint Venture

Hospitals engaged in joint ventures with the strategic intent to link the hospital with physicians and/or other organizations that allow access to resources required to adopt technology innovations (Barringer & Harrison, 2000; Goes & Park, 1997) grew over the ten-year study period from baseline of 27.1% to endline of 36.2% of hospitals in such an IOR. However, the finding of this study on joint ventures did not support Hypothesis 2.4 that hospitals in joint ventures are less likely to adopt a surgical robot than hospitals not linked by them ($p > 0.05$). The literature search also did not find any studies with statistically significant findings that supported joint ventures and the adoption of technology innovations. The finding of this study may be more in line with studies that suggested technology innovation leaders do not readily transfer technological expertise to a joint venture unless necessary (Harrigan, 1988) and joint ventures in health care play only a modest role in process innovation not technology innovation (Hennart, 1988; Robinson, 1997). The expectation that hospitals in joint ventures would be less likely to have adopted surgical robots was not supported by the study finding. Of the four types of IOR studied, only joint ventures (Hypothesis 2.4) did not have statistical significance.

This resulted in only partial support for Hypothesis 2.0 that the type of IOR is important to hospital adoption of surgical robots.

More Than One IOR

Hospitals that enter into multiple IORs can involve a high degree of interdependence and access to resources required to adopt technology innovation (Cropper et al., 2008; Galaskiewicz, 1985; Longest, 1990; Luke, Begun, & Pointer, 1989; Provan, 1984). The finding of this study shows support for hospitals engaged in more than one IOR being more likely to adopt a surgical robot than hospitals not in such an arrangement ($p < .01$). The strong support for Hypothesis 3 and multiple IORs as a predictor is consistent with earlier studies that showed positive relationship or suggested organizations, including hospitals, engaged in multiple IORs tend to be more likely to implement a technology innovation (Aiken & Hage, 1968; Goes & Park, 1997; Jenssen & Nybakk, 2013; Pennington & Harianto, 1992). The finding also is consistent with research that stated hospitals enter into more than one IOR arrangement for environmental factors and resources (Burns & Pauly, 2002; Shortell, 1988) and fits well within the resource dependence theory construct.

Resource Dependence

Since a major premise of resource dependence is the concept of interorganizational relationships creating dependencies among organizations at a cost to an organization’s autonomy (Provan, 1984), the hypotheses expected certain types of IOR in the study would be associated with hospital adoption of surgical robots. A hospital’s existing level of access to resources would define what it would concede and the relationship or type of IOR it would enter to access needed resources (Zinn et al., 1997). Findings on network, system and contract management, as discussed above, support earlier findings that certain types of IOR are more likely to lead to adoption than other IOR types (Burns & Wholey, 1993; Granovetter, 1985; Thorgren et al., 2009). Only joint venture did not support this.

Based on analyses results, Hypothesis 1 (hospitals engaged in IORs are more likely to adopt surgical robots than hospitals not engaged in IOR) and Hypothesis 2 (type of IOR is more likely to matter in hospital adoption of a surgical robot) are only partially supported by the findings. This is generally consistent with studies on the adoption of technology innovation that found an association with hospitals (McClellan & Kessler, 2002) and IORs (Goes & Park, 1997). Interorganizational relationships provide an organization access to resources for greater bargaining power (Kaluzny, 1974) and are associated with implementing technology innovation, especially with an organization with limited resources (Hanna & Walsh, 2002; Jenssen & Nybakk, 2013; Najafian & Colabi, 2014). The study findings partially support earlier studies.

Control Variables

Findings revealed there is a statistically significant association between hospitals with surgical robots and a number of the control variables. Specifically, there is statistically significant association between hospitals with surgical robots and number of technologies, operating margin, number of procedures, competition, hospital size, and teaching affiliation. This is in line with other study findings or observations (Basto et al., 2015; Barbash et al., 2014; Barbash & Glied, 2010; CGPSGS, 2015; Coye & Kell, 2006; Cundy et al., 2013; Halabi et al., 2013; Halm et al., 2002; Jin et al., 2011; Kent et al., 2014; Lee, 2014; Li et al., 2014; Makarov et al., 2011; Makarov et al., 2013; Neuner et al., 2012; Steers et al., 2004; Tsui et al., 2013; Yamasato et al., 2014). However, odds ratios for number of procedures and market competition ran counter to earlier studies. While the analysis indicated statistically significant association of number of procedures with hospitals having or adopting robotic surgery, increasing number of procedures does not affect the odds of a hospital having or adopting robotic surgery (OR = 1, $p < .01$). Market competition also showed a statistically significant association with hospitals having or adopting robotic surgery (p-value of 0.000) but lower odds (OR = 0.000).

Three other control variables of interest (teaching hospital, not-for-profit and urban) had odds ratios < 1. While most hospitals with robotic surgery operate in urban areas and have non-government, not-for-profit ownership, the odds ratios of these variables are associated with lower odds of outcome (hospital with robot) occurring.

