# An Integral Choice? Exploring Human Capital Integration as an Antecedent of Technology Adoption

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## ABSTRACT

I explore the link between human capital strategy and technology strategy by exploring one element of a firm's human capital strategy as an antecedent of technology adoption: whether a firm chooses an integrated or unintegrated relationship with the human capital needed to create value from a new technology. While it has been established that technological change can drive integration decisions, I establish contingencies for when integration may actually be a prerequisite for technology adoption. Analyzing the technology adoption decisions of U.S. hospitals, I find that hospitals that have integrated physicians as employees are more likely to adopt a new technology than hospitals that maintain an unintegrated relationship with physicians when the technology is paradigm-changing rather than paradigm-deepening, the new paradigm is still nascent, and local markets are competitive. Leveraging variation in state laws prohibiting the employment of physicians, I provide suggestive evidence that frictions impeding the integration of human capital may delay the adoption of paradigm-changing technologies. Thus, this paper finds that an integration strategy is linked to an early adopter technology strategy, but only for paradigm-changing technologies in competitive markets. It also sheds light on how obstacles to integration can preclude an early adopter strategy, and how choices related to organizational structure may ultimately shape patterns of technology adoption.

**Keywords**: technology investment, technology adoption, human capital, firm boundaries

## INTRODUCTION

The link between organizational structure and how firms respond to technological change is under-studied (Eggers and Park 2018). Emerging technologies such as robotics and artificial intelligence have brought renewed attention to how new technologies can change how firms organize (e.g., Bailey et al. 2019). However, there has been far less consideration of how the way a firm is organized may shape the decision to adopt a new technology in the first place. In particular, creating and capturing value from a new technology will ultimately depend, in part, on how a firm manages its relationships with individuals whose human capital will be critical to creating value from the new technology (Barley 1986, 1990, Leonard-Barton and Deschamps 1988, Orlikowski 1992, Tyre and Orlikowski 1994). Understanding the interplay between the structure of these relationships and selection into new technologies is an important piece of the technology-organizational structure puzzle because whether and when a firm adopts a new technology ultimately shapes the challenges a firm will confront in creating and capturing value from the technology, with consequences for firm performance that can be long-lasting (e.g., Eggers 2014, Garud et al. 1997, Hall and Khan 2003).

In this paper, I examine one key dimension of organizational structure as an antecedent of technology adoption: whether firms have an integrated or unintegrated relationship with human capital that will be relevant to creating value from a new technology. Human capital is an individual’s knowledge and skill that is relevant for achieving economic outcomes, such as creating value from a new technology (Ployhart et al. 2014). Creating value from a new technology requires the cooperation and coordination of individuals who have the human capital needed to use the technology to improve processes or product offerings (e.g., Leonard-Barton 1988, Orlikowski 1992). For example, an airline adopting a new navigation technology or a hospital adopting a new robotic surgery system will the cooperation and coordination of pilots and physicians, respectively. Capturing value requires managing the risk that these individuals engage in expropriative (Singh and Agrawal 2011) or opportunistic (Becker 1964, Williamson 1985) behavior. When confronted with a new technology, firms can access the human capital they need through an integrated relationship, where an individual holding relevant human capital is an employee of the firm. Or they can access it through an unintegrated relationship in which market-based contracts govern the relationship between the firm and individual, such as when an individual provides a service to the firm as an independent contractor.

I ask: Are firms more or less likely to adopt a new technology if they have an integrated rather than unintegrated relationship with individuals holding human capital that will be relevant to creating value from the technology? Research indicates that the need to innovate can be an important trigger for firms to integrate human capital (Chatterji et al. 2019, Mayer and Nickerson 2005, Monteverde and Teece 1982), suggesting that technology adoption, or anticipation of technology adoption, can actually be an antecedent of human capital integration. But this research does not provide insight into the extent to which an integrated relationship is a *prerequisite* for technology adoption. This is an important gap because organizational and environmental conditions can preclude firms from organizing human capital in a particular way, and changing the structure of relationships can be costly and time-consuming (Mahoney and Qian 2013, Nickerson and Silverman 2003). Developing a better understanding of how human capital integration and technology strategy are linked, and how frictions on integration may delay technology adoption, can enrich our understanding of the challenges firms face in navigating technological change.

Studies of firm boundaries as an antecedent of technology investment are rare, but an important exception is Kapoor and Lee's (2013) finding that integrated firms are no more likely than firms that do not integrate human capital to adopt a new technology. While integration is often associated with advantages in cooperation, coordination, and value appropriation, they argue that the costs of integration offset any benefits that may have otherwise increased the likelihood of adoption. However, research examining human capital integration from both transaction cost economics (Mayer and Nickerson 2005) and relational governance (Chatterji et al. 2019) perspectives finds that, notwithstanding the costs of integration, the relative advantage of integration for solving problems of cooperation, coordination, and loyalty is context-dependent. Hence, there may be heterogeneity in the effect of human capital integration on technology adoption.

I explore this possibility by considering how the relative advantage of human capital integration may vary within and across technology paradigms (Ahuja et al. 2014, Dosi 1982, Sahal 1985, Silverberg et al. 1988). A technological paradigm defines a particular set of problems and a pattern of solutions to those problems regarding the scientific principles and material technology to be used (Dosi 1988). Synthesizing prior findings about the relative advantage of human capital integration in solving the problems of cooperation, coordination, and loyalty (Chatterji et al. 2019, Mayer and Nickerson 2005) along with insights from the strategic human capital literature regarding when individuals are likely to want to use a new technology (e.g., Coff and Raffiee 2015, Wang and Barney 2006), I theorize that it is important to distinguish whether a technology is "paradigm-deepening" versus "paradigm-changing." Following Ahuja et al. (2014), a paradigm-deepening technology advances existing technological paradigms, while a paradigm-changing technology represents a new technological paradigm. I hypothesize that having an integrated relationship with relevant human capital is a stronger antecedent of technology adoption when the technology is more paradigm-changing than paradigm-deepening. Probing underlying mechanisms leads to the additional hypotheses that the effect of integration on the adoption of paradigm-changing technologies will be smaller as new technological paradigms mature and in less competitive local markets.

One reason for the dearth of research studying human capital integration—as well as firm boundaries more broadly defined—as an antecedent of technology adoption is that it is challenging to identify a setting that offers comparable firms being confronted by comparable new technologies while also providing sufficient variation in integration choices. However, I test my arguments in a context that meets these criteria: hospital adoption of new technologies in the United States. I examine whether hospitals that integrate physicians as employees adopt new technologies sooner or later than hospitals that have an unintegrated relationship with physicians. There is considerable variation in physician integration among hospitals, and it is also a context in which I can identify and analyze the adoption of technologies that differ in the degree to which they are paradigm-changing versus paradigm-deepening. Finally, the presence of corporate practice of medicine laws in certain states prevents hospitals in those states from employing physicians. This feature allows me to explore the extent to which any observed relationship between human capital and technology adoption is purely the result of selection or whether frictions that inhibit integration might constrain technology adoption.

I find support for the notion that the relationship between human capital integration and technology adoption is contingent in its nature. First, I demonstrate that the type of human capital in question matters. It has been argued in prior research that unintegrated firms may respond to technological change faster when new technologies render individuals' human capital obsolete to the firm (e.g., Matusik and Hill 1998, Schilling and Steensma 2001), but I find conditions under which unintegrated firms can be slower to adopt a new technology when individuals' human capital is relevant to creating and capturing value from the technology. Second, while prior research finds no evidence that integrating relevant human capital increases technology adoption (e.g., Kapoor and Lee 2013), I find the relationship to be contingent on the type of technology as well as technological paradigm maturity and local market competition. I also provide suggestive evidence that firms subject to frictions on integrating the relevant human capital are slower to adopt paradigm-changing technologies.

Overall, while the findings should be interpreted cautiously given this study examines only one industry, the study offers novel, nuanced insights into the relationship between human capital integration and technology adoption decisions while raising new questions about the interplay between human capital organization and responses to new technologies. This paper also demonstrates the value of combining firm boundaries and strategic human capital perspectives along with a technology paradigms framework to uncover sources of heterogeneity in technology adoption.

## THEORY & HYPOTHESES

Firms decide whether to adopt a new technology at a given point in time based, in part, on expectations about creating and capturing value from the technology (Hall and Khan 2003, Kapoor and Lee 2013, Silverberg et al. 1988). Human capital relationships are critical to value creation (Barley 1986, 1990, Leonard-Barton 1988, Leonard-Barton and Deschamps 1988, Orlikowski 1992) and capture (Pisano 1990, Singh and Agrawal 2011) from new technologies. As alternatives to traditional employment for structuring relationships with human capital become more relevant (Anderson and Bidwell 2019, Business Talent Group 2021, Cappelli and Keller 2013, Katz and Krueger 2019), it is important to examine the implications of this element of human capital strategy for technology adoption decisions.

Existing research shows that the need to innovate or create new knowledge can affect firms' integration choices concerning human capital (Chatterji et al. 2019, Mayer and Nickerson 2005), suggesting technology adoption or anticipation of technology adoption can be an antecedent of human capital integration. This paper aims to complement that research by exploring human capital integration as an antecedent of technology adoption. Even if the anticipation of technology adoption influences integration decisions among some firms, to what extent are integrated firms really more or less likely to invest in a technology than unintegrated firms?

It has been suggested that having an unintegrated relationship with human capital, such as an independent contracting relationship, hastens incumbent responses to technological change (e.g., Matusik and Hill 1998, Schilling and Steensma 2001). Greater flexibility to end relationships with individuals whose human capital is no longer relevant to the firm can benefit firm innovation (Keum 2020), and it is easier to end unintegrated, market-based relationships than employment relationships (Cappelli and Keller 2013). But these arguments do not apply when the human capital in question will be relevant for creating value from the technology. In one of the few studies examining how firm boundary choices concerning human capital that will be relevant to creating value from a new technology may affect technology adoption, Kapoor and Lee (2013) examine how firms organize with respect to their complementors and find no evidence that integration increases the likelihood of technology adoption. They posit that the costs of organization offset any advantages integration might offer.

I propose that contingencies for when human capital integration is an antecedent of technology adoption can be uncovered by taking a theoretical approach that combines a technology life cycle framework (e.g., Ahuja et al. 2014, Dosi 1982, Rosenberg 1982, Silverberg et al. 1988) with a contingent view of relational governance (e.g., Chatterji et al. 2019, Mayer and Nickerson 2005) and insights from the strategic human capital literature (e.g., Becker 1964, Coff 1997, Coff and Raffiee 2015). To lay the foundation for this approach, I begin by characterizing the human capital challenge associated with technology adoption.

## Technology Adoption and the Human Capital Challenge

Firms create value from new technologies by using them to improve processes or product and service offerings, and they rely on individuals to do this: firms need individuals with relevant human capital to (1) apply the relevant knowledge and skill that they already possess, (2) develop, assimilate, and apply new knowledge and skill as needed, and (3) make any necessary changes to their roles and patterns of interpersonal interaction within the firm (Barley 1986, 1990, Leonard-Barton 1988, Orlikowski 1992, Tyre and Orlikowski 1994). This is a problem of cooperation (Gulati et al. 2005). The individuals must also be able to align their actions as they engage in these activities, recognizing and navigating any task interdependencies (Barley 1986, 1990, Leonard-Barton 1988). This is a problem of coordination (Gulati et al. 2005).

To then capture value from a new technology, firms will need to be able to manage the risk that the individuals who are instrumental in creating value from the new technology will leave or wield the possibility of leaving opportunistically. To the extent that the relevant human capital is rare or that developing it has required relationship-specific investments on the part of the firm, the individuals may be in a position to take value created from the technology for themselves (Becker 1964, Coff 1997, Williamson 1975). Individuals can also engage in expropriative behavior, diffusing the knowledge and skills relevant to the new technology to competitors who can then leverage the knowledge and skill for advantage (Alcácer and Zhao 2012, Singh and Agrawal 2011). I will refer to this as the problem of loyalty.

A challenge for firm management when confronted with a new technology is that it is difficult to ensure ex ante that the firm will be able to solve the problems of cooperation, coordination, and loyalty. Forging a complete contract for cooperation, coordination, and loyalty can be prohibitively challenging. The specifics of the activities for which firms will need cooperation and coordination are typically uncertain ex ante given that a technology can evolve in unpredictable ways, as can the processes of learning and adapting (Dixit and Pindyck 2012, Hall and Khan 2003, McGrath 1997). Contracting on the outcome ex ante can be equally difficult, as this requires parties to agree upon realistic, objective measures of the quality of individuals' efforts ex ante, yet uncertainty about the technical properties of the technology and how the technology will evolve makes it difficult to establish what success can or should look like (Manso 2011, Mayer and Nickerson 2005). Finally, no contract can force the loyalty of individuals. Firms may try to minimize vulnerability to value appropriation through the implementation of non-compete clauses, patenting, and exploiting trade secret law, but these are imperfect solutions (Shapiro et al. 1999).

The less assurance that the problems of cooperation, coordination, and loyalty will be solved when a firm invests in a new technology, the greater the risk that the firm will ultimately incur the costs of adoption without ever realizing the benefits. In light of this challenge, choices about how to organize human capital relationships become relevant to the technology adoption decision to the extent that such choices can provide more or less assurance about achieving cooperation, coordination, and loyalty. In particular, firms have a choice about how to structure their relationships with the individuals from whom they need cooperation, coordination, and loyalty: they can integrate the individuals as employees, or they can maintain an unintegrated relationship through, for example, independent contracting.

## Human Capital Integration and Technology Adoption

Integration is often associated with advantages in solving problems of cooperation, coordination, and loyalty, especially when there is ex ante uncertainty about the tasks for cooperation and coordination and a need for relationship-specific investments (e.g., Simon 1951, Williamson 1975). Traditionally, this advantage is rooted in directive control, i.e., the ability to solicit cooperation and coordination by fiat (Cappelli and Keller 2013, Internal Revenue Service, Simon 1951, Williamson 1975). Integration also offers managers the ability to mix salaried compensation with supplemental forms of compensation like profit-sharing, bonuses, and promotion (Baker et al. 1994, Lazear and Rosen 1981, Williamson 1975, 1991), which can be useful when the exercise of directive control is in doubt.[1] The lower-powered productivity incentives of a salary can give individuals the bandwidth to develop new knowledge and skill while the supplemental forms of compensation can be used to more precisely tailor incentives for cooperation and coordination. All this stands in contrast to the relatively rigid incentive structure for unintegrated human capital, where terms of compensation are well-defined ex ante.

Furthermore, integration is associated with a mutual expectation of a longer, continuous relationship that emerges between a firm and integrated individuals (Anderson and Bidwell 2019, McLean Parks et al. 1998, Pearce 1993, Williamson 1985). The expectation of a longer, continuous relationship improves the likelihood of cooperation by improving individual identification with organizational goals and performance (Ang and Slaughter 2001, Bidwell 2009, Chatman 1991, Dukerich et al. 2002, Tsui et al. 1997). It also improves coordination by facilitating the development of relational capital in the form of trust, routines, norms of behavior, and codes of communication (Chatterji et al. 2019). Finally, while integration does not solve the problem of loyalty since it does not confer ownership of the individual (Coff 1997), an expectation of a continuous relationship can minimize expropriative behavior as well.

Yet the possibility of repeat contracting with unintegrated individuals introduces relational governance mechanisms that can provide sufficient incentive to cooperate and accept coordinative direction. The mutual expectation of a continuous relationship may not be as strong as that between a firm and integrated individuals, but the possibility of repeat contracting nonetheless introduces the "shadow of the future" to the relationship that can incentivize cooperation (Baker et al. 2002). Repeated interaction also fosters the development of the relational capital that facilitates coordination (Chatterji et al. 2019, Gulati et al. 2005). Relational governance mechanisms may reduce concerns about value appropriation as well by reducing individuals' incentives to engage in expropriative behavior (Baker et al. 2002, Elfenbein and Zenger 2014, Poppo and Zenger 2002).

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[1] While legally-conferred directive control is the sharpest distinguishing feature of the employment relationship, there are limits to the exercise of control within the firm (Barnard 1938, Gibbons 2005, Simon 1951).

