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# An Examination Of Medical Technology Disadoption And Its Relation To Technology Adoption And Physician Organization

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**Abstract**
Medical technology disadoption, a topic which has not previously been studied in great detail by health economists, is of great importance in a health care system where technology is understood to be a major driver of expenditure growth and the adoption of new technologies is consistently promoted by cultural norms and financial incentives. The disadoption of technologies with sub-optimal efficacy or safety is a key to improving the quality and value of care, and thus there is obvious utility to learning more about factors that influence technology disadoption. This dissertation establishes a novel theoretical framework to characterize the disadoption process along multiple dimensions, and then develops a simple mathematical model to describe physician disadoption behavior. Disadoption is examined empirically by analyzing the use of coronary drug-eluting stents (DES) in 2006-07(following their rapid adoption in 2003-04) using New York and Florida hospital discharge data, national practice organization data, and physician characteristic data. Preceding DES adoption behavior and physician group size are the primary factors studied for association with DES disadoption behavior. Empirical analyses indicate that faster DES adoption may be weakly associated with later DES disadoption, which may be consistent with physician risk aversion or product loyalty playing roles in disadoption decisions. Also, analyses suggest that there may be a week negative relationship between group size and timing of DES disadoption, suggesting that physicians in larger groups may begin the disadoption process later. These empirical results, which are subjected to instrumental variable analysis and extensive robustness checks, generally lack statistical significance, which highlights the current level of uncertainty surrounding disadoption behavior, including the observation that it does not appear to be empirically either similar or related to adoption behavior. Thus, this work both promotes and guides future research on medical disadoption and its determinants.

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# AN EXAMINATION OF MEDICAL TECHNOLOGY DISADOPTION AND ITS RELATION TO TECHNOLOGY ADOPTION AND PHYSICIAN ORGANIZATION

Henry Bergquist

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AN EXAMINATION OF MEDICAL TECHNOLOGY DISADOPTION AND ITS RELATION TO TECHNOLOGY ADOPTION AND PHYSICIAN ORGANIZATION

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# ABSTRACT

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Medical technology disadoption, a topic which has not previously been studied in great detail by health economists, is of great importance in a health care system where technology is understood to be a major driver of expenditure growth and the adoption of new technologies is consistently promoted by cultural norms and financial incentives. The disadoption of technologies with sub-optimal efficacy or safety is a key to improving the quality and value of care, and thus there is obvious utility to learning more about factors that influence technology disadoption. This dissertation establishes a novel theoretical framework to characterize the disadoption process along multiple dimensions, and then develops a simple mathematical model to describe physician disadoption behavior. Disadoption is examined empirically by analyzing the use of coronary drug-eluting stents (DES) in 2006-07(following their rapid adoption in 2003-04) using New York and Florida hospital discharge data, national practice organization data, and physician characteristic data. Preceding DES adoption behavior and physician group size are the primary factors studied for association with DES disadoption behavior. Empirical analyses indicate that faster DES adoption may be weakly associated with later DES disadoption, which may be consistent with physician risk aversion or product loyalty playing roles in disadoption decisions. Also, analyses suggest that there may be a week negative relationship between group size and timing of DES disadoption, suggesting that physicians in larger groups may begin the disadoption process later. These empirical results, which are subjected to instrumental variable analysis and extensive robustness checks, generally lack statistical significance, which highlights the current level of uncertainty surrounding disadoption behavior, including the observation that it does not appear to be empirically either similar or related to adoption behavior. Thus, this work both promotes and guides future research on medical disadoption and its determinants.

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## **CHAPTER 1**: Introduction

In the realm of United States health policy, few topics have received as much widespread attention as the level and growth rate of the country's overall health care expenditure. Though the rate of growth of health care expenditures has dropped to historically low rates in recent years (which has resulted in the level of expenditures as a percentage of GDP remaining relatively constant), growth rates are still positive and the overall level of spending is remarkably high, at more than 17% of GDP. (For data and discussions, see for example: Chernew & Newhouse 2012 Handbook Health Econ; Emanuel et al 2012 NEJM; MedPAC 2014; CBO 2013.) Indeed, despite the more favorable recent trends in growth rate, health care spending remains a major concern for the US federal budget in the immediate and foreseeable future (CBO 2013).

While there is common understanding and agreement about the high level of health care spending in the US, there is less agreement on whether or not the level of spending is *too* high. On one side, there is the belief that spending rates are too high, a belief that has spread as the level of spending has continued to climb. This view, which has long been held by some within health policy research and academic medical circles, can now be found frequently in newspaper and magazine articles, which has helped bolster widespread concern about health care spending levels and make health care a hot-button political topic over the past decade. Support for the view that the US is over-spending on health care is frequently found in comparisons between the US and other countries, which show that the US, while spending much more than all other countries, lags behind all other developed (and many developing) countries on various health-outcome metrics (see for example, Davis et al 2014 Cmmnwlth Fund; OECD 2014). Though these findings are compelling and prompt justifiable concern and inquiry, such data do not necessarily indicate that the US is spending "too much" on health care. For example, differences between the levels of spending in the US and other countries may relate to differences in preferences for health care, particularly relative to other types of consumption. Such cultural variations could explain how Americans and Europeans can both be utility-maximizing, while exhibiting different health care spending habits and achieving different health outcome measures. More generally, even though the US is spending a large portion of its GDP on health care, it is not clear that the country's utility or welfare would be increased by diverting those funds to other sectors. As long as there are positive marginal returns to each additional dollar spent on health care, the question of whether or not that dollar should be spent elsewhere is a subjective one.

Though economists have cautioned policy-makers and health services researchers from assuming that the US is *over*-spending on health care, recent studies have begun to document serious inefficiencies in the health care industry. Researchers have observed many examples where modest patient benefit does not seem to justify the cost of medical tests or treatments, or where there is complete lack of benefit despite increased spending (e.g. Lakdawalla et al 2015 Health Aff; Baicker & Chandra 2011 Fed econ symp; Garber, Goldman, Jena 2007 Health Aff; Konski et al 2007 J Clin Onc; Lodge et al 2007 Radtx

Onc). Other researchers have observed many examples of "inappropriate" use of therapies, e.g. the continued use of treatments despite the lack of evidence-based criteria (e.g. Al-Khatib et al 2011 JAMA; Kachalia et al 2015 Ann Int Med; Korenstein et al 2012 Arch Int Med); the continued use of therapies (e.g. preventative hormone replacement therapy and prostate-specific antigen screening) that have been shown to have health risks that exceed their benefits (e.g. WGWHII 2002 JAMA; Andriole et al 2009 NEJM); or the continued use of therapies that provide no benefit relative to placebo (e.g Buchbinder et al 2009 NEJM). Furthermore, other studies have avoided the question of clinical appropriateness and focused on system-level waste, i.e. aspects of the US health care system that lead to spending without any identifiable patient benefit (e.g. Bentley et al 2008 Millbank Q; Berwick & Hackbarth 2012 JAMA). Of course, one could debate this evidence of over-spending, noting for example that individual examples of inefficiency do not imply overall system- or country-level inefficiency. That said, as the body of evidence grows alongside the common concern over excessive spending and utilization, it is clear that this issue must be addressed; there is, if not a need, a strong desire to identify ways to decrease spending or increase value in the US health care system.

When considering ways to decrease US health care spending, one natural place to start is by focusing on medical technologies. Researchers have shown that the development and diffusion of new medical technologies are the primary drivers of US health care expenditure growth—being responsible for up to nearly 50% of average annual growth in

US healthcare spending—a fact which is facilitated by the structure of health care delivery and financing in the US, which encourage such diffusion (e.g. Newhouse 1992 J Econ Persp; Chernew & Newhouse 2012 Handbook Health Econ; Emanuel & Fuchs 2008 JAMA; Smith, Newhouse, Freeland 2009 Health Aff; MedPAC 2014; Thornton & Beilfuss 2016 App Econ Let). Of course, given that new medical technologies are typically designed to improve medical testing, treatment, or care delivery, it does not seem optimal to generally discourage the development and diffusion of new technologies, unless the population is willing to forego potential improvements in health care. One approach that has become the topic of extensive research and debate is the development and use of cost-effectiveness information to direct health care utilization, particularly in the setting of medical technologies. (For general discussions of cost-effectiveness analysis in the health care setting, see for example Meltzer & Smith 2012 Handbook Health Econ; Garber & Sculpher 2012 Handbook Health Econ; or Chandra, Jena, Skinner 2011 JEP.) Though cost-effectiveness analysis (CEA) has become increasingly common in the health services and clinical medicine literatures, unfortunately there is also growing evidence that clinical practice recommendations and guidelines suggested by such studies have only limited influence on clinical practice and health care utilization (Liang 2007 Health Aff; Howard & Shen 2012 AHEHSR; Deyell et al 2011 Arch Int Med; Grimshaw, Eccles, Tetroe 2005 JCEHP; Grol & Grimshaw 2003 Lancet; Cochrane et al 2007 JCEHP; Timmermans & Mauck 2005 Health Aff). Furthermore, recent research has shown that if CEA were used to guide technology adoption decisions, the results would not be very different from the current use of clinically-based comparative effectiveness research (CER), which thus raises the question of how much value could be realized if CEA data were widely disseminated and used to shape clinical practice (Glick et al 2015 Health Aff).

However, even if CEA data *were* used optimally to shape the diffusion of medical technologies, thus inhibiting the adoption of technologies for which costs outweighed benefits, there is no guarantee that the US health care system would achieve maximum value, because the data used for CEA cannot be perfect. In the same way that medications are considered to be safe at the time they receive FDA approval, but new data from widespread use can reveal previously-unknown risks[1], post-approval technology use can provide more insight into a technology's value. The data on new medical technologies typically comes from carefully designed and controlled experiments, which are very different from real-world clinical practice. Ignoring the likely possibility that a new technology will be used in patients who do not perfectly match the evidence-based clinical recommendations or guidelines (as mentioned above, which would naturally lead to inappropriate or low-value care), non-experimental patients generally do not receive the same intense scrutiny and detail-focused care, which means that their outcomes may differ significantly from those observed in the experiments that generated the original data. That is, the non-experimental patient population can never be expected to have the same exact outcomes as the experimental patient population. Still, even when real-world care and utilization of a new technology

[1] The story of rofecoxib (Vioxx) is one such example, starting with approval and widespread adoption, followed by the realization of major safety concerns, and ultimately concluding in market withdrawal (and legal action against the drug manufacturer).

perfectly mimics experimental conditions, the high cost of clinical trials generally means that the number of patients studied in such experiments is relatively small. After a technology receives FDA approval and diffuses widely, though, that technology can be used in a much larger patient population, allowing the acquisition of new and broader data on the technology, which may provide different insights into the efficacy, side effects, and value of that technology. In sum, even if CEA is optimally used to drive the adoption of high-value medical technologies, it is entirely possible (if not likely) that, over time, new information and data will emerge that changes the general understanding of the efficacy, safety, and value of a given medical technology. In that setting, once a technology is in use and deemed to be low-value or have previously-unknown risks, a researcher or policy-maker who seeks to find a way to reduce costs or improve quality of care is left to ask, "how can we drive the *dis*adoption of medical technologies?"

Thus, there is a unique value to studying and developing an understanding of the disadoption of medical technologies. Indeed, this not a unique realization: one specific goal of the widely-publicized Choosing Wisely campaign is to decrease the use of low-value services by educating physicians (and patients) (e.g. Morden et al 2014 NEJM; Rabin 20120404 NYTimes). For this initiative, the American Board of Internal Medicine (ABIM) Foundation collaborated with Consumer Reports and nine medical specialty societies to produce, for each specialty involved, a list of the top 5 "tests, treatments, or services that are commonly used in that specialty and for which the use should be reevaluated" (Cassel & Guest 2012 JAMA). Thus, by encouraging the disadoption of specific low-value tests and procedures, the goal was to attempt to decrease some of the over-utilization of services that has helped contribute to the massive cost of US health care (Morden et al 2014 NEJM). This problem of technology disadoption—or, more specifically, the lack of technology disadoption—within the healthcare industry is of major importance.

In this dissertation, I will study physician technology disadoption, focusing specifically on how it relates to technology adoption and physician organization. I focus specifically on the behavior of physicians because they play an active role in almost all major medical care decisions, including the use of most (if not all) high-cost medical technologies. In fact, by some estimates, the decisions made by physicians are ultimately responsible for over 80% of all dollars spent on health care (Crosson 2009 Commonwealth Fund). When studying physicians' technology disadoption behavior, I will first focus on its relationship with physicians' technology adoption behavior. As I will discuss more below (particularly in Chapters 3 and 4), there are many similarities between technology adoption and disadoption. Not only does an individual need to adopt a technology before she can disadopt that technology, the processes represent a change in technology use. While the topic of technology adoption has not yet been the topic of extensive research (as will be discussed in Chapter 2), technology adoption and diffusion are the focus of a very extensive literature. For these reasons, it is natural to try to determine if there are any empirical relationships between technology adoption and disadoption behaviors.

I next focus on the relationship between medical technology disadoption and physician group size. While there are many factors that may influence technology disadoption, the organization of physician groups is both conceptually significant and a topic of current and future interest in health policy. Not only have doctors progressively moved into larger groups over the past two decades (Burns, Goldsmith, Sen 2013 AHCM; Welch et al 2013 Health Aff), the passage of the Patient Protection and Affordable Care Act (ACA), with its emphasis on accountable care organizations (ACOs), will likely lead to continued health care reorganization and grouping of physicians in the immediate future (Greaney 2011 NEJM; Richman & Schulman 2011 JAMA; Vaughan & Coustasse 2011 Hosp Top; Blumenthal et al 2013 AJMC; Baicker & Levy 2013 NEJM). Understanding how changes in physician organization may influence physician behavior and technology disadoption will be valuable in considering the future course of medical technology use and cost growth in the US health care system.

In this dissertation, I study physicians' medical technology disadoption behavior, relating that behavior to preceding technology adoption behavior and to physicians' group size. In Chapter 2, I discuss the relevant background for this work, including a review of the literature and detailed description of coronary artery drug-eluting stents (DES), which serve as the example medical technology that I study in the empirical portion of my analysis. In Chapter 3, I delve into the details of adoption and disadoption behavior, developing a conceptual framework to both consider and measure these behaviors, while also evaluating the similarities and differences between them. Then in Chapter 3, I develop a basic decision-theoretic model to (a) provide structure for our understanding of technology disadoption behavior and how it relates to group size, and (b) generate empirically testable hypotheses about the disadoption behavior of physicians. I then turn to empirical analyses, examining physicians' adoption and disadoption of DES in the mid to late 2000s, using data from New York and Florida. In Chapter 5, I look first at the empirical relationship between physicians' adoption behavior and subsequent disadoption behavior. In Chapter 6, I turn to physician organization and study the empirical relationship between physician group size and disadoption behavior. In Chapter 7, I combine the perspectives of the previous two chapters and consider the differential relationship between physician group size and both adoption behavior and disadoption behavior. Finally, in Chapter 8, I provide a concluding summary evaluation and discussion.

# **CHAPTER 2: Background**

In Chapter 1, I provided the general motivation for the research questions I am asking in this dissertation. In this chapter, I will further develop the setting for this research and situate this work in the existing literature.

## 2.1 – Review of relevant literature

This dissertation relates to many different segments of the scientific literature. Here, I will discuss the areas of the literature that are most relevant and closely related to the current work.

*Technology adoption*

The topic of technology adoption has been extensively studied, both in health care and the broader scientific literature. The academic economic study of technology adoption dates back to the work of Joseph Schumpeter in the early 20$^{th}$ century, with the earliest empirical studies typically focused on agriculture and the diffusion of hybrid corn, as seen in the work of both sociologists (e.g. Ryan & Gross 1943 Rural Soc) and economists (Griliches 1957 Econmetrica) (Fagerberg 2003 J Evol Econ; Diamond 2003 Res Pol). Some of the most impactful early work was done by the economist Edwin Mansfield, who produced significant advances in the theoretical and empirical study of technology diffusion, noting the familiar *s*-shaped diffusion curve across several different industries and technologies, and finding a positive relationship between rate of adoption and both technology profitability and firm size (Mansfield 1961 Econometrica; Mansfield 1963 QJE; Mansfield 1963 Rev Econ Stat). Much of the early work on technology adoption focused on industry-wide phenomena, developing mathematical models that focused on the technology itself and mapping the observed diffusion of that technology by using probability distributions to describe the behavior of firms. Subsequent work, including most notably the studies by Reinganum (1981 Rev Econ Stud) and Jensen (1982 J Econ Theory), advanced the literature by developing decision-theoretic models of individual firm behavior, providing additional insights into specific behaviors and factors that influence the technology adoption process. Along with these peer-reviewed journal articles in forming the foundation of the technology adoption literature is Everett Rodgers' classic work *Diffusion of Innovations* (published first in 1962 and most recently updated in 2003). In his book, Rodgers provides as extensive discussion of the diffusion and adoption of new technologies (along with a broad history of past diffusion research), developing a language and methodology for studying technology adoption by describing: the elements of diffusion (innovation, communication channels, time, and social systems); phases of the diffusion process (e.g. innovation generation, communication, evaluation, decision, implementation, etc.); relevant aspects of innovations (e.g. complexity, compatibility, trialability, relative advantage, etc.); stakeholders in the diffusion process (e.g. adopters, opinion-leaders, change agents, organizations); and consequences of innovation (e.g. direct/indirect, desirable/undesirable). Since the publication of Rodgers' book and those early studies on technology diffusion, countless other papers have been published, coming from various academic disciplines and covering myriad technologies, including those used in the practice of clinical medicine.

*Medical technology adoption*

As was the case in the broader literature on technology diffusion, early work on medical technology adoption was found in the sociology literature, including the study by Coleman, Katz, and Menzel examining physicians' use of a new medication (Coleman, Katz, Menzel 1957 Sociometry). The topic has since been studied by researchers from the disciplines of (among others) sociology, management, statistics, public health, economics, and medicine itself. Reviews of this extensive literature can be found in Rye & Kimberly (2007 MCRR), Fleuren, Wiefferink, Paulussen (2004 IJQHC), Phelps (2000 Handbook Health Econ), Chandra, Culter, Song (2012 Handbook Health Econ), and Scott (1990 Med Care Rev). As the literature on medical technology adoption has grown, it has expanded to address a growing number of questions, consider countless different technologies, and provide progressively more nuanced detail about the various aspects that influence and shape the diffusion process, including stakeholders and environmental factors. Indeed, when approaching and evaluating this broad literature, studies can be considered using different organizing principles. For example, one way to categorize the literature is according to the adoption agent or stakeholder being studied. Patients' technology adoption behavior has studied relatively infrequently, with some articles examining the extent of patients' adoption health-related technologies—including smartphone-based mobile health apps (Murnane, Huffaker, Kossinets 2015 UBICOMP;

Krebs & Duncan 2015 JMIR) or pedometers (Craig, Tudor-Locke, Bauman 2007 Health Ed Res)—and other articles evaluating the patient characteristics, such as age and education, that shape the rate of technology adoption (Olson et al 2011 Ageing Int; Lleras-Muney & Lichtenberg 2002 NBER wp). Similarly, payers are another party in the health care marketplace who've received little attention from technology adoption researchers, with few studies considering the influence of payer structure (e.g. health maintenance organization versus fee-for-service indemnity plans) or market share on rates of technology diffusion (Ramsey & Pauly 1997 Inquiry; Baker 2001 JHE; Hirth, Chernew, Orzol 2000 Inquiry). On the other hand, unlike with patients and payers, the technology adoption behavior of health care providers has been exhaustively studied. Indeed, this difference is entirely reasonable, given that providers are understood to play a fundamental role in recommending, selecting, and/or providing medical technology for use in the clinical care of patients. Given this influence and the importance of technology in shaping both the cost and quality of medical care, it is unsurprising that there is a vast literature evaluating the technology adoption behavior of hospitals (e.g. Skinner & Staiger 2009 NBER wp; Teplensky et al 1995 HSR; Epstein et al 2004 JACC; Greenberg et al 2005 IJTAHC; Kimberly & Evanisko 1981 Acad Mgmt J; Lee & Waldman 1985 JHE) and physicians (e.g. Coleman, Katz, Menzel 1957 Sociometry; Freiman 1985 Med Care; Selder 2005 JHE; Hu et al 1999 JMIS; Navathe & David 2009 J Hum Cap; Escarce et al 1995 Med Care). Of particular interest in the current dissertation—in which I study the disadoption of coronary artery stents—is the adoption behavior of cardiologists (who implant coronary artery stents), which has been the subject of several studies.

Researchers have looked at the variation in cardiologists' rates of adoption of surgical techniques, technologies, and equipment, along with medications and imaging modalities (e.g. Artis et al 2006 J Med Syst; Pisano et al 2001 Mgmt Sci; Webb & Barbanti 2013 JACC; Burke, Fournier, Prasad 2007 SEJ; Pozen et al 1984 Med Care; Steinberg et al 2013 JAHA).

To help digest the large literature on medical technology adoption by health care providers, we can consider another means of categorizing this literature: according to the technology that is being adopted. Unsurprisingly, given the role of technology in the growth of health care spending (as discussed in Chapter 1), researchers have done considerable work on the diffusion of expensive, new medical technologies[2]. For example, there have been several studies examining the diffusion of magnetic resonance imaging (MRI) (e.g. Weigel 2006 J Surg Onc; Teplensky et al 1995 HSR; Baker 2001 JHE; Palesh et al 2007 IJTAHC; Fujimura et al 2004 Acta Neurochir; Schmidt-Dengler 2006 wp) and computed tomography (CT) imaging (e.g. Ladapo et al 2009 Health Aff; McHugh et al 2011 JACR; Hillman & Schwartz 1985 Med Care; Scheyerer et al 2014 EJNMMI; Hopkins et al 2013 Ped Rad; Nystrom, Ramamurthy, Wilson 2002 JETM). Equipment aside, many researchers have examined the diffusion of medications, studying how rapidly new medications enter into normal clinical practice and how that diffusion is shaped by marketing, education, pricing, and/or policy changes (e.g. Crawford & Shum

[2] Of course, "new" and "expensive" are both relative terms. Technologies that are considered "new" here are ones that have been recently (at the time the research was conducted) introduced to a market. "Expensive" refers generally to the cost faced by payers and patients, as opposed to the true cost of the technology (e.g. development or production). As is the case in many other industries, how new or expensive a medical technology is can change drastically (generally, both decrease) with time.

2005 Econometrica; Coscelli & Shum 2004 J Econometrics; Berndt et al 1995 AER; Skinner & Staiger 2005 NBER wp; Serra-Sastre & McGuire 2013 App Econ; Berndt, Pindyck, Azoulay 2003 J Indust Econ; Azoulay 2002 JEMS; Bradford & Kleit 2013 wp; Ching & Ishihara 2010 Quant Mrkt Econ; Nair, Manchanda, Bhatia 2010 J Mrkt Res).
In addition to work on diagnostic and therapeutic medical technologies, there has also been extensive research on other diffusion of other innovations in the health care sector, including a large and growing literature on electronic medical records and their impact on health care quality, efficiency, and cost (e.g. Chaudhry et al 2006 Ann Int Med; Gans et al 2005 Health Aff;  Hillestad et al 2005 Health Aff; Menachemi et al 2008 HCMR; Desai 2015 dissertation; Angst et al 2010 Mgmt Science; Bhattacherjee et al 2007 Info Sys Mgmt; Miller & Sim 2004 Health Aff).  Even further abstracted from physical technology are clinical guidelines, policies, or diagnostic/therapeutic algorithms, each of which has also been examined by medical and social science researchers (e.g. LaBresh et al 2014 Pediatrics; Bernhardt et al 2015 Stroke; Faust et al 2015 AJTMH; Fiks et al 2015 HSR; Schauffler, Mordavsky, McMenamin 2001 Am J Prev Med; Bellows, McMenamin, Halpin 2007 Med Care; Brehaut, Stiell, Graham 2006 Acad EM; LeFevre 2013 Prof Case Mgmt; Gold et al 2012 Cancer Imag; Gupta et al 2014 JAMIA; Durston 2014 AJEM; Sen 2015 dissertation).  Bridging the realm of treatment algorithms and physical technology are various surgical techniques and methods, which have also been studied by diffusion researchers (e.g. Sloan et al 1992 JHE; Hollingsworth et al 2008 Med Care; Escarce 1996 JHE; Escarce et al 1995 Med Care; Gross et al 2002 Am J Gastro; Giannopoulos et al 2013 SLEPT; Ho 2002 JHE).  One specific surgical technology is coronary drug-eluting

stents (DES), which is the technology that I study empirically in this dissertation. The adoption of coronary stents in general (which include bare-metal stents, BMS) and DES specifically have already been studied by many researchers, (e.g. Sfekas & Antwi 2014 wp; Chandra, Malenka, Skinner 2014 NBER chap; Karaca-Mandic & Town 2013 wp; Epstein et al 2012 Med Care; Xu, Avorn, Kesselheim 2012 CCQO; Huesch 2011 Soc Sci Med; Krone et al 2010 JACC Card Int; Shih & Berliner 2008 Health Aff; Burke, Fournier, Prasad 2007 SEJ). This work, which has examined various factors that influence stent adoption and the results of such adoption, provides relevant background and groundwork upon which the current dissertation is built.

Yet another way to categorize the large literature on medical technology adoption is by the various determinants that have been shown to influence adoption. To attempt to detail each of the different factors that has been shown to influence technology diffusion, or at least correlated with variations in adoption behavior, would be an exercise in futility due to how many different factors have been studied. However, these determinants can be divided into different groups. First, there are environmental factors, which exist outside of the firm or adoption agent and do not relate specifically to the technology itself. For example, studies have examined the relationships between medical technology adoption and both geographical factors (e.g. Eisenberg et al 1989 JAMA; Poulsen et al 2001 Health Pol; Knudsen, Ducharme, Roman 2006 JSAT) and regulatory environment (e.g. Bradford & Kleit 2013 wp; Chintagunta, Jiang, Jin 2009 Quant Mrkt Econ; Teplensky et al 1995 HSR; Castle 2001 Gerontologist). Economists have also extensively studied the impact of market structure and competition—both between health care providers and payers—on medical technology adoption (e.g. Barbash et al 2014 Ann Surg; Karaca-Mandic & Town 2014 wp; Baker & Wheeler 1998 Health Aff; Baker & Phibbs 2002 RAND; Roman & Johnson 2002 JSAT; Hirth, Chernew, Orzol 2000 Inquiry; Kimberly & Evanisko 1981 Acad Mgmt J; Lee & Waldman 1985 JHE; Wang et al 2005 HCMR). A second set of factors related to the rate of medical technology diffusion are the characteristics of the technology itself. As one would predict from theory and intuition, empirical research has shown that both the profitability or financial implications and the clinical quality or efficacy of a technology is strongly related to its adoption rate (e.g. Selder 2005 JHE; Hillman & Schwartz 1986 Am J Roent; Cappallaro, Ghislandi, Anessi-Pessina 2011 Health Pol; Schreyogg, Baumler, Busse 2009 Health Pol; McHugh et al 2011 JACR; Abrishami, Boer, Horstman 2014 Soc Sci Med; Teplensky et al 1995 HSR; Randeree et al 2003 JHIM; Lee & Waldman 1985 JHE). Third, the characteristics of the adoption stakeholders are frequently related to the observed rate of technology adoption. In the case of medical technology, this group of factors includes characteristics of patients, physicians, hospitals, and other health care provider organizations, all of which have been shown to be associated with technology diffusion rates in empirical studies (e.g. Lleras-Muney & Lichtenberg 2002 NBER wp; Navathe & David 2009 J Hum Cap; Sato & Zouain 2012 Einstein; Roman & Johnson 2002 JSAT; Knudsen, Ducharme, Roman 2006 JSAT; Burke, Fournier, Prasad 2007 SEJ; Nair, Manchanda, Bhatia 2010 J Mrkt Res). For the current dissertation, which will examine the role of physician organization in relation to technology adoption and disadoption, this third category is most relevant. Most notably, because I will specifically focus on physician group size, it is worth noting that a large number of studies have examined the association of provider organization size and technology diffusion (e.g. Nystrom, Ramamurthy, Wilson 2002 JETM; Poulsen et al 1998 Health Pol; Hirth, Chernew, Orzol 2000 Inquiry; Knudsen & Roman 2004 JSAT; Walston, Kimberly, Burns 2001 MCRR).