Strengths of the Study

This study tracked the same hospitals and used repeated observations at the individual hospital level that lent itself to a longitudinal study. This helped to minimize differences observed resulting from a change or difference across time. A strength of doing a longitudinal study was it had more power than a cross-sectional study with regard to observing temporal order and excluding time-invariants and unobserved differences.

The use of a longitudinal study permitted the researcher to discover predictors or indicators of hospitals adopting surgical robots and determine changes in behavior regarding IORs. It further allowed the analysis to determine variable patterns more efficiently over the ten-year period and learn more about cause-and-effect relationships. The study allowed for observation of how a particular set of circumstances such as IORs or an end state (hospital adoption of surgical robots) would occur. This provided for better results in ascertaining long-term changes.

The large amount of AHA Annual Survey data to test the hypotheses was advantageous to the study. The size of the dataset and the recording of data annually helped to ensure a high level of conclusion validity. The sample size was large enough to predict meaningful relationships between the variables studied. It also provided real data to test the statistical model.

Limitations of the Study

There are a few limitations to the study associated with longitudinal studies: the institutional environment and the use of secondary data. The increase in the number of hospitals in systems and changes in the other types of IOR during the ten-year period, including the increase in the number of hospitals in more than one IOR, may be one of the reasons systems, networks and multiple IORs were strong predictors of hospitals with surgical robots. The presence of the various types of IOR and the use of multiple IORs by hospitals may not be present in other industries. While the findings and insights from this study could be generalized to hospital adoption of other technology innovations, they may be less applicable to organizations in other industries.

While the secondary analysis of existing data was crucial to this study, the available data was not specifically collected to address this study’s research questions or test its hypotheses (Cheng & Phillips, n.d.). Individuals who collected the data would not have been aware of study-specific nuances in the data collection that could have been important to interpreting the study variables. They also may have missed or incorrectly gathered and entered data important to this study. This could have accounted for the high number of outliers for hospital operating margins and the quality of joint venture data.

As with the use of any secondary data, the dataset and the associated risk of data collected may not be completely reliable. Because data was collected by AHA annually over a ten-year period, there is an inherent lack of uniform control over the data collection process and what may have happened between observations. The AHA dataset had varied and missing data that might be a result of incomplete surveys or information or the accuracy of information on IORs, robotic surgery, financial, and other data provided by a hospital. Outlier data could have been due to one or more of these concerns given the ten-year period and the large number of observations.

While there are many strengths associated with a longitudinal study, a limitation of conducting a longitudinal study is panel attrition or change. As the AHA Annual Survey relied on the same group of subjects, there is the possibility that some hospitals may not have been able to participate over the whole ten-year period for various reasons, e.g., mergers and acquisitions. New hospital administrations, personnel turnover, new processes, and/or systems also could have affected the collection and quality of data.

Implications for Practice

By analyzing the relations between IORs and hospital adoption of surgical robots over a ten-year period, healthcare executives and policy makers are offered a better understanding of IORs as a competitive strategy to gain access to resources and enable hospitals to adopt surgical robots. A significant contribution of this study is that the findings offer a more complete understanding of variables that affect hospital adoption of technology innovations as it continues to account for a significant portion of capital budgets and operating costs. They also provide insight into the role of IOR type and number in adoption of technology innovation. In a competitive environment where more than 50 percent of the capital budget can go to innovative technologies (and operating margins are declining for a number of hospitals), knowing that hospitals in systems, networks or more than one IOR are more likely to have surgical robots could lead to generalization toward other technologies.

The broader significance of the research might be the difficulty of adopting technology without an IOR strategy in a competitive resource dependent environment. Resource dependency can influence hospital decision makers on strategies and ways to access scarce resources. Depending on organizational factors (e.g., operating margin, technology level and number of procedures), hospitals not engaged in certain types and numbers of IORs may value the findings more than those already engaged in or not in need of such strategies. The findings of network, system and more than one IOR most likely to adopt a surgical robot may help decision makers when deciding to pursue an IOR strategy.

The surprise for decision makers may be the absence of support for joint ventures and hospital adoption of surgical robots. Based on the research, the expectation was joint ventures would not be associated with hospitals with surgical robots. The lack of significance of the findings was surprising. Still, it contributes to the overall understanding of IORs and hospital adoption of technology when evaluating joint ventures as part of a strategy for technology adoption.

Recommendations

The findings of this study afford opportunities for the researcher to explore whether some IORs have or adopt more technologies or adopt differently from others. Or, within the different types of IOR, studies could explore which systems or networks are more likely to be associated with the adoption of technology innovations. Building upon this study, and a limited number of related studies, can lead to a better understanding of IORs and the role of IORs in hospitals' adoption of technologies in an uncertain environment of resource dependence. Given the findings on control variables, such studies might also include the relations of the adoption of technology by hospitals with positive operating margins, high levels of technology, and engaged in certain types of IOR. Future studies might even explore whether certain types of IOR are associated with hospitals that may have discontinued offering robotic surgery.