Prior research examining human capital integration choices from both transaction cost economics (Mayer and Nickerson 2005) and relational governance (Chatterji et al. 2019) perspectives finds conditions under which, notwithstanding the costs of integration, human capital integration can carry advantages in cooperation, coordination, and loyalty even when there is accumulated relational capital with unintegrated individuals and the shadow of the future looms. Synthesizing this research in combination with insights from the strategic human capital literature about when individuals are more likely to invest in new knowledge and skill (e.g., Coff and Raffiee 2015, Wang and Barney 2006), there are at least three conditions under which human capital integration is likely to hold a relative advantage in facilitating cooperation, coordination, and loyalty.

First, prior research indicates that the relative advantage of integration increases when the development of relational capital is interrupted (Chatterji et al. 2019). Any accumulated relational capital that can facilitate cooperation and coordination can lose value if, for example, individuals will no longer interact with the members of the firm with whom they had developed trust and norms or if the context in which they interact is so different that the trust and norms are no longer relevant (Chatterji et al. 2019). In the absence of relevant relational capital, integration becomes more advantageous as both legally-conferred directive control and the stronger interest alignment enabled by greater incentive structure flexibility and longer expected continuity of association increase the likelihood that individuals will cooperate and accept coordinative direction from management.

Second, as uncertainty about the net private benefits of cooperation for individuals increases, the more advantageous integration. Unintegrated individuals may be sufficiently willing to cooperate and accept coordinative direction even in the absence of relevant relational capital if the net private benefits of cooperation for the individual are sufficiently high—for example if productivity gains are expected to be large enough or the knowledge and skills needed to create value from the technology are expected to carry enough value in the labor market to outweigh the costs of developing them (Coff and Raffiee 2015, Knight 2015, Wang and Barney 2006). But as uncertainty about either these benefits or the cost of acquiring them increases, integration's directive control and the stronger interest alignment enabled by greater incentive structure flexibility and a longer expected continuity of association again increase the likelihood that cooperation and accepting coordinative direction will be attractive (Chatman 1991, Dukerich et al. 2002, Wang et al. 2009, Wang and Barney 2006). Furthermore, greater incentive structure flexibility also makes it easier to attract and retain the kind of individuals who have a predisposition to cooperate in working with new technologies despite uncertainty about net private benefits with respect to productivity and potential labor market value (e.g., Burns and Muller 2008, Lucht 2009).

Finally, research indicates that the advantage of integration is larger when the cost of potential expropriation is higher (Mayer and Nickerson 2005, Pisano 1990). Even if there is an expectation of a future relationship with unintegrated individuals, legislative and regulatory policies make it costlier to hire and fire integrated rather than unintegrated individuals (Bidwell 2009, Cappelli and Keller 2013), and integrated individuals are less likely to have the complementary assets needed to redeploy their skills and knowledge elsewhere (Mayer and Nickerson 2005). Thus, integration still holds a relative advantage in mitigating the problem of loyalty, and this becomes more relevant the higher the cost of potential expropriation (Mayer and Nickerson 2005).

Given these conditions, integration is more likely to be associated with technology adoption when (1) the development of relational capital is disrupted, (2) the net private benefits of cooperation are uncertain, and (3) the cost of potential expropriation is high. I explore this possibility by considering how these conditions vary within and across technology paradigms.

### Human Capital Integration as an Antecedent of Paradigm-changing vs Paradigm-deepening Technologies

Technological progress is often characterized as progressing along trajectories marked by a particular set of economic and technological trade-offs given by the current technological paradigm (Dosi 1982, 1988, Sahal 1985). A technological paradigm "defines contextually the needs that are meant to be fulfilled, the scientific principles utilized for the task, the material technology to be used," (Dosi 1988, p. 1127). In other words, technological paradigms define a particular set of problems and a pattern of solutions to those problems (Dosi 1988). "Paradigm-deepening" technologies advance existing technological trajectories, building on cumulated knowledge from prior advances within the bounds of the paradigm's technological and economic guideposts, whereas "paradigm-changing" technologies represent new technological paradigms, introducing new patterns of inquiry under different sets of techno-economic tradeoffs (Ahuja et al. 2014).

The development of relational capital is more likely to be disrupted in the process of creating value from a paradigm-changing technology relative to paradigm-deepening technologies because creating value from paradigm-changing innovations is more likely to require changes to roles and patterns of interpersonal interaction (Rosenberg 1982, Silverberg et al. 1988). This increases the likelihood that any preexisting routines and norms for interpersonal interaction that may have otherwise facilitated voluntary cooperation and coordination lose relevance as individuals interact with new individuals or in new contexts (Chatterji et al. 2019).

The net private benefits of cooperation are more uncertain for paradigm-changing technologies than paradigm-deepening technologies because paradigm-changing technologies require individuals to develop more new-to-the-world knowledge and skill (Rosenberg 1982, Silverberg et al. 1988). There is naturally more ex ante uncertainty about the degree to which new-to-the-world knowledge and skill will result in productivity gains or redeploy to other firms (Silverberg et al. 1988). Paradigm-changing technologies also require a longer period of mutual adaptation (Rosenberg 1982, Silverberg et al. 1988), in which the producer of the technology continues to modify and improve it in response to feedback from users (von Hippel 1994, Leonard-Barton 1988, Rosenberg 1982). The prospect of a longer period of mutual adaptation increases uncertainty about how the technology itself will evolve (Dosi 1982, Rosenberg 1982, Silverberg et al. 1988), again making it difficult to anticipate productivity gains or how any new knowledge and skill will be valued in the labor market. The need to develop new-to-the-world knowledge and skill and a longer mutual adaptation process also increase uncertainty about the private costs of cooperation as there is less likely to be relevant priors to inform expectations about the time and resources required (Silverberg et al. 1988).

Finally, the cost of potential expropriation is higher because not only will the firm have to invest relationship-specific time and resources enabling the relevant individuals to develop knowledge and skill, but the lack of a robust supply of that knowledge and skill itself opens up opportunities for opportunism (Becker 1964, Williamson 1985). Even if the new knowledge and skill developed by the individual is largely firm-specific, the risk that the individuals eventually leave the firm remains and individuals retain the power to appropriate value.

Thus, paradigm-changing technologies are more likely to produce conditions under which prior literature has established that the relative advantage of human capital integration for solving the problems of cooperation, coordination, and loyalty is higher. Therefore, I expect a stronger link between technology adoption and human capital integration when a technology is paradigm-changing. Yet a stronger link does not necessarily imply that firms that do not have an integrated relationship with relevant human capital are less likely to adopt a new paradigm-changing technology than firms that do have an integrated relationship. Setting up an employment relationship requires time and resources, and both organizational and environmental frictions can obstruct such efforts (Mahoney and Qian 2013, Nickerson and Silverman 2003). Deferring adoption until such frictions can be overcome often means ceding to competitors opportunities to build difficult-to-surmount advantages in reputation, brand, knowledge, experience, or intellectual property to competitors (Hall and Khan 2003, Lieberman and Montgomery 1988, Schilling 1998, Spence 1981). Thus, firms facing organizational or environmental frictions on integration may choose either to adopt the paradigm-changing technology first and then integrate or to try to create and capture value with unintegrated human capital despite the advantages of integration.

However, a firm will not be able to create value from a paradigm-changing technology—never mind building advantages for itself in productivity, knowledge, and experience—if the relevant individuals do not cooperate or prove incapable of coordination. Efforts to burnish a reputational advantage by investing early in new paradigm-changing technologies are also jeopardized if those technologies ultimately fail to be a source of value. Adopting without establishing the infrastructure for employment increases the risk that the costs of adoption are incurred while the benefits are never realized. Even if the firm integrates following adoption, while the firm is putting time and resources into integration it has also taken on the risk that the technology evolves unexpectedly or a different standard or dominant design emerges (Anderson and Tushman 1990, Garud et al. 1997, Hall and Khan 2003, Lieberman and Montgomery 1988, Schilling 1998, Spence 1981).

Therefore, I expect that firms that have established an integrated relationship with the type of human capital that will be relevant to creating value from a new technology will be more likely to adopt it than firms that have an unintegrated relationship when the technology is paradigm-changing rather than paradigm-deepening.

*Hypothesis 1: Integration is associated with a larger increase in the probability of adoption of a new technology for paradigm-changing technologies than paradigm-deepening technologies.*

### Exploring Mechanism Implications: Integration and Adoption as a New Paradigm Matures

The basis for the hypothesis that integration will be associated with a higher probability of technology adoption when a technology is paradigm-changing rather than paradigm-deepening is that paradigm-changing technologies are more likely to disrupt the development of relational capital, present more uncertainty about the net benefits of cooperation for individuals, and are associated with a higher cost of expropriation. However, as a new technological paradigm matures, these distinguishing features of a paradigm-changing technology begin to fade, and the tradeoffs concerning the decision to adopt a paradigm-changing technology shift.

As a new technological paradigm matures, there are two important developments. First, the need to develop new-to-the-world knowledge and skill in order to create value from the technology dissipates. Creating value from the technology may require new-to-the-firm knowledge and skill, but an external supply of that knowledge and skill becomes available as individuals at early adopter firms are available to move to other firms while producers of the technology and/or other third parties begin to diffuse the knowledge and skill through operating manuals, training courses, or degree programs (Silverberg et al. 1988). Second, the period of mutual adaptation eventually wanes as consensus emerges around key technical and performance attributes of the technology (Anderson and Tushman 1990, Dosi 1982, Leonard-Barton 1988, Sahal 1985).

One implication is that uncertainty about the net private benefit of cooperation declines, making it easier both to assess whether the net private benefit will be positive enough to induce cooperation and to alter formal contracts to incentivize cooperation when it is not. Consensus around key performance attributes of the technology reduces uncertainty about the benefits of cooperation in terms of productivity gains and the labor market value of the new knowledge and skills (Silverberg et al. 1988). Consensus around the nature of the knowledge and skill needed to use the new technology as well as the emergence of more well-defined training programs reduces uncertainty about the time and effort the learning process will require. An external supply of the requisite knowledge and skill also makes it possible for firms to by-step the learning process associated with cooperation altogether by contracting with individuals who already have the requisite knowledge and skill.

Another implication is that the cost of expropriation decreases. Later adopters have already forgone the possibility of building the advantages in knowledge or experience associated with early adoption, meaning the costs of an individual taking her knowledge and skill to a competitor are lower. The growing external supply of individuals with the requisite knowledge and skill to create value from the technology also reduces the extent to which firms have to make relationship-specific investments in individuals' training. The overall bargaining power of individuals therefore declines, reducing opportunities for individuals to wield the threat of leaving opportunistically.

Finally, changes to interpersonal interactions may still disrupt the development of relational capital, but without the need to develop new-to-the-world knowledge and skill and to navigate a period of mutual adaptation, both the cooperative and coordinative challenges are smaller. Therefore, I hypothesize that integration should be more positively associated with technology adoption when the new technological paradigm is still nascent, becoming less positive as the technological paradigm matures.

*Hypothesis 2: For paradigm-changing technologies, the effect of integration on adoption of paradigm-changing versus paradigm-deepening technologies is less positive as the new technological paradigm matures.*

**Exploring Mechanism Implications: Integration and Adoption in Competitive Markets**

Another implication of the proposed mechanisms for the more positive relationship between integration and adoption of paradigm-changing technologies is that if the cost of expropriation is one of the key reasons why integration is more positively associated with technology adoption for paradigm-changing technologies, then the relationship between integration and technology adoption for a given paradigm-changing technology at a given point in time should be more positive when expropriation is either more likely or more costly (Mayer and Nickerson 2005, Pisano 1990).

Expropriation is both more likely and more costly in more competitive markets, as there are more firms with incentive to try to access and leverage competitors' knowledge and skill for their benefit (Pisano 1990). It is especially likely in competitive local markets, as expropriation is easier when firms are collocated in the same geographic area (Alcácer and Zhao 2012, Myles Shaver and Flyer 2000). There is more intermingling of individuals associated with different firms, which can lead to knowledge spillovers; furthermore, there are relatively fewer frictions with respect to individuals switching firms. For example, when there are no other local competitors, then moving-related frictions may dampen the problem of loyalty. But when there are many firms in close geographic proximity, then all else equal, it is relatively easier for individuals to jump to other firms and redeploy knowledge and skill related to a new technology. Thus, I hypothesize that for paradigm-changing technologies, the relationship between integration and adoption is more positive in more competitive local markets.

*Hypothesis 3: For paradigm-changing technologies, the effect of integration on the adoption of paradigm-changing versus paradigm-deepening technologies is more positive in more competitive local markets.*

## EMPIRICAL APPROACH

### Context

I test the hypotheses in the context of hospital adoption of new technologies among non-federal, general acute care and surgical specialist hospitals in the U.S., where physicians are individuals whose human capital is needed to create value from the new technologies. A hospital may maintain an arm’s length relationship with physicians, where the hospital and physician remain legally separate entities.

Alternatively, a hospital may choose to integrate physicians as legally-defined employees.  I analyze whether hospitals that employ physicians are more likely to adopt new technologies than hospitals that keep an arms-length relationship with physicians.

There are several features of hospital technology adoption that make it a useful setting for examining the relationship between technology adoption and human capital integration. First, hospital adoption of new technologies in the U.S. has been studied extensively, and industry-specific antecedents are well-documented over time, including during my sample period. Consistent with the theorizing of this paper, the healthcare economics and healthcare policy literature has firmly established that hospital executives consider physicians' cooperation, coordination, and loyalty in deciding whether to adopt new technologies (Burns et al. 2011, Burns and Muller 2008, Coye and Kell 2006, Friedman and Goes 2000). More broadly, the ability to draw on a wealth of existing research documenting how hospital executives approach technology adoption enables me to consider and account for alternative explanations.

Second, there is sufficient variation among hospitals in whether they employ physicians or keep an arms-length relationship, and both the reasons why hospitals choose to integrate physicians or not and the reasons why physicians become employees or stay unintegrated are well-documented. I provide a detailed summary of trends of hospital-physician integration over the past 50 years in Appendix A and use this context to inform my empirical design. Again consistent with the theorizing of this paper, surveys of hospital administrators indicate that hospital executives associate integration with advantages in physician cooperation, coordination, and loyalty (Burns and Muller 2008).

For example, the leaders of the Cleveland Clinic in Ohio believe that they are better equipped to engage in and navigate new and "revolutionary" opportunities because their physicians are salaried employees of the Clinic (Porter and Teisberg 2019). This belief is grounded in each of the three distinguishing features of the employment relationship that have been highlighted in this paper. Consistent with the directive control mechanism, hospital administrators cited the fact that integrated physicians must obey administrative ordinances as an advantage of integration in navigating change, whereas unintegrated physicians have no obligation to obey administrative ordinances (Porter and

Teisberg 2019). Consistent with adaptive advantages of greater incentive structure flexibility, Cleveland Clinic administrators leverage the lower-powered productivity incentives of a salary combined with more subjective bonuses and rewards for excellence to attract and retain physicians and to solicit cooperation and coordination (Porter and Teisberg 2019). Consistent with a mutual expectation of a continuous association facilitating alignment of interests, administrators believe that employed physicians are more engaged and invested in organizational initiatives (Porter and Teisberg 2019).

Third, the setting offers an exogenous constraint on hospital-physician integration in the form of state corporate practice of medicine laws. The theorizing in this paper endogenizes integration and adoption in the sense that it is assumed that integrated firms may be more likely to adopt a new technology at a given point in time because firms integrate either in anticipation of the adoption of a new technology or as a strategy to be prepared to adopt new technologies as they emerge. Nonetheless, measurement error in whether hospitals are integrated can bias results. The theorizing also implies that there may be unintegrated firms that would have adopted a paradigm-changing technology sooner if not for obstacles—whether environmental or organizational—to integration. To address the former issue and explore the latter, I exploit variation in state corporate practice of medicine laws, where certain states prevent hospitals in those states from employing physicians.

Fourth, the setting allows me to examine the adoption of two technologies that are comparable on features such as costs and the physicians who will use them but differ in the extent to which they are paradigm-changing versus paradigm-deepening. The two technologies are robotic surgery and 64+-slice multi-slice computed tomography (64+ MSCT). For both technologies, hospital executives make the final adoption decision, regardless of the relationship the hospital has with physicians. The upfront costs and maintenance costs associated with adoption are comparable (Barbash and Glied 2010, Fornell 2010). Both technologies seemed to offer advantages on certain key performance dimensions when introduced, but it was unclear whether the benefits would be worth the costs (Chitwood et al. 2001, Fornell 2010).