*Technology disadoption*

While technology adoption has been the subject of a vast and growing literature, the topic of technology disadoption has been studied much less commonly. As with technology diffusion, much of foundational work on technology disadoption if found in the literature on farming and agriculture (e.g. An & Butler 2012 CJAE; An 2013 AEPP; Fernandez-Cornejo et al 2002 ARER; Gedikoglu 2010 wp). While these papers offer general guidance for ways to evaluate technology disadoption, the dissimilarities between the agriculture and medical industries and their associated technologies are significant enough to prohibit any deeper insight or revelations. Fortunately, there is a specific literature dedicated to technology disadoption, though this literature is remarkably small.

Almost all of the current studies on medical technology disadoption have a similar design and motivation in that they evaluate the decrease in use of a technology following the publication of updated clinical guidelines or research that recommended abandonment of the technology. For example, Shen et al (2013 Arch Gyn Ob), Howard et al (2011 HSR), and Howard & Shen (2013 HSR) all assess the impact of a major trials (whether systematic reviews or large randomized controlled trials) recommending against the use of a specific technique or technology (episiotomy, high-dose chemotherapy/ hematopoietic cell transplant, and percutaneous coronary intervention, respectively). Howard et al (2012 Health Aff) similarly look at (and find as significant) the impact on arthroscopic knee debridement and lavage of multiple research studies indicating no benefit of that procedure for osteoarthritis, but the picture is compounded by multiple payers contemporaneously dropping coverage for the procedure. Considering another even that is arguably even more impactful than the publication negative research results, Dorsey et al (2010 Arch Int Med) examine the impact of an FDA black box advisory regarding the increased mortality risk linked to the use of atypical antipsychotics in elderly patients with dementia, and they find a significant (negative) impact of the advisory.

Another group of disadoption studies does not specifically examine the impact of a specific publication or advisory, but instead focuses on the determinants that shape health care providers' disadoption behavior. For example, Duffy & Farley (1992 Med Care) study the abandonment of intermittent positive pressure breathing (IPPB), an outdated technology, and how that disadoption relates to various hospital, patient, and physician traits. Similarly, Berez et al (2014 wp) study the role of physician peer influence on the decrease in utilization of pulmonary artery (PA) catheters (following the publication of a high-impact paper and multiple subsequent randomized controlled trials). Sen (2015 dissertation) also examines the influence of physician peer effects, looking at the change in prostate and breast cancer screening rates (using prostate-specific antigen and mammography, respectively) following updates to nationally-published screening guidelines. In sum, these articles, building on the other disadoption studies that demonstrate the impact of external information (publications or advisories), show that physicians influence each others' practice patterns, presumably via information transfer.

While these studies individually and collectively provide novel insights into medical technology disadoption, they have significant limitations. First, most of these studies lack a decision-theoretic economic model. Such studies, while providing empirical evidence of technology disadoption, focus simply on whether or not a past intervention, announcement, or policy change triggered disadoption. Generally speaking, such studies do not attempt to provide insight into the fundamental mechanisms or incentives driving technology adoption, or how that process relates to various structural characteristics that define a physician's practice environment. Similarly, while a few studies evaluate the role of peer interactions in shaping disadoption behavior, they generally do not propose theoretical foundations to explain such peer effects. Second, along these same lines, rather than studying physician characteristics, several of the studies relate technology disadoption behavior to hospital characteristics. Given the fundamental role of physicians in the medical technology adoption and disadoption processes, there is value to be gained from examining physician characteristics relative to those processes. Third, these studies generally take a simplistic view of technology disadoption, either treating it as a simple event or not measuring it specifically. As I will discuss in detail in Chapter 3, I propose that technology disadoption (like adoption) is not an event, but instead a process that can be characterized along multiple dimensions. The studies that do not treat disadoption as a single event instead examine it by simply studying technology use during a period of general downward trends in population-level technology use, which does not define or measure disadoption per se. In both cases, the studies generally lack a detailed empirical measurement of the technology disadoption process. Fourth, while some studies address the relationship of physician groups to medical technology disadoption, they typically do so by empirically testing for the presence of loosely-defined peer effects. Such studies provide value in showing that physicians' disadoption behavior relates to that of their peers, but they do not provide further insight into the mechanisms for this relationship or the structural characteristics of a physician group that might influence the relationship. Finally, and most importantly, none of the current studies have related medical technology disadoption to a physician's past adoption behavior and very few of the studies consider the role of group size (and the ones that do, measure disadoption very differently than I will, as mentioned above). It is this series of limitations among the existing medical technology disadoption literature that the current dissertation seeks to address, thus making it a novel and significant contribution to the scientific literature.

*Physician group size*

The literature on physician group size is also directly related to this dissertation. Though group size has been only occasionally related to technology disadoption behavior, the topic of group size has been the subject of frequent examination in the broader technology adoption literature, as mentioned above. Dating back to one of the earliest seminal works on technology adoption, Ryan and Gross identify connection and communication between neighboring farmers as one of the key determinants in driving differences in rates of diffusion of hybrid seed corn technology in Iowa in the 1930s (Ryan & Gross 1943 Rural Soc). As Geroski (2000 Res Pol) notes, "firm size turns out to be a very commonly explored variable [that characterizes the timing of technology adoption] in the empirical literature on diffusion." (However, he continues, this is "partly because it is typically taken as a proxy for all kinds of things," though there is no real consensus on how exactly group size proxies for different characteristics[3].) Despite these findings and the similarities between technology adoption and disadoption, which will be discussed at length below (in Chapter 3), there is very little work examining the relationship between group size and technology disadoption.

Aside from its specific relationship to technology adoption, group size has also been the topic of increasing interest in the health services and health economics literatures. Multiple studies have examined the changing organization and group sizes of physicians, showing a two-decade trend away from solo practices and toward larger groups (e.g. Bauer et al 2012 Med Care; Burns & Muller 2008 Milbank Q; Welch et al 2013 Health

[3] Indeed, some researchers present reasons to believe that larger firms will adopt new technology sooner, while others argue that larger firms will adopt later. It is worth noting that some of the researchers who consider group or firm size to be an important determinant of technology adoption study technologies that are very different from drug-eluting stents, the technology that I study here. (For example, a technology that requires a large capital investment but can reduce per-employee costs would be more beneficial to firms with more employees.) Thus, it is not clear that the observations from these other studies can be applied or translated directly to the current dissertation, but they still provide some motivation for studying the important of group size in this setting.

Aff; Burns, Goldsmith, Sen 2013 AHCM; Berenson, Ginsburg, Kemper 2010 Health Aff; Liebhaber & Grossman 2007 CSHSC rep). Furthermore, there is a long literature studying the role of physician organization in shaping physician behavior. Early studies in the health economics literature have examined the general economic theory surrounding physician group practice (e.g. Newhouse 1973 JHR; Pauly 1996 JACM), and more recent studies have focused on the empirical association between group size and physician behavior. Findings from some of the most recent examples from this literature include that group-based physicians perform better on certification exams (e.g. Lipner et al 2011 Acad Med); solo practitioners seem less likely to follow clinical guidelines (Ketcham, Baker, MacIsaac 2007 Health Aff); larger group size is associated with great engagement in quality improvement (Audet et al 2005 Health Aff); group-based physicians offering more health promotion programs (McMenamin et al 2004 Am J Prev Med); and large group size is associated with greater use of information technology tools (Audet et al 2004 Medscape GM). Though this is an extensive literature, it has limitations. First, many of the studies in this literature, which were published in clinical or health services journals, are based on physician survey, and thus lack the ability to draw causal inference between group size and physician behavior. Second, this literature is generally lacking decision-theoretic models, which can provide insight into physician behavior and the mechanisms through which group size influences actions. Third, medical technology disadoption is a topic that appears only rarely in this literature, and never with a detailed characterization of the disadoption process, as I will develop in this dissertation.

Despite these limitations, this sizeable (and growing) literature depicting the benefits to increasing group size has understandably garnered a considerable amount of support. Throughout the medicine and health policy literature, one can find many researchers, thought-leaders, and policy-makers who promote continued growth of health provider group size (e.g. Weeks et al 2010 Health Aff; Enthoven 2009 AJMC; Crosson 2005 Health Aff; Shih et al 2008 Cmnwlth Fund; Solberg et al 2009 AJMC; Casalino 2006 Ann Int Med). As this sentiment becomes increasingly common, the need to evaluate the impact of group size on various behaviors and outcomes—for example, on the disadoption of high-cost, low-efficacy, and/or low-value medical technologies—grows commensurately.

## 2.2 – Empirical setting: drug-eluting coronary stents

*Technology function and history*

Through most of my discussion of technology adoption and disadoption thus far, I've only referred to generically to "medical technology," but to study these processes empirically, it is necessary to choose a specific technology. In this dissertation, I focus my empirical examination on coronary artery stents, the relevant details of which I will describe here.

Coronary artery stents are tiny mesh tubes that are placed inside of coronary arteries to hold open those arteries, as shown in Figure 2.1. Coronary arteries are the blood vessels which supply oxygenated blood to the heart, allowing it to pump and supply blood to the entire body. Blockage of (or damage to) these vessels produces coronary artery disease, the most common type of heart disease, which is the leading cause of death in the US. (A complete blockage of a coronary artery can lead to myocardial infarction, or a heart attack, an acutely severe and potentially lethal form of coronary artery disease.) Coronary stents are implanted into the coronary arteries by interventional cardiologists via percutaneous coronary intervention (PCI), a surgical procedure during which a thin catheter is inserted into a large vessel (most typically in the femoral artery in the leg or the radial artery in the arm) and threaded up through blood vessels to the heart, where the coronary arteries are then accessed. The tip of the catheter generally contains a balloon, which can be inflated in the lumen of a partially occluded vessel, thus pushing open that vessel in a procedure known as percutaneous transluminal coronary angioplasty (PTCA), or simply balloon angioplasty. PCI with angioplasty with was first used in the 1970s, but had become widely used in medical center around the world by the mid-to-late 1980s (Gresh 2003 BMJ). While angioplasty was capable of opening occluded vessels, there was natural risk for those vessels to re-occlude (or restenose), which prompted the logical development of coronary artery stents. The original coronary artery stents, which were simple metal mesh, now referred to as bare-metal stents (BMS), were first implanted in the late 1980s, but were in widespread use by the mid-to-late 1990s (Serruys, Kutryk, Ong 2006 NEJM).

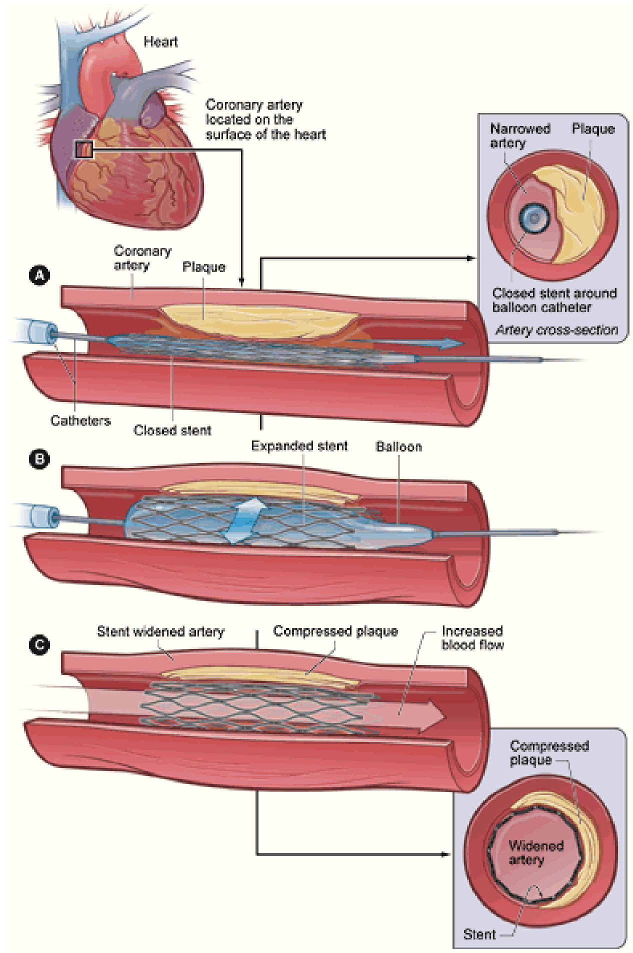


**Figure 2.1**: Coronary artery stent diagram (Source: NHLBI, NIH)

Though the BMS provides the structural presence to hold open coronary vessels, clinical experience over several years with coronary stents revealed that in-stent restenosis of the vessel was a common problem. This persistent issue motivated the development of drug-eluting stents (DES), which were similar structurally to BMS, but also coated with pharmaceutical products that decreased the coronary vessels' natural restenosis process. The high prevalence of restenosis with BMS (with rates up to 50%) and the drastic reduction in restenosis observed in early DES trials (rates between 0 and 9%) lead to tremendous excitement in the interventional cardiology community and rapid DES adoption following FDA approval in April 2003 (Serruys, Kutryk, Ong 2006 NEJM). A year after approval, more than 50% of coronary stents implanted were DES, with rates continuing to climb and exceeding 90% by 2005 (Krone et al 2010 JACC Card Int). (See literature review in Section 2.1 above for references to studies that examined the initial diffusion of DES.)

However, this rapid diffusion was accompanied by continued research and real-world experience with DES, which revealed potential concerns with the new technology. While DES were designed to address the issue of in-stent coronary artery stenosis, another critical issue was that of thrombosis, or the formation of new blood clots inside the stent, which can then occlude the coronary vessel, leading to myocardial infarction or dysfunction. In January 2004, Virmani and colleagues published the first case study reporting late (i.e. several weeks or months after implantation) coronary stent thrombosis and death in an individual who had received DES (Virmani et al 2004 Circ). Additional similar cases were reported in *The Lancet* in October 2004 by McFadden and colleagues, which was followed by the report of similar findings in a small study of "real-world" patients in JAMA in May 2005, creating the first signs of momentum around concerns for late stent thrombosis in DES (McFadden et al 2004 Lancet; Iakovou et al JAMA 2005). In September 2006, these concerns reached their peak at the World Congress of Cardiology in Barcelona, where Camenzind and colleagues presented meta-analysis of the DES randomized clinical trials, which showed not only increased rates of late stent thrombosis DES relative to BMS, but also increased risk of myocardial infarction and death (Camenzind 2006 World Cong Card). These findings—which represented a coalescence and validation of the diffuse and generally muted concerns over DES safety—received widespread publicity and marked the beginning of a period during which DES rates began to sharply decline (Krone et al 2010 JACC Card Int). Eventually, further research showed that the risk of late stent thrombosis in DES could be mitigated with dual anti-platelet therapy (DAPT), which then lead to the eventual resurgence of DES rates, beginning in 2008 (Lee et al 2007 Am J Card; Buonamici et al 2007 JACC; Lee et al 2008 JACC; Gori et al 2008 JACC; Epstein et al 2011 JAMA). Figure 2.2 graphs the trend in physician-level DES implantation rates over this time period in Florida and New York (using the data that will be later used for empirical analyses throughout this dissertation).

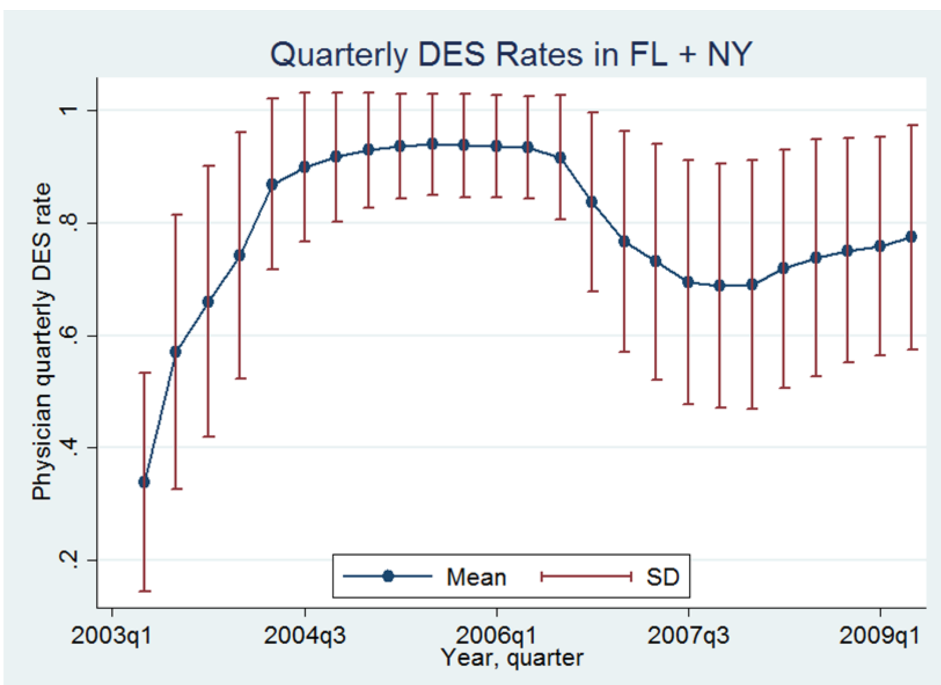


**Figure 2.2**: DES usage rates in the 2000s in Florida and New York

*Important features of DES*

Having established the general history of DES, there are several aspects of this technology that make it an appropriate choice of setting for the empirical study of medical technology disadoption. First, the technology was widely used (with usage rates exceeding 90% from 2005 into 2006) and showed both significant increases and decreases in use over time, which makes for easy observation of both adoption and disadoption behavior in the data and improves both internal and external validity of any study. Also, the relatively rapid changes in usage rates make it possible to observe both the adoption and disadoption processes in a relatively small time window. Furthermore, we are able to observe the diffusion of DES with high fidelity because, due to the early excitement surrounding the technology, the Center for Medicare and Medicaid Services established procedure codes allowing for DES implantation prior to FDA approval of the technology. Hence, unlike many other medical technologies, which come to market and in use before specific billing codes are established for the new technology, DES implantation could be appropriately coded from its first approved implantation and thus appears reliably in hospital discharge data files throughout its history, significantly reducing the amount of error introduced by the data generation and collection processes.

Another advantage of using DES as the setting for empirical examination of medical technology adoption and disadoption is the fact that there was significant variation between cardiologists in DES usage rates. As seen in Figure 2.1, though the global trend of adoption, disadoption, and re-adoption is clear, there is significant deviation in DES usage rates around that trend, which increases the statistical potential to empirically identify factors that may partially be responsible for causing that variation. This varation is the result of the fact that, unlike some other examples of medical technology, a cardiologist's choice of coronary stent (BMS vs DES) is largely subjective, based on individual knowledge, experience, and preferences (as opposed to strict, well-established guidelines). While some patients may have had clinical presentations that provided obvious indications for one technology or the other, cardiologists were faced with many patients whose coronary artery disease could be reasonably treated with implantation of either BMS or DES, subject to the cardiologists' judgement and inclinations. Indeed, even though the FDA approval of DES brought with it specific indications for use, high levels of enthusiasm for the new technology led to rapid, widespread adoption and frequent off-label use. After the September 2006 publicization of data that indicated increased risk of late stent thrombosis, the global decrease in DES implantation rates was not due to general change in patient characteristics or concrete guidelines for DES use. Rather, the appearance of evidence that was unfavorable towards DES simply led many physicians to recalibrate their preferences and decision processes, leading them to favor BMS over DES in patients who were on the technology choice margin. Thus, the fact that a cardiologist's specific choice of coronary stent was frequently a judgment call lead to significant within-population variation in DES rates, which provide a favorable setting for empirical analysis.

Yet another strength of this empirical setting of medical technology use is that the decision to use DES can be isolated with relative certainty to the physician and her perception of the relative clinical value or appropriateness of DES. With many new technologies, an individual's ability to adopt or disadopt is directly influenced or constrained by several external factors. For example, with medical technologies that require pieces of expensive equipment (e.g. a surgical robot or a cyclotron for proton beam therapy), an individual physician can only adopt the technology if a larger organization (typically a hospital) makes the major capital investment in that equipment. Similarly, if the organization decides to sell or eliminate the equipment, physicians who were using that technology may be forced to disadopt it. In the case of DES, though there were some supply constraints early on (as is the case with most new, popular technologies), the technology was relatively small and cheap, in addition to being extremely popular among physicians, so hospitals were able and motivated to make the DES accessible to all physicians who wanted to implant it, even after September 2006. Indeed, even though hospitals' margins were lower for DES than BMS[4], DES was wildly popular among cardiologists and was generally considered to be the standard of care, which resulted in persistently high physician (and patient) demand for DES. Thus, because hospitals did not want to provide (or appear to provided) below-standard care or run the risk of alienating their revenue-generating interventional cardiologists, hospitals routinely provided physicians with unfettered access to DES (Shih & Berliner 2008 Health Aff).

[4] Even though Medicare created a separate diagnosis-related group (DRG) for DES which provided more payment than BMS, the acquisition cost of DES was more than commensurately higher, resulting in the hospitals realizing lower per stent margin for DES than BMS (Epstein et al 2012 Med Care).

In the same way that access to equipment can shape an individual's ability to adopt technology, acquisition of skills is often an important factor in shaping both adoption and disadoption. Individuals may hesitate to adopt a technology due to the required fixed cost of acquiring new skills necessary for its use, or they may be disinclined to disadopt a technology if they believe their skills with it are so great that they can achieve greater production with it than any other alternative. In the case of coronary stents, there is no differential skill level required for DES relative to its substitute technology, BMS. Thus, neither adoption nor disadoption of DES would be confounded by differences in provider skill. Another external factor that can shape individuals' technology adoption and disadoption behavior is the difference in financial incentives between technology options. If an individual gets paid more to use an old technology than a newer technology, that may likely incentivize her to continue using the old technology. However, in the case of coronary stents, physicians received the same financial reimbursement per stent implanted, regardless of whether the stent was DES or BMS, so financial incentives likely played no role in driving physicians' adoption or disadoption behavior[5].

Given all of these factors, DES provide a convenient setting to empirically study medical technology disadoption, and I will use this empirical setting in the following chapters.

[5] As mentioned above, the cost and reimbursement to the hospital that provided the stent and the setting for its implantation differed significantly between BMS and DES, resulting in hospitals earning lower margins for DES. Thus, there may have been an incentive for hospitals to try to influence physicians' choice of coronary stent away from DES, but appears to have been counterbalanced by incentives in favor of DES (e.g. reputation for quality, relationship with physicians, which is critical for long-term revenue generation). Furthermore, I am unaware of any evidence that hospitals attempted to persuade physician stent choice in practice.

However, before beginning this empirical investigation, I first must establish a framework for characterizing the technology adoption and disadoption processes.

# CHAPTER 3: Characterizing technology adoption and disadoption

Having provided the motivation and background to substantiate this dissertation and the specific topic of inquiry, I now begin the process of identifying and elucidating the specific research questions to be addressed. My primary interest here is the examination of medical technology disadoption, which will require thinking deeply about the meaning and measurement of this phenomenon. In this chapter, I start by providing a conceptual characterization of both technology adoption and disadoption. This characterization will provide the framework for the creation of measurements that will be used in the subsequent empirical analyses of the adoption and disadoption of drug-eluting stents.

## 3.1 – Conceptual framework

As described above in Chapter 2, technology adoption has been the subject of a large and growing scientific literature. When studied empirically, the adoption of technology is typically described by a simple definition: adoption occurs when an individual first uses a technology. Disadoption, on the other hand, has been studied less frequently and, when studied, has not been consistently defined. In fact (as described in Chapter 2), many of the studies that claim to examine disadoption do not actually define disadoption at all, but instead simply perform empirical analyses of technology use while restricting their focus to a time period in which that technology's usage rates are generally decreasing within a population. While such analyses may broadly explore technology disadoption, it is unclear that they provide insight specifically into disadoption itself, per se. However, some studies do provide a specific definition for disadoption and, among these studies, the typically used definition is the inverse of that used most frequently for adoption: disadoption occurs after an individual has used a technology for the final time. As shown in Figure 3.1, which provides a graphical depiction of technology adoption and disadoption, these common definitions focus on technology use as a binary, "yes-no" state.

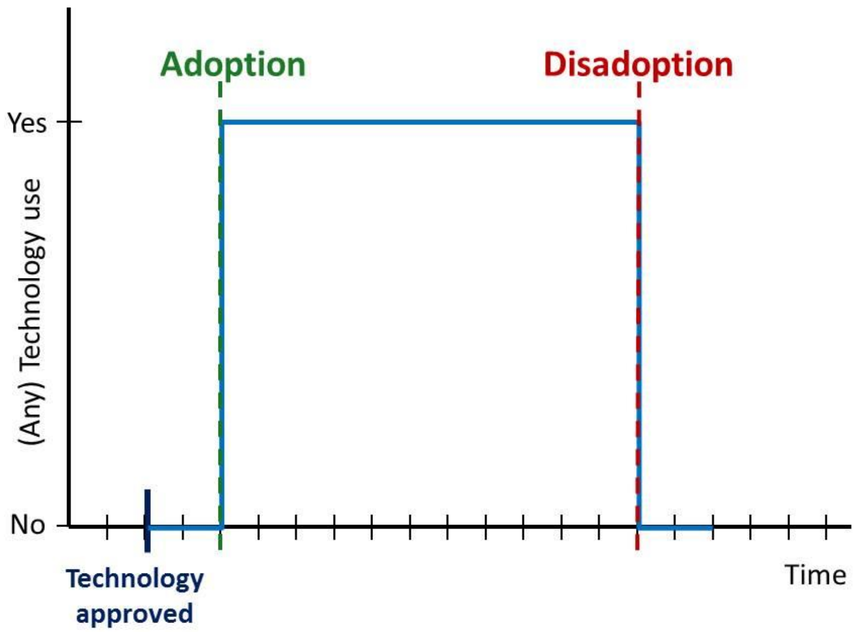


**Figure 3.1**: Technology adoption and disadoption with binary technology use

While this framework for understanding technology adoption and disadoption is both well-defined and commonplace, there are at least two issues with it. First, though the definitions are (in a way) symmetric, they actually create disparate measures of two processes that we may wish to view through a similar lens. When studying adoption, it is both natural and informative to examine the time when a technology is first used—hence the traditional definition of adoption that is used in the literature. However, if we are similarly interested in examining the *initial change* that represents technology disadoption, we see that this information is absent from the traditional definition of disadoption, i.e. as occurring after a technology is used for the final time. Thus, if we want to examine the similarities or relationships between technology adoption and disadoption (which may be motivated by our understanding of the two phenomena as being relatively similar, as will be discussed below), it seems that we may want to consider a different definition of disadoption, if not also adoption.

Second, deeper examination of the technology use reveals that the traditional views of adoption and disadoption may be overly simplistic and ignore some important aspects of the adoption and disadoption processes. To consider these processes in more detail, we start by examining Figure 3.2, which depicts technology use in greater detail than was shown in Figure 3.1. Rather than reducing technology use to a binary, on-off state, this figure plots technology *usage rate*, which can vary between 0 and 100%. As an example, technology usage rate may be measured as the percentage of a physician's patients who receive the specified technology. Even if a physician adopts a new technology (e.g. purchases a surgical robot or starts prescribing a given medication), she may not use that technology to treat all of her patients. Thus, even for individuals who adopt (and disadopt) a technology at the same time, there may be significant differences between those individuals in terms of how much that technology is used. This type of variation is depicted in Figure 3.2, which shows four individuals with visibly different technology usage rates, even though each of the four individuals adopts and disadopts the technology in the same time periods and would thus appear identical if depicted in the framework used in Figure 3.1, which ignores the intensive margins of technology use.