A future longitudinal study could examine the relationship of IORs and hospitals with surgical robots at various stages of adoption over a ten-year period. As medical technology can account for more than half of a hospital's capital budget and a significant portion of operating costs, this could provide hospitals a better understanding of where in the process, if at all, IORs or certain types of IOR provide access to resources that allow hospitals to innovate. Findings would provide healthcare decision makers insight into the relationship of IOR or types of IOR with hospitals at various stages of technology adoption. Such a study would explore IORs and hospital innovators, early adopters, early majority, late majority, and laggards in the adoption process (Rogers 2003).

Based on one of the findings of this study and the continued integration of healthcare services, physician joint ventures and other interorganizational relationships (e.g., supply chain such as the large group purchasing organizations (GPOs) for hospitals), further research on specific joint ventures or GPOs and hospital adoption of technology innovations would advance the understanding of IORs and hospital adoption of technologies. In this study all outcomes were logical and helped answer the research questions except for the joint venture relationship with hospitals' adoption of surgical robots. While the chi-square test showed a statistically significant relationship between joint venture and hospital with robotic surgery ($p < .001$), the GEE analysis for these variables was statistically insignificant ($p = 0.506$). This could be the result of the need for better fidelity with type of joint venture and the data. This recommendation for further study points to the need to examine closer and better understand these relationships and hospital adoption of technology innovations.

Conclusions

Knowing hospitals are constrained by interdependencies and enter IORs to exchange or acquire resources for capital from the external environment in order to survive (Alexander & Morrissey, 1989; Rossignoli & Ricciardi, 2015), this study employed a resource dependence theory conceptual framework to examine the impact of IORs as a competitive strategy for acute care hospitals to adopt surgical robots. The study specifically explored if type of IOR (networks, systems, contract management, and joint ventures) or being in more than one IOR was associated with hospital adoption of surgical robots. Using the GEE method, which proved to be an effective methodology for examining the research questions and hypotheses, study findings supported or partially supported hospitals that employ IORs, more than one IOR, and certain types of IOR as a strategy are more likely to adopt surgical robots. Findings revealed hospitals with surgical robots are more likely to be in a network or system or more than one IOR and less likely to be in a contract management arrangement. As the relationship between joint ventures and hospitals with surgical robots was not supported, the results could indicate that the question on joint ventures was possibly poorly phrased, ill-conceived or misunderstood by respondents. Except for joint ventures, the findings are consistent with studies noted in the literature search and within the stated framework of the resource dependence theory. The data analyses logically and sequentially addressed all research questions and hypotheses.

The results contribute to the discussion of environmental uncertainty and scarcity of resources leading to hospitals seeking interdependencies to acquire resources for technology innovation and manage uncertainties while minimizing threats to organizational autonomy (Alexander & Morrisey, 1989; Barringer & Harrison, 2000; Harrigan & Newman, 1990; Hillman et al., 2009; Jenssen & Nybakk, 2013; Oliver, 1990; Pfeffer, 1987; Pfeffer & Salancik, 1978; Pfeffer & Salancik, 2003). In exploring whether IORs matter in the adoption of surgical robots, resource dependence theory provided a reasonable framework given the scarcity or competition for resources, tight operating margins, and the high cost to adopt a surgical robot. The significant relationship found between certain types of IOR and/or more than one IOR and hospital adoption of surgical robots implies that IORs capture and rationalize the exchange of resources to adopt technologies, in line with the RDT construct. The significant positive relationship between networks, systems or being in more than one IOR and hospital adoption of surgical robots suggests that these interorganizational links help hospitals overcome resource dependence. This is consistent with the findings put forth in earlier studies that organizations in uncertain environments will engage in IORs to gain access to resources and stability. Study results suggest that these IORs are important strategies by which hospitals can adopt technology innovations while managing environmental uncertainty.

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APPENDIX

IRB NSHR DETERMINATION

THE UNIVERSITY OF ALABAMA AT BIRMINGHAM

Office of the Institutional Review Board for Human Use

470 Administration Building
701 20th Street South
Birmingham, AL 35294-0104
205.934.3789 | Fax 205.934.1301 | irb@uab.edu

NHSR DETERMINATION

TO: Cullen, Stephen G

FROM: University of Alabama at Birmingham Institutional Review Board
Federalwide Assurance Number FWA00005960
IORG Registration # IRB00000196 (IRB 01)
IORG Registration # IRB00000726 (IRB 02)

DATE: 16-Mar-2018

RE: IRB-300000354
INTERORGANIZATIONAL LINKS AND HOSPITAL ADOPTION OF SURGICAL ROBOT

The Office of the IRB has reviewed your Application for Not Human Subjects Research Designation for the above referenced project.

The reviewer has determined this project is not subject to FDA regulations and is not Human Subjects Research. Note that any changes to the project should be resubmitted to the Office of the IRB for determination.

if you have questions or concerns, please contact the Office of the IRB at 205-934-3789.