Both technologies can be used across multiple surgical specialties (Hayes, 2006; Soomro et al., 2019). Although radiologic technicians and radiologists play important roles in creating value from 64+

MSCT, surgeons across specialties are linchpins of value creation; they decide to order images, they read the images themselves, and they use the images to inform operating decisions (Bolan 2008, Donners et al. 2021, Epstein et al. 2015, Matsumoto et al. 2011, Tzou et al. 2018). Although nurses and scrub technicians play important roles in creating value from robotic surgery, surgeons are again linchpins of value creation as they decide to use the robotic system as opposed to traditional methods and they must use the console to operate the robot (Beane 2019).

However, 64+ MSCT represents a paradigm-deepening technology while robotic surgery represents a more paradigm-changing technology. I provide a detailed justification for this distinction in Appendix B. But in summary, 64+ MSCT deepened an established paradigm for diagnostic imaging. The well-defined problem was to produce cross-sectional images of internal anatomy using x-ray technology while minimizing patient exposure to radiation and maximizing image quality. The 64+ CT scanner introduced in 2004 reflected an established pattern of solutions to that problem: increasing the number of detectors on CT scanners from one to four to sixteen to sixty-four and beyond. There was little uncertainty about what new knowledge and skill was needed, little disruption to existing patterns of interaction among physicians and other hospital staff, and training time involved only a few days (Hayes, 2006). For the surgeons ordering and reading images, the technology looks and operates similarly to prior iterations and produces very similar images (Arthurs et al. 2009, Fornell 2010).

Robotic surgery, on the other hand, represented a new technological paradigm—a fundamental departure in both physician use of robots in healthcare settings and the underlying technology used (Beane 2019, Joseph et al. 2005). Creating value required changes to patterns of interpersonal interactions among surgeons and staff within the operating room, developing new-to-the-world knowledge and skill, and navigating a period of mutual adaptation (Beane 2019, Chitwood et al. 2001, Herrell and Smith 2005, Joseph et al. 2005, Steinberg et al. 2008).

## Data & Sample

I use data from the American Hospital Association's (AHA) annual survey to create a dataset spanning the years 2003-2015. The AHA surveys are the gold standard for data on U.S. hospital characteristics, including physician integration choices and adoption of new technologies. I was unable to obtain AHA data for the year 2004, so I extrapolated hospital characteristics using the surveys from 2003 and 2005. The results are robust to the exclusion of 2004 as well as alternate methods of extrapolation. The AHA surveys provide information about when hospitals adopt the new technologies. The AHA survey began including both robotic surgery adoption and 64+ MSCT adoption in the year 2005. This is suitable for 64+ MSCT because 64+ MSCT was released at the end of 2004 (The Medical Advisory Secretariat 2005). However, robotic surgery received FDA approval in 2000, making censoring a relevant issue. Therefore, I manually confirmed the year in which general acute care and surgical specialist hospitals adopted robotic surgery using hospital and media releases. A table of these adjustments is available in Appendix E. The presented results are based on the adjusted data, but the results are robust to the year of adoption as recorded by the AHA and available upon request.

I create a pooled, panel dataset, where the unit of analysis is the hospital-technology-year. The sample includes 2,425 non-government, non-physician-owned general acute care or surgical specialist hospitals. I aim to balance keeping sample selection criteria minimal with the need to construct a sample of hospitals that are reasonably comparable and at risk of investing in the focal technologies. I limit the sample to non-government general acute care and surgical specialist hospitals because government-run hospitals and/or non-general acute, non-surgical specialist hospitals may differ in how they evaluate new technologies or how they view integrated versus unintegrated physicians in ways for which I cannot account sufficiently. I exclude hospitals in which physicians may own equity because such arrangements alter incentives in ways not captured by my arguments—although such arrangements present interesting research opportunities for the future. I exclude hospitals with residency programs; given their imperative to train the surgeons of the future, their calculus for technology adoption is also likely to be meaningfully different from regular, non-government, general acute-care or surgical specialist hospitals. However, results are robust to the inclusion of these hospitals in the sample and can be provided by the author upon request.

## Measures

***Dependent Variable*** The dependent variable is equal to zero for a given hospital-technology-year observation if hospital $i$ has not yet invested in technology $j$ by the end of year $t$. It is equal to one for the year $t$ in which hospital $i$ invests in technology $j$.

***Explanatory Variables*** The main explanatory variable is whether a hospital has an integrated relationship with physicians. Hospitals integrate physicians as employees report using an integrated salary model (ISM) in AHA surveys. I define *physicians integrated* to be an indicator variable equal to one if the hospital reports using an ISM, zero otherwise. This is a standard measure of physician integration that has been used in both the strategic management literature (e.g., Kapoor and Lee 2013) and the health economics literature (e.g., Everson et al. 2016, McCullough and Snir 2010). The second explanatory variable is an indicator *64+ MSCT* equal to 1 for observations associated with 64+ MSCT and 0 for observations associated with robotic surgery. 64+MSCT is the *paradigm-deepening* technology whereas robotic surgery is the more paradigm-changing technology. The AHA reports when a hospital has invested in a CT scanner with 64 or more slices, hence the "+" designation.

To proxy for the maturity of a technological paradigm, I use a time trend variable, *time*, since technological paradigms mature over time. To measure *local market competition*, I follow prior literature in defining a hospital's local market as all general acute care and surgical specialist hospitals within a thirty-mile radius (Wong et al. 2005). I measure competition as one minus the Herfindahl-Hirschman Index that is calculated based on the share of total surgeries performed by hospitals.

***Control Variables*** A hospital's financial resources can affect the feasibility of both technology adoption (Coye and Kell 2006, Friedman and Goes 2000) and physician integration (Burns and Muller 2008). Therefore, I control for hospital *total revenue*, *margins*, and additional variables that are strongly correlated with hospital profitability (e.g., Bai and Anderson 2016): hospital size measured as the *number of surgeries*, *for-profit* status, hospital *system membership*, whether a hospital is categorized as a *critical access hospital*, and the percent of inpatient days for which the hospital receives Medicare reimbursement (*% Medicare inpatient days*). I control for the percent of net revenue from capitation payments as opposed to fee-for-service payments that the hospital receives each year (*percent capitation*) to account for the possibility that payment models alter incentives to adopt new technologies as hospitals subject to capitation payment models are more likely to integrate physicians (Cuellar and Gertler 2006). Finally, an idiosyncratic feature of this context is that capital-intensive technologies are sometimes funded with the aid of charitable donations. Therefore, I include a control for *donations* received each year.

I also include the following variables that have been shown to influence the likelihood of adoption of robotic surgery and 64+ MSCT in prior work (e.g., Barbash and Glied 2010, Fornell 2010): the number of *surgeries* conducted by the hospital, whether the hospital performs *cardiac surgery*, whether the hospital offers *neurological services*, and whether the hospital's *cancer program* is approved by the American College of Surgeons. Local market conditions may also increase both the likelihood of investing in a new technology and the likelihood of integrating physicians (Barbash and Glied 2010), so I include the natural log of the total *number of surgeries within 30 miles.* Network ties (DiMaggio and Powell 1983, Rogers 2003) and geographic proximity to prior adopters (e.g., Audretsch and Feldman 2004, Owen-Smith and Powell 2004) are both established determinants of technology adoption. Therefore, I include an indicator variable for whether at least one other *hospital within 30 miles has already invested*. I also include an indicator for whether *another hospital within the focal hospital's system has invested*. Finally, to account for the possibility that certain states may have policy characteristics that both increase the likelihood of integration and increase the likelihood of technology adoption, I included a control for whether average insurance *reimbursement rates are low*, the *state physician rate*, the *percent of state physicians under 40 years old*, and the *percent of state physicians over 60 years old*.

## Estimation Procedure

I estimate a pooled logit model where the dichotomous outcome variable is equal to zero if hospital $i$ has not yet invested in technology $j$ by the end of year $t$, and equal to one if hospital $i$ invests in technology $j$ in year $t$ as given in equation (1).[2] The probability that hospital $i$ invests in technology $j$ in

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[2] The decision to invest in a given technology can occur at any time (i.e., on any given day), suggesting a continuous time-to-investment process. But because time of investment is recorded as the year of investment, there are a large

year $t$ conditional on not investing in technology $j$ previously is given $P_{ijt} = \Pr\left(T_{ij} = t \middle| T_{ij} \geq t\right)$, where $T_{ij}$ is an integer-valued random variable giving the year in which a given hospital $i$ invests in technology $j$. $\boldsymbol{x}_{it}$ is the vector of control variables observed for hospital $i$ and technology $j$ in year $t$, and $\eta_{ijt}$ is the error term. $Time_{jt}$ proxies for technological paradigm maturity To test whether the effect of integration depends on the type of technology, I interact $PhysInt_{ijt}$ and $64MSCT_{ijt}$. To test whether the positive association between integration and adoption of more paradigm-changing technologies depends on the maturity of the new technological paradigm and local market competition, I interact $PhysInt_{ijt} * 64MSCT_{ijt}$ with $Time_{jt}$ and $MktComp_{ijt}$. Thus, I estimate the following pooled logit model:

$$\begin{aligned}\log\left[\frac{P_{ijt}}{1-P_{ijt}}\right] = {} & \beta_0 + \beta_1 * PhysInt_{ijt} + \beta_2 * 64MSCT_{ijt} + \beta_3 * Time_{jt} + \beta_4 * MktComp_{it} \\ & +\beta_5 * PhysInt_{ijt} * 64MSCT_{ijt} + \beta_6 * PhysInt_{ijt} * Time_{jt} \\ & +\beta_7 * 64MSCT_{ijt} * Time_{jt} + \beta_8 * PhysInt_{ijt} * 64MSCT_{ijt} * Time_{jt} \\ & +\beta_9 * PhysInt_{ijt} * MktComp_{it} + \beta_{10} * 64MSCT_{ijt} * MktComp_{it} \\ & +\beta_{11} * PhysInt_{ijt} * 64MSCT_{ijt} * MktComp_{it} + \boldsymbol{\psi x}_{ijt} + \eta \end{aligned} \quad (1)$$

I also estimate unpooled logit models, where adoption of each technology is modeled separately.

## RESULTS

I start by analyzing whether hospitals that have an integrated relationship with physicians demonstrate different patterns of technology adoption than hospitals that have an unintegrated relationship with physicians. Tables 1 and 2 display the summary statistics and correlation table for the full, pooled sample in the main analysis as well as technology-specific subsamples. Technology adoption is virtually uncorrelated with physician integration, but variation across technologies and over time in correlations between technology adoption and hospital size, resources, and services suggests it is important to account for such factors before drawing any conclusions.

Table 3 columns 1-4 display the pooled logit estimates generated for examining the correlation between integrating physicians and the probability of investing in a new technology. Columns 1-2 display

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number of "ties" in which many hospitals have the same time-to-investment. Under such a condition, the use of a model like the Cox proportional hazards model is inappropriate, and a logit model is more suitable (Allison, 2009; Carnahan et al. 2016).

the estimated coefficients for the pooled logit models described in equations (1) and (2) with no additional control variables. To facilitate interpretation of results, I include graphical representations of the results. Figure 2 displays the baseline estimated probabilities of investment in the two technologies by time and hospital size. Because it appears that baseline probabilities of investment vary by technology, time, and hospital size, I graphically report semi-elasticities of integration for technology adoption. Figure 3 shows the main effect of integration on the probability of adoption as estimated in Table 3 Column 3. The main effect is insignificant for both robotic surgery (p=0.521) and 64+ MSCT (p=0.536), and the effects are not significantly different from one another (p=0.941). This does not provide support for hypothesis 1, that the effect of integration is larger for paradigm-changing technologies like robotic surgery systems.

However, Figure 4 displays the results from Table 3 Column 4, in which the effect is allowed to vary over time. Consistent with hypothesis 2, for robotic surgery, the effect of integration on the probability of technology adoption is more positive when the technological paradigm is still nascent but matters less over time, but is still insignificant. There is no such dynamic for 64+MSCT, and the effect of integration is consistently insignificant. The difference between the technologies in the effect of integration on technology adoption is marginally significantly different in 2005 (p=0.099) but then loses significance over time.

To test hypothesis 3, that the effect of integration for paradigm-changing technologies is larger in more competitive local markets, I split the sample into competitive local markets (Herfindahl-Hirsch Index < 1500) and those that are less competitive (HHI 1500+). These estimates are displayed in Columns 5 and 6 of Table 3 and illustrated in Figure 6. Here we observe that the effect of integration on technology adoption is quite significant and positive in competitive local markets and when the technological paradigm is relatively immature. The reported semielasticity of integration for adoption of robotic surgery in 2003 can be interpreted as integration increases the probability of adoption by 135.3% (p=0.003), and then declines over time. However, no such pattern is observed for adoption of robotic surgery in less competitive markets or for adoption of 64+MSCT in either competitive or less competitive markets. Figure 6b illustrates that the difference in the effect of integration on the two technologies continues to be significantly different.

Columns 7-10 of Table 3 display the results of unpooled analyses in which adoption of the two technologies and how the effect of integration varies by time and local market competition are analyzed separately. Figure 5 displays again how integration is associated with a higher probability of adoption of paradigm-changing technologies in more competitive local markets and when the new technological paradigm is still nascent.

### Sample Selection Robustness

The minimal sample selection criteria used for the above analyses reduce the likelihood of systematically excluding certain types of hospitals in a way that may bias the results. However, one potential concern is that some hospitals included in the sample will never adopt the new technology, regardless of whether physicians are integrated, for reasons that are not captured by the control variables. To explore how dependent the results are on the selection criteria used for the main sample, I repeat the above analysis on a narrower sample of hospitals that excludes hospitals that perform less than 500 surgeries per year and are in local markets that perform less than 50,000 surgeries per year. Physician integration aside, these hospitals are less likely to consider adoption because they do not have the scale to support technologies requiring such large capital investments. The analysis of the narrower sample is provided in Appendix C. The estimated probabilities of adoption are higher overall, as expected, but the pattern of results holds.

### Exploiting State Corporate Practice of Medicine Laws

While I have included an extensive set of control variables based on research examining drivers of integration and technology adoption, both the possibility that I have still omitted key variables and the possibility of measurement error with respect to hospital-physician integration introduce the possibility of biased estimates. I attempt to address these issues using variation in state corporate practice of medicine laws. I construct the instrument, *CPOM restriction*, at the hospital level as an indicator variable equal to one if a hospital is prohibited from employing physicians by its state's corporate practice of medicine law, zero otherwise. Arkansas, California, and Texas have corporate practice of medicine laws that prohibit physician employment by most hospitals.[3] Michigan, Nevada, North Carolina, South Carolina, Washington, and West Virginia prohibit for-profit hospitals from employing physicians (Lammers 2013). Because 2SLS is inappropriate for nonlinear models with a binary endogenous variable, I take the control function with generalized residuals approach (Wooldridge 2015).

Corporate practice of medicine laws predate the emergence of the new technologies in question, making it plausible that the only channel through which these laws affect technology adoption is through the physician integration choice (Lammers 2013). This provides reasonable confidence that the exclusion restriction is satisfied. However, a concern is that differences in corporate practice of medicine laws may reflect unobserved differences in culture, laws, or markets, which might also affect the propensity of a hospital to adopt new technologies. In Appendix D, I examine this possibility by estimating placebo regressions. If states that restrict physician employment also reduce the propensity of hospitals to invest in new technologies for other unobserved reasons, then we would expect to find that being located in a state with physician integration restrictions even if a hospital is not subject to those restrictions themselves lowers the likelihood of technology adoption. Consistent with prior work (Lammers 2013), I find no supporting evidence for this possibility.