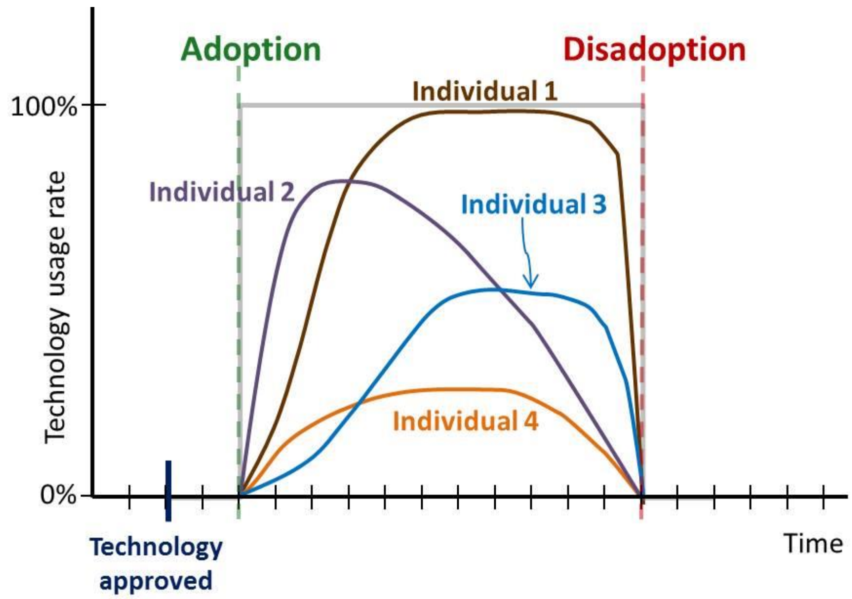


**Figure 3.2**:  Technology adoption and disadoption with continuous technology usage rate

The distinction noted here raises a question:  when studying technology adoption and disadoption, do we think there are significant differences between the four individuals depicted if Figure 3.2, or do we believe that all four individuals can be treated as identical?  In this dissertation, I take the stance that these individuals should be treated as different.  Rather than using the simple traditional definitions to characterize technology adoption and disadoption, I choose to take a more detailed perspective.  While we can all agree that each of the four individuals in Figure 3.2 first uses and last uses the specified technology at the same times, it is not entirely clear when each of the individuals starts the process of disadopting that technology.  Indeed, instead of treating adoption and disadoption as events, I view these as processes which can be characterized along multiple dimensions, which I will explain below.

It is important to note here that this concept of technology "usage rate," like any other rate, is composed of two parts mathematically: a numerator and denominator. In the example described here, the denominator could be a physician's total number of patients (at least those who would be eligible for use of the given technology) and the numerator would be the number of patients for whom the given technology is actually used. In this framework, then, it is important to keep in mind that changes in technology usage rate, which will be used to define adoption and disadoption (as explained below), may be the result of changes in either the numerator or denominator, or both. Generally, if we assume a physician's patient volume and mix are relatively consistent—i.e. changes in patient volume are due to addition or removal of patients who are similar in number and characteristics—we would not expect the numerator or denominator to change out of proportion to each other, and technology usage rate should theoretically be a reliable and consistent measure of physician behavior. However, an influx of a unique type of patient (e.g. of a risk profile that made technology use very unlikely, or more importantly, significantly less likely than the physician's existing patient population) could lead to a disproportionate change in the denominator, causing a drastic change in technology usage rate, without an underlying change in physician preferences or behavior. Similarly, changes in total patient volume to the extreme (e.g. reduction to 1 or 0 patients) would also likely result in extreme fluctuations of a technology usage rate measure. Of course, such changes in patient population could also introduce problems for any other quantitative measure of physician technology use, including adoption or disadoption measures, but the unique potential for variation in a ratio-dependent metric must always be kept in mind.

Also, as with any analysis that is fundamentally temporal in nature (including adoption analyses under the traditional framework), measurement of time is a critical component of these calculations. If we again assume a relatively stable patient volume and characteristic mix, the parsing of time periods into larger or smaller pieces should only change temporal resolution of the analysis. However, in reality, use of progressively smaller time periods, which might seem preferable in the interest of improving temporal resolution, can reduce a physician's per-period patient volume (i.e. technology usage rate denominator) to the point where stochastic variations are on the same order as true variations, and the technology usage rate would become too noisy to use reliably. (For example, even if a physician generally sees the same number of patients every month or week, there will very likely be some days—due to illness, vacation, or other obligations—when the physician will treat few or no patients. As such, a blind comparison of that physician's day-to-day technology usage rate could produce bizarre results due to relatively significant changes in the patient volume, i.e. the use rate denominator.) Thus, there is a natural trade-off between limiting noise from expected time-based variations (by choosing larger time periods) and improving resolution of a fundamentally temporal analysis (by choosing smaller time periods), and the balance of these countervailing forces can only be determined empirically.

## 3.2 – Dimensions of technology adoption and disadoption

Figure 3.3 provides a simple, stylized graphical depiction of an individual's technology usage rate over time. Given that the empirical setting of interest in this dissertation is the use of coronary artery stents, we can imagine that the curve drawn here represents a physician's quarterly DES rate, i.e. the fraction of coronary stents placed by the physician that are drug-eluting (as opposed to bare-metal) in each quarter. There are several important aspects to note in this figure. First, rather than adoption and disadoption being illustrated as discrete events, they are depicted as processes that take place over multiple time periods. These processes, however, are still characterized by multiple different discrete events. For example, there is a time period labeled with "technology approved," which marks when the medical technology received FDA approval and reached the market, and is thus the first time period in which the technology adoption process could begin. Similarly, we may also be interested in identifying the first time period in which the technology *dis*adoption process could begin. In this respect, though, disadoption is not perfectly analogous to adoption because the disadoption process can begin any time after the technology is in use. However, there generally is (and should be) a reason for individuals to disadopt a technology, whether it's the availability of a new, superior technology or the development of disfavor with the existing technology. In the specific case of DES (as was discussed in Chapter 2), the announcement of safety concerns (at the

World Congress of Cardiology in September 2006) regarding increased risk of thrombosis with DES lead to the widespread decline in DES placement rates. Thus, we can use this point to delineate the first time period in which individuals could begin the DES disadoption process[6].

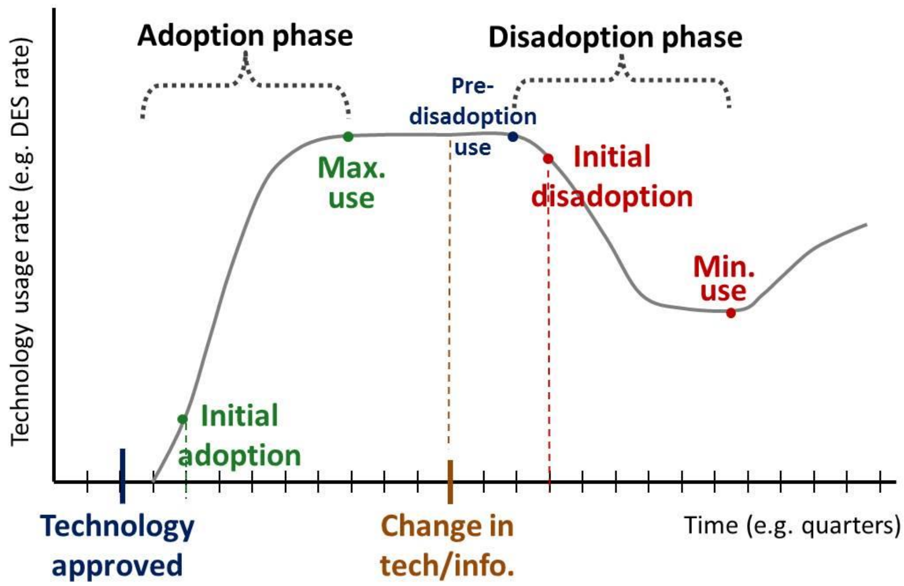


**Figure 3.3**: Graphical characterization of technology adoption and disadoption processes

To further characterize the adoption and disadoption processes, there are other events or points along the technology use curve to consider. In an attempt to simplify analyses of these processes while still gathering useful information, I focus specifically on the two points that can be used to mark the beginning and end of the processes, as shown in Figure 3.3 and further highlighted in Figure 3.4. For the adoption process, the starting

[6] In reality, it was indeed possible for cardiologists to disadopt DES before September 2006. However, in practice, this was very rarely observed, as population-wide DES placement rates remained stable above 90%, up until September 2006. As such, and also for empirical reasons to be described later, many of the analyses in this dissertation restrict definitions of DES disadoption to start no earlier than September 2006.

point is the "initial adoption" and the ending point is the "maximum technology use[7]." On the disadoption side, the starting point is the "initial disadoption" and the ending point is the "minimum technology use.[8]" Providing more detailed description and definitions of these points, we start with the first point, "initial adoption." This point marks the time period when an individual first uses a technology and the level of technology use in that time period. Of course, this is just one criteria (albeit a logical one) that can be used to define "initial adoption." Alternatively, one could choose to define "initial adoption" based on some threshold level of technology use. That is, rather than setting that threshold at zero and saying an individual begins adoption when she starts using any technology, one could set the threshold at, for example, 50% and label individuals as having initiated the adoption process when their technology usage rate first exceeds 50%. In the empirical analyses of this dissertation, I will focus primarily on the first and more intuitive definition, whereby initial adoption is recognized as occurring upon the first use of the technology. The second point, "maximum technology use," leaves relatively little room for interpretation: this point occurs when an individual reaches her maximum level of technology use (before beginning the disadoption process).

[7] Given the development of this framework and the creation of these distinct terms to describe the adoption and disadoption processes, it is clear that the term "initial adoption" is a big incongruous with the current framework; rather, the term for this first point would more precisely be "initiation of adoption process." However, in the interest of being succinct, I will continue to use the somewhat imprecise and potentially confusing term "initial adoption" to label this first point (and analogously, "initial disadoption" on the disadoption side).

[8] The terms "maximum" and "minimum" here are meant to be local, not global, extrema.

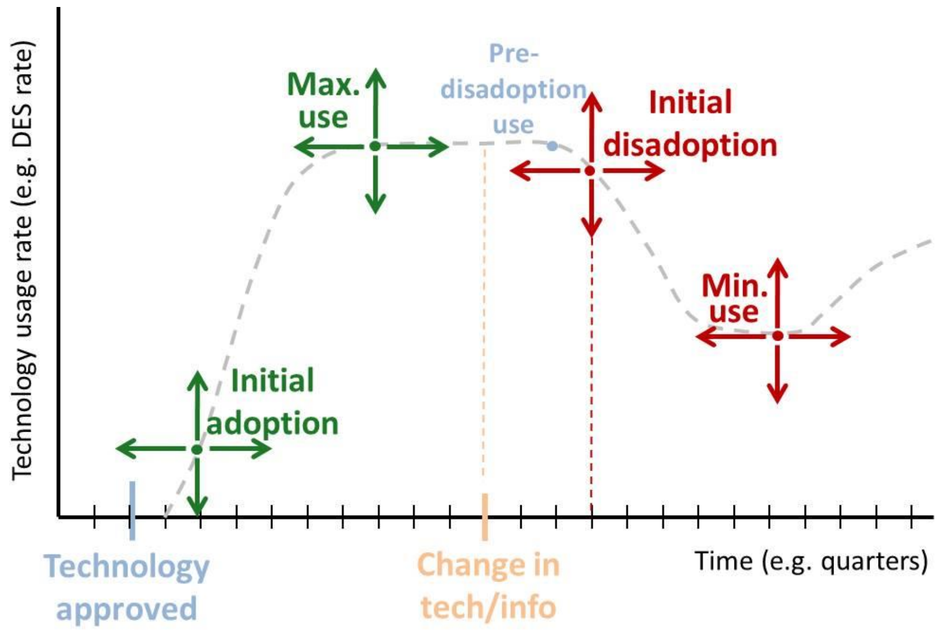


**Figure 3.4**: Quantification of the adoption and disadoption processes using two points

The third point in the sequence, which labels "initial disadoption," is the point whose exact definition and location is least obvious. Logically, this point should occur when an individual's technology usage rate begins to decline, which is easily observed in the illustrations used here (Figures 3.3 and 3.4). However, in reality, an individual's observed usage rate will not follow a path as smooth as that depicted here; for many technologies, usage rate may vary slightly from period to period. With such variation, a definition that identified "initial disadoption" as occurring "when an individual's technology usage first declines" would likely result in a noisy measure that may occur long before the development of a persistent downward trend in technology use, which we would believe to be consistent with the "true" disadoption process. As a result of natural variation or noise in the data, I impose additional conditions on the definition of "initial disadoption" to make the point a more reliable marker for the beginning of the disadoption process. For example, in the empirical analyses of this dissertation, the primary definition used for "initial disadoption" labels it as occurring in the first time period when an individual's technology rate decreases from the previous time period *and* does not increase in the subsequent time period[9]. At the other end of the disadoption process is the fourth point, which has a definition as simple and obvious as the second point: this point occurs when an individual reaches her minimum level of technology use (after beginning the disadoption process).

These four, now-defined points depicted in Figure 3.4 provide the foundation for my quantification of the adoption and disadoption processes in this dissertation. By measuring the distance between the points, each of which can move along two different dimensions (as depicted in Figure 3.4), I can provide a measurable characterization of the adoption and disadoption processes. To describe the quantification of the processes, I will consider the two different dimensions of the process separately. The first dimension is *timing*, which is measured along the horizontal axis in Figures 3.2 – 3.6. For both the adoption and disadoption processes, two measurements can be made along this dimension, as shown in Figure 3.5. The first measurement gives the time to the initial change (adoption or disadoption), measured from when that change was first possible (e.g. from technology approval or safety concern announcement, respectively). The

[9] To test the sensitivity of the results to this definition, I also perform robustness checks where I use other definitions for this "initial disadoption" period, varying (a) the threshold for decrease in technology usage rate, (b) the logical conditions of sequential changes in rate, and (c) the possible implementation of global time criteria, e.g. only allowing the initiation of the disadoption after a specified time period. These will be described in more detail in the subsequent chapters, starting with Chapter 4.

second measurement gives the length of the process (adoption or disadoption), or the time between the points that define the beginning and end of the process. This second measurement, by providing an indicator of how long an individual takes to progress from initial change to maximum change, gives a sense of the speed with which that individual goes through the given process. The introduction of this metric is novel, providing a quantitative characterization of both the adoption and disadoption processes that has been, to the best of my knowledge, absent from all past empirical work.

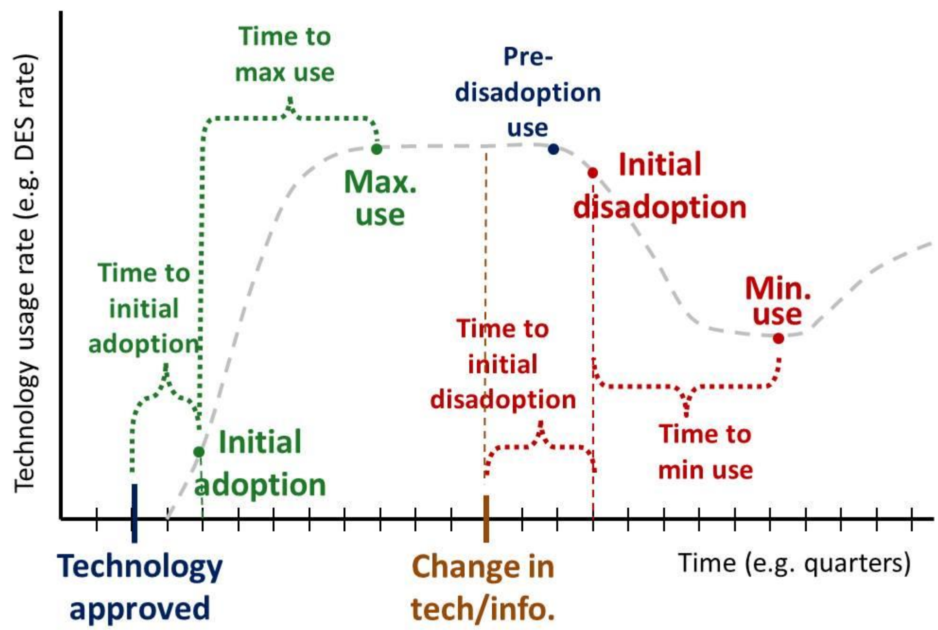


**Figure 3.5**: Measurement of adoption/disadoption processes along the time dimension

Along this dimension of technology use, our discussion of adoption and disadoption can be facilitated with terminology. When discussing movement of the first point (i.e. time to initial adoption or time to initial disadoption) forward or backward in time, I refer to individuals as “early” or “late” adopters/disadopters. This terminology is consistent with that generally used by the greater literature on technology adoption and disadoption, though it is admittedly simplified; though I may say "early disadopter," I truly mean "early *initial* disadopter," because I consider disadoption as a process instead of an event. For the second measurement of process timing, which gives the amount of time between the first and second points of the adoption or disadoption process, as I mentioned above, this measurement gives a sense of the speed of the process. For that reason, I refer to individuals who have smaller observed values of this measure as "faster" adopters/disadopters (because they reach their maximum change of technology usage rate in less time), whereas individuals who have larger values are "slower" adopters/disadopters. Thus, there is an important distinction between an individual being, for example, an "early adopter" and a "fast adopter," as I use these two terms to refer to two distinct measures of the adoption process. So, for example, a "late" adopter would be someone who lets a lot of time pass before first using a technology (e.g. due to risk aversion, or lack of knowledge about the technology), whereas a "slow" adopter would be someone who, even if she first uses a technology very early, takes a lot of time to transition from initial adoption to maximum use of that technology.

The second dimension along which to quantify the processes of technology adoption and disadoption is *extent* or *level of use*, which is measured along the vertical axes in Figures 3.2 – 3.6. As with the dimension of timing, the quantification of the extent of adoption and disadoption involves the measurement of two distances between the same points discussed above and shown in Figure 3.6. The first measurement gives the initial extent of change at the beginning of the process, which in the case of adoption is the individual's level of technology use in the first period of the adoption process, and in the case of disadoption is the difference in level of use from pre-disadoption to the first period of the disadoption process. The second measurement gives the full extent of change over the course of the process, which for adoption is the maximum level of technology use (following adoption), and for disadoption is the overall decrease in technology use from pre-disadoption level to the minimum use rate (following disadoption). Along this dimension of extent of adoption/disadoption, the terminology I will use in discussions will be relatively straightforward, referring to individuals with large values for either of these two measures as "large" or "big" adopters/disadopters (making sure to indicate, of course, whether that is *initial* or *full* adoption/disadoption). Conceptually, we can think of "big" adopters as individuals who show a big "commitment" to the technology in use it in a (relatively) large fraction of cases (e.g. eligible patients), whereas a "small" adopter uses the new technology a (relatively) small fraction of cases (e.g. eligible patients), which could be the result of such factors as risk aversion, distaste for the technology, or simple difference in technology preferences.

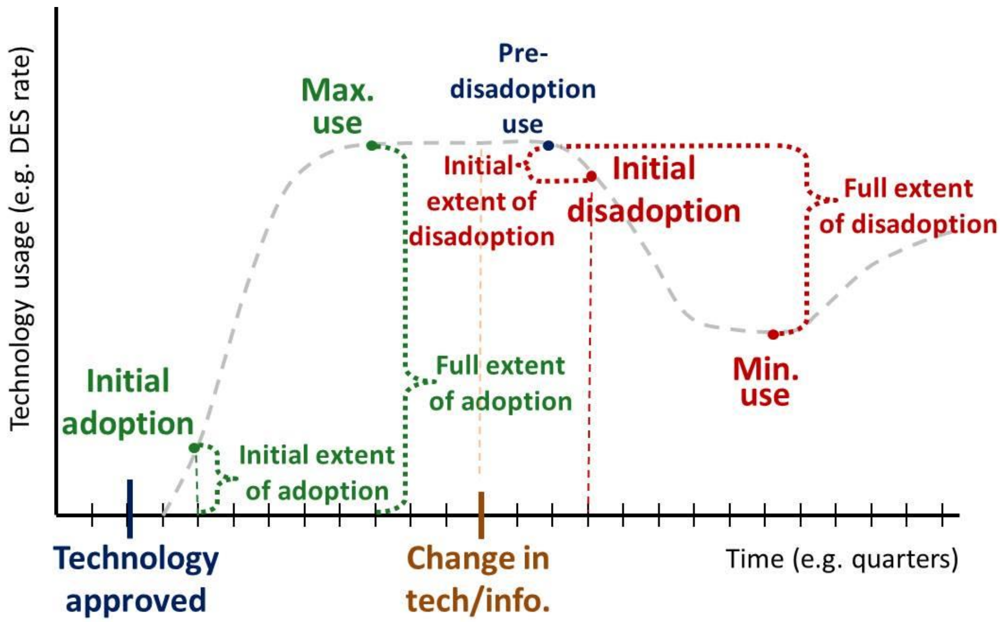


**Figure 3.6**: Measurement of adoption/disadoption processes along extent dimension

Using these two dimensions and points to characterize the adoption and disadoption processes, there are four separate measurements, which are generally independent[10], to quantify each process. This compares to the literature's traditional use of a single empirical quantification of adoption, which matches the "time to initial adoption" measure described here. By characterizing adoption and disadoption as processes instead of events, adding an additional dimension to characterize these processes, and establishing three more measures of these processes, I am able to develop greater insight

[10] These measures are not all truly independent of each other due to some natural constraints that exist on the location of the points described above. For example, an individual's full extent of adoption can never be smaller than her initial extent of adoption (and similarly for disadoption), and her full extent of disadoption can never be larger than her full extent of adoption. However, aside from basic requirements such as these, the fact that the four different points that characterize adoption and disadoption can exhibit great freedom in their location in the time-use space leads to the understanding that the four different measures of adoption and disadoption can be treated as generally independent. Examples of the loose relationship between these measures are exhibited in Appendix 3, which provides illustrative examples of different individuals' adoption and disadoption processes.

into both technology adoption and disadoption behaviors. While I am still interested in the question of what drives earlier or later technology adoption or disadoption, I am also able to investigate other aspects of these processes, including the difference between individuals who are aggressive versus tentative adopters or disadopters, and the connection (if any) between the timing and the extent of adoption or disadoption.

However, while this novel framework for measuring the adoption and disadoption processes offers new benefit, it is not without cost. This multidimensional characterization of these processes obviously introduces added complexity, which complicates both analysis and interpretation. In the interest of simplification, we can combine the two dimensions of adoption/disadoption to make a single measure of technology change, as depicted in Figure 3.7. Rather than separately measuring the vertical (extent of technology use/change) and horizontal (timing/speed) distances covered by the technology use curve, we can instead measure the area above or below the curve. Specifically, we measure area below the curve for the adoption phase (because this process represents deviation from low/no technology usage rate) and we measure area above the curve for the disadoption phase (because this process represents deviation from high technology usage rate). While these area measures simplify the evaluation of the technology change processes by reducing their quantification to a single value for each process, it also captures information ignored by the previous two-point system. Though that framework measured two dimensions, it reduced the relevant segments of the technology use curve to two points, thus forming simple linear measurements and ignoring the contour of the technology use curve. By measuring area below or above the curve, we are now able to capture the information contained within the specific shape of the technology use curve. (Appendix 3 depicts a series of different technology use curves, helping to illustrate how different curve shapes could yield similar vertical and horizontal dimensions, but describe different paths of technology use change.)

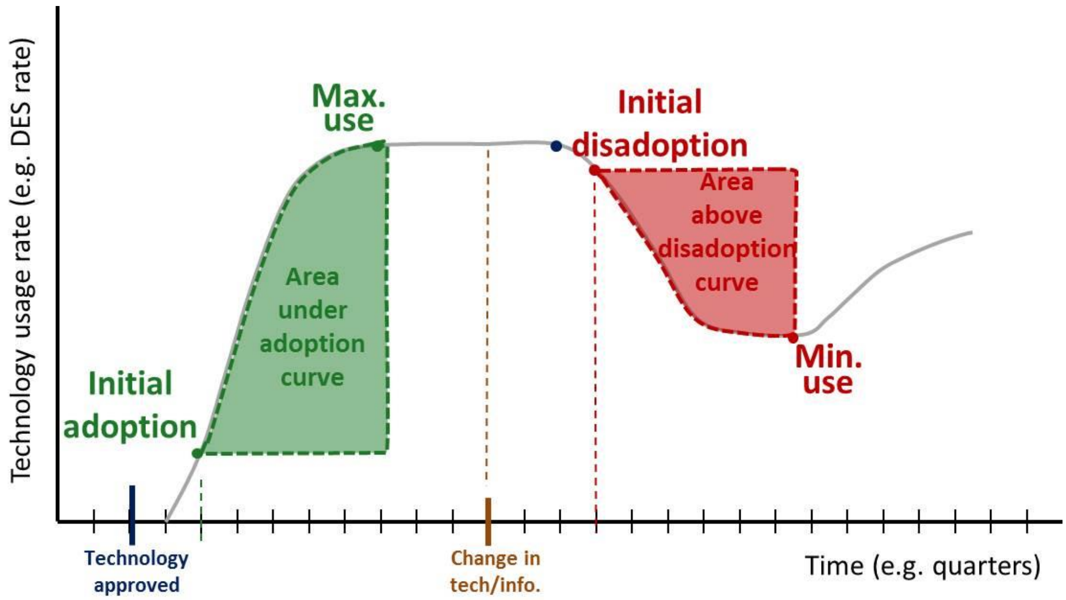


**Figure 3.7:** Composite measures of adoption/disadoption processes using area under/above the technology use curve

## 3.3 – Comparing adoption and disadoption

Above, I characterized the adoption and disadoption processes in parallel. The dimensions of timing and extent are relevant for both processes, and the defined measurements are almost identical for the two processes. Indeed, aside from the fact that adoption represents an increase in use of a given technology whereas disadoption represents the decrease in use, these two processes share many similarities. For example, both processes represent changes in an individual's choice of technology, which requires a change in knowledge or beliefs about the technology and/or a change in access to the technology. In fact, when taking a very simplistic view of these processes, they become virtually identical (which will become more apparent below, in Chapter 4, when I develop a theoretical model of disadoption).

However, in reality, there are several differences between adoption and disadoption, beyond the simple positive versus negative change in technology use. The first and biggest difference between the two processes is the difference in knowledge of and experience with the product. By definition, an individual adopting a technology has no previous experience with that technology, whereas an individual disadopting the technology has obviously used it. Because disadoption occurs among individuals who have experience with a technology, whereas adoption occurs among individuals who are not using the technology, there is potential for behavioral or psychological factors—including to status quo bias, inertia, optimism, and confirmation bias—to play a bigger role in disadoption (Roman & Asch 2014 Ann Int Med). As such, we may expect a traditional rational economic model to have greater success describing the technology adoption process, whereas a more complex behavioral model may be necessary to provide the same level of fidelity for the disadoption process. Also, more simply, an individual who is disadopting a technology inevitably knows more about the technology than she did when adopting that same technology[11]. Furthermore, the additional information that an individual has about a technology when she is in a position to

[11] This assumes that knowledge about a technology cannot be lost or destroyed, and that experience generates knowledge.

disadopt that technology necessarily includes personal knowledge of the technology gained through experience, which has the potential to be more detailed and nuanced than information that can be practically learned from other people (Burns & Wholey 1993 Acad Mgmt J, Berez et al 2014 wp). Not only does real-world experience offer the ability to learn technology complexities that cannot be conveyed secondhand, but personal characteristics and work environment can shape both the individual's technology-use experience and her interpretation and understanding of information from that experience. For example, a particularly skilled (and arrogant) surgeon may disregard information about technology failure if she hasn't used the technology herself because she believes that other the other surgeons for whom the technology has failed are less skilled than herself. Even if self-learned information about a technology could be identical to that gained from external sources, an individual may place greater value in or certainty on information gained through personal experience. Risk aversion is another critical factor in shaping technology adoption or disadoption decisions, and the fact that uncertainty about the technology is greater during the adoption phase may mean that an individual's level of risk aversion, while likely an important factor for both processes, may play a larger role during the adoption process than the disadoption process. Of course, the shape of an individual's utility curve and the choices that that individual faces (i.e. the alternative choices faced, and their outcome likelihoods and relative utilities) are the most important factors that determine how risk aversion will manifest its influence on either adoption or disadoption.

Second, the adoption and disadoption processes differ in the role and influence of other potential stakeholders. These roles are illustrated well if we focus on a specific example: prescription pharmaceuticals. When a new pharmaceutical is coming to market (and still under patent protection), the drug's manufacturer will often invest heavily in marketing for that new product. This marketing can, for example, take the form of both physician detailing (by pharmaceutical company representatives) and direct-to-consumer (DTC) advertising (in general media, e.g. magazines and television). Ultimately, the physician controls access to the new drug (because she must write a prescription for a patient to be able to acquire the drug), but both of these marketing streams seek to influence the physician's prescribing patterns, whether directly (via detailing by representatives) or indirectly (through patients' inquiries about or requests for the drug). On the other hand, after a physician has already "adopted the technology," i.e. started prescribing the given drug, and is considering disadoption, the roles of these stakeholders has changed. Rarely (if ever) do pharmaceutical companies attempt to dissuade a physician from prescribing their products[12]. Patients are also in a different position, having taken the medication that is "at risk" for disadoption, so the physician is able to gain valuable information from the patients' opinions and experiences with the technology.

The third difference between the adoption and disadoption processes is individuals' access to the technology. In the case of disadoption, if an individual is facing the choice

[12] As I describe below, my focus here on disadoption does not view this process in terms of adoption of an outside good, i.e. the active move towards another technology. Were that the case, the role of the pharmaceutical manufacturers' marketing efforts could obviously play a role in the adoption of that new technology and thus disadoption of the current technology.

of abandoning a technology[13], she has access to it and the ability to continue using it. However, on the adoption side, it is not uncommon for the diffusion of technology to be limited by producers' supply of the technology; even if individuals are aware of a technology and interested in adopting it, they simply may be unable to do so because they cannot acquire that technology. Even when the market for a technology is not facing supply-side constraints, some new technologies represent large capital investments and challenging financial situations. On the other hand, if a technology has already been purchased, that cost is sunk, so the disadoption decision is not usually complicated by the same financial issues[14]. Related to these issues of technology access, researchers who attempt to study these two processes also face distinct challenges. In the case of adoption, some technologies may be so new that they are not yet well-recognized, so data characterizing their use may not be developed. With disadoption, however, if the technology is long-established, these data issues are less likely to be present, making technology use easier to study by researchers.

Despite all of these differences, there is still a fundamental similarity between the technology adoption and disadoption processes because they both represent decisions regarding changes in technology use. It is this similarity that motivates the desire to study the relationship between disadoption behavior and the preceding adoption behavior

[13] Of course, there are cases where disadoption can be "forced" upon an individual when she loses access to a technology, e.g. a surgeon working at a hospital where a given piece of technology is discarded or replaced. This, however does not represent a willing choice or behavior on the part of the disadopting individual, so such situations are outside of my realm of interest for this dissertation.
[14] There are some examples of technologies were there may be a secondary market for used capital. In such cases, the full cost of capital is not truly sunk, as some may be recouped.

with the same technology. Given the vast literature focused on technology adoption (as discussed above in Chapter 2), we are left to wonder if our knowledge of adoption behavior is (at least partially) transferrable to disadoption behavior. Even if these processes are sufficiently distinct that conclusions about determinants do not translate between the two behaviors, both behaviors may be equally influenced by the same unspecified characteristics. This will become relevant when we later study how some factors (e.g. physician group size) impact medical technology disadoption, but we want to control for various physician- or technology-specific characteristics that shape behavior but are unknown or unobservable to us. The inherent similarity between adoption and disadoption behaviors may allow us to control for such unobservable characteristics by controlling instead for the observed adoption behavior with the same technology. Also relating to the similarity between adoption and disadoption decisions, we'll see that a basic decision-theoretic model must represent these two processes similarly, if not identically, thus generating symmetric predictions for the two different behaviors. (As will be discussed below in Chapter 4, the incorporation of the factors discussed above that distinguish adoption and disadoption behaviors from a theoretical perspective requires fairly complex model construction.)

Again putting differences aside, if we consider the adoption and disadoption processes together in practical settings, we realize another way that the two are linked: disadoption of one technology occurs when it is being replaced by another technology, i.e. when adoption of that other substitute technology is occurring. From this perspective, when the adoption of a new technology is the active process that results in abandonment of an older technology, the description and evaluation of disadoption per se seems irrelevant, because disadoption is passive and the disasdopted technology is an innocent bystander in the process. Indeed, depending on the specific setting, it may well be that the majority of cases of medical technology disadoption are more appropriately characterized and studied through the lens of the adoption of another substitute technology[15]. However, as described in Chapter 1, there are cases in which newly discovered information indicates that an old technology is actually providing lower than desired clinical benefit, safety, or value. In these cases, disadoption is a process to be undertaken independent of the development of a new substitute technology and, as such, the disadoption process itself is worth characterizing and examining[16]. It is these types of "disadoption-driven" cases for which my work in this dissertation has the most direct and pertinent application. (Of note, the disadoption of DES following the publicization of safety concerns regarding late in-stent thrombosis is one such case, making it an ideal empirical setting to be used in this dissertation. )

Though the above conceptual framework of the adoption and disadoption processes provides methods for quantifying these processes along multiple dimensions, this

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[15] In both clinical practice and clinical research, providers generally have a professional and ethical obligation to provide patients with treatment that meets the "standard of care." In the setting of new technology development, this obligation precludes the adoption of technologies that do not improve (or at least maintain) this standard of care. Thus, the motivation to maximize patient health and benefit prompts technology change when it improves care, which usually means adopting newer, superior substitute technology.

[16] Indeed, the adoption of a substitute technology does likely often occur in these "disadoption-driven" cases. However, because disadoption is the driving motivation, I will generally disregard the replacement technology, understanding that the decision is not made in a vacuum and the benefit, safety, and value of the two technologies are only meaningful relative to each other.

framework is focused specifically on the empirical measurement of technology use. Before we can use the above framework to empirically evaluate technology disadoption, we first want to provide some basic theoretical structure to guide our conception of the physician incentives and behaviors that shape the disadoption process. Thus, to further frame our understanding and guide our examination of disadoption, I will next develop a basic decision-theoretic model of medical technology disadoption by physicians.

# CHAPTER 4: Theoretical model of medical technology disadoption

In the previous chapter, I developed a framework to help understand and empirically measure the technology adoption and disadoption processes. However, to develop further insight into the technology disadoption process and how physicians behave during that process, I next seek to develop a basic decision-theoretic model of that process. My goal here is not to develop a structural model that perfectly captures that disadoption process or can be used to estimate fundamental parameters that dictate that process. Instead, my aim is simply to use a theoretical model to provide basic structure and guidance for our evaluation and empirical analysis of the disadoption process, offering insight into how underlying factors may influence that process. One factor that I will focus on specifically in the development of this model is group size, motivated by an inherent interest in this organizational feature (as discussed in Chapters 1 and 2), and detailed further below.

## 4.1 –Background and approach

*Adoption vs. disadoption*

As described at length above (in Chapter 3), though there are differences between the technology adoption and disadoption decisions, there are also many similarities between the two processes; fundamentally, both are processes of change in choice of technology utilization. Though the aspects of disadoption that make it distinct from adoption (e.g. the roles of inertia and "learning-by-doing") are important, the incorporation of such aspects into a decision-theoretic model is non-trivial. Given that my goal here in developing a model is simply to provide basic structure and guidance for our evaluation of the disadoption process—something that is generally lacking in the current literature on disadoption—the attempt to specifically distinguish between adoption and disadoption behaviors in the decision-theoretic model would require an increase in complexity of the model that extends beyond my basic goals here. So, while it is important to keep in mind the distinct features and implications of the two processes, we will see that there is very little about the model developed here that is truly specific to disadoption per se. One product of this approach is that the model, as developed, should make symmetric predictions about the adoption and disadoption processes. For example, if the model predicts that larger groups will begin to disadopt a technology earlier than small groups, then the same model would also predict that larger groups would similarly begin to adopt (or would have begun to adopt, given that adoption necessarily precedes disadoption) that technology earlier. Even without having yet created a specific model, we now know one theoretically generated empirical prediction, i.e. that there is symmetry between the adoption and disadoption processes. As already mentioned, one could choose to make a sufficiently sophisticated model (e.g. by incorporating behavioral factors, or measures of technologic experience) that (may) generate desperate predictions for adoption and disadoption behaviors, but such complications are beyond the purview of the current model-building exercise. However, it should be noted that, just as the theoretical disadoption process can be complicated by various other factors, so too is the adoption process confounded by various issues (e.g. technology supply issues, greater uncertainty, requirements for capital investment), so in that way, one could argue that the relatively simple model developed below provides a more accurate depiction of disadoption than adoption.

As mentioned in Chapter 2, not only is the medical technology disadoption literature relatively sparse, it also appears to be largely devoid of theoretical economic models. However—having just revisited the issue of similarities and differences between the adoption and disadoption processes—the vast literature on technology adoption does include many theoretical models, to which we can look for guidance in developing the current model. Much of the early work on technology diffusion and adoption focused on the population-level phenomena. In these papers, researchers developed mathematical models that produced the widely-observed S-shaped curve of new technology diffusion, typically modeling "infection rate," i.e. the spread of a technology to non-users, as proportional to the number of current users. (For a general discussion and examples, see for example Geroski 2000 Res Pol.) Though these models provide insight into the diffusion process and are historically valuable, their application here is limited because, whereas they focus on the population-level process, my interest is in the individual-level technology use decision and the determinants that shape that. Of course, after these works were published, other economists who studied diffusion made the same observation, which lead to the publication of several studies with decision-theoretic models of individuals' technology adoption behavior. (Again, see Geroski 2000 Res Pol for a general discussion and examples.) Generally, these papers' models focus on individuals' beliefs about the expected productivity or value (e.g. expected profits) of the new technology and the process of updating those beliefs (typically, a Bayesian perspective), with the endpoint for that updating processing being a sufficiency threshold for adoption of the new technology.

While each of these general categories of theoretical models represents a valuable contribution to the economic literature on technology adoption and diffusion, in my survey of the literature, I have been unable to identify any models that can be appropriately applied to capture one of the key relationships of interest in this dissertation, i.e. the impact of physician group size on technology disadoption.[17] While I can take some guidance from past models in establishing my own theoretical model, my approach here is primarily to start from scratch. That is, rather than attempting to take the given characteristic of interest, i.e. group size, and build it into one of the existing models, thus creating an even more complicated model, my approach is instead to start with an even simpler model. Though this approach requires additional work to establish the basic foundations of the theoretical model, it allows the creation of a simpler model, which enhances the goals of providing basic structure and guidance for my evaluation and analysis of the disadoption process, specifically in terms of how an individual's group size may influence that individual's disadoption behavior.

[17] Of course, I cannot and do not claim definitively that *no* economists have previously created a model that describes the topic of interest in this dissertation; the literature is too vast (especially on the topic of technology diffusion) to examine every published work.

*Group size*

As discussed above, there are many motivations for examining the relationship between group size and technology disadoption, especially when evaluating physician behavior. However, groups or networks of physicians are becoming increasingly complicated. Not only are physicians increasingly organized into groups and those groups are growing in size (as discussed in Chapter 2), different types of physician groups and organizations continue to appear in practice. In addition to multi-office practices and multi-practice groups, physicians can also belong (simultaneously) to independent physician associations (IPAs), accountable care organizations (ACOs), or other types of clinical or administrative organizations. To keep the theoretical model here relatively simple, intuitive, and mathematically tractable, I will focus on a very basic characteristic of physician groups: group size, i.e. the number of physicians in a group. Of course, though this is a conceptually simple measurement, given the complexities of current physician organization that I've just alluded to, the practical measurement of physician group size may be a non-trivial issue. When calculating the number of physicians in a given physician group, which group to we consider and which physicians do we count? When measuring group size, which physician groups should we consider: offices, practices, networks (e.g. IPAs, ACOs), or hospitals? Also, given that we're interested in technology choice, do we only count the physicians using a given type of technology, or do we count all physicians regardless of technology usage? Though there may be theoretical grounds to identify preferred answers to some of these questions, the model I develop here will remain generalizable and not take a stance on such specific group-based characteristics.  Instead, I will defer attempts to answer these questions to the empirical section of this dissertation (namely, Chapters 6 and 7), looking to the data to reveal which specific physician groupings have significant relationships with physicians' choices of medical technology.

*Information and knowledge*

In addition to the inclusion of group size, there are two other primary features of my model that distinguish it from the bulk of other decision-theoretic adoption models.  First, while previous models have focused on a set of knowledge and beliefs (about technology) that evolve over time, I choose to deconstruct those beliefs by focusing on a single piece of knowledge or information.  Indeed, any set of beliefs can ultimately be decomposed into a series of binary ("yes" or "no") pieces.  By using this deconstruction, the view of disadoption drastically simplifies.  Rather than treating it as a change that is triggered when a composite set of beliefs crosses some threshold, we can instead see disadoption as a change that occurs when a single specific belief is acquired.  This "single specific belief" in the simplified view is merely the final incremental belief that pushes an individual over the threshold to change behavior in the "composite beliefs" model.

Second, whereas the bulk of decision-theoretic models focus on each individual's decision to adopt technology, that decision is based on beliefs that evolve over time by basic Bayesian updating (e.g. a periodic draw from a probabilistic distribution of beliefs, which depends on the observed behaviors in the population, and is incorporated with past beliefs to created updated beliefs). That is, these models focus specifically on the behavior of adoption, rather than on the behavior that leads to the evolution of beliefs, which thus leads to adoption. In contrast, the model I develop here considers the determinants that drive changes in beliefs (e.g. acquisition of knowledge, which requires effort and can be shared within a group) and examines how those determinants can thus shape the disadoption process.

*Dimensions of technology use*

As described at length in Chapter 3, the disadoption (and adoption) process can be characterized along the two different dimensions of time and level of technology use. Here, as I begin to construct a theoretical model of this process, I again consider these two dimensions. As described above, my attention here is focused on the acquisition of critical information that persuades an individual to change their behavior, i.e. disadopt technology. It is easy to see that in studying *when* an individual acquires critical knowledge I am examining the timing dimension of disadoption, i.e. when the initial disadoption process begins. However, the translation of the empirical measurement of the other dimension of the disadoption process, i.e. the extent of disadoption, into a theoretical framework is less obvious. Evaluating this dimension, we want to ask: why would different individuals have smaller or larger extents of disadoption? One possible explanation for observed differences between individuals in the level of technology use following disadoption is characteristics of each individual's environment, as opposed to inherent characteristics of the individuals themselves. For example, in the case of physicians, one may observe differences in the level of technology use simply because different physicians care for different patient populations, and patient characteristics may drive technology use decisions. Though such factors may shape an individual's technology use, they are not directly related to the individual's behavior or choices, so they are orthogonal to my focus and interest in developing the current decision-theoretic model[18].

Another possible explanation for differences in the extent of disadoption (i.e. the level of technology use during the disadoption process) is the presence of differences in intrinsic individual characteristics like risk aversion. Though two individuals may learn the same critical information at the same time, differences in preferences for risk and uncertainty may influence how drastically those individuals change their levels of technology use. Indeed, in his classical work on diffusion of innovations, Rogers notes that it is "useful to conceptualize the diffusion and adoption of innovations in terms of a framework based on information and uncertainty" (2003). Here, in the interest of keeping the theoretical model simple and tractable, my focus will be on the information aspect and the timing of that information acquisition. Though there is little doubt that individual's risk preferences play a critical role in determining their levels of technology, specifically *how* those preferences would relate to extent of disadoption is ambiguous. For example, upon learning critical information that initiates the disadoption process, would risk-loving individuals have a larger or smaller initial extent of disadoption? It is unclear whether

[18] Obviously, this ignores the endogeneity of environment; it is not only possible but likely that individuals have an active role in determining the environment that they work in. In the interest of keeping the current theoretical model simple, I will ignore such complexities here.

uncertainty surrounding the technology itself or uncertainty of the newly acquired information is more important, which is particularly confounding during a "negative" process like disadoption, when such uncertainties can have effects that act in opposite directions. Thus, for these reasons, the model I develop here will focus on the timing dimension of the disadoption process, leaving the consideration of the other dimension (extent of disadoption) to the empirical analysis.

## 4.2 – Model setup and assumptions

Consider a utility-maximizing physician who faces a multi-period choice over how much effort, $e$, to expend on the process of acquiring of knowledge (i.e. learning), $k$. As described above, the acquisition of knowledge is treated as a binary event, so I consider a single discrete piece of information, which the physician either acquires or does not acquire in the given period. In the context of disadoption, this piece of knowledge is the critical information that sways a physician to disadopt a technology; without this knowledge, the physician continues to use the current technology. The physician can acquire this critical knowledge (i.e. learn), $k^*$, by either of two different mechanisms, one of which involves effort and one that is effort-independent, but both of which are treated as probabilistic processes. For the former, the physician can expend effort to increase her likelihood of acquiring knowledge. Obvious examples of this type of learning are the reading of medical journals or attending educational meetings, but neither of these behaviors (or any other effort-based learning) guarantees the acquisition of critical knowledge. Rather, the expenditure of effort merely increases the likelihood of gaining knowledge. Thus, I use a function $g(e)$, which has a non-negative domain and a range [0,1), to represent the probability that a physician gains critical knowledge in a given period by expending effort $e$. However, it is also possible that a physician gains knowledge without spending any effort, for example when informed by a colleague or contacted by a pharmaceutical/biotech sales representative. So, for effort-independent learning, I simply use $\theta$ to represent the likelihood that a physician gains critical knowledge in a given period, regardless of the level of effort expended by that physician. Now, given these two knowledge-acquisition processes, we can determine a physician's likelihood of gaining critical knowledge in a given period as a function of effort, $e$:

$$\Pr(k = k^*) = 1 - (1-\theta)\big(1 - g(e)\big) \qquad (1)$$

Though equation (1) gives the likelihood that an individual physician acquires critical, disadoption-triggering knowledge in a single period, I want to introduce two additional layers of complexity. First, consider that the physician belongs to a group, which has a total count of $n$ physicians, and assume that if any physician in the group acquires information in a given period, that information is shared among all members of the group. I again want to determine the probability that a given physician acquires critical knowledge in a given period. If I further assume that each physician in a group has both the same effort-independent learning likelihood and the same effort-based knowledge production likelihood function[19], the updated probability expression (which can

[19] In fact, the actual assumption here is merely that a given physician *believes* that all other members of her group have the same effort-based and effort-independent knowledge acquisition likelihood expressions, which is more benign than assuming that each physician in a group actually *has* the same knowledge acquisition likelihood expressions.

alternatively be described as "the probability that, in a given period, nobody in the given physician group does *not* acquire the critical knowledge") is as follows:

$$\Pr(k = k^*) = 1 - \left[(1-\theta)\big(1 - g(e)\big)\right]^n \tag{2}$$

Second, because I am interested in studying the timing of the disadoption process, I am also naturally interested in incorporating multiple periods into the model. With multiple time periods, my shift focuses from a single period to a string of periods, so we now ask: what's the probability that a physician has acquired critical knowledge by time period $t$? If I assume that a physician's behavior and decision-making is the same in all periods and that $t$ is an integer that counts up from 1 in the initial period, then equation (2) simply becomes:

$$\Pr(k = k^*) = \kappa(e,t) = 1 - \left[(1-\theta)\big(1 - g(e)\big)\right]^{nt} \tag{3}$$

where I now use $\kappa$ to represent a physician's likelihood of acquiring critical knowledge.

Having established how a physician's effort translates into the acquisition of knowledge, and how that acquisition of knowledge relates to both time and group size, I can now turn to the physician's utility maximization problem. Obviously, a physician's utility will depend on many different factors, including income, leisure, and consumption, but if I assume that the physician's utility function is additively separable (at least in the variables of interest), then I can restrict my attention to the factors of interest here because, when maximizing the physician's utility function, all terms relating to other factors will fall out of the equation. For the current theoretical model, then, the factors of interest are physician knowledge and effort. With respect to these two factors, I make the relatively mild assumptions that a physician's utility increases with increasing knowledge but decreases with increasing effort. However, the model constructed above focuses on a physician's likelihood of acquiring knowledge, $\kappa$, not on the level of that knowledge itself, $k$, so we're left to ask how a physician's utility is related to $\kappa$. Though it may be difficult to understand a conceptual link between $\kappa$ and physician utility at the level of an individual technology, if we consider a very large set of medical technologies, it becomes clear that increasing the likelihood of critical knowledge for multiple technologies will increase a physician's overall level of knowledge (with increasing certainty as the number of technologies increases). Using this logic, I assume that a physician's utility is increasing with increasing $\kappa$. Given these assumptions, the first order condition of the physician's utility-maximizing choice of effort can be expressed as follows:

$$\frac{dU}{de} = \frac{\partial U}{\partial \kappa}\frac{\partial \kappa}{\partial e} + \frac{\partial U}{\partial e} = 0 \tag{4}$$

While this theoretical model is very simple and it focuses on an individual physician, it is important to note that this formulation of the model still allows for variation within a population of physicians. That is, this model does not predict that all physicians will exhibit the same technology disadoption behavior. Variation in the timing of a physician's disadoption can be driven by between-physician differences in any of the following: utility from effort and knowledge; effort-independent and effort-dependent probabilities of knowledge acquisition; or group size.

Before further analyzing the theoretical model, I want to briefly summarize and provide more details on the assumptions used in formulating the model:

- The physician's utility is additively separable in knowledge and effort, and it increases with increasing knowledge, but decreases with increasing effort.
- The physician's utility from effort, $e$, (i.e. effort expended on knowledge acquisition) is represented by a negative concave downward function, as exemplified in Figure 4.1, which has negative first and second derivatives with respect to effort. The shape of this function can be justified and understood if we believe that effort is directly proportional to time and that a physician faces a binding time constraint. The disutility from effort increases as a physician spends more effort (time) on knowledge acquisition. There is an upper limit to how much effort a physician can spend (e.g. in a day or week), and her disutility from effort increases as she asymptotically approaches that limit.

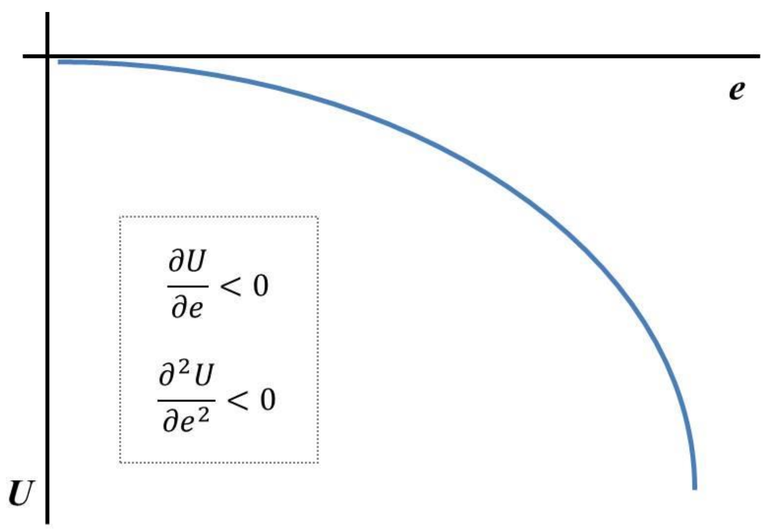


**Figure 4.1:** Physician utility as a function of effort expended on knowledge acquisition

- The physician gains positive utility from knowledge, $k$, and, because knowledge is directly proportional to the likelihood of acquiring critical information, $\kappa$, the physician's utility is increasing with increasing probability of learning critical knowledge. We believe that a physician's utility will increase with knowledge if knowledge helps provide superior medical care to patients and a physician gains positive utility from providing superior care for patients.
- The physician's effort-dependent probability of knowledge acquisition, $g(e)$, which is effectively a probabilistic effort-based knowledge production function, is a positive concave downward function, as exemplified in Figure 4.2, which has a negative first derivative and a positive second derivative with respect to effort. This production function represents the probability of acquiring knowledge with effort, so it increases as effort increases and its range is bounded between 0 and 1.

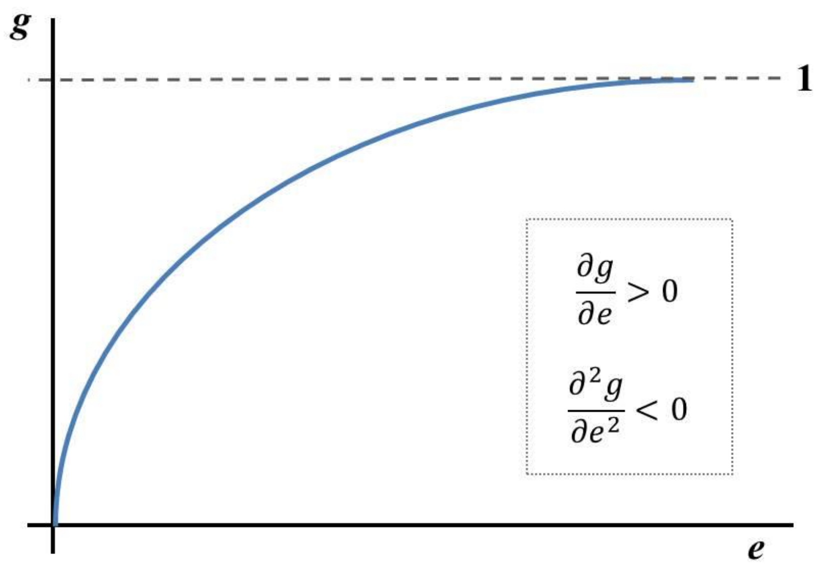


**Figure 4.2**: Physician likelihood of acquiring critical knowledge as a function of effort

- If any physician in a group acquires knowledge, that information is instantly and costlessly shared among all members of that group.
- The physician believes that (and acts as if) all other physicians in her group have both the same effort-independent ($\theta$) and effort-dependent ($g(e)$) probabilities of knowledge acquisition.
- The physician treats all time periods the same, i.e. spends the same amount of effort on knowledge acquisition in each period.

These assumptions were made only to simplify the math in this model; most of them can be relaxed without changing the intuition of or predictions generated by the model. Of course, this model can be extended by relaxing some of the above assumptions or introducing additional complexities. For example, instead of assuming that information is immediately and costlessly shared between group members, one could choose to model how knowledge is transferred between members of a group. Similarly, one could impose more structure on the acquisition of knowledge by, for example, modelling the presence of experts or thought-leaders in a group or community. Also, as discussed above, the model could be complicated by introducing physician risk preferences, which would require the imposition of additional structure on the functional form of physician utility from knowledge and effort. However, as stated above, the purpose of the model in this dissertation is simply to provide guidance for my analysis of physician technology disadoption, and some of this guidance is gained by examining the comparative statics produced by the model.