Table 4 Columns 1 and 4 display the coefficients for the naive unpooled logit models for the sub-sample being used for the control function model. As expected, these are similar to the coefficients generated for the main sample found in Table 3. Table 4 Columns 2 and 5 display the coefficients for the first stage probit regression with physician integration as the dependent variable and the variable *CPOM restriction* as the instrument. Hospitals subject to such restrictions are significantly less likely to employ physicians than hospitals that are not subject to such restrictions (p=0.000). The Kleibergen-Paap rk Wald F statistic is 60.8, which well exceeds the Stock-Yogo 10% critical value of 16.38, suggesting that the null that the instrument is weak can be ruled out. Columns 3 and 6 display the estimates for the second stage regressions. The estimated coefficient for the residual from the first stage regression is insignificant,

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[3] California allows non-profit teaching hospitals to employ physicians, while Ohio allows non-profit teaching hospitals and rural hospitals to employ physicians (Lammers 2013).

rejecting the null that physician integration is endogenous to technology adoption. Figure 7 illustrates that the same pattern of results found in the naïve models is present in the control function models: integration has the strongest positive effect on technology adoption when the technology is paradigm-changing, the new technological paradigm is still nascent, and in more competitive local markets.

Columns 7-9 represent an alternative approach. Rather than estimating a control function model, I use coarsened exact matching to create a subsample of hospitals that were unintegrated in the year 2000. Hospitals in CPOM states are matched to hospitals outside CPOM states. The firms were matched on size, number of surgeries, revenue, margins, services, governance, and local market characteristics. I included only minimal control variables for the coarsened exact matching process because otherwise there would be too many variables given the number of adoptions in the sample. I again find that even within this sample of firms that were unintegrated 2000 and half of which are subject to restrictions on integration, integration is still associated with an increase in the probability of technology adoption.

## DISCUSSION

While prior research finds that firms that have an integrated relationship with human capital that will be relevant to creating value from a new technology are no more likely to adopt the technology than firms that have an unintegrated relationship with relevant human capital (e.g., Kapoor and Lee 2013), I argue that a contingency approach is necessary for understanding the link between human capital integration and technology adoption decisions. I find that hospitals that integrate physicians as employees do adopt new technologies sooner than hospitals that maintain an arms-length relationship with physicians when a technology is paradigm-changing rather than paradigm-deepening—but only when the new paradigm is still nascent and local market competition is high.

A limitation of this analysis is that I do not directly observe hospital decision-makers' rationales for whether and when they choose to invest in robotic surgery and 64+ MSCT. However, the pattern of results is consistent with the core argument that integration is a stronger antecedent of paradigm-changing technology adoption because creating value from paradigm-changing technologies is more disruptive to the development of relational capital, uncertainty about the net benefit of cooperation is greater, and the cost of expropriation is higher. Adopting paradigm-changing technologies will be more disruptive to the development of relational capital, carry higher uncertainty about the net benefit of cooperation, and carry higher costs of expropriation when a paradigm-changing technology first emerges. As the technological paradigm matures, these conditions moderate. Accordingly, I find that integration weakens as an antecedent of paradigm-changing technology adoption. Furthermore, expropriation is a greater concern when local market competition is higher, and I find that integration is a stronger antecedent of paradigm-changing technology adoption when local market competition is higher. Given that the positive relationship between integration and robotic surgery adoption is largely driven by hospitals in more competitive markets in the early years of the new paradigm, the relative advantage of integration in minimizing concerns about expropriation appears to be particularly important.

Furthermore, the proposed mechanisms are corroborated by surveys of hospital administrators and qualitative and case research on both hospital adoption of new technologies and physician integration. It is well-established that hospitals are more likely to adopt a new technology when physician cooperation, coordination, and loyalty are expected (Burns et al. 2011, Burns and Muller 2008, Coye and Kell 2006, Friedman and Goes 2000). It is also well-established that hospital executives associate physician integration with advantages in cooperation, coordination, and loyalty (Burns and Muller 2008, Cuellar and Gertler 2006, Lammers 2013, Porter and Teisberg 2019). Hospital administrators have reported that they expect integration to produce superior interest alignment with physicians, making the physicians more cooperative and effective in executing hospital initiatives and navigating change such as adopting new technologies (Burns and Muller 2008). Moreover, the inability to integrate physicians due to corporate practice of medicine laws limits hospitals' ability to achieve the desired alignment and loyalty (e.g., Lucht 2009). Consistent with the empirical results, integration's advantage in physician loyalty is particularly salient (Burns et al. 2011, Burns and Muller 2008, Lucht 2009).

Another potential limitation of this study is its generalizability. Any study in the U.S. healthcare industry should be undertaken with a rigorous appreciation for its complexities. However, there is robust evidence that the U.S. hospital sector is far more similar to "traditional" sectors of the economy in terms of competitive dynamics and the role of both market forces and management practices in shaping firm performance outcomes than conventional wisdom presumes (Chandra et al. 2016; Sadun, Bloom, et al). The healthcare industry is also an important sector in its own right, representing nearly one-fifth of the U.S. economy.[4] Understanding the implications of using an employment contract to govern a central relationship in the industry—that between hospitals and physicians—has long been an important area of inquiry (e.g., Burns and Muller 2008, Burns and Wholey 2000, Cuellar and Gertler 2006).

Nevertheless, it is important to account for the scope of the problem under analysis (Eggers & Park, 2018). One important boundary condition is that this paper analyzes the integration of high-skilled individuals who, if they leave the firm, take with them their valuable and relatively scarce human capital. An implication is that they are relatively more likely than lower-skilled individuals to be in a position to extract value from the firm through contract negotiations or threatening to leave the firm altogether (Becker 1964, Coff 1997, Simon 1951). Considerations of whether individuals will cooperate and accept coordinative direction, for example, may become less relevant regardless of integration choices as firms gain more relative power over lower-skilled individuals.

Another important boundary condition is that I analyze the adoption of technologies when it is top management making the ultimate adoption decision. Though firm management's decision may of course be informed by the opinions of other firm stakeholders, it is top management who have the final say. This is different from contexts in which the firm-level adoption decision is delegated to smaller teams or individuals, where the decision-maker him- or herself may be integrated or not. Future research may examine how technology adoption changes when the integration decision changes the locus of the technology adoption decision.

## CONCLUSION

This paper seeks to further our understanding of the link between organizational structure and how firms adapt to technological change by focusing on a key element of organizational structure—

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[4] https://www.cms.gov/files/document/highlights.pdf

human capital integration—and a key element of technology strategy—whether and when to adopt a new technology. Organizational structure has been cited as a potentially critical factor in how firms respond to technological change (Eggers 2014, Eggers and Park 2018). However, existing research primarily focuses on the implications of traditional forms of vertical integration for either overall firm performance and survival (e.g., Afuah 2001, Balakrishnan and Wernerfelt 1986) or product development (Kapoor and Adner 2012) during periods of technological change rather than specific elements of technology strategy. Kapoor and Lee (2013) provide a noteworthy exception in examining how firm boundary choices with respect to complementors affect technology adoption decisions. I build on their efforts to understand how organizational structure might shape technology adoption decisions by focusing on the structure of relationships with human capital that will be relevant to creating value from a new technology. I establish conditions under which the relative advantage of integration might be strong enough to be a prerequisite for technology adoption.

The theorizing and results presented in this paper point to a link between an early adopter strategy for the most radical, paradigm-changing technologies and an integration strategy for human capital that will be relevant to creating value. This is an important result because we know that organizational and environmental frictions can preclude firms from adopting a particular organizational structure (Mahoney and Qian 2013, Nickerson and Silverman 2003), meaning frictions on changing structure may also preclude early adopter technology strategy. Analyses exploiting state corporate practice of medicine laws that prohibit some hospitals from integrating physicians is consistent with frictions on integration delaying technology adoption. The results also demonstrate the value of synthesizing insights from multiple literatures to uncover heterogeneity in the relationship between human capital integration and technology adoption. I draw on a technological paradigms framework (e.g., Ahuja et al. 2014, Dosi 1982, Silverberg et al. 1988) as well as insights from transaction cost economics (e.g., Mayer and Nickerson 2005), relational governance (e.g., Chatterji et al. 2019), and strategic human capital perspectives (e.g., Coff and Raffiee 2015, Wang and Barney 2006).

Finally, this paper highlights important directions for future research. First, this paper examines the relationship between human capital integration and the firm-level decision to adopt a new technology; future research should explicitly examine the consequences of integration for value creation and capture. Second, future research efforts may seek to better understand what types of frictions on human capital integration, or frictions related to organizational structure more broadly, might inhibit firms from pursuing early adopter strategies. Third, this paper sheds light on the potential importance of integrated firms as "seeds" for technology diffusion. Researchers interested in understanding patterns of technology diffusion and why some technologies diffuse more quickly than others may examine how market or industry frictions and norms related not only to integration but other elements of organizational structure may delay the "seeding" of a new technology. Lastly, this paper focuses on technology adoption decisions, but future research may use this paper as a framework for understanding how human capital integration may affect other choices related to innovation and technology strategy, such as the technology investment in R&D contexts (e.g., Eggers 2014, Eggers and Park 2018, Henderson 1993, Henderson and Clark 1990).

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## Table 1. Summary Statistics

### Panel A: Sample split by technology

| | Robotic Surgery | | | | | 64+ MSCT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of hospitals: 2,398 | | | | | Number of hospitals: 2,302 | | | | |
| | n | Mean | Std. Dev. | Min | Max | n | Mean | Std. Dev. | Min | Max |
| Invest in technology | 17998 | 0.03 | 0.18 | 0.00 | 1.00 | 12212 | 0.10 | 0.30 | 0.00 | 1.00 |
| Physicians integrated (yes=1) | 17998 | 0.28 | 0.45 | 0.00 | 1.00 | 12212 | 0.27 | 0.45 | 0.00 | 1.00 |
| Size: # Surgeries | 17998 | 4934 | 5165 | 0 | 81946 | 12212 | 4483 | 5090 | 0 | 70700 |
| Cancer program (yes=1) | 17998 | 0.28 | 0.45 | 0.00 | 1.00 | 12212 | 0.25 | 0.43 | 0.00 | 1.00 |
| Neurological services (yes=1) | 17998 | 0.49 | 0.50 | 0.00 | 1.00 | 12212 | 0.44 | 0.50 | 0.00 | 1.00 |
| Cardiac surgery (yes=1) | 17998 | 0.21 | 0.41 | 0.00 | 1.00 | 12212 | 0.19 | 0.39 | 0.00 | 1.00 |
| Specialist hospital (yes=1) | 17998 | 0.01 | 0.08 | 0.00 | 1.00 | 12212 | 0.01 | 0.09 | 0.00 | 1.00 |
| For-profit (yes=1) | 17998 | 0.14 | 0.34 | 0.00 | 1.00 | 12212 | 0.14 | 0.34 | 0.00 | 1.00 |
| System member (yes=1) | 17998 | 0.62 | 0.49 | 0.00 | 1.00 | 12212 | 0.63 | 0.48 | 0.00 | 1.00 |
| Critical access hospital (yes=1) | 17998 | 0.28 | 0.45 | 0.00 | 1.00 | 12212 | 0.34 | 0.47 | 0.00 | 1.00 |
| Total revenue ($ mil.) | 17998 | 261 | 321 | 0.09 | 3480 | 12212 | 233 | 319 | 0.09 | 4920 |
| Profit margin | 17998 | 0.03 | 0.15 | -7.17 | 7.97 | 12212 | 0.03 | 0.17 | -7.17 | 7.97 |
| Donations ($ mil.) | 17998 | 0.2 | 0.7 | 0.0 | 42.2 | 12212 | 0.2 | 0.6 | 0.0 | 17.9 |
| % Capitation | 17998 | 0.50 | 3.80 | 0.00 | 100.00 | 12212 | 0.56 | 4.17 | 0.00 | 93.00 |
| % Medicare inpatient days | 17998 | 0.53 | 0.19 | 0.00 | 1.00 | 12212 | 0.54 | 0.20 | 0.00 | 1.00 |
| % Local market share | 17998 | 0.21 | 0.26 | 0.00 | 1.00 | 12212 | 0.20 | 0.26 | 0.00 | 1.00 |
| High local market competition (yes=1) | 17998 | 0.30 | 0.46 | 0.00 | 1.00 | 12212 | 0.29 | 0.45 | 0.00 | 1.00 |
| # Surgeries in local market (thousands) | 17998 | 108 | 199 | 0.00 | 1478 | 12212 | 102 | 194 | 0 | 1478 |
| Another hospital in system invested (yes=1) | 17998 | 0.08 | 0.28 | 0.00 | 1.00 | 12212 | 0.11 | 0.31 | 0.00 | 1.00 |
| Hospital within local market invested (yes=1) | 17998 | 0.43 | 0.49 | 0.00 | 1.00 | 12212 | 0.51 | 0.50 | 0.00 | 1.00 |
| State physician rate | 17998 | 252 | 49 | 163 | 890 | 12212 | 249 | 50 | 163 | 890 |
| % State physicians under 40 years old | 17998 | 17.86 | 1.71 | 10.60 | 24.47 | 12212 | 17.91 | 1.75 | 10.60 | 24.47 |
| % State physicians over 60 years old | 17998 | 24.22 | 3.70 | 11.21 | 36.45 | 12212 | 23.89 | 3.60 | 11.21 | 36.45 |
| Low Medicare reimbursement state (yes=1) | 17998 | 0.13 | 0.34 | 0.00 | 1.00 | 12212 | 0.13 | 0.34 | 0.00 | 1.00 |
| Mixed integration (yes=1) | 17998 | 0.15 | 0.35 | 0.00 | 1.00 | 12212 | 0.15 | 0.35 | 0.00 | 1.00 |
| Quasi-integration (yes=1) | 17998 | 0.32 | 0.46 | 0.00 | 1.00 | 12212 | 0.31 | 0.46 | 0.00 | 1.00 |

### Panel B: Sample split by integration

| | Hospitals with Integrated Physicians | | | | | Hospitals with Unintegrated Physicians | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Number of hospitals: 945 | | | | | Number of hospitals: 2,084 | | | | |
| | n | Mean | Std. Dev. | Min | Max | n | Mean | Std. Dev. | Min | Max |
| Invest in technology | 8285 | 0.05 | 0.22 | 0.00 | 1.00 | 21925 | 0.06 | 0.24 | 0.00 | 1.00 |
| Physicians integrated (yes=1) | 8285 | 1.00 | 0.00 | 1.00 | 1.00 | 21925 | 0.00 | 0.00 | 0.00 | 0.00 |
| Size: # Surgeries | 8285 | 3805 | 4627 | 0 | 41177 | 21925 | 5109 | 5276 | 0 | 81946 |
| Cancer program (yes=1) | 8285 | 0.22 | 0.41 | 0.00 | 1.00 | 21925 | 0.29 | 0.45 | 0.00 | 1.00 |
| Neurological services (yes=1) | 8285 | 0.40 | 0.49 | 0.00 | 1.00 | 21925 | 0.49 | 0.50 | 0.00 | 1.00 |
| Cardiac surgery (yes=1) | 8285 | 0.14 | 0.35 | 0.00 | 1.00 | 21925 | 0.22 | 0.42 | 0.00 | 1.00 |
| Specialist hospital (yes=1) | 8285 | 0.01 | 0.08 | 0.00 | 1.00 | 21925 | 0.01 | 0.09 | 0.00 | 1.00 |
| For-profit (yes=1) | 8285 | 0.08 | 0.27 | 0.00 | 1.00 | 21925 | 0.16 | 0.37 | 0.00 | 1.00 |
| System member (yes=1) | 8285 | 0.59 | 0.49 | 0.00 | 1.00 | 21925 | 0.64 | 0.48 | 0.00 | 1.00 |
| Critical access hospital (yes=1) | 8285 | 0.45 | 0.50 | 0.00 | 1.00 | 21925 | 0.25 | 0.43 | 0.00 | 1.00 |
| Total revenue ($ mil.) | 8285 | 198 | 281 | 0.09 | 4150 | 21925 | 269 | 332 | 0.10 | 4920 |
| Profit margin | 8285 | 0.03 | 0.16 | -2.53 | 7.97 | 21925 | 0.03 | 0.15 | -7.17 | 7.42 |
| Donations ($ mil.) | 8285 | 0.16 | 0.60 | 0.0 | 18.3 | 21925 | 0.2 | 0.7 | 0.0 | 42.2 |
| % Capitation | 8285 | 0.24 | 1.93 | 0.00 | 65.00 | 21925 | 0.64 | 4.48 | 0.00 | 100.00 |
| % Medicare inpatient days | 8285 | 0.52 | 0.22 | 0.00 | 1.00 | 21925 | 0.54 | 0.18 | 0.00 | 1.00 |
| % Local market share | 8285 | 0.24 | 0.28 | 0.00 | 1.00 | 21925 | 0.19 | 0.24 | 0.00 | 1.00 |
| High local market competition (yes=1) | 8285 | 0.21 | 0.41 | 0.00 | 1.00 | 21925 | 0.33 | 0.47 | 0.00 | 1.00 |
| # Surgeries local market (thousands) | 8285 | 68 | 154 | 0 | 1448 | 21925 | 120 | 209 | 0 | 1478 |
| Another hospital in system invested (yes=1) | 8285 | 0.09 | 0.28 | 0.00 | 1.00 | 21925 | 0.10 | 0.29 | 0.00 | 1.00 |
| Hospital within local market invested (yes=1) | 8285 | 0.43 | 0.50 | 0.00 | 1.00 | 21925 | 0.47 | 0.50 | 0.00 | 1.00 |
| State physician rate | 8285 | 250 | 48 | 165 | 890 | 21925 | 251 | 50 | 163 | 890 |
| % State physicians under 40 years old | 8285 | 17.81 | 1.88 | 10.60 | 23.90 | 21925 | 17.91 | 1.67 | 10.60 | 24.47 |
| % State physicians over 60 years old | 8285 | 24.42 | 3.61 | 11.21 | 36.45 | 21925 | 23.96 | 3.67 | 11.21 | 36.45 |
| Low Medicare reimbursement state (yes=1) | 8285 | 0.10 | 0.30 | 0.00 | 1.00 | 21925 | 0.15 | 0.35 | 0.00 | 1.00 |
| Mixed integration (yes=1) | 8285 | 0.00 | 0.00 | 0.00 | 0.00 | 21925 | 0.20 | 0.40 | 0.00 | 1.00 |
| Quasi-integration (yes=1) | 8285 | 0.00 | 0.00 | 0.00 | 0.00 | 21925 | 0.43 | 0.50 | 0.00 | 1.00 |