**4.3 – Comparative statics**

By using equation (3) and the above assumptions to solve the model's first-order condition (equation (4)), I can generate comparative statics that provide basic predictions about relationships between various model parameters. One of the relationships of interest here is that between group size and time to disadoption. Specifically, I want to ask: does time to acquisition of critical information, i.e. time to initiation of the disadoption process, increase or decrease as group size increases? I can use the theoretical model to generate an answer to this question by using it to solve for $dt/dn$. Using equations (3) and (4), and applying the implicit function theorem (see Appendix 4 for details of these calculations), the expression for this derivative is as follows:

$$\frac{dt}{dn} = \frac{-\frac{\partial U}{\partial \kappa}(1-\theta)\frac{\partial g}{\partial e}t\left[nt\ln\left(f(e)\right)+1\right](f(e))^{nt-1}}{\left[\frac{\partial U}{\partial \kappa}(1-\theta)^{nt}nt\left(\left(1-g(e)\right)^{nt-1}\frac{\partial^2 g}{\partial e^2}+(nt-1)\left(1-g(e)\right)^{nt-2}\frac{\partial g}{\partial e}\right)+\frac{\partial^2 U}{\partial e^2}\right]\left[\frac{\ln\left(f(e)\right)f(e)n}{(1-\theta)\frac{\partial g}{\partial e}}\right]}$$

While this expression is very complicated, my purpose in developing this model was not to calculate specific quantitative relationships, but merely to provide general qualitative insight. So here, I only want determine the sign (positive or negative) of the above expression. To do this, we consider the signs of the individual components, an exercise that is shown in detail in Appendix 4. Ultimately, this exercise shows that the sign of $dt/dn$ is ambiguous, i.e. we cannot know if it is positive or negative without more information. That is to say, this model predicts that time to the initiation of the disadoption process may either increase or decrease with increasing group size. Examination reveals that the sign of the above expression depends on the relative magnitudes of the different factors that appear in the first large term of the denominator, including: physician utility from knowledge and disutility from effort; time (i.e. number of periods) and group size; and both the effort-based and effort-independent likelihoods of acquiring critical knowledge.

Though lack of a definitive prediction by the model here may seem disappointing, further reflection shows that this prediction (or lack thereof) by the model agrees with intuition. On one hand, a physician may begin the disadoption process sooner if in a larger group because she (and the other members of her group) receive high utility from knowledge and have high probability of acquiring knowledge when applying effort, so a larger group leads to more effort and faster knowledge acquisition. On the other hand, a different physician may begin the disadoption process later if in a larger group because she has high disutility from effort and, as group size increases, is inclined to attempt to "free-ride" off the effort of her group members with whom she shares knowledge, so a larger group leads to less effort and slower knowledge acquisition. This acquisition of knowledge is what ultimately triggers the technology disadoption decision and initiation, though it is worth remembering at this point that the model was of sufficiently generic construction that it may similarly be used to depict the technology adoption decision. Indeed, as was mentioned before, for this reason, the model makes symmetric predictions technology adoption and disadoption decisions. So, if balance of relevant factors (e.g. disutility from effort and group size) is such that the sign of $dt/dn$ is negative, the model predicts that increasing group size will result in decreased time to acquire critical information, and earlier initiation of both the adoption *and* disadoption processes.

In summary, while the theoretical model has provided a framework to guide our understanding of a physician's technology disadoption process (via acquisition of critical information) and how the timing of that process relates to group size, it has also shown that the relationship between group size and the timing of disadoption is theoretically ambiguous. Thus, the question is an empirical one, for which I must turn to data to search for an answer, which I will do in the following chapters. However, before focusing on the empirical relationship between group size and technology disadoption, it is worth noting that, as with any theoretical model, the model developed here is a gross simplification of a real-world process that neglects many potentially important factors. Though I focus specifically on the role of physician knowledge-acquisition effort and how that effort can be shaped by group size, there are many other physician characteristics and practice environment qualities that may shape her technology use decisions. For example, as discussed briefly above (in Chapter 3), a physician's risk preferences may shape that physician's willingness to disadopt a technology in light of new, uncertain information. Similarly, other behavioral factors—including status quo bias, confirmation bias, and loss aversion—may influence a physician's disadoption behavior[20]. Indeed, there is a potentially endless list of factors that may shape the disadoption process, which complicates our ability to empirically investigate that process with great clarity. However, as discussed at length above (in Chapter 3), there are many

[20] Recalling the similarities between adoption and disadoption behaviors, these factors may also be relevant for the technology adoption process. However, as mentioned in Chapter 1, the delivery structure and financing of the US health care system, combined with the predominant culture of American clinical medicine, provide significant pressures promoting technology adoption, whereas such pressures are not present for the technology disadoption process.

parallels between the technology adoption and disadoption processes. Insofar as we think these processes are similar, we might be able to use measures of the technology adoption process to proxy for unidentified or unobservable factors that influence the technology disadoption process. Of course, theory aside, the question of "how similar are these distinct processes?" can also be treated as an empirical one. It is this empirical question that I will examine in the following chapter.

# CHAPTER 5: Relating medical technology disadoption to adoption

In the preceding chapters, I provided the motivation and background for the study of technology disadoption, established a framework to empirically characterize the processes of adoption and disadoption, and developed a theoretical model of a physician's technology disadoption behavior. Though the theoretical model focuses specifically on the relationship between group size and the timing of disadoption, we also understand now that the disadoption is considerably more complex (being characterized along multiple dimensions and potentially influenced by a wide range of factors) and that, as discussed above, there is reason to believe that it shares many similarities with the technology adoption process, while also being noticeably different. This understanding sets the stage for the first empirical analysis of this dissertation: an examination of the empirical relationship between the various measure of disadoption and adoption.

As described above, while the topic of technology disadoption has been the subject of relatively few research studies, technology adoption has been studied exhaustively. Given the vast existing knowledge surrounding technology adoption and the understanding that this process parallels technology disadoption in many ways, it becomes natural to ask: what is the empirical relationship between these two different processes? To answer this question, I will focus on the setting of coronary stents, where cardiologists could choose between bare-metal stents (BMS) and drug-eluting stents (DES), with DES serving as the technology that was originally adopted and subsequently disadopted. In these analyses, the primary outcome of interest will be an individual's "time to initial disadoption" (the variable which was also examined in the theoretical model developed in Chapter 4), which I will relate to an individual's "time to initial adoption" and the other measures of adoption. I focus specifically on this outcome variable because, as discussed above (in Chapters 2 and 3), the question of the timing of adoption and disadoption—whether that timing refers to the occurrence of an event or the beginning of a process—has been the one most frequently studied in the literature and is of obvious interest and practical application. The other measures of disadoption, which were described in Chapter 3, provide important characterizations of the disadoption process, but represent a relatively unusual and less intuitive framework for studying disadoption, so they will serve as secondary outcomes.

## 5.1 – Research questions

1) What is the observed empirical relationship between a cardiologist's *time to initial disadoption* of DES and the various measures of that physician's adoption of DES?
2) What are the observed empirical relationships between the other measures of cardiologist's disadoption of DES (namely, *time to minimum use*, *initial extent of disadoption*, *full extent of disadoption,* and *area below the DES adoption curve*) and the various measures of that physician's adoption of DES?
3) How do various covariates and controls, including cardiologist characteristics (e.g. age and training) and experience (e.g. DES volume), shape the observed empirical relationships between DES disadoption measures and adoption measures?

## 5.2 – Data and methods

*Original data*

In the empirical analyses performed throughout this dataset, I use three primary datasets. First, in order to study physicians' use—or, more accurately, placement or implantation—of coronary stents, I use hospital discharge data from the states of Florida and New York. These datasets are available as annual releases, and I focus specifically on the years 2002 through 2011. Providing a record for each hospital discharge within the states, these datasets include hospital identifiers and basic patient data, such as sex, ZIP Code of residence, age, insurance type, and multiple diagnosis and procedure codes. Most importantly, both datasets also include physician identifiers (either state license number or National Provider Identifier, NPI, or both), which allows me to track physicians both over time and across datasets, as will be discussed below. Though the New York dataset details the specific month of admission associated with each hospital stay, the date information in the Florida discharge dataset is specified down to the quarter level. To allow combination of the two datasets and provide consistent time measurements, I reduce the date granularity of the New York discharge dataset to the quarter level.

The second dataset I use is the AMA Physician Masterfile, which is produced by the American Medical Association. This dataset provides various details about physicians and their training, including sex, year of birth, specialties of practices (self-identified), medical school, residency, fellowship, and the years of completion for each phase of training. Using state license numbers, I am able to link this dataset to the discharge dataset at the physician level, thus being able to identify doctors' basic demographics, training, and experience. This dataset, like the Florida and New York datasets, is used frequently in published research studies.

The third dataset that I use in the dataset is less well-known than either of the first two datasets. It is a dataset, which is produced by SK&A, a healthcare marketing company that provides an annual list of office-based physicians throughout the country. The dataset, which is compiled and updated annually by repeated phone surveys, is created with the purpose of providing companies (e.g. pharmaceutical or medical device companies) with detailed information on the practice location, organization, and hours of physicians (so that those physicians may be targeted by marketing efforts). Organized at the physician-office level, the dataset includes basic physician information (e.g. specialty, title, state license number, and NPI) and detailed practice information (including name, location, hours, size, and estimated patient volume). For this dissertation, I use the portion of this dataset that covers Florida and New York from 2005 to 2011, and I focus specifically on cardiologists (which I detail more, below). This dataset is relatively new to the health care economics and policy researchers, so only a few recent studies can be found in the current literature (e.g. Dunn & Shapiro 2014 J Law Econ; Dunn & Shapiro 2015 JHE; Frech et al 2015 Rev Ind Org; Capps, Dranove, Oddy 2015 wp).

*Data processing*

While the original datasets described above contain all of the necessary information, some processing of the data is necessary to generate the desired variables for analysis. All data processing performed in this dissertation (unless otherwise noted) is performed using the statistical software package Stata (StataCorp), with most work completed using the Stata 13 release. To start, by using patient procedure codes in the hospital discharge data along with physician identifiers, I am able to track each physician's history of coronary stent placement, separately identifying BMS and DES, and restricting the hospital discharge files to only include hospitalizations in which a stent was placed. As already mentioned in Chapter 2, one reason that I chose to study the technology of DES is the fact that, thanks to the publicity and excitement leading up to the FDA approval of DES (in April 2004), the Centers for Medicare and Medicaid Services (CMS) established novel procedure codes to identify (and bill for) DES placement and made these codes available by the time DES was introduced into the market. Thus, I am able to observe, with high fidelity, physicians' initial adoption of DES, along with their continued use and later disadoption (if and when it occurs). Throughout this empirical work, I make frequent reference to and use of each physician's "DES use rate" or "DES rate," which is defined as the fraction of coronary stents placed by a physician that are DES in a given time period (e.g. quarter). This is the measure of physician DES use rate that is used for various purposes and calculations, including the determination of each physician's DES adoption and disadoption measures, which will be defined below.

Considerable processing of the SK&A dataset was required before it could be used for analyses. To start, because the dataset covers the entirety of US office-based physicians, its scope exceeds the interest of this dissertation and its size made it difficult to work with (particularly for the processing of practice identifiers, which will be discussed below). To restrict the dataset to a more manageable and useful sample, I exclude any physician-practice pairs that have addresses that are not in Florida or New York. Next, to focus on the specific physicians of interest (i.e. cardiologists who implant coronary stents), I also exclude any physician who is not identified as specializing in cardiology by any of the three specialty variables that are associated with each physician observation in the dataset. Because these specialty variables are self-identified (or identified by the practice members or administrators who provided the information to SK&A) and not necessarily based on formal training (e.g. cardiology fellowship), this sample inclusion criterion is generous and is very unlikely to exclude many (if any) physicians who regularly implant coronary stents.

Next, in the original SK&A dataset, many observations (physician-office pairs) are missing values for physician identifiers such as state license number or NPI. However, this can be addressed by taking advantage of the facts that individual physicians appear multiple times (in different years and sometimes multiple times per year, if they practice in multiple offices) and the dataset includes multiple identifiers, including state license number, NPI, DEA number, Unique Physician Identification Number (UPIN), SK&A-specific identifiers, and name (first, middle initial, and last). By connecting shared values of identifiers across observations (while making sure to exclude identifier values that are ambiguous or not shared uniquely), I am able to impute missing values of NPI and state license number, which ultimately allows both the consistent tracking of physicians' practice membership and the combination of this data with the discharge data at the physician-year level.

Similar to the physician identifiers, the practice identifiers in the SK&A dataset also require processing, though of a different nature. Whereas the physician identifiers are plagued by missing values in the original dataset, the original practice identifiers, which include the listed name and location of practices, are almost always non-missing but compromised by frequent errors (e.g. incorrect or inconsistent spellings), which are likely due to data collection and/or entry[21]. To deal with these errors, I use Google Refine[22], a tool designed to clean and transform "messy data," to help identify and group together similar practice identifier values. By organizing the data by practice name, address, and phone number and by physician identifier, and then checking each unique value, I exhaustively comb through the dataset to identify practices, manually changing the practice names where appropriate (e.g. when two practices have the same physicians, address, and phone number, but differently spelled names)[23]. With these changes (which

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[21] In fact, the SK&A dataset provides an SK&A-specific identifier variable for practices, but cursory examination reveals that this variable has both frequent missing and inconsistent values (e.g. a single practice—as identified by name, address, and phone number—will have different values for the variable in different years). Due to these frequent problems, I ignore this practice identifier and instead use the variable that provides practice name to identify practices, combining this name with other information (e.g. state, street address, and/or phone number) to uniquely identify practices within the dataset.
[22] This software package has since become known as OpenRefine.
[23] Admittedly, this process of manually identifying practices, with the help of Google Refine, is not only labor intensive, but also occasionally subjective; it is not always immediately obvious whether or not two

occasionally include adding the name of a city to a practice name if that name is very generic, e.g. “Cardiology Associates”), the practice name variable becomes a consistent identifier for practices and is used as such in analyses throughout this dissertation. This use includes the creation of practice dummy variables, which are used to include practice-level fixed effects in regression analyses, and the calculation of group size, which will be discussed in more detail in Chapter 6.

With the individual files processed, they can be combined to form a single composite dataset. The AMA Physician Masterfile data, which contains one observation per unique physician, can be simply merged (by physician identifier) with either the SK&A or discharge data, but the combination of those two larger datasets is less trivial. The discharge data contains an observation for each unique discharge, with time granularity at the quarter level. On the other hand, the finest level of time gradation in the SK&A dataset is at the year level, not the quarter level. Furthermore, not only does the SK&A dataset combine multiple separate years of data, physicians can also appear multiple times per year if they belong to multiple different groups, practices, or practice locations in a given year. Thus, the combination of these datasets requires a “many-to-many” merge[24] to allow each discharge to be matched with the appropriate physician-practice-year in the SK&A dataset, creating a file at the discharge level, with discharges repeated

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practice names represent the same practice. The application of logic, careful consideration, and basic investigation (e.g. Google searches of practices and physicians) are used to sort through potentially ambiguous cases, and the default decision is to *not* change the names of practices unless there is a very high level of confidence in the change.

[24] In fact, though the Stata “merge” function allows for “many-to-many” merges, these are very messy and unreliable in practice. Thus, the files are combined instead using the “joinby” function.

(within a given quarter-year) for each practice attributed to a physician (within a year) by the SK&A data.

*Defining and measuring adoption*

The adoption and disadoption of DES are the primary processes of interest in this chapter, but to be studied empirically, they must be precisely defined and measured. As described in Chapter 3, there are four different measures of interest for both the adoption and disadoption processes: time to initial DES adoption/disadoption, initial extent of adoption/disadoption, time to maximum/minimum DES use, and full extent of adoption/disadoption. To calculate each of these eight measures, the first step is to identify the two key points in each of the two processes (recall Figures 3.3 – 3.6 for an illustration of these points and the measures that they delineate). Starting with the adoption process, the point of initial adoption is identified as the first period in which the physician placed any DES. With this first point, the first two DES adoption measures can be calculated: *time to initial adoption* is calculated as the number of time periods (quarters) from FDA approval of DES (in April 2003, or 2003Q2) to the physician's period of initial adoption; and *initial extent of adoption* is calculated as the physician's DES use rate in the period of initial adoption. (More precisely, this initial extent of adoption is meant to be the change from pre-adoption use to initial adoption, but because pre-adoption use is 0, we can simply take the level of use in the initial adoption period.) The second key point in the adoption process is the point of maximum DES use, which is calculated as the point in which the physician's DES use rate reaches a maximum. The determination of this point's location allows for the calculation of the next two DES adoption measures: *time to maximum use* is calculated as the number of time periods from the physician's initial DES adoption (*not* from DES approval) to her period of maximum DES use; and *full extent of adoption* is calculated as the physician's DES use rate at its maximum. (Again, this is more precisely calculated as the difference between the maximum use rate and pre-adoption use rate, which is 0.)

Having established the two key points that characterize the beginning and end of the DES adoption process, we can then use these points, along with the technology use curve, to calculate the *area below the DES adoption curve,* as was described in Chapter 3 and depicted in Figure 3.7. Because the empirical reality of this technology use curve is a connection of discrete data points, the area above (or below) the curve can be calculated with a simple Riemann sum. Thus, to determine the area below the observed DES adoption curve for a physician, I simply sum together that physician's DES use rate in all periods between (and including) each physician's period of initial adoption period and period of maximum DES use.

*Defining and measuring disadoption*

The process to establish the DES disadoption measures is very similar to that used for the DES adoption measures, but some more intricacies are required when establishing the location of the relevant points. First, we consider the point that identifies initial DES disadoption. As discussed briefly in Chapter 3, this point should logically represent the point when an individual's technology use rate begins to decline, though issues with noise in the data (i.e. natural fluctuations in DES use rate over time) make the precise identification of this point somewhat challenging. In an attempt to deal with this noise and appropriately identify the time period when a physician begins the DES disadoption process, I impose the following conditions when defining the initial DES disadoption point:

(i) It must occur after DES adoption has occurred (and, by obvious logical extension, can only occur if DES adoption has occurred).

(ii-a) It must occur after the widespread publicization of DES safety concerns in September 2006 (2006Q3) (coinciding with the presentation of results from a comprehensive study at the World Congress of Cardiology, and subsequent popular press coverage).

(iii-a) It occurs in the first time period when a physician's DES use rate decreases from the previous period and does not increase in the following period.

Because these conditions—or more specifically, conditions (ii) and (iii)—may be viewed as somewhat restrictive, I also relax them in various analyses to test how sensitive findings are to these definitions. Specifically, I also allow for the following replacements for condition (ii):

(ii-b) It must occur after the earliest publicization of DES safety concerns in January 2004 (2004Q1) (when concerns over increased risk of thrombosis with DES were first published by Virmani et al in *Circulation*).

(ii-c) It must occur after the earliest conference presentation of suggestions for modified implantation guidelines and post-implementation medication regimen in March 2005 (at the American College of Cardiology annual meeting) (Huesch 2011 Soc Sci Med).

(ii-d) It must occur after the first conference presentation of detailed evidence for increased DES safety concerns, due to increased risk of late stent thrombosis, in March 2006 (at the American College of Cardiology annual meeting) (Huesch 2011 Soc Sci Med).

and the following replacements for condition (iii):

(iii-b) It occurs in the first time period when a physician's DES use rate decreases from the previous period (with no condition for DES use in the following period).

(iii-c) It occurs in the first time period when a physician's DES use rate drops below 80% (a condition which obviously also requires that a physician's use reach or exceed 80% before she can meet this definition for initial disadoption).

While the use of these different conditions provide robustness checks for the analysis results, it must be noted that, given the concerns (about natural noise in the data) that motivated the creation of these conditions, variation of the conditions represents a tradeoff between sensitivity and specificity of the DES initial disadoption definition; relaxing a condition may allow for more physicians to fulfill the definition, but it will also increase the number of inappropriately or erroneously labeled DES initial disadoption points (because those points actually just represent noise), with the converse also being true (i.e. tightening a condition will decrease the number of physicians who meet criteria to be measurable DES disadopters, but that tightening of the condition also decreases the noise). For this reason, my analyses will focus on the definition of DES initial disadoption that uses the primary set of conditions (i, ii-a, and iii-a), which seem to balance the sensitivity-specificity tradeoff, with results based on other DES disadoption definitions relegated to the appendices. With these conditions set, the point of initial disadoption is identified and the first two DES disadoption measures can be calculated: *time to initial disadoption* is calculated as the number of time periods (quarters) from the publicization of DES safety concerns to the physician's period of initial disadoption; and *initial extent of disadoption* is calculated as the change in physician's DES use rate from the immediate pre-disadoption period to the period of initial disadoption.

Next, we turn to the second key point of the disadoption process: the point of minimum DES use. Though this point is somewhat simpler to define than the point of initial DES disadoption, we still need to impose some basic logical conditions when defining this point. Specifically, the point occurs in the period in which the physician's DES use rate reaches a minimum after initial DES disadoption, which thus makes this point conditional on the DES initial disadoption definition. With this second point determined, the calculation of the last two DES disadoption measures is possible: *time to minimum use* is calculated as the number of time periods form the physician's initial DES disadoption (*not* from the DES safety concern publicization) to her period of minimum DES use; and *full extent of disadoption* is calculated as the change in the physician's DES use rate from the immediate pre-disadoption period to the minimum DES use rate level. Figure 5.1 provides histograms of the four DES disadoption measures used as outcome variables in this chapter's analyses.

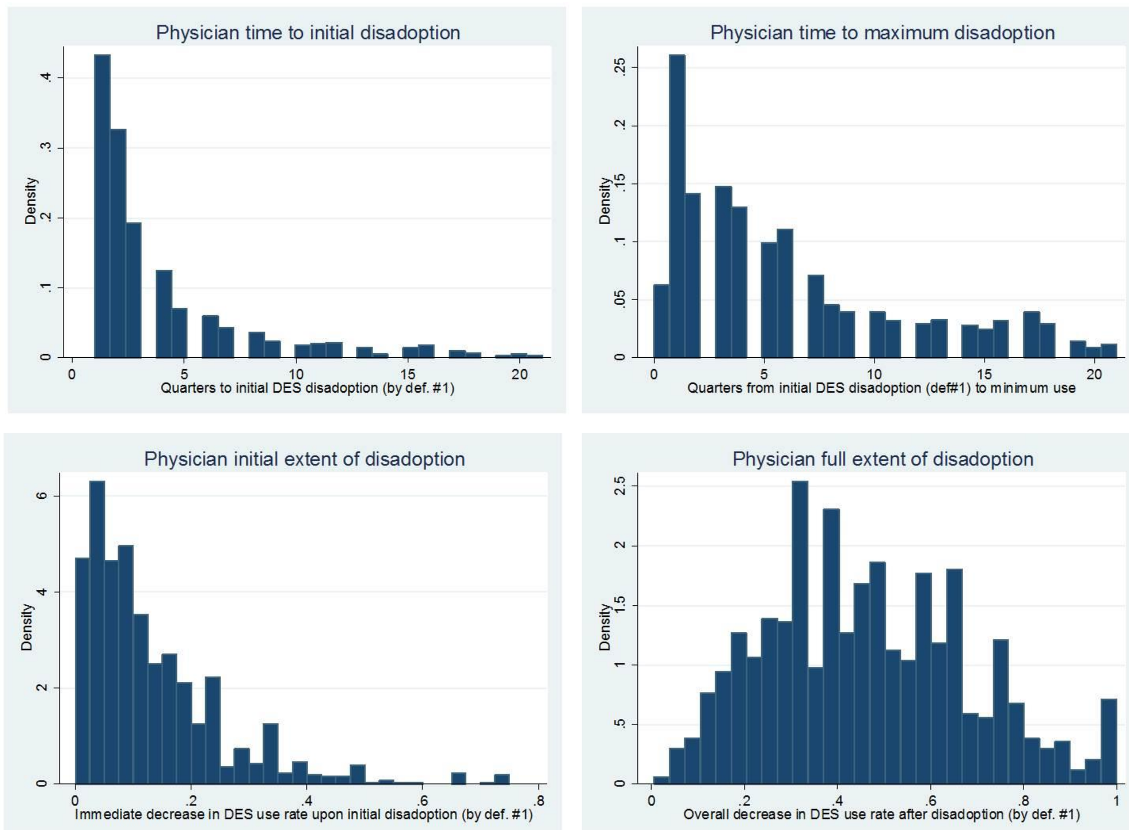



**Figure 5.1**: Distributions of DES disadoption measures observed in discharge data

Having now established the two points that characterize the beginning and end of the DES disadoption process, we can use these points, along with the technology use curve itself, to calculate the *area above the DES disadoption curve*, as was described in Chapter 3 and depicted in Figure 3.7. As was the case with adoption, we can determine the desired area by using a simple Riemann sum because the empirical technology use curve is a connection of discrete data points. However, the area above the DES disadoption curve requires a slightly more involved calculation than the area below the DES adoption curve. First, having identified the time period of initial DES disadoption, along with the level of DES use in that time period, and the time period of minimum DES use (post-disadoption), I calculate the area of an imaginary rectangle of "DES disadoption potential," which is bounded above by the level of DES use prior to disadoption, bounded below by 0 DES use, bounded on the left by the initial DES disadoption period, and bounded on the right by the end of the DES disadoption period (i.e. minimum DES use). I then use the observed DES use curve to calculate the area below the curve, as was done with the adoption curve. By subtracting this area below the disadoption curve from the area of the full "DES disadoption potential" rectangle, I then calculate the area above the observed DES disadoption curve.

*Covariates*

Though these measures of DES adoption and disadoption are the primary outcome and explanatory variables of interest in the following analyses, there are other variables of interest that I wish to use as covariates that need to be calculated. First, there are variables generally grouped together as "physician characteristics." These include physician age, years of experience, and training. Age and years of experience are calculated by finding the difference between the current year and the physician's year of birth and final year of training (whether residency or fellowship), respectively. Physician training is described using dummy variables that label physicians who have, according to the AMA Physician Masterfile, completed cardiology fellowship or interventional cardiology fellowship, with a separate variable for the different types of fellowship. These variables are included in the analyses to address concerns that physicians of different age, experience, or training may exhibit different DES disadoption behaviors. A second set of variables are grouped together as "physician DES use measures," which are included because, as discussed in Chapter 3, it is reasonable to expect an individual's disadoption behavior to be influenced by that individual's experience with the given technology. For this reason, I calculate two different measures of a physician's DES use: the total cumulative number of DES implanted by a physician *before* she was at-risk for disadoption (i.e. across all time periods before DES safety concerns were publicized), and the total number of DES implanted by the physician during a fixed time period after becoming "at-risk for disadoption" phase (i.e. from the publicization of DES safety concerns through 2007). (The second measure was specifically chosen be defined over a fixed period, *not* one based on the physician's time period if initial disadoption, due to concern over a potential mechanical relationship between an outcome variable based on time period length and an explanatory variable whose definition is also based on that time period length.) Together, these variables provide a general measure of each physician's total experience with the technology in question.

In addition to physician-specific variables, I also wish to control for other factors that may impact a physician's DES disadoption behavior. Specifically, there may be concern that some unobserved group-level characteristics are systematically related to DES disadoption behavior, and an inability to control for such characteristics would systematically bias the results. In these analyses, a specific concern is that some unobservable characteristics of groups (e.g. the use of electronic health records, or regular access to medical device specialists/representatives) might influence DES disadoption behavior, thus biasing the results. If these unobservable characteristics are time-invariant, the inclusion of group-level dummy variables (or fixed effects)—which are thus perfectly collinear with all time-invariant group-level variation in the model—in the regression analyses will control for all such unobserved characteristics, thus eliminating those potential sources of bias. Specifically, I want to include both hospital- and practice-level fixed effects in the regression analyses. Hospital fixed effects are determined easily, as the discharge data, which provides information on physicians' stent use, includes hospital identifiers for both Florida and New York. Practice-level fixed effects, however, required additional data processing and the incorporation of the SK&A dataset, which was described above.

*Sample selection*

Though the datasets are processed and combined, the original datasets include physicians and patients outside of the purview of this dissertation, so the dataset should be reduced in size. The first steps in sample selection, which were already described above, include restricting the file to only include physicians located in Florida or New York (according to the SK&A data) and physicians who implant coronary stents (according to the hospital discharge data from Florida and New York).

The next steps of sample selection, which are delineated in Table 5.1 (for the primary outcome variable), can be broken into two general categories: (1) selection of appropriate physicians for the given research questions and (2) exclusion of physicians who are missing data necessary for the desired analyses. The first type of selection was already begun when the sample was restricted to Florida and New York physicians who implant coronary stents, but we can restrict this even more. First, I can narrow the date range of the sample to a window that focuses on DES adoption and disadoption. For the beginning of the time window I use 2003, as this was the year in which the FDA approved DES, and for the end of the time window I use 2009, as our observation of global trends in DES use indicate that the population-wide disadoption phase was finished by this year (as shown in Chapter 2). Next, given that I am specifically interested in studying the disadoption of DES, I can exclude any physicians who never implanted any DES. I also want to exclude physicians who *adopt* DES *after* September 2006 (when DES safety concerns were widely publicized), as this date was set as the initial period in which physicians were able to disadopt DES (or at risk for DES disadoption) and I want to focus my attention on a sample in which all physicians are capable of having the same values of the DES disadoption measures. (If I did not exclude physicians who adopted DES after September 2006, those physicians' measures for *time to initial disadoption* would be inappropriately measured.) Next, given that the measures of disadoption are based on DES usage rates and there are concerns about natural noise in these measures (as discussed at length above), I want to exclude physicians who implant very few stents per time period. For example, if a physician implants only 1 or 2 stents per time period and we expect there to be natural variation (e.g. patient differences) that can drive changes in stent choice, such low stent use volume would make it difficult to make an accurate empirical determination of the time period in which that physician's DES disadoption process begins. Thus, I choose to only include physicians who implant at least 4 coronary stents per quarter on average, where the choice of this number is somewhat arbitrary, but is driven by a desire to have physicians who implant at least 1 stent per month and also weigh the trade-offs of decrease sample size against increased noise in the DES disadoption measures. The final step in the selection of desired physicians for the analysis is the exclusion of physicians who disadopt DES after 2009. Though the sample was restricted to the years 2003-2009 above, that selection was made at the observation level, so physicians may have been remained in the dataset if they appeared between 2003 and 2009, but we only want to keep them in the dataset if they started the DES disadoption process before 2009[25].

The second general step in sample selection is the exclusion of physicians who are missing information that I wish to use for the desired analyses. This sample selection step is motivated by the fact that, when performing statistical analyses with the dataset, the given software package (Stata) will exclude from an analysis any observation that is missing a variable used in that analysis. Table 5.1 shows how the sample size changes as

[25] An examination of Table 5.1 indicates that different sample restriction steps reduce the number of physicians included in the sample by different numbers. For example, it appears that, in terms of percentage change in sample size, the exclusion physicians who implant less than 4 stents/qtr (on average) has the largest sample reduction impact. However, it is worth noting that these sample selection steps are not order-dependent (i.e. combining the sample selection steps in any order will produce the same final sample), so determining the marginal impact of each selection step is difficult. For example, if the first step is the exclusion of physicians who disadopt DES after 2009, the number of physicians in the sample immediately drops from 10,669 to 992.

physicians are excluded for having missing values of any variable in the different groups of variables used in the planned analyses. We observe here that, while the data does not have issues with missing values of the DES disadoption, adoption, or use variables (at least after having gone through the first set of sample restriction steps, discussed above), there are issues with physicians missing values of the "physician characteristic" variables. Given that the information in those variables comes from the AMA Physician Masterfile, this problem is indicative of issues with the match between the AMA Masterfile and the combined SK&A/discharge dataset.

*Methods*

With the final sample selected, analyses of the data can now be performed. After initial data processing, the combined dataset is at the discharge level, I then reduce it to the physician-time-period (i.e. physician-quarter) level to simplify calculation of the DES adoption and disadoption measures. However, the primary variables of interest here—namely the measures of DES adoption and disadoption—are all determined at the physician level, i.e. each physician will only have one value for each of these measures, regardless of time period. Thus, after these measures are calculated (by using data cross multiple time periods), the dataset can be further reduced to the physician level (i.e. one observation per physician) for the bulk of the analyses to be performed here.

As described above (first generally in Chapter 3 and then specifically in this chapter), the different measures of DES adoption and disadoption are all continuous variables. The measures along the time dimension (i.e. *time to initial adoption/disadoption* and *time to maximum/minimum use*) have integer values (numbers of quarters), and the measures along the level dimension (i.e. *initial extent of adoption/disadoption* and *full extent of adoption/disadoption*) can have any values along the range of DES use, which varies continuously between 0 and 1. Given variables in this format, I use ordinary least squares (OLS) linear regression to examine the relationship between the disadoption measures and the adoption measures. As mentioned above, the primary outcome of interest is a physician's *initial time to DES disadoption*, and secondary outcomes are *initial extent of DES disadoption*, *time to minimum DES use*, and *full extent of DES disadoption*. For each outcome, each of the four measures of adoption (*initial time to DES adoption*, *initial extent of DES adoption*, *time to maximum DES use*, and *full extent of DES adoption*) will be the primary explanatory variables of interest. In addition to these explanatory variables, I also include as covariates various measures of "physician characteristic" (i.e. age, years of experience, and relevant fellowship training status) and "physician DES use" (i.e. the total number of DES implanted by a physician before becoming "at risk" for DES disadoption and the total number of DES implanted during a fixed window after becoming "at risk"). Furthermore, due to potential concerns for unobservable physician characteristics that may relate to both DES adoption and disadoption behavior, I also include practice- and hospital-level fixed effects. Though physician-level fixed effects would more directly control for unobserved physician characteristics, the outcome variables used in these analyses are determined at the physician-level, which prevents the use of physician-level fixed effects.

While the measures of both DES adoption and disadoption are continuous variables, as described above, I also convert these continuous measures into binary variables by using the sample mean of each variable and identifying individuals who have values above the mean (or below the mean, depending on the specific measure). Though the continuous forms of these variables provides information on the levels of the different measures (and effect sizes relative to those levels), the conversion of the variables to binary form allows me to perform a more general investigation for relationships between the variables. Though the use of binary explanatory variables does not require any change in analysis approach, the use of binary outcome variables suggests the use of a *probit* or *logit* model. However, the inclusion of practice- and hospital-level fixed effects in these models makes the use of these binary outcome models very computationally intensive. Thus, motivated by resource constraints and comforted by the qualitative similarity of results from selective applications of *logit* models, I use OLS regression with the binary measures of DES disadoption behavior, thus assuming a linear probability model. Also, I use these binary variables to generate descriptive statistics and compare physicians with high versus low values of the different DES disadoption measures. Tables 5.2 – 5.5 provide these basic descriptive statistics. For example, Table 5.2 compares early versus late DES disadopters in terms of their means (and standard deviations) of the various independent variables (i.e. DES adoption measures) and covariates (i.e. physician characteristics). These statistics reveal that, across each of the different DES disadoption measures, there are not obvious differences between physicians who fall on either side of these binary variables.

### 5.3 – Results

The results for regression analyses in this chapter are displayed in the Tables 5.6a – 5.9d. The analyses that produced these results, and all other results in this chapter, should be generally viewed as exploratory analyses that seek to determine associations between the variables of interest; it is understood that these analyses to not specifically identify causal relationships between these variables. With that said, there is still value to be gained from these exploratory analyses. Though there is no exogenous source of identification in these regression analyses, the concerns about endogeneity are relatively limited. For example, there are no specific reasons to believe that there is systematic measurement error in the measures of DES disadoption, nor should we believe that there is simultaneity or reverse causality, given that DES disadoption is a distinct process that occurs after adoption. Of course, it is impossible to rule out the existence of a relevant omitted variable, but the inclusion of "physician characteristics" and "physician DES use" variables should address concerns about physician-level factors that are likely related to the adoption and disadoption processes, while the use of hospital- and practice-level fixed effects can control for some unobservable time-invariant characteristics that may be important. Thus, the associations identified here between DES disadoption measures and adoption measures, while not causal, are still informative and valuable.

Tables 5.6a – 5.6d show the results from the analyses with the primary outcome variable, *initial time to DES disadoption*. As described above, both the outcome variable and explanatory variables of interest can be presented in continuous or binary form, and each of these four tables represents a different combination of the continuous vs. binary variables, with each table using the same series of model specifications, each of which is presented in a separate column, where Model 1 is the most basic model and Model 9 has the complete set of covariates included. Looking across these models and different choices of variable formulations, we can observe that, except for *time to maximum DES use*, the various measures of DES adoption—which importantly includes *initial time to DES adoption*—are not associated with *initial time to DES disadoption*. Across all models and variable formulations, there is a negative relationship between *initial time to DES disadoption* and *time to maximum DES use*, though this relationship is only statistically significant in some models and choices of variable formulation. (It must be noted here that in binary formulation of all of the time-based adoption and disadoption variables, including *initial time to DES disadoption* and *time to maximum DES use*, the binary variables were given a value of 1 for smaller times, representing earlier or faster adoption/disadoption behavior, and a value of 0 for larger values. As a result, a negative relationship between these two measures will present with a positive coefficient estimate when one of the variables is represented with a binary formulation and the other is in continuous form, as is seen in Tables 5.6b and 5.6c.) In other words, we observe that physicians who were slower to adopt DES (i.e. took longer to reach their maximum DES use rate) are generally earlier to start disadopting (i.e. take less time to begin the DES disadoption process), or conversely, physicians who were faster to adopt DES generally start disadopting later.

In addition to this association, we can also observe relationships between the outcome variable and the different covariates in Tables 5.6a – 5.6d. For example, we see that neither the hospital- nor practice-level fixed effects offer significant predictive power in modelling *time to initial DES disadoption*, as indicated by the *p*-values (> 0.05) for the incremental *F*-statistics in the models where those fixed effects were added. On the other hand, the sets of "physician characteristic" variables and "physician DES use" variables both (separately) significantly increase the statistical power of the models. Examining individual variables, both physicians with interventional cardiology fellowship training and those who implant a greater number of DES *before* the publication of safety concerns start disadopting DES earlier, while those who implant a greater number of DES *after* the publication of safety concerns start disadopting DES later.

As described above, the definition of DES disadoption is based on various criteria, for which multiple options exist. Thus, in sensitivity analyses, I repeat the analyses performed above with the primary outcome variable but use different DES disadoption definitions (twelve different definitions in total), varying the conditions (both for the change in DES use rate and for the earliest allowable time period) that identify the initial period of DES disadoption. Figures 5.2 and 5.3 provide summaries of the estimated coefficients—plotted with bars depicting their 95% confidence intervals—on the four measures of DES adoption from the analyses using each of the different DES disadoption criteria to define *time to initial DES disadoption*, selecting the coefficient estimates from the models run with the most complete set of covariates (i.e. Model 9, as displayed in Table 5.6). Figure 5.2 provides coefficient estimates from models that use continuous measures of both *time to initial DES disadoption* and the DES adoption explanatory variables, whereas Figure 5.3 provides coefficients estimates from models where both DES disadoption and adoption measures are represented in binary formulations. As these figures show, by examination of both the different point estimates and the calculated averages of the coefficients (with corresponding 90% confidence intervals), the point estimate results are indeed sensitive to the choice of DES disadoption definition criteria, but the estimates are mostly not different from zero with statistical significance and it is generally difficult to identify relationships that are consistently different from zero across the different DES disadoption definitions. One may note, though, that the relationship that is closest to achieving statistical significance in its difference from 0 is the negative relationship between *initial time to DES disadoption* and *time to maximum DES use*.

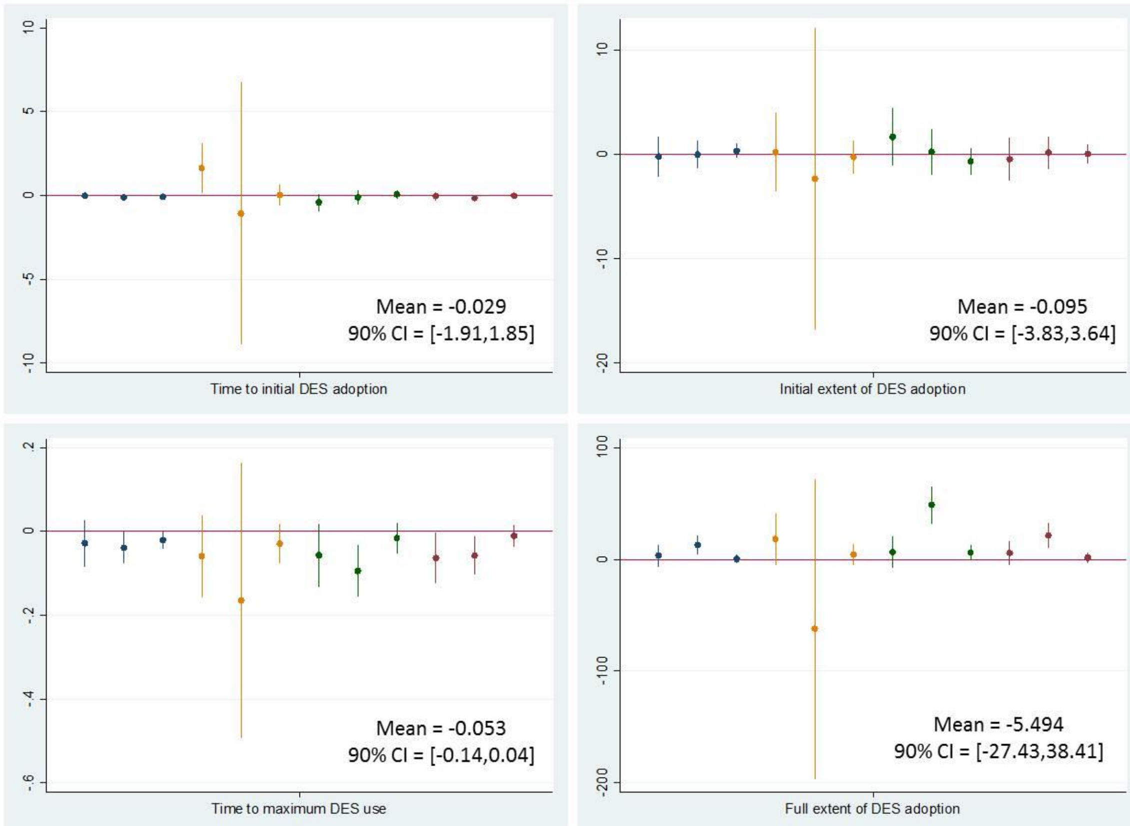



**Figure 5.2**: Coefficient estimates from models relating continuous DES adoption measures to continuous DES disadoption outcome measures (basic OLS regression), using different DES disadoption definitions; coefficient means with 90% CI are shown in text.

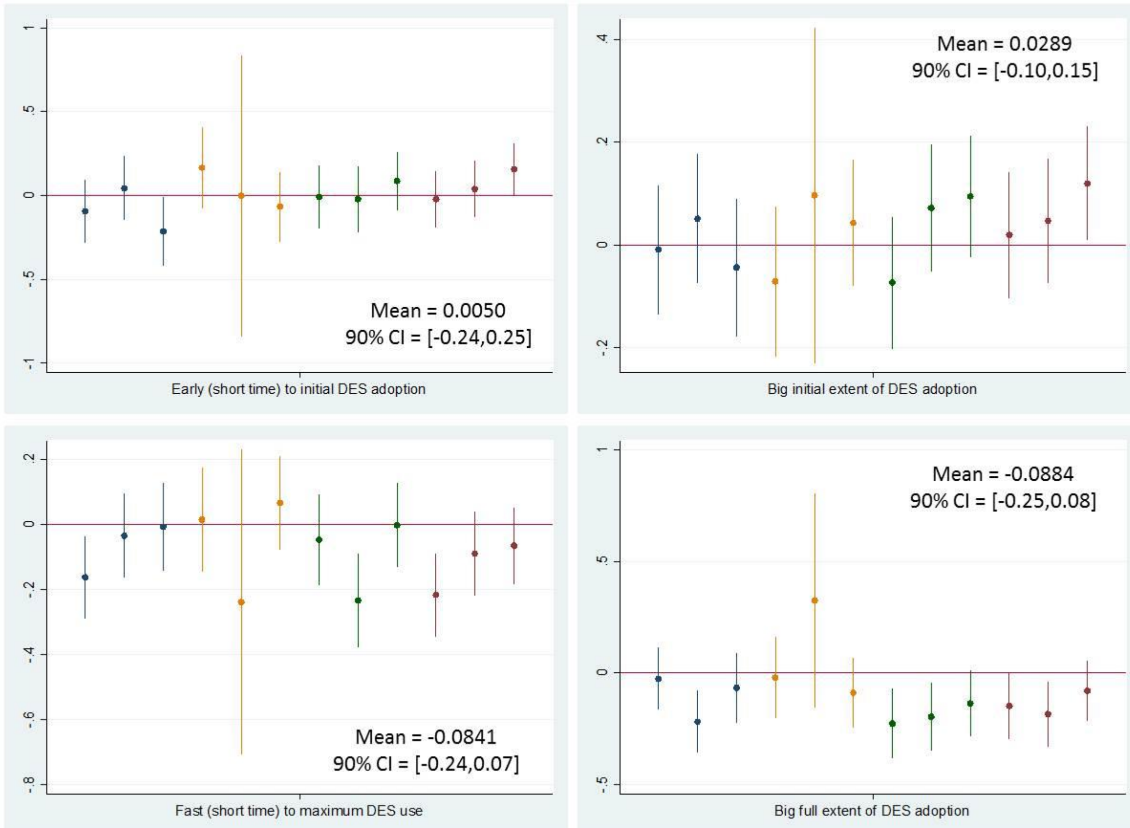



**Figure 5.3**: Coefficient estimates from models relating binary DES adoption measures to binary DES disadoption outcome measures (basic OLS regression), using different DES disadoption definitions; coefficient means with 90% CI are shown in text.

Results from the analyses of the secondary outcomes of interest are shown in Tables 5.7 – 5.10. For the sake of space, I have only included the results of analyses where either both DES disadoption and adoption measures were in continuous form (tables with "a") or both were in binary form (tables with "d"). Across these analyses, we observe very few statistically significant relationships, both for the measures of individual DES disadoption measures and for the measure of area above the DES disadoption curve. There is a positive and significant relationship between *time to minimum DES use* (i.e. a disadoption measure) and *extent of full DES adoption*, indicating that physicians who had higher maximum DES use rates take more time to reach their minimum DES use level, i.e. move more slowly through the disadoption process. However, neither of the measures of extent of DES disadoption (*initial extent of disadoption* or *full extent of disadoption*) have statistically significant associations with any of the DES adoption measures in any of the specified models. Also, the individual covariates very rarely have statistically significant relationships with any of the secondary disadoption outcome measures. Of note, there is a positive and statistically significant relationship between a physician's *area above the DES disadoption curve* and that physician's level of DES use in the period prior to initiating disadoption.

### 5.4 – Discussion

The analyses performed in this chapter are meant to be exploratory. Because I do not identify a source of exogenous variation (of DES adoption behavior, or any other physician-level characteristic), I cannot and do not claim to observe any causal relationships in these analyses. However, there is still interesting information to be gleaned from the observed correlations. By including several different physician-level covariates, along with practice- and hospital-level fixed effects, I am able to control for many factors that potentially cofound any observed association between the various adoption and disadoption process measures. Furthermore, we need not worry about reverse causality in these analyses, because the DES adoption process is completed before disadoption begins. Thus, though I do not suggest that the differences in DES adoption behavior cause the observed differences in DES disadoption behavior, concerns that the observed relationships are spurious should be reduced.

One of the most interesting findings in the above analyses is the relationship between *time to initial DES disadoption* and *time to maximum DES use*: faster DES adopters (i.e. physicians who take less time to move from initial DES adoption to maximum use) tend to start disadoption later (i.e. take more time from DES safety concern publicization to initial disadoption) or conversely, slower DES adopters tend to start disadoption earlier. The reason for this association is unclear and could be explained by multiple possible factors. For example, this observation may be partially explained by a manifestation of risk aversion towards new technologies. Those cardiologists who are concerned about uncertainty associated with a new technology like DES when it first reaches the market may be slower to fully adopt the technology (i.e. longer *time to maximum DES use*) and then also more eager to begin disadoption (i.e. short *time to initial DES disadoption*) when they learn about safety risks associated with thrombosis. Another possible explanation for the observed behavior is that physicians who adopt DES faster have a superior knowledge of the technology, which then prevents them from hastily disadopting after the publicization of safety concerns (which were ultimately addressed, resulting in the observed global trend of DES "re-adoption", as discussed in Chapter 2). However, contrary to this story of experience-based knowledge of the technology, we observe that those who implanted more DES per quarter after the publicization of safety concerns actually started the disadoption process sooner. Another different factor that may partially explain the observed results is product loyalty: cardiologists who develop a strong preference for DES may quickly increase their use of the technology (i.e. short *time to maximum DES use*), and then be hesitant to stop using the technology (i.e. long *time to initial DES disadoption*). This notion that technology loyalty is important is further supported by the observed relationship between *time to minimum DES use* and *full extent of DES adoption*: cardiologists who had higher levels of DES use (post-adoption) tended to be slower to disadoption (i.e. take more time to move from initial DES disadoption to minimum use).

Aside from these results, the above analyses are also noteworthy for all of the relationships that were *not* statistically significant. Importantly, there were no positive relationships between any of the analogous measurements of DES adoption and disadoption (e.g. *time to initial adoption* and *time to initial disadoption*), i.e. the theoretical prediction of symmetry between the adoption and disadoption processes presented in Chapter 4 was not supported empirically. This result may indicate that the two processes are more different than can be explained by a simple theoretic model, or that the factors shaping the behaviors are beyond any of the basic measurable covariates included in the above analyses. As is frequently the case in economics, we see here that there could be increased empirical accuracy gained from either a more detailed model or comprehensive dataset.

Also, we note that neither *initial extent of DES disadoption* nor *full extent of DES disadoption* were found to be correlated with any DES adoption measures or many (if any) physician-level characteristics. As discussed in Chapter 3, one possible explanation for variation in an individual's extent of technology adoption or disadoption is risk aversion. Using this explanation, it would appear that it is difficult to predict cardiologists' risk aversion, or at least that risk aversion associated with DES adoption seems unrelated to the risk aversion associated with DES disadoption. Another possible explanation for variation in extent of technology adoption/disadoption is difference in physicians' patient populations. At first glance, this explanation seems problematic because we would generally expect a physician to be treating the same patient population during her DES adoption and disadoption processes. However, the paths of the technology use curve that describes adoption and disadoption are different. If differences in extent of technology use are driven by differences in patient characteristics, then we expect there to a spectrum of patient characteristics, where some would be very appropriate recipients of DES and these individuals would receive DES first (i.e. at low levels of use), whereas other patients would be less appropriate and would only receive DES later (i.e. at high levels of use). With this perspective and with an understanding that the paths of adoption and disadoption are different—because adoption represents movement up the technology use curve, from highly appropriate to less appropriate patients, whereas disadoption represents movement down the curve, from less appropriate to more appropriate patients—we can see that even if a physician's general patient population is the same during the adoption and disadoption phases, the marginal "adoption patient" is still different from the marginal "disadoption patient."

In addition to observed relationships between the DES disadoption outcomes and the DES adoption measures, we can also notice interesting relationships between some of the covariates and DES disadoption behavior. For example, interventional cardiology fellowship training is associated with earlier initial DES disadoption, which could be consistent with the belief that physicians with the most technically advanced coronary-stent-related training might be most likely to learn first about safety concerns, and thus disadopt earlier. Of course, learning earlier about safety concerns (and resultant earlier disadoption) could just as well be driven by greater experience with the technology, which we also observe empirically by noting the negative relationship between *time to initial DES disadoption* and physicians' average quarterly DES volume (after DES safety concern publicization). Indeed, we might just as likely expect the individuals who have interventional cardiology training to implant more DES (or coronary stents in general), which is observed in the data. It is interesting to note that, among the set of covariates are other physician-level factors that one might have expected to be related to an individual's adaptability with respect to technology, such as physician age and years of experience, but none of these is associated with *time to initial DES disadoption*. We also observe a positive and significant relationship between area above the DES disadoption curve and level of DES use prior to initiating disadoption, but there is reason to think this might be a mechanical relationship: lower levels of DES use prior to disadoption simply allow for lower area above the potential DES disadoption curve.

In addition to the main results presented above, there are also the sensitivity analyses, which test the use of different DES disadoption definitions. As noted above, the negative relationship between *time to initial DES disadoption* and *time to maximum DES use* does change with the use of different DES disadoption definitions, but the qualitative results remain when taking a global view across the different definitions. As discussed above when characterizing and precisely defining the DES disadoption process, it is not surprising that variation in the conditions used to characterize this process would influence the observed empirical results, given natural noise in the DES use data, the tradeoff between sensitivity and specificity of disadoption measures, and the relatively small sample size used here. This uncomfortable fact—that a precise definition of technology disadoption is required to develop a detailed characterization of the process, but that such precision is somewhat arbitrary—may partially explain why past researchers have either avoided studying disadoption altogether or have studied it by instead simply examining technology use during a period of general downward trends in use. However, as discussed above, I assert that there is distinct importance in studying the process of technology disadoption, particularly in the setting of medical technology, so as long as the definition and conditions used to characterize the disadoption process are transparent and justifiable, there is value in taking that stand and examining the process.

Of course, it is also important to note that the observed results must be discussed within the limitations of this examination. Though this dissertation has focused generally on technology disadoption, this empirical analysis has only examined one specific technology (coronary drug-eluting stents) in a relatively restricted population (cardiologists in New York and Florida). Thus, our ability to extrapolate from this setting to broader understandings about medical technology disadoption behavior depends on how representative we believe this group and setting is of the larger population. Also, the sample size used in these analyses is relatively small (640 physicians), which, when combined with the covariates and group-level fixed effects, provides low statistical power to detect modest effect sizes. Thus, an increase in sample size may allow us to uncover true relationships that the current analyses are unpowered to identify. Similarly, access to more data—bother observations and variables—would be useful. Despite the inclusion of various physician-level covariates and group-level fixed effects, we cannot rule out the possibility of omitted variable bias. As discussed above, patient characteristics likely play a large role in a physician's decision of which stent type to select, but these characteristics are unobserved here. Though there is no reason to suspect that there were any systematic changes in patient characteristics, the realization of increased thrombosis risk with DES lead to an indication for dual-anti platelet therapy for DES patients, and this change in medication regimen likely influenced physicians' selections of DES-appropriate patients, and also increased the role for patient preferences in the selection of stent type.

Despite these limitations, the above analyses provide some insight into the technology disadoption process. However, these analyses represent a very small step in this investigation of technology disadoption, and much more work is required. This work continues in the next chapter, where I begin to examine the relationship between disadoption and physician group size.