Table 2. Correlation Table

| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Invest in technology | 1.00 | | | | | | | | | | | | |
| 2 | Physicians integrated (yes=1) | -0.02 | 1.00 | | | | | | | | | | | |
| 3 | Size: # Surgeries | 0.18 | -0.11 | 1.00 | | | | | | | | | | |
| 4 | Cancer program (yes=1) | 0.13 | -0.07 | 0.54 | 1.00 | | | | | | | | | |
| 5 | Neurological services (yes=1) | 0.14 | -0.09 | 0.52 | 0.46 | 1.00 | | | | | | | | |
| 6 | Cardiac surgery (yes=1) | 0.16 | -0.09 | 0.53 | 0.40 | 0.42 | 1.00 | | | | | | | |
| 7 | Specialist hospital (yes=1) | 0.00 | -0.01 | 0.03 | -0.04 | -0.03 | -0.03 | 1.00 | | | | | | |
| 8 | For-profit (yes=1) | 0.02 | -0.11 | 0.02 | -0.07 | 0.04 | 0.09 | 0.04 | 1.00 | | | | | |
| 9 | System member (yes=1) | 0.03 | -0.04 | 0.01 | -0.01 | 0.02 | 0.08 | 0.00 | 0.25 | 1.00 | | | | |
| 10 | Critical access hospital (yes=1) | -0.11 | 0.19 | -0.50 | -0.37 | -0.46 | -0.32 | -0.06 | -0.14 | -0.08 | 1.00 | | | |
| 11 | Total revenue ($ mil.) | 0.21 | -0.10 | 0.67 | 0.49 | 0.50 | 0.60 | -0.01 | 0.09 | 0.12 | -0.44 | 1.00 | | |
| 12 | Profit margin | 0.03 | 0.00 | 0.08 | 0.07 | 0.04 | 0.05 | 0.05 | 0.00 | 0.02 | -0.04 | 0.08 | 1.00 | |
| 13 | Donations ($ mil.) | 0.03 | -0.01 | 0.16 | 0.13 | 0.10 | 0.11 | 0.01 | -0.10 | -0.09 | -0.07 | 0.17 | 0.02 | 1.00 |
| 14 | % Capitation | 0.01 | -0.05 | 0.04 | 0.01 | 0.01 | 0.06 | 0.01 | -0.04 | 0.01 | -0.04 | 0.08 | 0.01 | 0.00 |
| 15 | % Medicare inpatient days | -0.02 | -0.05 | -0.03 | 0.02 | 0.02 | -0.03 | -0.05 | 0.05 | 0.03 | -0.01 | -0.05 | -0.02 | -0.02 |
| 16 | % Local market share | -0.01 | 0.09 | -0.06 | -0.06 | -0.12 | -0.02 | -0.05 | -0.03 | -0.08 | 0.11 | -0.10 | 0.02 | 0.02 |
| 17 | High local market competition (yes=1) | 0.09 | -0.11 | 0.34 | 0.30 | 0.37 | 0.26 | 0.05 | 0.04 | 0.07 | -0.35 | 0.41 | 0.01 | 0.05 |
| 18 | # Surgeries in local market (thousands) | 0.06 | -0.12 | 0.29 | 0.25 | 0.31 | 0.17 | 0.04 | 0.01 | 0.03 | -0.29 | 0.37 | -0.02 | 0.04 |
| 19 | Another hospital in system invested (yes=1) | 0.00 | -0.02 | 0.07 | 0.07 | 0.13 | 0.00 | 0.05 | -0.07 | 0.21 | -0.10 | 0.13 | 0.02 | -0.01 |
| 20 | Hospital within local market invested (yes=1) | 0.10 | -0.03 | 0.13 | 0.13 | 0.21 | 0.10 | 0.04 | 0.02 | 0.11 | -0.18 | 0.27 | 0.01 | 0.02 |
| 21 | State physician rate | 0.01 | -0.01 | 0.20 | 0.22 | 0.20 | -0.04 | 0.01 | -0.19 | -0.16 | -0.17 | 0.10 | 0.00 | 0.08 |
| 22 | % State physicians under 40 years old | 0.01 | -0.02 | 0.04 | 0.02 | -0.01 | 0.05 | 0.02 | 0.00 | 0.04 | -0.04 | -0.04 | 0.02 | -0.02 |
| 23 | % State physicians over 60 years old | 0.01 | 0.06 | -0.12 | -0.06 | -0.02 | -0.09 | -0.01 | -0.02 | 0.01 | 0.05 | 0.09 | -0.03 | 0.03 |
| 24 | Low Medicare reimbursement state (yes=1) | 0.00 | -0.07 | 0.00 | -0.01 | -0.01 | -0.01 | -0.01 | 0.04 | -0.05 | -0.08 | 0.03 | -0.04 | 0.00 |
| 25 | Mixed integration (yes=1) | 0.03 | -0.25 | 0.14 | 0.16 | 0.11 | 0.07 | -0.02 | -0.10 | 0.06 | -0.10 | 0.08 | 0.00 | 0.02 |
| 26 | Quasi-integration (yes=1) | 0.01 | -0.42 | 0.05 | 0.05 | 0.05 | 0.09 | 0.00 | 0.01 | -0.02 | -0.08 | 0.08 | 0.01 | 0.02 |

| | | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 14 | % Capitation | 1.00 | | | | | | | | | | | | |
| 15 | % Medicare inpatient days | -0.01 | 1.00 | | | | | | | | | | | |
| 16 | % Local market share | -0.05 | -0.23 | 1.00 | | | | | | | | | | |
| 17 | High local market competition (yes=1) | 0.09 | 0.00 | -0.41 | 1.00 | | | | | | | | | |
| 18 | # Surgeries local market (thousands) | 0.09 | 0.00 | -0.33 | 0.61 | 1.00 | | | | | | | | |
| 19 | Another hospital in system invested (yes=1) | 0.03 | 0.01 | -0.15 | 0.21 | 0.17 | 1.00 | | | | | | | |
| 20 | Hospital within local market invested (yes=1) | 0.03 | 0.06 | -0.45 | 0.41 | 0.35 | 0.26 | 1.00 | | | | | | |
| 21 | State physician rate | 0.02 | 0.03 | -0.16 | 0.27 | 0.32 | 0.02 | 0.13 | 1.00 | | | | | |
| 22 | % State physicians under 40 years old | 0.00 | 0.06 | -0.17 | 0.04 | 0.00 | -0.01 | 0.05 | -0.09 | 1.00 | | | | |
| 23 | % State physicians over 60 years old | 0.01 | 0.01 | 0.04 | -0.02 | 0.06 | 0.11 | 0.24 | 0.14 | -0.38 | 1.00 | | | |
| 24 | Low Medicare reimbursement state (yes=1) | 0.00 | 0.11 | -0.07 | 0.04 | 0.08 | -0.01 | 0.05 | 0.00 | -0.08 | 0.12 | 1.00 | | |
| 25 | Mixed integration (yes=1) | 0.02 | 0.03 | -0.02 | 0.05 | 0.05 | 0.15 | 0.06 | 0.07 | -0.01 | 0.01 | -0.03 | 1.00 | |
| 26 | Quasi-integration (yes=1) | 0.04 | 0.02 | -0.04 | 0.06 | 0.08 | -0.02 | 0.01 | -0.02 | 0.05 | -0.04 | 0.03 | -0.28 | 1.00 |

## Table 3. Technology Adoption: Broader Sample, Logit Estimates

| | Pooled | Pooled | Pooled | Pooled | Pooled Local Market Comp.: | | Unpooled Robotic Surgery | | Unpooled 64+ MSCT | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Higher | Lower | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Integration (yes=1) | -0.115 | 0.474 + | -0.074 | 0.484 + | 1.186 ** | -0.361 | 0.568 + | 0.253 | -0.330 | -0.285 |
| | (0.112) | (0.265) | (0.115) | (0.273) | (0.403) | (0.380) | (0.309) | (0.321) | (0.249) | (0.268) |
| 64+ MSCT (yes=1) | 1.166 *** | 2.581 *** | 1.402 *** | 2.680 *** | 2.677 *** | 2.692 *** | | | | |
| | (0.073) | (0.211) | (0.088) | (0.231) | (0.346) | (0.239) | | | | |
| Integration * 64+ MSCT | -0.045 | -0.777 * | 0.005 | -0.831 * | -1.504 * | 0.066 | | | | |
| | (0.103) | (0.314) | (0.141) | (0.373) | (0.608) | (0.482) | | | | |
| Integration * Time | | -0.064 ** | | -0.060 * | -0.106 ** | 0.009 | -0.051 + | -0.040 | 0.023 | 0.021 |
| | | (0.024) | | (0.025) | (0.039) | (0.031) | (0.029) | (0.029) | (0.025) | (0.026) |
| 64+ MSCT * Time | | -0.155 *** | | -0.141 *** | -0.162 *** | -0.118 *** | | | | |
| | | (0.026) | | (0.028) | (0.037) | (0.030) | | | | |
| Integration * 64+ MSCT * Time | | 0.084 ** | | 0.095 ** | 0.124 + | 0.024 | | | | |
| | | (0.030) | | (0.036) | (0.065) | (0.044) | | | | |
| Integration * High local market competition | | | | | | | | 0.420 * | | -0.083 |
| | | | | | | | | (0.206) | | (0.176) |
| ln(# Surgeries) | | | 0.292 *** | 0.290 *** | 0.421 *** | 0.217 ** | 0.572 *** | 0.575 *** | 0.253 *** | 0.253 *** |
| | | | (0.076) | (0.076) | (0.100) | (0.078) | (0.148) | (0.146) | (0.075) | (0.075) |
| Cancer program (yes=1) | | | 0.114 | 0.112 | 0.121 | 0.030 | 0.220 + | 0.219 + | 0.027 | 0.029 |
| | | | (0.071) | (0.072) | (0.105) | (0.107) | (0.117) | (0.118) | (0.081) | (0.082) |
| Neurological services (yes=1) | | | 0.322 *** | 0.316 *** | 0.433 *** | 0.193 * | 0.643 *** | 0.639 *** | 0.237 ** | 0.237 ** |
| | | | (0.080) | (0.080) | (0.123) | (0.093) | (0.169) | (0.169) | (0.086) | (0.086) |
| Cardiac surgery (yes=1) | | | 0.293 ** | 0.298 ** | 0.045 | 0.525 *** | 0.356 * | 0.357 * | 0.190 + | 0.189 + |
| | | | (0.099) | (0.100) | (0.131) | (0.112) | (0.142) | (0.144) | (0.114) | (0.115) |
| Specialist hospital (yes=1) | | | -0.251 | -0.217 | -0.563 | 0.110 | 0.375 | 0.407 | -0.384 | -0.389 |
| | | | (0.243) | (0.236) | (0.559) | (0.383) | (0.513) | (0.510) | (0.304) | (0.303) |
| For-profit (yes=1) | | | -0.180 + | -0.179 + | -0.288 + | -0.092 | -0.176 | -0.177 | -0.217 | -0.218 |
| | | | (0.108) | (0.107) | (0.153) | (0.128) | (0.131) | (0.130) | (0.136) | (0.136) |
| System member (yes=1) | | | 0.144 + | 0.153 + | 0.250 *** | 0.100 | 0.453 ** | 0.451 ** | 0.021 | 0.023 |
| | | | (0.082) | (0.081) | (0.066) | (0.103) | (0.144) | (0.142) | (0.094) | (0.094) |
| ln(Total revenue) | | | 0.407 *** | 0.401 *** | 0.354 *** | 0.453 *** | 0.673 *** | 0.673 *** | 0.304 ** | 0.305 ** |
| | | | (0.083) | (0.083) | (0.098) | (0.103) | (0.104) | (0.106) | (0.094) | (0.095) |
| ln(Profit margin) | | | 0.310 * | 0.307 * | 0.162 | 0.549 * | 0.312 * | 0.295 * | 0.294 + | 0.297 + |
| | | | (0.143) | (0.143) | (0.140) | (0.214) | (0.152) | (0.150) | (0.158) | (0.158) |
| ln(Donations) | | | -0.005 | -0.005 | -0.011 | 0.002 | -0.005 | -0.006 | -0.004 | -0.004 |
| | | | (0.004) | (0.005) | (0.008) | (0.007) | (0.009) | (0.009) | (0.005) | (0.006) |
| % Capitation | | | -0.009 | -0.008 | -0.009 | -0.001 | -0.003 | -0.002 | -0.010 | -0.010 |
| | | | (0.007) | (0.007) | (0.008) | (0.012) | (0.013) | (0.012) | (0.008) | (0.008) |
| % Medicare inpatient days | | | -0.505 * | -0.502 * | -0.186 | -0.547 * | -0.882 * | -0.907 * | -0.318 | -0.316 |
| | | | (0.220) | (0.216) | (0.331) | (0.234) | (0.417) | (0.417) | (0.228) | (0.228) |
| % Local market share | | | 0.221 | 0.262 | 1.573 | 0.338 + | -0.601 | -0.574 | 0.413 * | 0.411 * |
| | | | (0.188) | (0.181) | (1.586) | (0.192) | (0.387) | (0.384) | (0.208) | (0.207) |
| High local market competition (yes=1) | 0.787 *** | 0.785 *** | 0.068 | 0.070 | | | 0.089 | -0.018 | 0.061 | 0.079 |
| | (0.070) | (0.070) | (0.081) | (0.080) | | | (0.141) | (0.156) | (0.085) | (0.082) |
| # Surgeries in local market | | | -0.000 | -0.000 | -0.000 | 0.000 ** | -0.000 | -0.000 | -0.000 | -0.000 |
| | | | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Another hospital in system invested (yes=1) | | | -0.868 *** | -0.864 *** | -0.928 *** | -1.037 *** | -0.701 *** | -0.703 *** | -0.936 *** | -0.936 *** |
| | | | (0.117) | (0.117) | (0.146) | (0.226) | (0.179) | (0.182) | (0.128) | (0.128) |
| Hospital within local market invested (yes=1) | | | 0.208 ** | 0.274 *** | 0.059 | 0.221 ** | 0.193 | 0.204 | 0.131 | 0.132 |
| | | | (0.064) | (0.065) | (0.150) | (0.080) | (0.125) | (0.125) | (0.094) | (0.094) |
| % State physicians under 40 years old | | | -0.034 | -0.035 | -0.041 | -0.034 | -0.108 *** | -0.107 *** | -0.004 | -0.005 |
| | | | (0.024) | (0.024) | (0.030) | (0.029) | (0.030) | (0.030) | (0.031) | (0.030) |
| % State physicians over 60 years old | | | -0.036 | -0.036 | -0.047 + | -0.025 | -0.048 * | -0.047 * | -0.030 | -0.031 |
| | | | (0.027) | (0.027) | (0.028) | (0.027) | (0.023) | (0.023) | (0.032) | (0.032) |
| Low Medicare reimbursement state (yes=1) | | | 0.012 | 0.010 | -0.252 * | 0.171 | -0.026 | -0.040 | -0.002 | 0.002 |
| | | | (0.168) | (0.171) | (0.125) | (0.196) | (0.265) | (0.263) | (0.132) | (0.130) |
| Mixed integration (yes=1) | 0.195 * | 0.197 * | -0.042 | -0.033 | -0.006 | -0.025 | 0.206 | 0.201 | -0.134 | -0.135 |
| | (0.079) | (0.079) | (0.092) | (0.089) | (0.121) | (0.125) | (0.127) | (0.127) | (0.104) | (0.104) |
| Time | 0.172 *** | 0.219 *** | 0.218 *** | 0.256 *** | 0.339 *** | 0.201 *** | 0.252 *** | 0.250 *** | 0.069 | 0.070 |
| | (0.041) | (0.041) | (0.053) | (0.055) | (0.081) | (0.047) | (0.050) | (0.050) | (0.221) | (0.221) |
| Observations | 30,210 | 30,210 | 30,210 | 30,210 | 9,029 | 21,181 | 17,998 | 17,998 | 10,917 | 10,917 |
| Number of firms | 2,425 | 2,425 | 2,425 | 2,425 | 984 | 1,725 | 2,398 | 2,398 | 2,288 | 2,288 |
| Pseudo R-squared | 0.086 | 0.091 | 0.188 | 0.191 | 0.158 | 0.207 | 0.249 | 0.250 | 0.108 | 0.108 |

Standard errors clustered by firm and state in parentheses. Two-sided p-values indicated by + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Year dummy variables included for all regressions. Additional controls not displayed that are insignificant across models: critical access hospital, % capitation, state physician rate.