**Table 5.1**: Sample selection for analyses relating time to initial DES disadoption to adoption measures

| **Sample restriction step** | **Unique docs** |
|---|---|
| *Initial sample* | 10,669 |
| *Selection of appropriate/desired physicians* | |
| After selecting years 2003 – 2009 | 8,694 |
| After excluding docs who never implant DES | 7,200 |
| After selecting docs who adopt DES before safety concern publicization | 4,822 |
| After selecting docs who implant, on average, at least 4 stents/quarter | 967 |
| After excluding docs who disadopt DES after 2009 | 760 |
| *Exclusion of physicians who are missing necessary data* | |
| After excluding docs missing DES disadoption outcome (*time to initial dis.*) | 760 |
| After excluding docs missing any DES adoption measure | 760 |
| After excluding docs missing any “physician characteristic” variable | 640 |
| After excluding docs missing any “physician DES use” variable | 640 |
| *Final sample size* | **640** |

**Table 5.2:** Descriptive statistics for early vs. late initial DES disadopters (*initial time to DES disadoption*)

| **Early DES disadopters** (time to initial dis < pop. Mean) | **Early** | | **Late** | |
|---|---|---|---|---|
| Sample size (physician count; total = 640) | 465 | | 175 | |
| | Mean | SD | Mean | SD |
| Physician time (quarters) to initial DES adoption | .4210905 | .2805479 | .4200931 | .2696884 |
| Physician initial level DES use (increase) upon adoption | .988361 | .0338622 | .9925691 | .0278064 |
| Physician time (quarters) from adoption to max DES use | 5.07957 | 2.668485 | 4.96 | 2.564927 |
| Physician full level DES use (increase) after adoption | 9.055914 | 6.420359 | 7.668571 | 6.337617 |
| Physician age (at time of DES safety concern publicization) | 369.6473 | 293.9991 | 302.0743 | 279.8314 |
| Physician years of experience (at time of DES safety concern pub) | 139.6495 | 123.7706 | 125.08 | 122.1802 |
| Physician has cardiology fellowship training | .9311828 | .2534157 | .9028571 | .297002 |
| Physician has interventional cardiology fellowship training | .1354839 | .3426083 | .0514286 | .221504 |
| Physician total num. DES placed before safety concerns | 47.66452 | 7.355748 | 49.33714 | 6.76838 |
| Physician total num. DES placed from safety concern pub. thru 2007 | 14.83011 | 7.867378 | 16.6 | 7.702067 |

**Table 5.3:** Descriptive statistics for big vs. small initial DES disadopters (*initial extent of DES disadoption*)

| **Big initial DES disadopters** (extent initial dis > pop. Mean) | **Big** | | **Small** | |
|---|---|---|---|---|
| Sample size (physician count; total = 640) | 191 | | 449 | |
| | Mean | SD | Mean | SD |
| Physician time (quarters) to initial DES adoption | .4179991 | .2769371 | .4220168 | .2779128 |
| Physician initial level DES use (increase) upon adoption | .9870316 | .0449179 | .9905666 | .0251696 |
| Physician time (quarters) from adoption to max DES use | 5.052356 | 2.686689 | 5.044543 | 2.621643 |
| Physician full level DES use (increase) after adoption | 8.659686 | 6.890451 | 8.683742 | 6.2212 |
| Physician age (at time of DES safety concern publicization) | 223.8743 | 154.132 | 405.3207 | 318.2908 |
| Physician years of experience (at time of DES safety concern pub) | 71.95812 | 49.1106 | 162.7661 | 135.0374 |
| Physician has cardiology fellowship training | .9267016 | .2613107 | .922049 | .2683935 |
| Physician has interventional cardiology fellowship training | .1413613 | .3493094 | .1002227 | .3006317 |
| Physician total num. DES placed before safety concerns | 48.37173 | 7.531201 | 48.01559 | 7.108673 |
| Physician total num. DES placed from safety concern pub. thru 2007 | 15.29319 | 7.943743 | 15.32294 | 7.827689 |

**Table 5.4:** Descriptive statistics for fast vs. slow DES disadopters (*time to minimum DES use*)

| **Fast DES disadopters** (time to min use < pop. Mean) | **Fast** | | **Slow** | |
|---|---|---|---|---|
| Sample size (physician count; total = 640) | 307 | | 333 | |
| | Mean | SD | Mean | SD |
| Physician time (quarters) to initial DES adoption | .4338178 | .2856613 | .4088327 | .2694569 |
| Physician initial level DES use (increase) upon adoption | .9876163 | .0384398 | .991259 | .0254218 |
| Physician time (quarters) from adoption to max DES use | 5.260586 | 2.858969 | 4.84985 | 2.406375 |
| Physician full level DES use (increase) after adoption | 8.452769 | 6.433182 | 8.882883 | 6.415914 |
| Physician age (at time of DES safety concern publicization) | 324.6417 | 302.0928 | 375.6276 | 279.6889 |
| Physician years of experience (at time of DES safety concern pub) | 124.6873 | 130.4181 | 145.7868 | 115.8613 |
| Physician has cardiology fellowship training | .9120521 | .2836815 | .9339339 | .2487714 |
| Physician has interventional cardiology fellowship training | .1270358 | .3335568 | .0990991 | .2992447 |
| Physician total num. DES placed before safety concerns | 47.76547 | 7.261933 | 48.45045 | 7.201998 |
| Physician total num. DES placed from safety concern pub. thru 2007 | 14.94463 | 8.0501 | 15.65465 | 7.669625 |

**Table 5.5:** Descriptive statistics for big vs. small complete DES disadopters (*full extent of DES disadoption*)

| **Big total DES disadopters** (extent total dis > pop. Mean) | **Big** | | **Small** | |
|---|---|---|---|---|
| Sample size (physician count; total = 640) | 327 | | 313 | |
| | Mean | SD | Mean | SD |
| Physician time (quarters) to initial DES adoption | .4308144 | .2859492 | .4103739 | .2682608 |
| Physician initial level DES use (increase) upon adoption | .9896447 | .0269476 | .9893726 | .0372142 |
| Physician time (quarters) from adoption to max DES use | 5.281346 | 2.918166 | 4.801917 | 2.291091 |
| Physician full level DES use (increase) after adoption | 8.281346 | 5.770168 | 9.089457 | 7.025935 |
| Physician age (at time of DES safety concern publicization) | 264.5719 | 199.9704 | 441.6422 | 340.9144 |
| Physician years of experience (at time of DES safety concern pub) | 92.55963 | 74.30534 | 180.6997 | 146.4343 |
| Physician has cardiology fellowship training | .9388379 | .2399946 | .9073482 | .2904081 |
| Physician has interventional cardiology fellowship training | .1406728 | .3482165 | .0830671 | .2764255 |
| Physician total num. DES placed before safety concerns | 47.52599 | 7.28296 | 48.74441 | 7.139533 |
| Physician total num. DES placed from safety concern pub. thru 2007 | 14.65443 | 7.768497 | 16.00319 | 7.900624 |

**Table 5.6a**: Relating continuous DES adoption measures to continuous *initial time to DES disadoption* (basic OLS regression results)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician time (quarters) to initial DES adoption | -0.028 [-0.14,0.08] | 0.002 [-0.15,0.15] | -0.014 [-0.14,0.12] | -0.007 [-0.19,0.18] | 0.030 [-0.08,0.15] | -0.070 [-0.19,0.05] | -0.042 [-0.21,0.12] | -0.040 [-0.18,0.10] | -0.014 [-0.22,0.19] |
| Physician initial level DES use (increase) upon adoption | -0.252 [-1.34,0.83] | -0.559 [-2.05,0.93] | -0.569 [-1.91,0.77] | -0.494 [-2.41,1.42] | -0.100 [-1.18,0.98] | 0.137 [-0.94,1.21] | -0.079 [-1.53,1.38] | -0.362 [-1.68,0.96] | -0.208 [-2.10,1.68] |
| Physician time (quarters) from adoption to max DES use | -0.054** [-0.09,-0.02] | -0.051* [-0.10,-0.00] | -0.045* [-0.09,-0.01] | -0.032 [-0.09,0.02] | -0.056** [-0.09,-0.02] | -0.043* [-0.08,-0.01] | -0.044 [-0.09,0.00] | -0.030 [-0.07,0.01] | -0.029 [-0.08,0.03] |
| Physician full level DES use (increase) after adoption | 2.956 [-3.56,9.47] | 2.735 [-5.07,10.54] | 3.884 [-3.96,11.73] | 4.688 [-5.49,14.87] | 3.319 [-3.16,9.80] | 2.559 [-3.84,8.95] | 3.734 [-3.88,11.35] | 2.423 [-5.29,10.14] | 3.239 [-6.80,13.28] |
| Physician age (at time of DES safety concern publicization) | | | | | 0.070 [-0.01,0.15] | 0.061 [-0.01,0.14] | 0.088 [-0.00,0.18] | 0.091* [0.01,0.17] | 0.100 [-0.02,0.21] |
| Physician years of experience (at time of DES safety concern pub) | | | | | -0.049 [-0.12,0.02] | -0.042 [-0.11,0.03] | -0.062 [-0.15,0.03] | -0.072 [-0.15,0.01] | -0.043 [-0.15,0.07] |
| Physician has cardiology fellowship training | | | | | -0.011 [-0.85,0.83] | -0.096 [-0.92,0.73] | 0.580 [-0.42,1.58] | 0.180 [-0.73,1.09] | 0.816 [-0.36,1.99] |
| Physician has interventional cardiology fellowship training | | | | | -1.098** [-1.92,-0.28] | -1.078** [-1.89,-0.27] | -1.346** [-2.36,-0.33] | -1.110* [-2.02,-0.20] | -0.929 [-2.20,0.34] |
| Physician total num. DES placed before safety concerns | | | | | | -0.003*** [-0.00,-0.00] | -0.004*** [-0.01,-0.00] | -0.004*** [-0.01,-0.00] | -0.003* [-0.01,-0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | 0.005** [0.00,0.01] | 0.005* [0.00,0.01] | 0.005* [0.00,0.01] | 0.004 [-0.00,0.01] |
| r2 | 0.018 | 0.378 | 0.214 | 0.520 | 0.040 | 0.070 | 0.427 | 0.259 | 0.550 |
| F | 2.849 | 0.979 | 1.117 | 0.948 | 3.277 | 4.729 | 1.151 | 1.355 | 1.027 |
| p | 0.023 | 0.571 | 0.206 | 0.684 | 0.001 | 0.000 | 0.108 | 0.011 | 0.407 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 0.948529188 | 1.058777225 | 0.86091859 | 3.656549095 | 10.15760808 | 1.002044551 | 1.070603998 | 0.85957032 |
| Prob > incrm F | | 0.672297465 | 0.333185646 | 0.882449912 | 0.00590517 | 4.55353E-05 | 0.489374894 | 0.305344644 | 0.884633047 |

**Table 5.6b**: Relating binary DES adoption measures to continuous *initial time to DES disadoption* (basic OLS regression results)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician early DES initial adopter (before sample mean) | 0.371 [-0.26,1.00] | 0.140 [-0.68,0.96] | 0.272 [-0.45,0.99] | 0.357 [-0.67,1.39] | -0.007 [-0.69,0.68] | 0.487 [-0.23,1.21] | 0.314 [-0.62,1.25] | 0.276 [-0.55,1.10] | 0.199 [-0.98,1.38] |
| Physician big DES initial adopter (more than sample mean) | -0.091 [-0.57,0.38] | -0.451 [-1.09,0.19] | -0.388 [-0.94,0.16] | -0.387 [-1.18,0.40] | -0.059 [-0.53,0.42] | 0.006 [-0.46,0.48] | -0.299 [-0.92,0.33] | -0.387 [-0.93,0.16] | -0.365 [-1.15,0.41] |
| Physician fast DES full adopter (less time than sample mean) | 0.808*** [0.36,1.26] | 0.902** [0.26,1.55] | 0.787** [0.24,1.33] | 0.840* [0.06,1.62] | 0.801*** [0.35,1.25] | 0.660** [0.21,1.11] | 0.751* [0.11,1.39] | 0.601* [0.05,1.15] | 0.721 [-0.07,1.51] |
| Physician big DES full adopter (more than sample mean) | 0.585* [0.03,1.14] | 0.601 [-0.14,1.34] | 0.663* [0.00,1.32] | 0.724 [-0.13,1.58] | 0.571* [0.02,1.13] | 0.372 [-0.19,0.93] | 0.465 [-0.27,1.21] | 0.372 [-0.29,1.04] | 0.491 [-0.38,1.36] |
| Physician age (at time of DES safety concern publicization) | | | | | 0.065 [-0.01,0.14] | 0.059 [-0.02,0.13] | 0.083 [-0.01,0.17] | 0.092* [0.01,0.17] | 0.090 [-0.02,0.20] |
| Physician years of experience (at time of DES safety concern pub) | | | | | -0.047 [-0.12,0.03] | -0.041 [-0.11,0.03] | -0.060 [-0.15,0.03] | -0.072 [-0.15,0.01] | -0.036 [-0.14,0.07] |
| Physician has cardiology fellowship training | | | | | -0.090 [-0.92,0.74] | -0.121 [-0.94,0.70] | 0.535 [-0.45,1.52] | 0.169 [-0.74,1.07] | 0.831 [-0.34,2.00] |
| Physician has interventional cardiology fellowship training | | | | | -0.940* [-1.74,-0.14] | -0.984* [-1.78,-0.19] | -1.282* [-2.27,-0.29] | -1.075* [-1.97,-0.18] | -0.856 [-2.11,0.40] |
| Physician total num. DES placed before safety concerns | | | | | | -0.003*** [-0.00,-0.00] | -0.004*** [-0.01,-0.00] | -0.003*** [-0.01,-0.00] | -0.003* [-0.01,-0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | 0.005** [0.00,0.01] | 0.005* [0.00,0.01] | 0.005* [0.00,0.01] | 0.004 [-0.00,0.01] |
| r2 | 0.034 | 0.391 | 0.228 | 0.532 | 0.052 | 0.077 | 0.433 | 0.267 | 0.557 |
| F | 5.659 | 1.033 | 1.217 | 0.995 | 4.317 | 5.272 | 1.180 | 1.413 | 1.057 |
| p | 0.000 | 0.386 | 0.074 | 0.520 | 0.000 | 0.000 | 0.072 | 0.005 | 0.313 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 0.957495591 | 1.068126243 | 0.885191382 | 2.906421921 | 8.672534568 | 1.009565407 | 1.086979631 | 0.871443394 |
| Prob > incrm F | | 0.642557136 | 0.310875371 | 0.833804968 | 0.021137844 | 0.000192558 | 0.463714518 | 0.268705009 | 0.862087994 |

**Table 5.6c**: Relating continuous DES adoption measures to binary (early) *initial time to DES disadoption* (linear probability model)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician time (quarters) to initial DES adoption | 0.005 [-0.01,0.02] | 0.001 [-0.02,0.03] | 0.002 [-0.02,0.02] | 0.005 [-0.03,0.03] | -0.005 [-0.02,0.01] | 0.009 [-0.01,0.03] | 0.006 [-0.02,0.03] | 0.005 [-0.02,0.03] | 0.006 [-0.03,0.04] |
| Physician initial level DES use (increase) upon adoption | 0.035 [-0.15,0.22] | 0.101 [-0.14,0.34] | 0.095 [-0.13,0.32] | 0.010 [-0.30,0.32] | 0.007 [-0.17,0.19] | -0.024 [-0.20,0.16] | 0.033 [-0.21,0.27] | 0.055 [-0.17,0.28] | -0.031 [-0.34,0.27] |
| Physician time (quarters) from adoption to max DES use | 0.007* [0.00,0.01] | 0.008* [0.00,0.02] | 0.006 [-0.00,0.01] | 0.003 [-0.01,0.01] | 0.008* [0.00,0.01] | 0.006* [0.00,0.01] | 0.007 [-0.00,0.01] | 0.004 [-0.00,0.01] | 0.003 [-0.01,0.01] |
| Physician full level DES use (increase) after adoption | -0.625 [-1.71,0.46] | -0.718 [-1.99,0.56] | -0.904 [-2.22,0.41] | -0.755 [-2.39,0.88] | -0.646 [-1.72,0.43] | -0.547 [-1.62,0.52] | -0.795 [-2.05,0.46] | -0.692 [-2.00,0.62] | -0.560 [-2.18,1.06] |
| Physician age (at time of DES safety concern publicization) | | | | | -0.004 [-0.02,0.01] | -0.003 [-0.02,0.01] | -0.001 [-0.02,0.01] | -0.003 [-0.02,0.01] | -0.003 [-0.02,0.02] |
| Physician years of experience (at time of DES safety concern pub) | | | | | 0.001 [-0.01,0.01] | -0.000 [-0.01,0.01] | -0.002 [-0.02,0.01] | 0.000 [-0.01,0.01] | -0.006 [-0.02,0.01] |
| Physician has cardiology fellowship training | | | | | 0.038 [-0.10,0.18] | 0.048 [-0.09,0.19] | -0.063 [-0.23,0.10] | -0.014 [-0.17,0.14] | -0.143 [-0.33,0.05] |
| Physician has interventional cardiology fellowship training | | | | | 0.178* [0.04,0.31] | 0.176* [0.04,0.31] | 0.197* [0.03,0.36] | 0.155 [-0.00,0.31] | 0.105 [-0.10,0.31] |
| Physician total num. DES placed before safety concerns | | | | | | 0.000*** [0.00,0.00] | 0.001** [0.00,0.00] | 0.001** [0.00,0.00] | 0.000* [0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | -0.001** [-0.00,-0.00] | -0.001 [-0.00,0.00] | -0.001* [-0.00,-0.00] | -0.001 [-0.00,0.00] |
| r2 | 0.013 | 0.397 | 0.194 | 0.549 | 0.034 | 0.053 | 0.428 | 0.219 | 0.572 |
| F | 2.147 | 1.060 | 0.992 | 1.063 | 2.739 | 3.514 | 1.158 | 1.089 | 1.127 |
| p | 0.074 | 0.302 | 0.511 | 0.295 | 0.006 | 0.000 | 0.097 | 0.259 | 0.146 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.041883 | 0.954604 | 1.059163 | 3.300173 | 6.426047 | 1.057413 | 0.894595 | 1.076876 |
| Prob > incrm F | | 0.357797 | 0.615519 | 0.320554 | 0.010867 | 0.001727 | 0.311724 | 0.770211 | 0.275135 |

**Table 5.6d**: Relating binary DES adoption measures to binary (early) *initial time to DES disadoption* (linear probability model)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician early DES initial adopter (before sample mean) | -0.091 [-0.20,0.01] | -0.113 [-0.25,0.02] | -0.085 [-0.21,0.04] | -0.123 [-0.29,0.04] | -0.027 [-0.14,0.09] | -0.094 [-0.21,0.03] | -0.133 [-0.29,0.02] | -0.076 [-0.22,0.06] | -0.095 [-0.29,0.10] |
| Physician big DES initial adopter (more than sample mean) | 0.010 [-0.07,0.09] | 0.021 [-0.08,0.13] | 0.054 [-0.04,0.15] | -0.009 [-0.14,0.12] | 0.005 [-0.07,0.08] | -0.003 [-0.08,0.08] | 0.004 [-0.10,0.11] | 0.051 [-0.04,0.14] | -0.009 [-0.13,0.12] |
| Physician fast DES full adopter (less time than sample mean) | -0.165*** [-0.24,-0.09] | -0.209*** [-0.31,-0.11] | -0.175*** [-0.27,-0.08] | -0.174** [-0.30,-0.05] | -0.166*** [-0.24,-0.09] | -0.151*** [-0.23,-0.08] | -0.189*** [-0.29,-0.08] | -0.159*** [-0.25,-0.07] | -0.162* [-0.29,-0.03] |
| Physician big DES full adopter (more than sample mean) | -0.056 [-0.15,0.04] | -0.053 [-0.17,0.07] | -0.074 [-0.18,0.04] | -0.053 [-0.19,0.08] | -0.054 [-0.15,0.04] | -0.031 [-0.12,0.06] | -0.032 [-0.15,0.09] | -0.045 [-0.16,0.07] | -0.026 [-0.17,0.11] |
| Physician age (at time of DES safety concern publicization) | | | | | -0.003 [-0.02,0.01] | -0.002 [-0.01,0.01] | -0.000 [-0.02,0.01] | -0.003 [-0.02,0.01] | -0.002 [-0.02,0.02] |
| Physician years of experience (at time of DES safety concern pub) | | | | | 0.000 [-0.01,0.01] | -0.001 [-0.01,0.01] | -0.002 [-0.02,0.01] | 0.000 [-0.01,0.01] | -0.007 [-0.02,0.01] |
| Physician has cardiology fellowship training | | | | | 0.051 [-0.09,0.19] | 0.053 [-0.08,0.19] | -0.059 [-0.22,0.10] | -0.012 [-0.16,0.14] | -0.154 [-0.34,0.03] |
| Physician has interventional cardiology fellowship training | | | | | 0.148* [0.02,0.28] | 0.155* [0.02,0.29] | 0.174* [0.01,0.34] | 0.142 [-0.01,0.29] | 0.087 [-0.11,0.29] |
| Physician total num. DES placed before safety concerns | | | | | | 0.000*** [0.00,0.00] | 0.001** [0.00,0.00] | 0.000** [0.00,0.00] | 0.000* [0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | -0.001** [-0.00,-0.00] | -0.001 [-0.00,0.00] | -0.001* [-0.00,-0.00] | -0.001 [-0.00,0.00] |
| r2 | 0.040 | 0.418 | 0.218 | 0.561 | 0.055 | 0.072 | 0.444 | 0.238 | 0.582 |
| F | 6.624 | 1.154 | 1.147 | 1.119 | 4.614 | 4.911 | 1.234 | 1.208 | 1.170 |
| p | 0.000 | 0.103 | 0.156 | 0.159 | 0.000 | 0.000 | 0.032 | 0.079 | 0.082 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.06109794 | 0.967185506 | 1.054158896 | 2.539282541 | 5.816588237 | 1.075347583 | 0.909163062 | 1.075595914 |
| Prob > incrm F | | 0.300537264 | 0.580413207 | 0.333948613 | 0.038903177 | 0.003140246 | 0.262212019 | 0.735371184 | 0.278321913 |

**Table 5.7a**: Relating continuous DES adoption measures to continuous *initial extent of DES disadoption* (basic OLS regression results)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician time (quarters) to initial DES adoption | 0.001 [-0.00,0.01] | 0.004 [-0.00,0.01] | 0.001 [-0.00,0.01] | 0.003 [-0.00,0.01] | 0.001 [-0.00,0.01] | -0.001 [-0.01,0.00] | 0.002 [-0.00,0.01] | 0.001 [-0.00,0.01] | 0.004 [-0.00,0.01] |
| Physician initial level DES use (increase) upon adoption | -0.012 [-0.06,0.03] | -0.034 [-0.09,0.02] | -0.020 [-0.07,0.03] | -0.037 [-0.11,0.04] | -0.012 [-0.06,0.03] | -0.005 [-0.05,0.04] | -0.029 [-0.08,0.03] | -0.032 [-0.08,0.02] | -0.050 [-0.12,0.02] |
| Physician time (quarters) from adoption to max DES use | -0.001 [-0.00,0.00] | -0.001 [-0.00,0.00] | -0.001 [-0.00,0.00] | -0.001 [-0.00,0.00] | -0.001 [-0.00,0.00] | 0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | -0.001 [-0.00,0.00] |
| Physician full level DES use (increase) after adoption | -0.121 [-0.39,0.14] | -0.095 [-0.40,0.21] | 0.090 [-0.22,0.40] | -0.016 [-0.40,0.37] | -0.122 [-0.39,0.14] | -0.149 [-0.40,0.10] | -0.105 [-0.39,0.18] | 0.047 [-0.25,0.35] | -0.026 [-0.40,0.34] |
| Physician age (at time of DES safety concern publicization) | | | | | 0.001 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.001 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.001 [-0.00,0.01] |
| Physician years of experience (at time of DES safety concern pub) | | | | | -0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | 0.001 [-0.00,0.00] | -0.001 [-0.00,0.00] |
| Physician has cardiology fellowship training | | | | | 0.015 [-0.02,0.05] | 0.007 [-0.03,0.04] | 0.013 [-0.02,0.05] | 0.015 [-0.02,0.05] | 0.006 [-0.04,0.05] |
| Physician has interventional cardiology fellowship training | | | | | 0.011 [-0.02,0.04] | 0.014 [-0.02,0.05] | 0.018 [-0.02,0.06] | 0.026 [-0.01,0.06] | 0.026 [-0.02,0.07] |
| Physician total num. DES placed before safety concerns | | | | | | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | -0.000*** [-0.00,-0.00] | -0.000*** [-0.00,-0.00] | -0.000*** [-0.00,-0.00] | -0.000*** [-0.00,-0.00] |
| r2 | 0.002 | 0.416 | 0.232 | 0.574 | 0.004 | 0.147 | 0.491 | 0.313 | 0.623 |
| F | 0.388 | 1.145 | 1.243 | 1.179 | 0.355 | 10.806 | 1.490 | 1.767 | 1.389 |
| p | 0.817 | 0.118 | 0.055 | 0.072 | 0.944 | 0.000 | 0.000 | 0.000 | 0.002 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.156733459 | 1.270416397 | 1.147875796 | 0.32388508 | 52.37759025 | 1.088642462 | 1.016648033 | 1.115299375 |
| Prob > incrm F | | 0.101312295 | 0.040602875 | 0.133059557 | 0.862009548 | 9.11553E-22 | 0.22873943 | 0.442414197 | 0.189926979 |

**Table 5.7d**: Relating binary DES adoption measures to binary (big) *initial extent of DES disadoption* (linear probability model)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician early DES initial adopter (before sample mean) | -0.013 [-0.13,0.10] | -0.090 [-0.24,0.05] | -0.012 [-0.14,0.12] | -0.120 [-0.30,0.06] | 0.016 [-0.11,0.14] | 0.066 [-0.06,0.19] | -0.008 [-0.17,0.15] | 0.021 [-0.12,0.17] | -0.076 [-0.27,0.12] |
| Physician big DES initial adopter (more than sample mean) | -0.049 [-0.14,0.04] | -0.118* [-0.23,-0.01] | -0.046 [-0.15,0.05] | -0.100 [-0.24,0.04] | -0.052 [-0.14,0.03] | -0.040 [-0.12,0.04] | -0.092 [-0.20,0.01] | -0.067 [-0.16,0.03] | -0.096 [-0.23,0.04] |
| Physician fast DES full adopter (less time than sample mean) | 0.058 [-0.02,0.14] | 0.027 [-0.09,0.14] | 0.089 [-0.01,0.19] | 0.056 [-0.08,0.19] | 0.055 [-0.03,0.14] | -0.005 [-0.08,0.07] | -0.030 [-0.14,0.08] | 0.033 [-0.06,0.13] | -0.008 [-0.14,0.12] |
| Physician big DES full adopter (more than sample mean) | 0.025 [-0.08,0.13] | 0.089 [-0.04,0.22] | 0.064 [-0.06,0.18] | 0.078 [-0.07,0.23] | 0.021 [-0.08,0.12] | -0.036 [-0.13,0.06] | 0.020 [-0.11,0.15] | 0.020 [-0.10,0.14] | 0.036 [-0.11,0.18] |
| Physician age (at time of DES safety concern publicization) | | | | | 0.009 [-0.00,0.02] | 0.007 [-0.01,0.02] | 0.013 [-0.00,0.03] | 0.003 [-0.01,0.02] | 0.009 [-0.01,0.03] |
| Physician years of experience (at time of DES safety concern pub) | | | | | -0.006 [-0.02,0.01] | -0.005 [-0.02,0.01] | -0.006 [-0.02,0.01] | 0.000 [-0.01,0.01] | -0.000 [-0.02,0.02] |
| Physician has cardiology fellowship training | | | | | -0.004 [-0.16,0.15] | -0.032 [-0.17,0.11] | 0.036 [-0.13,0.20] | 0.000 [-0.16,0.16] | 0.003 [-0.19,0.20] |
| Physician has interventional cardiology fellowship training | | | | | 0.121 [-0.03,0.27] | 0.131 [-0.01,0.27] | 0.159 [-0.01,0.33] | 0.164* [0.01,0.32] | 0.212* [0.00,0.42] |
| Physician total num. DES placed before safety concerns | | | | | | -0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | -0.001*** [-0.00,-0.00] | -0.001*** [-0.00,-0.00] | -0.001*** [-0.00,-0.00] | -0.002*** [-0.00,-0.00] |
| r2 | 0.005 | 0.407 | 0.226 | 0.553 | 0.012 | 0.130 | 0.487 | 0.293 | 0.606 |
| F | 0.846 | 1.105 | 1.197 | 1.081 | 0.942 | 9.408 | 1.465 | 1.605 | 1.295 |
| p | 0.496 | 0.191 | 0.092 | 0.246 | 0.481 | 0.000 | 0.000 | 0.000 | 0.011 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.10827248 | 1.207865737 | 1.026426148 | 1.038137181 | 42.77030415 | 1.118031336 | 0.965354199 | 1.069939514 |
| Prob > incrm F | | 0.183799686 | 0.084512413 | 0.414924959 | 0.386673175 | 3.83851E-18 | 0.16500122 | 0.585496174 | 0.29266046 |