Table 4. Technology Adoption: Control Function and Matched Sample Estimates

| | Robotic Surgery Broader Sample | | | 64+ MSCT Broader Sample | | | Pooled Matched Sample | | |
|---|---|---|---|---|---|---|---|---|---|
| | Logit | Probit | Logit | Logit | Probit | Logit | Logit | Logit | Logit |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| Integration restricted by CPOM law (yes= | | -0.547 * | | | -0.542 * | | | | |
| | | (0.214) | | | (0.219) | | | | |
| Generalized residual from 1st stage probit | | | -0.109 | | | -0.062 | | | |
| | | | (0.090) | | | (0.069) | | | |
| Any integration (yes=1) | 0.250 | | 0.318 | -0.325 | | -0.271 | | | |
| | (0.307) | | (0.360) | (0.210) | | (0.232) | | | |
| Any integration * Time | -0.036 | | -0.033 | 0.025 | | 0.026 | | | |
| | (0.028) | | (0.031) | (0.023) | | (0.024) | | | |
| Any integration * High local market competition | 0.439 * | | 0.430 * | -0.043 | | -0.054 | | | |
| | (0.173) | | (0.208) | (0.134) | | (0.146) | | | |
| Integration (yes=1) | | | | | | | 0.746 * | 1.915 *** | 5.831 *** |
| | | | | | | | (0.339) | (0.502) | (0.494) |
| 64+ MSCT (yes=1) | | | | | | | 1.601 *** | 2.785 *** | 6.423 *** |
| | | | | | | | (0.458) | (0.453) | (0.335) |
| Integration * 64+ MSCT | | | | | | | | -1.722 *** | -5.738 *** |
| | | | | | | | | (0.436) | (0.595) |
| Integration * Time | | | | | | | | | -0.367 *** |
| | | | | | | | | | (0.059) |
| 64+ MSCT * Time | | | | | | | | | -0.347 *** |
| | | | | | | | | | (0.089) |
| Integration * 64+ MSCT * Time | | | | | | | | | 0.397 *** |
| | | | | | | | | | (0.105) |
| Time | 0.255 *** | 0.045 * | 0.250 *** | 0.062 | 0.063 ** | 0.025 | 0.033 | 0.033 | 0.359 *** |
| | (0.052) | (0.020) | (0.046) | (0.222) | (0.022) | (0.025) | (0.028) | (0.028) | (0.036) |
| Additional controls (see note) | Y | Y | Y | Y | Y | Y | N | N | N |
| Observations | 17,998 | 17,998 | 17,998 | 10,917 | 10,917 | 10,917 | 501 | 501 | 501 |
| Number of firms | 2,398 | 2,398 | 2,398 | 2,288 | 2,288 | 2,288 | 126 | 126 | 126 |
| Pseudo R-squared | 0.250 | 0.078 | 0.250 | 0.108 | 0.068 | 0.108 | 0.086 | 0.104 | 0.113 |

Standard errors are clustered by firm and state in parentheses. Two-sided p-values indicated by + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Year dummy variables are included for regressions in Columns 1-6. Additional controls include: ln(# surgeries), cancer program, neurological services, cardiac surgery, specialist hospital, for-profit hospital, critical access hospital, system member, ln(total revenue), profit margin, ln(donations), % capitation payments, % Medicare inpatient days, % local market share, high local market competition, # surgeries in local market, another hospital in system already invested, hospital within local market invested, % state physicians under 40 years old, % state physicians over 60 years old, state physician rate, low Medicare reimbursement state.

Figure 1: Cumulative adoption of technologies, 2003-2015

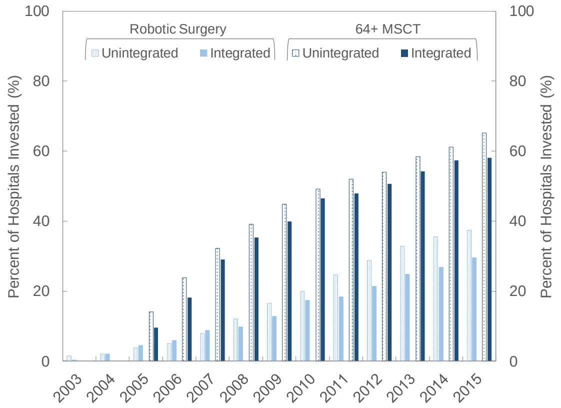
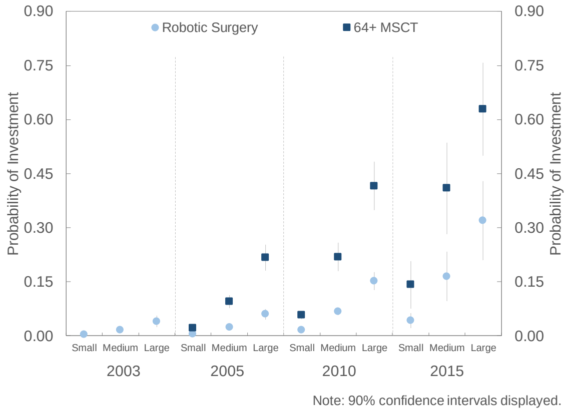
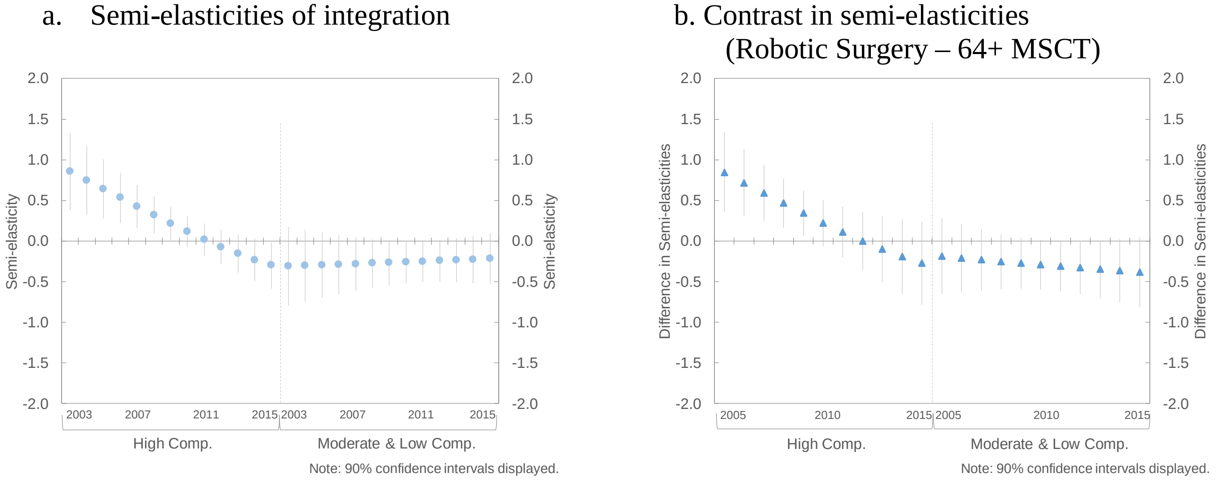


Figure 2: Probabilities of adoption, pooled logit estimates



Note: 90% confidence intervals displayed.

Figure 6: Effect of integration on adoption of robotic surgery for high and low market competition subsamples, pooled logit estimates

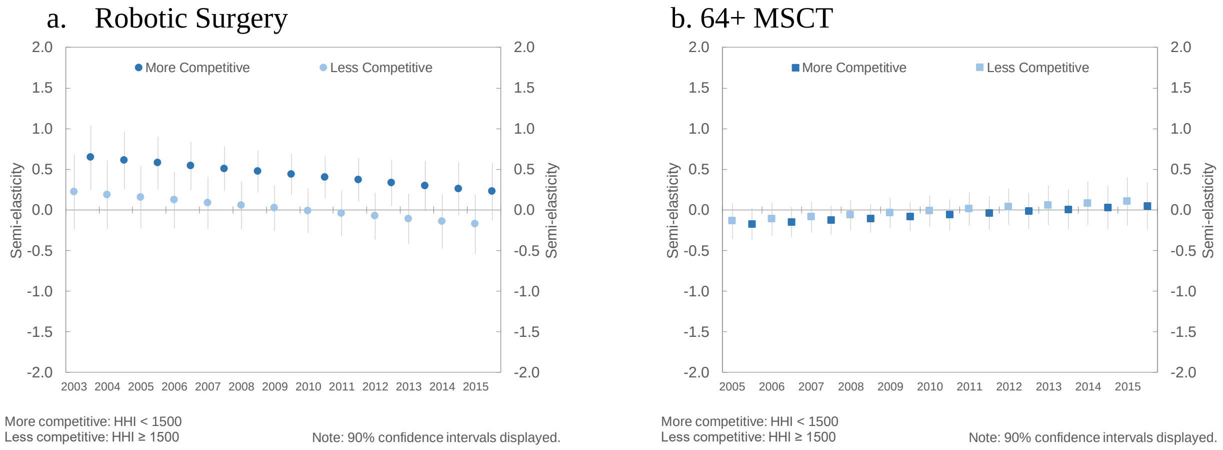

a. Semi-elasticities of integration

b. Contrast in semi-elasticities (Robotic Surgery – 64+ MSCT)

Note: 90% confidence intervals displayed.

Note: 90% confidence intervals displayed.

Figure 7: Semi-elasticities of integration for technology adoption, unpooled control function logit estimates


a. Robotic Surgery

b. 64+ MSCT

More competitive: HHI < 1500
Less competitive: HHI ≥ 1500

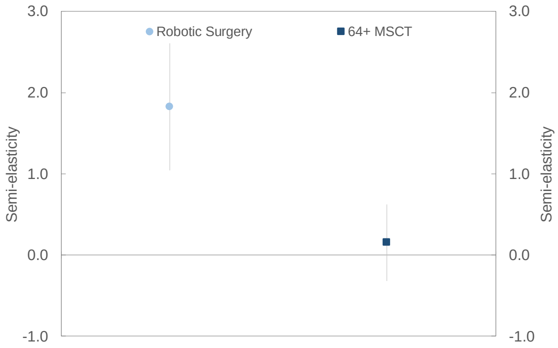
Note: 90% confidence intervals displayed.

More competitive: HHI < 1500
Less competitive: HHI ≥ 1500

Note: 90% confidence intervals displayed.

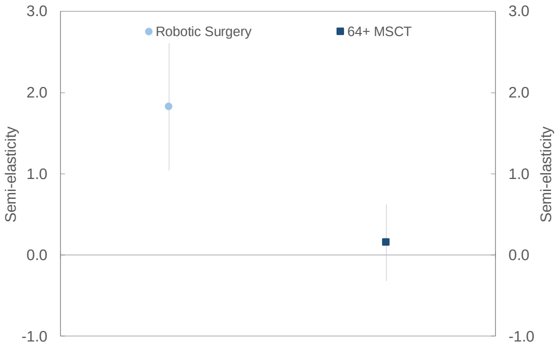
Figure 8: Effect of integration for technology adoption, pooled match sample logit estimates

a. Semi-elasticities of integration



Note: 90% confidence intervals displayed.

b. Contrast in semi-elasticities (Robotic Surgery – 64+ MSCT)



Note: 90% confidence intervals displayed.

## Appendix A: Hospital motivations for integrating physicians

Patterns of hospital-physician integration during my sample period are partly explained by the rise and fall of health maintenance organizations (HMOs) and capitation payment models during the managed care movement of the 1980s and 1990s. Prior research examining integration and technology adoption has even argued that the rise of the managed care movement offers a source of exogenous variation in a hospital-physician integration in the 1990s and 2000s (e.g., Kapoor and Lee 2013, McCullough and Snir 2010).

However, during my sample period from 2003-2015, physician integration was increasing again. In surveys, hospital administrators have reported that they expect the clinical and financial incentives of physicians to come into greater congruence with the clinical and financial incentives of the hospital upon entering into an employment contract, making the physicians more cooperative and effective in executing hospital initiatives and navigating change, such as investing in new technologies (Burns & Muller, 2008).

## Appendix B: Categorizing technology as a paradigm-changing versus paradigm-deepening

The 64-slice CT scanner received FDA approval in 2004. Robotic surgery received FDA approval in 2000. The upfront cost of investing in a 64-slice (or higher) multi-slice CT scanner is $1.5-$2.5 million (Fornell, 2010). The upfront cost of investing in a robotic surgery system is $1.5-$2 million (Barbash & Glied, 2010). The maintenance and service costs of both technologies depend on the particular needs in a given year (e.g., replacement parts), but both can range from the tens- to hundreds-of-thousands of dollars. Given the high costs, hospital top management makes the final adoption decision regardless of the relationship the hospital has with physicians.

Both technologies can be used across multiple surgical specialties (Hayes, 2006; Soomro et al., 2019). That said, creating value from either technology requires the cooperation and coordination of individuals other than surgeons. For 64+ MSCT, radiologic technicians are needed to carry out the tasks associated with actually taking an image. Radiologists play an important role in reading the images and providing a report to surgeons that surgeons often consult. However, surgeons across specialties play a critical role in value creation by making the decision to order images, reading the images themselves, and using what is learned from the image to inform operating decisions (Bolan 2008, Donners et al. 2021, Epstein et al. 2015, Matsumoto et al. 2011, Tzou et al. 2018). For robotic surgery, creating value requires the cooperation and coordination of nurses and scrub technicians (Beane 2019). But again surgeons are linchpins of value creation as they decide to use the robotic system as opposed to traditional methods and they must use the console to operate the robot (Beane 2019).

Here I provide more background information to support the assertion that 64+ MSCT is a paradigm-deepening technology while robotic surgery is more of a paradigm-changing technology.

***64+ MSCT*** Computed tomography (CT) scanners produce cross-sectional images of anatomy by revolving an x-ray around a patient. The technology is intended to improve treatment outcomes by providing clear, accurate images of the inside of a patient’s body. The first commercially-viable CT scanner was invented in 1967. If a technological paradigm “defines contextually the needs that are meant to be fulfilled, the scientific principles utilized for the task, the material technology to be used,” (Dosi

1988, p. 1127), then this first commercially-viable CT scanner represented the establishment of a new technological paradigm in which the needs to be fulfilled included maximizing image quality and minimizing patient radiation dosage while the technology to be used remained, fundamentally, an x-ray revolving around a patient.[5] Speed became a particularly well-established problem to be solved within this paradigm. Speed enables better image quality since there are fewer opportunities to disturb the image (this has been especially valuable in cardiac imaging), and a faster image also means that patients are less exposed to radiation (Arthurs et al. 2009, Fornell 2010).

In 1998, the multi-slice CT scanner was introduced, solving what had been a critical constraint on the speed at which CT scanners could produce images: CT scanners had only able to produce one image slice per revolution of the x-ray because they only had one detector. The multi-slice CT scanner, however, introduced four rows of detectors, enabling four image slices per revolution instead of just one, and thereby increased the speed of image production (Rubin 2014). Thus, the 64-slice multi-slice CT scanner, introduced in 2004, with its 64 rows of detectors, emerged as an answer to a well-defined problem within the existing paradigm—speed—and reflected an established pattern of solutions to that problem—increasing the number of detectors on CT scanners. Further demonstrating that it represented a deepening of an existing paradigm rather than a break away, 128-, 156-, and 320-slice CT scanners followed.

Moreover, in accordance with being a paradigm-changing technology, 64+ MSCT requires physicians to develop relatively little new knowledge and skill. For each increase in the number of slices of a CT scanner, there is also little uncertainty about what new knowledge and skill is needed, and there is little disruption to existing patterns of interaction among physicians and other hospital staff. Training programs typically last only a few days long followed by radiologists performing a series of scans under supervision (Hayes, 2006). For the physicians who read images, which includes surgeons, the technology looks and operates similarly to prior iterations and produces very similar images, just with higher resolution and fewer artifacts (e.g., discrepancies) (see Figure B.1) (Arthurs et al. 2009, Fornell 2010).

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[5] https://www.isct.org/computed-tomography-blog/2017/2/10/half-a-century-in-ct-how-computed-tomography-has-evolved

Figure B.1 Comparing thoracic images from 16- versus 64-slice CT scanners.

*O J Arthurs, S J Yates, P A K Set et al*

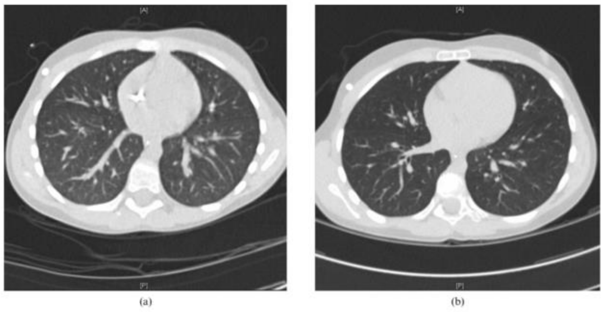


**Figure 2.** An example of differences in image quality. A 10-year-old girl with Ewing's sarcoma and previous pulmonary metastases underwent unenhanced 2 mm slice thickness spiral (a) 16 multislice CT (16CT) and (b) 64 multislice CT (64CT) examinations within a 3-month period to assess treatment response. Image quality was scored as "3" for the 16CT image and "5" for the 64CT image. The dose–length product was similar (72 mGy cm and 74 mGy cm, respectively) for this particular example.

Source: Arthurs, O.J., S.J. Yates, P.A.K. Set, D.A. Gibbons, A.K. Dixon. 2009. Evaluation of image quality and radiation dose in adolescent thoracic imaging: 64-slice is preferable to 16-slice multislice CT. *The British Journal of Radiology*, 82 (February): 157-161.

When a hospital upgrades to a CT scanner with a greater number of image slices, training is expected to be minimal as the main change that readers of images have to make is in their approach to identifying artifacts:

> "I had to change my reading habits. I was so used to reading 64-slice that I just assumed many things I saw were artifacts. But now what I am seeing is a lesion, it's not an artifact any more. We are so used to artifacts on 64-slice that we discount many things. You have to look at the 320 under a different light." – Dr. Michael Poon as quoted by Fornell (2010).
>
> "We started asking ourselves if we were calling things abnormal when they were actually OK. It was really sobering." – Dr. Michael Vannier speaking about reading a higher quality image, as quoted by Fornell (2010).

***Robotic Surgery*** Robotic surgery is a type of minimally invasive surgery in which a surgeon performs a surgery not by using his or her hands to operate on the patient but by using a robot that is controlled by the surgeon from a console in the operating room (Lanfranco et al. 2004). The robot acts as an extension of a surgeon's fingers but with superior dexterity and precision. Robotic surgery is intended to improve the quality of surgical outcomes by improving surgical dexterity and precision and minimizing surgeon fatigue, leading to improved patient outcomes such as less trauma on the body, minimal scarring, and faster recovery times (Lanfranco et al. 2004). The U.S. Food and Drug Administration first approved a robotic surgery system for use in the year 2000.

From both hospital and physician perspectives, robotic surgery represents a more paradigm-changing technology than 64+ MSCT in terms of the amount of change in core knowledge and skill needed to create value from it and the uncertainty about what new knowledge and skill needed to be acquired. It has previously been established that the introduction of robotic surgery represented a fundamental departure in physician use of robots in healthcare settings both from a technological perspective and in terms of the knowledge and skill physicians needed in order to use it to improve the quality of surgical procedures (Beane 2019, Joseph et al. 2005). Creating value from a robotic surgery system required a hospital to either hire new physicians who had the requisite knowledge and skill to use the robotic surgery system effectively or provide the time and resources for physicians to develop the requisite knowledge and skill. Yet when the technology first emerged, hiring physicians with the requisite knowledge and skill was virtually unviable because, given how new the knowledge and skill required was, there were only a handful of physicians located in academic research hospitals who had experience with a robotic surgery system, and the number of procedures for which the robotic surgery system could be used was actively evolving.

As an example of the amount of new knowledge and skill needed, consider Dr. Joseph Smith, Jr., an experienced surgeon who had performed over 2,000 non-robotic paradigm-changing retropubic prostatectomy (RRP) procedures. He began using a surgical robot for prostatectomies in 2003. The procedure is called robotic-assisted laparoscopic prostatectomy (RALP). The surgeon reported that it took performing more than 150 RALP procedures to achieve results comparable to what he was able to achieve with the traditional RRP procedure, and over 250 RALP procedures to achieve comparable levels of self-perceived confidence and comfort (Herrell and Smith 2005). As context, the median number of prostatectomies performed per year by a urologist at that time was seven (Herrell and Smith 2005). The time it takes to master the learning curve will depend on the type of surgical procedure and the idiosyncrasies of individual physicians (Soomro et al. 2020), but even conservative estimates of the time it takes to become sufficiently proficient at robotic surgery suggest it costs tens, if not hundreds, of thousands of dollars per surgeon (Steinberg et al. 2008).

Vocalized questions about the time and expense that would be required to learn to use the technology are indicative not only of the need to develop significant new knowledge and skill (Chitwood et al. 2001), but of uncertainty about the nature of the knowledge and skill that needed to be acquired and what the learning curve might look like. At the 2001 Annual Meeting of the American Surgical Association, Dr. Randolph Chitwood, a pioneer of robotic surgery, observed:

> "How do you know what they have learned? Well, it is very difficult. That is next part of our laboratory, to develop specific methods and training paradigms that will provide us with a number, a quantitative number, to say ready or not. I will make one comment, that I think many of these individuals, whether they are experienced laparoscopic surgeons or cardiac surgeons, who really never had any interest or work in videoscopic surgery, when they come through the tunnel it normalizes everyone. Because laparoscopic surgeons, who have a lot of talent and do many things, are taken down to a learning curve that they have to accept. So to answer your question, it is still pretty qualitative," (Chitwood et al., 2001).

Herrell and Smith (2005) suggest that variation in learning curves across physicians even for the same procedure further speaks to the lack of objective criteria for the knowledge and skill required; for instance, they posit that surgeons who had been masters of non-robotic procedures may set a higher bar for what constitutes "mastery."

## Appendix C: Narrower sample analyses

The analyses displayed here replicate the analyses in Table 3 and corresponding Figures 1-6 for a narrower sample of hospitals (hospitals that have performed at least 500 surgeries in the prior year in local markets with at least 50,000 surgeries in the prior year.

Table C.1: Technology Adoption: Narrower Sample, Logit Estimates

| | Pooled | Pooled | Pooled | Pooled | Pooled Local Market Comp.: | | Unpooled Robotic Surgery | | Unpooled 64+ MSCT | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Higher | Lower | | | | |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
| Integration (yes=1) | 0.080 | 0.915 ** | 0.010 | 0.818 ** | 1.270 ** | -0.977 | 0.863 ** | 0.090 | -0.206 | -0.350 |
| | (0.115) | (0.286) | (0.141) | (0.306) | (0.391) | (0.611) | (0.335) | (0.403) | (0.341) | (0.471) |
| 64+ MSCT (yes=1) | 1.049 *** | 2.509 *** | 1.247 *** | 2.647 *** | 2.653 *** | 2.555 *** | | | | |
| | (0.084) | (0.278) | (0.100) | (0.279) | (0.360) | (0.477) | | | | |
| Integration * 64+ MSCT | -0.236 + | -0.860 * | -0.212 | -1.062 * | -1.599 ** | 0.956 | | | | |
| | (0.129) | (0.386) | (0.188) | (0.483) | (0.614) | (0.897) | | | | |
| Integration * Time | | -0.090 ** | | -0.087 ** | -0.115 *** | 0.044 | -0.081 * | -0.070 * | -0.005 | -0.001 |
| | | (0.029) | | (0.030) | (0.035) | (0.061) | (0.034) | (0.034) | (0.038) | (0.039) |
| 64+ MSCT * Time | | -0.164 *** | | -0.158 *** | -0.164 *** | -0.128 * | | | | |
| | | (0.034) | | (0.033) | (0.040) | (0.053) | | | | |
| Integration * 64+ MSCT * Time | | 0.069 + | | 0.095 + | 0.140 * | -0.082 | | | | |
| | | (0.040) | | (0.050) | (0.065) | (0.086) | | | | |
| Integration * High local market competition | | | | | | | | 0.885 ** | | 0.159 |
| | | | | | | | | (0.282) | | (0.278) |
| ln(# Surgeries) | | | 0.489 *** | 0.483 *** | 0.477 *** | 0.646 *** | 0.714 *** | 0.718 *** | 0.419 *** | 0.419 *** |
| | | | (0.089) | (0.089) | (0.095) | (0.150) | (0.125) | (0.124) | (0.101) | (0.101) |
| Cancer program (yes=1) | | | 0.104 | 0.102 | 0.128 | -0.014 | 0.301 * | 0.313 * | -0.018 | -0.019 |
| | | | (0.092) | (0.094) | (0.105) | (0.207) | (0.130) | (0.131) | (0.105) | (0.105) |
| Neurological services (yes=1) | | | 0.368 *** | 0.358 *** | 0.421 *** | 0.037 | 0.616 * | 0.610 * | 0.332 ** | 0.331 ** |
| | | | (0.102) | (0.099) | (0.120) | (0.177) | (0.256) | (0.257) | (0.107) | (0.107) |
| Specialist hospital (yes=1) | | | -0.614 + | -0.544 | -1.086 ** | 0.272 | 0.190 | 0.264 | -0.896 + | -0.878 + |
| | | | (0.355) | (0.346) | (0.387) | (0.461) | (0.575) | (0.596) | (0.495) | (0.506) |
| For-profit (yes=1) | | | -0.280 + | -0.273 + | -0.290 * | -0.277 | -0.195 | -0.207 | -0.343 + | -0.347 + |
| | | | (0.152) | (0.148) | (0.145) | (0.274) | (0.156) | (0.155) | (0.197) | (0.198) |
| System member (yes=1) | | | 0.203 * | 0.217 ** | 0.242 *** | 0.128 | 0.438 * | 0.443 * | 0.080 | 0.078 |
| | | | (0.081) | (0.080) | (0.064) | (0.185) | (0.182) | (0.177) | (0.119) | (0.119) |
| ln(Total revenue) | | | 0.347 *** | 0.341 *** | 0.346 *** | 0.440 ** | 0.626 *** | 0.626 *** | 0.209 * | 0.211 * |
| | | | (0.092) | (0.091) | (0.099) | (0.163) | (0.128) | (0.128) | (0.104) | (0.103) |
| ln(Profit margin) | | | 0.209 + | 0.206 + | 0.174 | 0.316 + | 0.289 | 0.278 | 0.155 | 0.151 |
| | | | (0.116) | (0.119) | (0.141) | (0.180) | (0.179) | (0.177) | (0.131) | (0.132) |
| ln(Donations) | | | -0.010 + | -0.010 + | -0.012 | -0.001 | -0.005 | -0.006 | -0.011 | -0.011 |
| | | | (0.006) | (0.006) | (0.008) | (0.012) | (0.010) | (0.010) | (0.008) | (0.008) |
| % Medicare inpatient days | | | -0.423 | -0.416 | -0.240 | -0.710 | -1.059 * | -1.095 * | 0.012 | 0.009 |
| | | | (0.353) | (0.346) | (0.356) | (0.674) | (0.466) | (0.476) | (0.441) | (0.442) |
| % Local market share | | | 1.170 | 1.323 | 1.388 | 0.094 | -0.645 | -0.315 | 2.387 * | 2.376 * |
| | | | (0.819) | (0.817) | (1.624) | (1.013) | (1.314) | (1.222) | (0.979) | (0.973) |
| High local market competition (yes=1) | 0.155 + | 0.154 + | -0.012 | -0.006 | | | 0.054 | -0.137 | -0.045 | -0.075 |
| | (0.094) | (0.092) | (0.121) | (0.118) | | | (0.169) | (0.174) | (0.153) | (0.162) |
| Another hospital in system invested (yes=1) | | | -0.892 *** | -0.879 *** | -0.923 *** | -0.924 *** | -0.727 *** | -0.743 *** | -0.975 *** | -0.975 *** |
| | | | (0.129) | (0.127) | (0.149) | (0.261) | (0.195) | (0.197) | (0.161) | (0.161) |
| Hospital within local market invested (yes=1) | | | -0.057 | 0.086 | -0.098 | 0.555 ** | 0.047 | 0.082 | -0.066 | -0.069 |
| | | | (0.127) | (0.124) | (0.168) | (0.195) | (0.222) | (0.224) | (0.304) | (0.300) |
| % State physicians under 40 years old | | | -0.043 + | -0.048 + | -0.043 | -0.097 + | -0.132 *** | -0.135 *** | 0.018 | 0.018 |
| | | | (0.025) | (0.026) | (0.029) | (0.052) | (0.029) | (0.029) | (0.034) | (0.034) |
| % State physicians over 60 years old | | | -0.040 | -0.041 | -0.047 | -0.033 | -0.054 * | -0.054 * | -0.030 | -0.030 |
| | | | (0.028) | (0.029) | (0.029) | (0.032) | (0.027) | (0.026) | (0.037) | (0.037) |
| Low Medicare reimbursement state (yes=1) | | | -0.165 | -0.162 | -0.255 + | -0.058 | -0.252 | -0.263 | -0.106 | -0.109 |
| | | | (0.134) | (0.136) | (0.139) | (0.133) | (0.191) | (0.190) | (0.118) | (0.119) |
| Mixed integration (yes=1) | 0.114 | 0.114 | -0.026 | -0.017 | -0.007 | 0.026 | 0.349 * | 0.347 * | -0.242 | -0.241 |
| | (0.113) | (0.113) | (0.109) | (0.108) | (0.126) | (0.189) | (0.143) | (0.142) | (0.149) | (0.150) |
| Time | 0.164 *** | 0.215 *** | 0.243 *** | 0.283 *** | 0.347 *** | 0.151 * | 0.277 *** | 0.278 *** | 0.145 | 0.147 |
| | (0.046) | (0.045) | (0.060) | (0.061) | (0.079) | (0.067) | (0.055) | (0.054) | (0.524) | (0.523) |
| Observations | 11,505 | 11,505 | 11,505 | 11,505 | 8,447 | 3,058 | 7,055 | 7,055 | 3,849 | 3,849 |
| Number of firms | 2,425 | 1,179 | 1,179 | 1,179 | 896 | 425 | 1,153 | 1,153 | 1,060 | 1,060 |
| Pseudo R-squared | 0.073 | 0.080 | 0.155 | 0.160 | 0.154 | 0.213 | 0.195 | 0.197 | 0.077 | 0.077 |

Standard errors clustered by firm and state in parentheses. Two-sided p-values indicated by + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Year dummy variables included in all regressions. Additional controls not displayed that are insignificant across models: cardiac surgery, critical access hospital, % capitation, ln(number of surgeries in local market), state physician rate.

Figure C.1: Cumulative adoption, 2003-2015

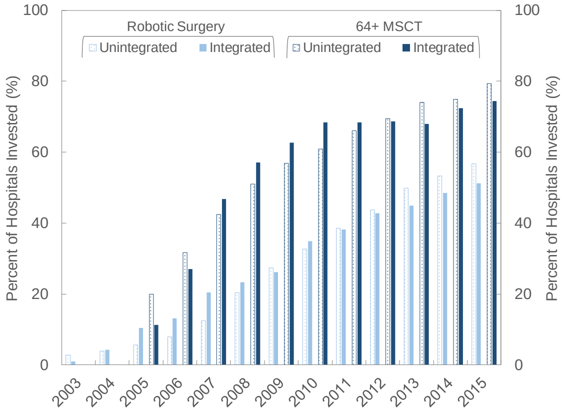
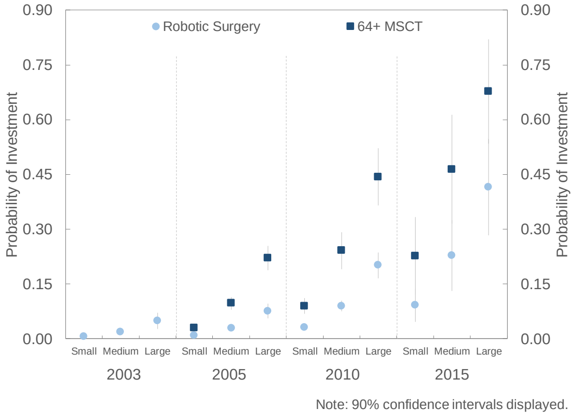
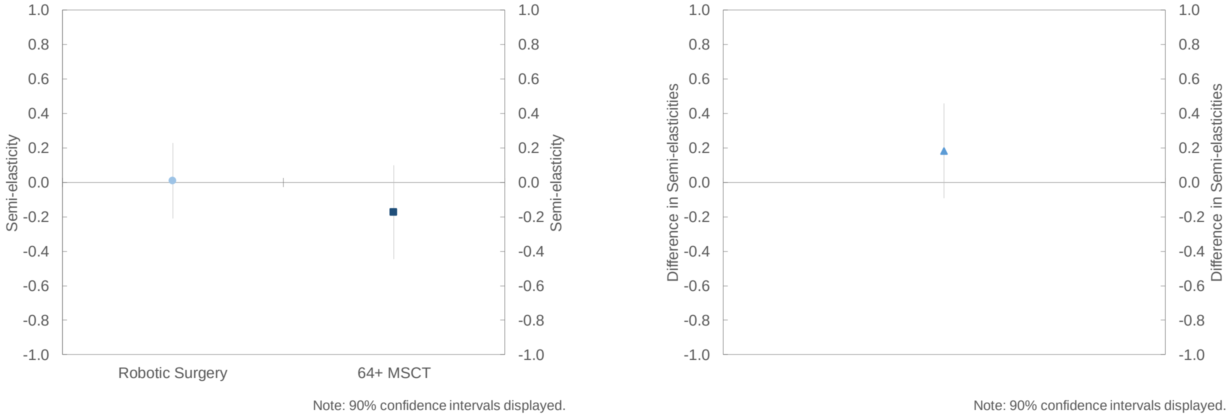


Figure C.2: Probabilities of adoption, pooled logit estimates



Note: 90% confidence intervals displayed.

Figure C.3: Main effect of integration on technology adoption, pooled logit estimates



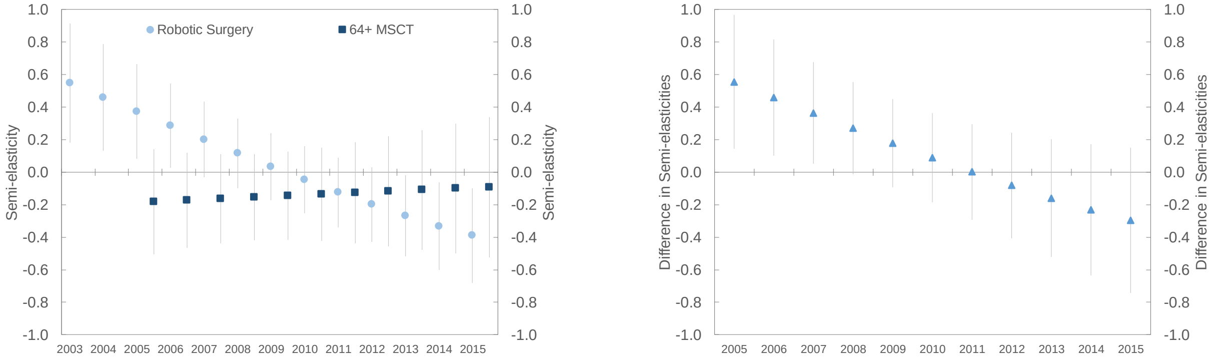
a. Semi-elasticities of integration

b. Contrast in semi-elasticities (Robotic Surgery – 64+ MSCT)

Note: 90% confidence intervals displayed.

Note: 90% confidence intervals displayed.

Figure C.4: Effect of integration on technology adoption over time, pooled logit estimates

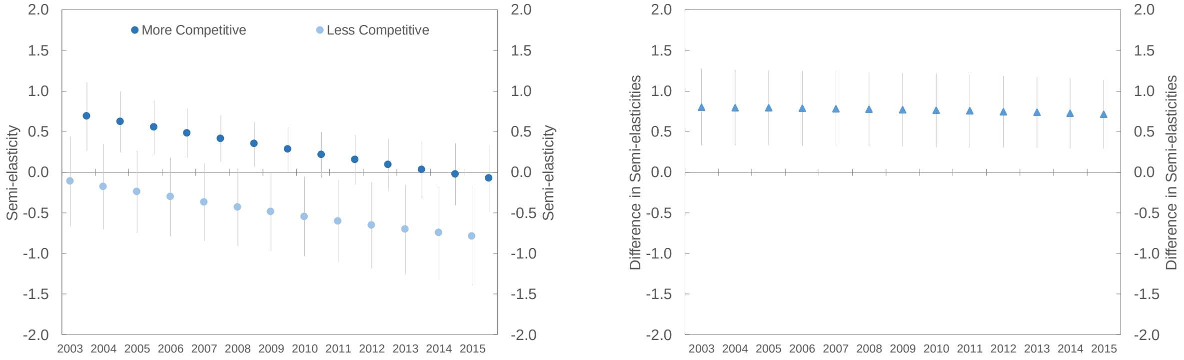

a. Semi-elasticities of integration

b. Contrast in semi-elasticities (Robotic Surgery – 64+ MSCT)

Note: 90% confidence intervals displayed.

Note: 90% confidence intervals displayed.

Figure C.5: Effect of integration on adoption of robotic surgery by local market competitiveness, unpooled logit estimates


a. Semi-elasticities of integration

b. Contrast in semi-elasticities (More competitive – Less competitive)

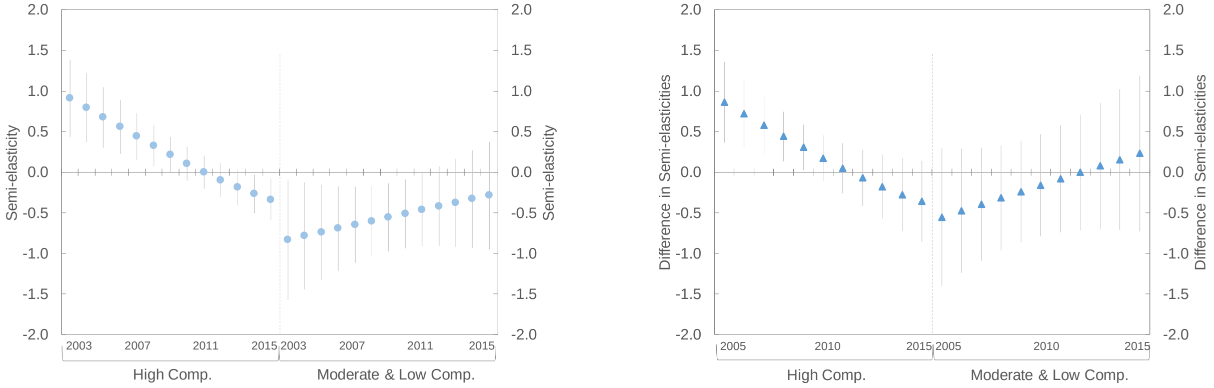
More competitive: HHI < 1500
Less competitive: HHI ≥ 1500

Note: 90% confidence intervals displayed.

More competitive: HHI < 1500
Less competitive: HHI ≥ 1500

Note: 90% confidence intervals displayed.

Figure C.6: Effect of integration on adoption of robotic surgery for high and low market competition subsamples, pooled logit estimates


a. Semi-elasticities of integration

b. Contrast in semi-elasticities (Robotic Surgery – 64+ MSCT)

Note: 90% confidence intervals displayed.

Note: 90% confidence intervals displayed.

## Appendix D: Placebo estimates

| | Broader Sample | | | | Broader Sample plus teaching hospitals | | | |
|---|---|---|---|---|---|---|---|---|
| | Robotic Surgery | | 64+ MSCT | | Robotic Surgery | | 64+ MSCT | |
| | No controls | Controls | No controls | Controls | No controls | Controls | No controls | Controls |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| CPOM state (yes=1) | -0.029 | 0.182 | -0.090 | -0.028 | -0.125 | 0.538 + | -0.094 | -0.040 |
| | (0.187) | (0.378) | (0.141) | (0.257) | (0.157) | (0.283) | (0.128) | (0.212) |
| CPOM state * Time | | -0.056 * | | -0.034 | | -0.085 *** | | -0.030 |
| | | (0.027) | | (0.034) | | (0.024) | | (0.027) |
| CPOM restrictions * High local market competition | | 0.791 ** | | 0.308 | | 0.247 | | 0.243 |
| | | (0.268) | | (0.264) | | (0.260) | | (0.197) |
| ln(# Surgeries) | 0.491 ** | 0.487 ** | 0.205 ** | 0.203 ** | 0.694 *** | 0.691 *** | 0.107 * | 0.104 * |
| | (0.170) | (0.167) | (0.075) | (0.075) | (0.110) | (0.108) | (0.048) | (0.049) |
| Cancer program (yes=1) | 0.230 + | 0.237 + | 0.010 | 0.012 | 0.169 + | 0.177 + | -0.062 | -0.061 |
| | (0.129) | (0.126) | (0.102) | (0.103) | (0.093) | (0.093) | (0.086) | (0.087) |
| Neurological services (yes=1) | 0.467 ** | 0.461 ** | 0.149 | 0.149 | 0.409 ** | 0.409 ** | 0.213 * | 0.214 * |
| | (0.165) | (0.168) | (0.099) | (0.100) | (0.136) | (0.136) | (0.094) | (0.095) |
| Cardiac surgery (yes=1) | 0.355 * | 0.338 * | 0.158 | 0.143 | 0.418 *** | 0.410 *** | 0.261 * | 0.254 * |
| | (0.157) | (0.155) | (0.140) | (0.139) | (0.101) | (0.101) | (0.108) | (0.106) |
| Specialist hospital (yes=1) | 0.798 | 0.712 | -0.344 | -0.367 | 0.730 * | 0.739 * | -0.409 | -0.409 |
| | (0.632) | (0.646) | (0.338) | (0.342) | (0.303) | (0.305) | (0.290) | (0.290) |
| Teaching hospital (yes=1) | | | | | 0.310 * | 0.304 * | 0.248 * | 0.246 * |
| | | | | | (0.136) | (0.134) | (0.123) | (0.121) |
| System member (yes=1) | 0.364 * | 0.379 ** | 0.095 | 0.098 | 0.393 *** | 0.395 *** | 0.007 | 0.006 |
| | (0.147) | (0.145) | (0.088) | (0.087) | (0.101) | (0.102) | (0.057) | (0.057) |
| ln(Total revenue) | 0.870 *** | 0.886 *** | 0.399 *** | 0.405 *** | 0.688 *** | 0.695 *** | 0.475 *** | 0.477 *** |
| | (0.122) | (0.121) | (0.095) | (0.095) | (0.090) | (0.090) | (0.067) | (0.068) |
| ln(Profit margin) | 0.411 * | 0.435 ** | 0.287 | 0.296 | 0.571 ** | 0.577 ** | 0.275 | 0.283 |
| | (0.161) | (0.159) | (0.183) | (0.185) | (0.221) | (0.218) | (0.188) | (0.190) |
| % Medicare inpatient days | -1.203 * | -1.202 * | -0.290 | -0.291 | 0.291 | 0.312 | -0.055 | -0.043 |
| | (0.491) | (0.491) | (0.249) | (0.248) | (0.390) | (0.381) | (0.173) | (0.171) |
| % Local market share | -0.823 + | -0.852 * | 0.466 * | 0.459 * | -0.271 | -0.276 | 0.450 ** | 0.456 ** |
| | (0.424) | (0.408) | (0.232) | (0.232) | (0.293) | (0.295) | (0.153) | (0.155) |
| High local market competition (yes=1) | 0.155 | -0.023 | 0.034 | -0.025 | 0.065 | 0.007 | 0.097 | 0.045 |
| | (0.151) | (0.173) | (0.099) | (0.099) | (0.132) | (0.144) | (0.083) | (0.080) |
| # Surgeries in local market | -0.000 * | -0.000 | 0.000 | 0.000 | -0.000 ** | -0.000 ** | 0.000 | 0.000 |
| | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) | (0.000) |
| Another hospital in system invested (yes= | -0.721 ** | -0.751 *** | -1.079 *** | -1.101 *** | -0.634 *** | -0.654 *** | -0.930 *** | -0.945 *** |
| | (0.227) | (0.219) | (0.113) | (0.109) | (0.138) | (0.136) | (0.109) | (0.106) |
| Hospital within local market invested (yes | 0.102 | 0.110 | 0.169 | 0.179 + | 0.279 * | 0.288 * | 0.112 | 0.118 |
| | (0.151) | (0.155) | (0.111) | (0.108) | (0.128) | (0.129) | (0.102) | (0.101) |
| State physician rate | -0.003 | -0.003 | -0.001 | -0.000 | -0.001 | -0.001 | -0.000 | -0.000 |
| | (0.003) | (0.003) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) | (0.001) |
| % State physicians under 40 years old | -0.085 ** | -0.083 ** | 0.040 | 0.041 | -0.059 * | -0.059 * | 0.022 | 0.023 |
| | (0.030) | (0.030) | (0.028) | (0.028) | (0.030) | (0.029) | (0.028) | (0.028) |
| % State physicians over 60 years old | -0.003 | -0.007 | 0.001 | -0.001 | -0.004 | -0.008 | -0.010 | -0.012 |
| | (0.025) | (0.026) | (0.034) | (0.034) | (0.020) | (0.020) | (0.024) | (0.025) |
| Low Medicare reimbursement state (yes= | -0.317 | -0.316 | -0.170 | -0.169 | -0.230 | -0.226 | 0.028 | 0.033 |
| | (0.269) | (0.263) | (0.131) | (0.129) | (0.177) | (0.177) | (0.163) | (0.161) |
| Time | 0.181 *** | 0.196 *** | 0.148 | 0.160 | 0.137 *** | 0.159 *** | 0.079 | 0.090 |
| | (0.048) | (0.054) | (0.243) | (0.245) | (0.025) | (0.028) | (0.195) | (0.196) |
| Observations | 14,781 | 14,781 | 8,908 | 8,908 | 26,272 | 26,272 | 16,424 | 16,424 |
| Number of firms | 2,001 | 2,001 | 1,908 | 1,908 | 3,449 | 3,449 | 3,381 | 3,381 |
| Pseudo R-squared | 0.258 | 0.260 | 0.115 | 0.116 | 0.283 | 0.285 | 0.142 | 0.143 |

Standard errors clustered by firm and state in parentheses. Two-sided p-values indicated by + $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. Year dummy variables included in all regressions. Additional controls not displayed that are insignificant across models: critical access hospital, % capitation, for-profit, ln(donations).