**Table 5.8a**: Relating continuous DES adoption measures to continuous *time to minimum DES use* (basic OLS regression results)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician time (quarters) to initial DES adoption | -0.060 [-0.29,0.17] | -0.131 [-0.42,0.16] | -0.219 [-0.47,0.03] | -0.066 [-0.40,0.27] | -0.044 [-0.28,0.19] | 0.008 [-0.25,0.26] | -0.101 [-0.43,0.22] | -0.221 [-0.50,0.06] | -0.087 [-0.46,0.29] |
| Physician initial level DES use (increase) upon adoption | -0.525 [-2.75,1.70] | -1.199 [-4.10,1.71] | 0.923 [-1.68,3.52] | -0.810 [-4.26,2.64] | -0.465 [-2.70,1.77] | -0.639 [-2.87,1.59] | -1.396 [-4.30,1.51] | 1.132 [-1.49,3.75] | -0.744 [-4.20,2.71] |
| Physician time (quarters) from adoption to max DES use | 0.048 [-0.02,0.12] | 0.017 [-0.07,0.11] | 0.036 [-0.04,0.11] | 0.031 [-0.07,0.13] | 0.047 [-0.02,0.12] | 0.027 [-0.05,0.10] | 0.003 [-0.09,0.09] | 0.023 [-0.06,0.10] | 0.025 [-0.08,0.13] |
| Physician full level DES use (increase) after adoption | 16.082* [2.77,29.39] | 18.478* [3.27,33.68] | 12.770 [-2.50,28.04] | 24.607** [6.28,42.93] | 16.055* [2.68,29.43] | 16.686* [3.39,29.98] | 18.183* [3.00,33.36] | 13.590 [-1.77,28.95] | 25.531** [7.16,43.90] |
| Physician age (at time of DES safety concern publicization) | | | | | -0.002 [-0.16,0.15] | 0.009 [-0.15,0.16] | -0.077 [-0.26,0.11] | -0.028 [-0.19,0.14] | -0.116 [-0.33,0.09] |
| Physician years of experience (at time of DES safety concern pub) | | | | | 0.013 [-0.14,0.16] | 0.006 [-0.14,0.16] | 0.070 [-0.11,0.25] | 0.034 [-0.13,0.19] | 0.048 [-0.15,0.25] |
| Physician has cardiology fellowship training | | | | | 0.843 [-0.89,2.57] | 0.991 [-0.73,2.71] | 0.524 [-1.47,2.51] | 0.425 [-1.39,2.24] | -0.253 [-2.40,1.89] |
| Physician has interventional cardiology fellowship training | | | | | -0.059 [-1.75,1.63] | -0.125 [-1.81,1.55] | 0.392 [-1.63,2.41] | 0.106 [-1.71,1.92] | -0.359 [-2.68,1.96] |
| Physician total num. DES placed before safety concerns | | | | | | 0.001 [-0.00,0.00] | 0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | -0.000 [-0.01,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | 0.005 [-0.00,0.01] | 0.008 [-0.00,0.02] | 0.005 [-0.00,0.01] | 0.006 [-0.00,0.02] |
| r2 | 0.015 | 0.433 | 0.285 | 0.627 | 0.017 | 0.034 | 0.452 | 0.294 | 0.637 |
| F | 2.427 | 1.228 | 1.636 | 1.466 | 1.325 | 2.223 | 1.275 | 1.614 | 1.480 |
| p | 0.047 | 0.035 | 0.000 | 0.000 | 0.228 | 0.015 | 0.016 | 0.000 | 0.000 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.205090315 | 1.601046526 | 1.311972235 | 0.234141036 | 5.73897918 | 1.227937112 | 1.544549215 | 1.30326249 |
| Prob > incrm F | | 0.051327298 | 0.000254092 | 0.01432907 | 0.919142032 | 0.003388916 | 0.036674704 | 0.000692133 | 0.016650375 |

**Table 5.8d**: Relating binary DES adoption measures to binary (fast) *time to minimum DES use* (linear probability model)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician early DES initial adopter (before sample mean) | -0.145* [-0.26,-0.03] | -0.142 [-0.28,0.00] | -0.185** [-0.31,-0.06] | -0.097 [-0.27,0.08] | -0.132* [-0.26,-0.01] | -0.140* [-0.27,-0.01] | -0.143 [-0.31,0.02] | -0.194** [-0.34,-0.05] | -0.108 [-0.31,0.09] |
| Physician big DES initial adopter (more than sample mean) | 0.005 [-0.08,0.09] | 0.055 [-0.06,0.17] | -0.029 [-0.13,0.07] | 0.019 [-0.11,0.15] | 0.002 [-0.08,0.09] | 0.003 [-0.08,0.09] | 0.059 [-0.05,0.17] | -0.036 [-0.13,0.06] | 0.019 [-0.11,0.15] |
| Physician fast DES full adopter (less time than sample mean) | 0.039 [-0.04,0.12] | -0.007 [-0.12,0.11] | 0.011 [-0.08,0.11] | -0.031 [-0.16,0.10] | 0.039 [-0.04,0.12] | 0.029 [-0.05,0.11] | -0.027 [-0.14,0.09] | -0.001 [-0.10,0.10] | -0.048 [-0.18,0.09] |
| Physician big DES full adopter (more than sample mean) | -0.107* [-0.21,-0.01] | -0.143* [-0.27,-0.01] | -0.154** [-0.27,-0.04] | -0.155* [-0.30,-0.01] | -0.107* [-0.21,-0.01] | -0.113* [-0.22,-0.01] | -0.160* [-0.29,-0.03] | -0.161** [-0.28,-0.04] | -0.169* [-0.32,-0.02] |
| Physician age (at time of DES safety concern publicization) | | | | | 0.000 [-0.01,0.01] | -0.000 [-0.01,0.01] | 0.002 [-0.01,0.02] | 0.002 [-0.01,0.02] | 0.005 [-0.01,0.02] |
| Physician years of experience (at time of DES safety concern pub) | | | | | -0.000 [-0.01,0.01] | -0.000 [-0.01,0.01] | -0.002 [-0.02,0.01] | -0.000 [-0.01,0.01] | 0.000 [-0.02,0.02] |
| Physician has cardiology fellowship training | | | | | -0.079 [-0.23,0.07] | -0.085 [-0.24,0.07] | -0.081 [-0.26,0.10] | -0.028 [-0.19,0.13] | -0.015 [-0.21,0.18] |
| Physician has interventional cardiology fellowship training | | | | | 0.032 [-0.11,0.18] | 0.037 [-0.11,0.18] | -0.008 [-0.18,0.17] | 0.040 [-0.12,0.20] | 0.058 [-0.16,0.27] |
| Physician total num. DES placed before safety concerns | | | | | | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | -0.001 [-0.00,0.00] | -0.001* [-0.00,-0.00] | -0.001 [-0.00,0.00] | -0.000 [-0.00,0.00] |
| r2 | 0.022 | 0.428 | 0.274 | 0.591 | 0.024 | 0.031 | 0.440 | 0.280 | 0.597 |
| F | 3.557 | 1.203 | 1.555 | 1.263 | 1.943 | 2.044 | 1.213 | 1.510 | 1.247 |
| p | 0.007 | 0.052 | 0.000 | 0.019 | 0.051 | 0.027 | 0.044 | 0.001 | 0.025 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.160458 | 1.477689531 | 1.06153333 | 0.344023268 | 2.415069409 | 1.172885754 | 1.450919287 | 1.051470098 |
| Prob > incrm F | | 0.096427643 | 0.002067931 | 0.313814256 | 0.8482221 | 0.090189357 | 0.082165781 | 0.003203999 | 0.342259512 |

**Table 5.9a**: Relating continuous DES adoption measures to continuous *full extent of DES disadoption* (basic OLS regression results)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician time (quarters) to initial DES adoption | 0.008 [-0.00,0.02] | 0.008 [-0.00,0.02] | 0.006 [-0.00,0.02] | 0.006 [-0.01,0.02] | 0.007 [-0.00,0.02] | 0.005 [-0.00,0.01] | 0.006 [-0.01,0.02] | 0.007 [-0.00,0.02] | 0.007 [-0.01,0.02] |
| Physician initial level DES use (increase) upon adoption | -0.054 [-0.14,0.03] | -0.041 [-0.15,0.07] | -0.022 [-0.12,0.07] | -0.005 [-0.14,0.13] | -0.057 [-0.14,0.03] | -0.046 [-0.12,0.03] | -0.044 [-0.15,0.06] | -0.055 [-0.15,0.04] | -0.035 [-0.16,0.09] |
| Physician time (quarters) from adoption to max DES use | -0.002 [-0.00,0.00] | 0.001 [-0.00,0.00] | -0.002 [-0.00,0.00] | -0.001 [-0.00,0.00] | -0.002 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.001 [-0.00,0.00] | -0.001 [-0.00,0.00] | -0.001 [-0.00,0.00] |
| Physician full level DES use (increase) after adoption | 0.078 [-0.44,0.60] | 0.248 [-0.33,0.82] | 0.456 [-0.11,1.03] | 0.470 [-0.23,1.17] | 0.077 [-0.45,0.60] | 0.030 [-0.44,0.50] | 0.265 [-0.28,0.81] | 0.408 [-0.13,0.95] | 0.507 [-0.16,1.17] |
| Physician age (at time of DES safety concern publicization) | | | | | 0.000 [-0.01,0.01] | -0.001 [-0.01,0.00] | 0.003 [-0.00,0.01] | -0.003 [-0.01,0.00] | 0.004 [-0.00,0.01] |
| Physician years of experience (at time of DES safety concern pub) | | | | | 0.000 [-0.01,0.01] | 0.001 [-0.00,0.01] | -0.004 [-0.01,0.00] | 0.003 [-0.00,0.01] | -0.005 [-0.01,0.00] |
| Physician has cardiology fellowship training | | | | | 0.070* [0.00,0.14] | 0.053 [-0.01,0.11] | 0.049 [-0.02,0.12] | 0.047 [-0.02,0.11] | 0.050 [-0.03,0.13] |
| Physician has interventional cardiology fellowship training | | | | | 0.039 [-0.03,0.11] | 0.048 [-0.01,0.11] | 0.045 [-0.03,0.12] | 0.074* [0.01,0.14] | 0.044 [-0.04,0.13] |
| Physician total num. DES placed before safety concerns | | | | | | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | -0.001*** [-0.00,-0.00] | -0.001*** [-0.00,-0.00] | -0.001*** [-0.00,-0.00] | -0.001*** [-0.00,-0.00] |
| r2 | 0.008 | 0.467 | 0.346 | 0.647 | 0.019 | 0.213 | 0.540 | 0.430 | 0.689 |
| F | 1.357 | 1.411 | 2.177 | 1.602 | 1.547 | 17.060 | 1.816 | 2.928 | 1.866 |
| p | 0.247 | 0.001 | 0.000 | 0.000 | 0.138 | 0.000 | 0.000 | 0.000 | 0.000 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.40815134 | 2.193975922 | 1.220522796 | 1.730812709 | 77.60824616 | 1.144036196 | 1.597696908 | 1.176320223 |
| Prob > incrm F | | 0.001347295 | 1.35907E-09 | 0.054149969 | 0.141463186 | 7.50784E-31 | 0.120214825 | 0.000274851 | 0.095887016 |

**Table 5.9d**: Relating binary DES adoption measures to binary (big) *full extent of DES disadoption* (linear probability model)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician early DES initial adopter (before sample mean) | -0.160** [-0.28,-0.04] | -0.182* [-0.33,-0.04] | -0.090 [-0.22,0.04] | -0.090 [-0.26,0.08] | -0.119 [-0.25,0.01] | -0.079 [-0.21,0.05] | -0.088 [-0.25,0.08] | -0.042 [-0.19,0.10] | 0.009 [-0.19,0.21] |
| Physician big DES initial adopter (more than sample mean) | -0.020 [-0.11,0.07] | 0.004 [-0.11,0.12] | 0.046 [-0.05,0.14] | 0.112 [-0.02,0.24] | -0.022 [-0.11,0.07] | -0.010 [-0.09,0.07] | 0.019 [-0.09,0.13] | 0.032 [-0.06,0.13] | 0.121 [-0.01,0.25] |
| Physician fast DES full adopter (less time than sample mean) | -0.023 [-0.11,0.06] | -0.083 [-0.20,0.03] | 0.007 [-0.09,0.10] | -0.052 [-0.18,0.08] | -0.023 [-0.11,0.06] | -0.087* [-0.17,-0.01] | -0.122* [-0.23,-0.01] | -0.032 [-0.13,0.06] | -0.084 [-0.22,0.05] |
| Physician big DES full adopter (more than sample mean) | 0.008 [-0.10,0.11] | 0.005 [-0.13,0.13] | 0.012 [-0.10,0.13] | -0.017 [-0.16,0.13] | 0.009 [-0.10,0.11] | -0.048 [-0.15,0.05] | -0.037 [-0.17,0.09] | -0.007 [-0.12,0.11] | -0.041 [-0.19,0.10] |
| Physician age (at time of DES safety concern publicization) | | | | | -0.001 [-0.02,0.01] | -0.003 [-0.02,0.01] | 0.004 [-0.01,0.02] | -0.005 [-0.02,0.01] | 0.008 [-0.01,0.03] |
| Physician years of experience (at time of DES safety concern pub) | | | | | -0.001 [-0.01,0.01] | 0.000 [-0.01,0.01] | -0.005 [-0.02,0.01] | 0.003 [-0.01,0.02] | -0.009 [-0.03,0.01] |
| Physician has cardiology fellowship training | | | | | 0.067 [-0.09,0.22] | 0.037 [-0.11,0.18] | 0.022 [-0.15,0.19] | 0.076 [-0.08,0.23] | 0.075 [-0.12,0.27] |
| Physician has interventional cardiology fellowship training | | | | | 0.090 [-0.06,0.24] | 0.103 [-0.04,0.24] | 0.152 [-0.02,0.32] | 0.177* [0.02,0.33] | 0.180 [-0.03,0.39] |
| Physician total num. DES placed before safety concerns | | | | | | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | -0.002*** [-0.00,-0.00] | -0.001** [-0.00,-0.00] | -0.001*** [-0.00,-0.00] | -0.001 [-0.00,0.00] |
| r2 | 0.012 | 0.461 | 0.308 | 0.623 | 0.018 | 0.151 | 0.501 | 0.354 | 0.644 |
| F | 1.891 | 1.373 | 1.831 | 1.445 | 1.456 | 11.168 | 1.552 | 2.121 | 1.522 |
| p | 0.110 | 0.003 | 0.000 | 0.001 | 0.170 | 0.000 | 0.000 | 0.000 | 0.000 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.359913924 | 1.819443019 | 1.185013959 | 1.022024597 | 49.12642054 | 1.129706909 | 1.316634717 | 1.115563613 |
| Prob > incrm F | | 0.003536302 | 4.00888E-06 | 0.085146686 | 0.395106713 | 1.49817E-20 | 0.143585277 | 0.022540796 | 0.189412357 |

**Table 5.10a**: Relating area below DES adoption curve to *area above DES disadoption curve* (basic OLS regression results)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician area below DES adoption curve | -0.024 [-0.05,0.01] | -0.012 [-0.05,0.03] | -0.034* [-0.07,-0.00] | -0.011 [-0.05,0.03] | -0.022 [-0.05,0.01] | -0.002 [-0.03,0.03] | -0.010 [-0.05,0.03] | -0.021 [-0.05,0.01] | -0.010 [-0.05,0.03] |
| Physician age (at time of DES safety concern publicization) | | | | | -0.001 [-0.06,0.05] | -0.002 [-0.06,0.05] | 0.003 [-0.06,0.07] | -0.023 [-0.08,0.03] | 0.008 [-0.06,0.08] |
| Physician years of experience (at time of DES safety concern pub) | | | | | 0.013 [-0.04,0.07] | 0.010 [-0.04,0.06] | 0.006 [-0.06,0.07] | 0.033 [-0.02,0.09] | -0.008 [-0.07,0.06] |
| Physician has cardiology fellowship training | | | | | 0.476 [-0.13,1.08] | 0.431 [-0.15,1.02] | 0.596 [-0.10,1.29] | 0.362 [-0.25,0.98] | 0.717* [0.02,1.41] |
| Physician has interventional cardiology fellowship training | | | | | 0.449 [-0.12,1.02] | 0.492 [-0.06,1.05] | 0.375 [-0.30,1.05] | 0.521 [-0.06,1.11] | 0.279 [-0.42,0.98] |
| Physician total num. DES placed before safety concerns | | | | | | 0.001 [-0.00,0.00] | 0.001 [-0.00,0.00] | 0.001 [-0.00,0.00] | 0.001 [-0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | -0.005*** [-0.01,-0.00] | -0.004** [-0.01,-0.00] | -0.004** [-0.01,-0.00] | -0.003 [-0.01,0.00] |
| Physician age (at time of DES safety concern publicization) | | | | | | 3.753*** [2.11,5.39] | 4.039*** [1.98,6.09] | 4.976*** [3.11,6.84] | 6.027*** [3.84,8.22] |
| r2 | 0.004 | 0.422 | 0.282 | 0.653 | 0.011 | 0.081 | 0.459 | 0.342 | 0.692 |
| F | 2.455 | 1.196 | 1.662 | 1.674 | 1.346 | 6.944 | 1.327 | 2.051 | 1.915 |
| p | 0.118 | 0.058 | 0.000 | 0.000 | 0.243 | 0.000 | 0.006 | 0.000 | 0.000 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.190276009 | 1.653347903 | 1.446711723 | 1.068241057 | 16.11283337 | 1.12939667 | 1.668351474 | 1.51504688 |
| Prob > incrm F | | 0.063459848 | 9.74193E-05 | 0.001390972 | 0.371285697 | 4.20075E-10 | 0.14385962 | 7.57559E-05 | 0.000411753 |

**Table 5.10d**: Relating area below DES adoption curve to *area above DES disadoption curve*, binary measures (linear prob model)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 8 (β/[95%CI]) | Model 9 (β/[95%CI]) |
|---|---|---|---|---|---|---|---|---|---|
| Physician big area below DES adoption curve (> sample mean) | -0.045 [-0.14,0.05] | -0.054 [-0.16,0.05] | -0.054 [-0.15,0.05] | -0.012 [-0.13,0.11] | -0.050 [-0.14,0.04] | -0.006 [-0.10,0.09] | -0.054 [-0.17,0.06] | -0.014 [-0.12,0.09] | -0.005 [-0.14,0.13] |
| Physician age (at time of DES safety concern publicization) | | | | | -0.003 [-0.02,0.01] | -0.003 [-0.02,0.01] | -0.006 [-0.02,0.01] | -0.006 [-0.02,0.01] | -0.005 [-0.02,0.01] |
| Physician years of experience (at time of DES safety concern pub) | | | | | 0.008 [-0.00,0.02] | 0.008 [-0.01,0.02] | 0.009 [-0.01,0.02] | 0.011 [-0.00,0.02] | 0.009 [-0.01,0.03] |
| Physician has cardiology fellowship training | | | | | 0.107 [-0.04,0.26] | 0.095 [-0.05,0.24] | 0.134 [-0.03,0.30] | 0.094 [-0.06,0.25] | 0.155 [-0.03,0.34] |
| Physician has interventional cardiology fellowship training | | | | | 0.107 [-0.03,0.25] | 0.111 [-0.03,0.25] | 0.061 [-0.10,0.22] | 0.123 [-0.03,0.27] | 0.029 [-0.16,0.22] |
| Physician total num. DES placed before safety concerns | | | | | | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | | | | -0.001*** [-0.00,-0.00] | -0.001* [-0.00,-0.00] | -0.001* [-0.00,-0.00] | -0.001 [-0.00,0.00] |
| Physician age (at time of DES safety concern publicization) | | | | | | 0.846*** [0.44,1.25] | 0.854*** [0.36,1.35] | 1.286*** [0.81,1.77] | 1.422*** [0.83,2.01] |
| r2 | 0.001 | 0.459 | 0.216 | 0.591 | 0.009 | 0.069 | 0.487 | 0.280 | 0.628 |
| F | 0.941 | 1.394 | 1.171 | 1.289 | 1.168 | 5.870 | 1.487 | 1.537 | 1.441 |
| p | 0.332 | 0.002 | 0.124 | 0.012 | 0.323 | 0.000 | 0.000 | 0.001 | 0.001 |
| N | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 | 640.000 |
| Unique docs | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Practice FEs | | X | | X | | | X | | X |
| Hospital FEs | | | X | X | | | | X | X |
| Incremental F stat | | 1.395132576 | 1.172522462 | 1.263658209 | 1.224244386 | 13.59196166 | 1.317472931 | 1.233635279 | 1.268174827 |
| Prob > incrm F | | 0.001730064 | 0.122801889 | 0.029075629 | 0.29921226 | 1.3313E-08 | 0.007998101 | 0.06330788 | 0.027915548 |

# CHAPTER 6: Relating medical technology disadoption to physician group size

In the previous chapter, I examined the relationship between physicians' disadoption of technology and their preceding adoption of the same technology, focusing on the empirical setting of drug-eluting stents. While this analysis provides insight into the two related processes of adoption and disadoption, I am interested in developing a deeper understanding of technology disadoption by examining how it is related to other factors. In Chapter 4, I developed a theoretical model that related physician group size to technology disadoption, and in this chapter I will empirically study that relationship.

As already mentioned above (e.g. in Chapters 1 and 2), an examination of the relationship between physician group size and medical technology disadoption is one of the core aims of this dissertation. As discussed in Chapter 2, the topic of group size has already been the subject of frequent examination in both the broader technology adoption literature and the health services research literature. The relationship and similarities between technology adoption and disadoption (discussed at length above, in Chapter 3), suggest that if research has shown group size to be a relevant determinant of technology adoption, it likely also warrants investigation for its relationship to disadoption. Aside from the fact that group size may correlate closely with technology-adoption-relevant factors (e.g. firm profits or access to investment capital), there are also theoretical reasons to believe that group size could influence the technology disadoption (or adoption) decision, as was discussed and modeled in Chapter 4. If information is or can be shared among members of a group, then there is reason to believe that the size of an individual's group will help determine that individual's access to information, and thus influence that individual's technology disadoption behavior.

Not only is there reason to believe that group size is potentially of importance to technology disadoption in general, it is also a factor of specific interest within the field of health care. The trend of increasing physician group size in the US (as described in Chapter 2) suggests that this is an important organization characteristic to consider when studying physician behavior, with significant relationships previously identified for some physician behaviors. Not only are physician group sizes changing (namely, increasing) and group size can influence physician practice in general, there is also reason to think that group size is of particular relevance for physicians' choice of technology. As Schiller says (1995 AEA P&P), groups play an important role in shaping decisions and behavior "not [on] matters of plain fact (which way is north), but subtle matters, for which many pieces of information are relevant, and for which limitations of time and natural intelligence prevent each individual from individually discovering all relevant information." This description is a near perfect match for the physicians' clinical practice environment. As described by Phelps (2000 Handbook Health Econ), the practice of clinical medicine requires knowledge so vast that uncertainty is inevitable. "The set of diseases that healers must recognize is immense [and] the relevant code book for treatments also has thousands of treatments, many of which can potentially affect numerous diseases. For doctors to understand well the complete set of relationships between these treatments and the myriad of diseases that their patients may bring to the patient encounter is literally impossible." Add to this the continuous flow of new technology into the realm of medical diagnosis and treatment, and it becomes clear that physicians are constantly facing difficult decisions with nuanced choices. Thus, when practicing in groups, it is only natural for physicians to turn to their peers for information.

Given these factors, it is also natural for researchers to study how group size may be an important factor in shaping physicians' technology disadoption behavior. I began is inquiry in Chapter 4 with the development of a basic theoretical model that related physician group size to disadoption behavior. As shown there, the model predicted an ambiguous relationship between group size and the timing of technology disadoption. Thus, I continue the investigation by examining the empirical relationship between group size and disadoption, again focusing on the setting of physician DES use.

## 6.1 – Research questions

1) What is the observed empirical relationship between a physicians's *time to initial disadoption* of DES and that physician's group size?
2) What are the observed empirical relationships between the other measures of physician's disadoption of DES (namely, *time to minimum use*, *initial extent of disadoption*, *full extent of disadoption*, and *area below the DES adoption curve*) and that physician's group size?

3) How do various covariates and controls, including physician characteristics (e.g. age and training) and experience (e.g. DES volume), shape the observed empirical relationships between DES disadoption measures and that physician's group size?

4) Can empirical analysis identify a causal relationship between a physician's group size and that physician's DES disadoption behavior by using an instrumental variable for physician group size?

5) Given that a physician can belong to multiple different groups (e.g. office, practice, and hospital) with different types of members (e.g. general cardiologists vs. cardiologists who implant stents), how do the sizes of those different groups relate differentially to that physician's DES disadoption behavior, as measured with the various different measures?

## 6.2 – Data and methods

*Data processing*

That data used in this chapter is the same as that used in Chapter 5; see above for a detailed description of the original data and how the data has been processed. In addition to the processing discussed there, additional work is needed here to create a measure of physician group size, which will be the primary explanatory variable of interest in this chapter's analyses.

As described above, the SK&A physician database provides information on which practices a physician belongs to, along with the location of those practices. This dataset thus provides the information on the size of the first two types of physician groups: practices and office (or practice locations). Whereas practices are identified simply by their given practice or company name, an office (or practice location) is represented by the combination of a practice/company name and a physical location, which is determined by state, city, and street address. Thus, offices are nested within practices; a practice may (or may not) consist of multiple different offices and a physician who belongs to an office necessarily belongs to the corresponding "parent" practice. How exactly physicians are organized and managed within offices and practices is unclear. Though we can reasonably expect a physician to have more direct interaction with other physicians in the same office than with other physicians who belong to different offices in the same practice, the level of communication between or integration of different offices in a practice is unclear and likely varies across practices. Thus, the question of how a physician's group size relates to behavior, namely DES disadoption behavior, is one that must be addressed empirically, as will be done below. The third type of group that physicians can be assigned to within the data used here is a hospital, which requires less description than practice or office. Physicians who implant stents (of any kind) in the same hospital in a given year are considered to "belong" to that hospital (in the same way that they belong to practices or offices) in that year[26]. Figure 6.1 plots the distributions of group size observed in the dataset, using each of the three different group types.

[26] In fact, because the hospital discharge data has time granularity at the quarter level (whereas the SK&A dataset is only defined at the year level), physicians' hospital groups can be defined at either the quarter or year level. However, because the practice and office measures are defined at the year level (on account of the SK&A dataset), my analyses here will focus on hospital groups defined at the year level.

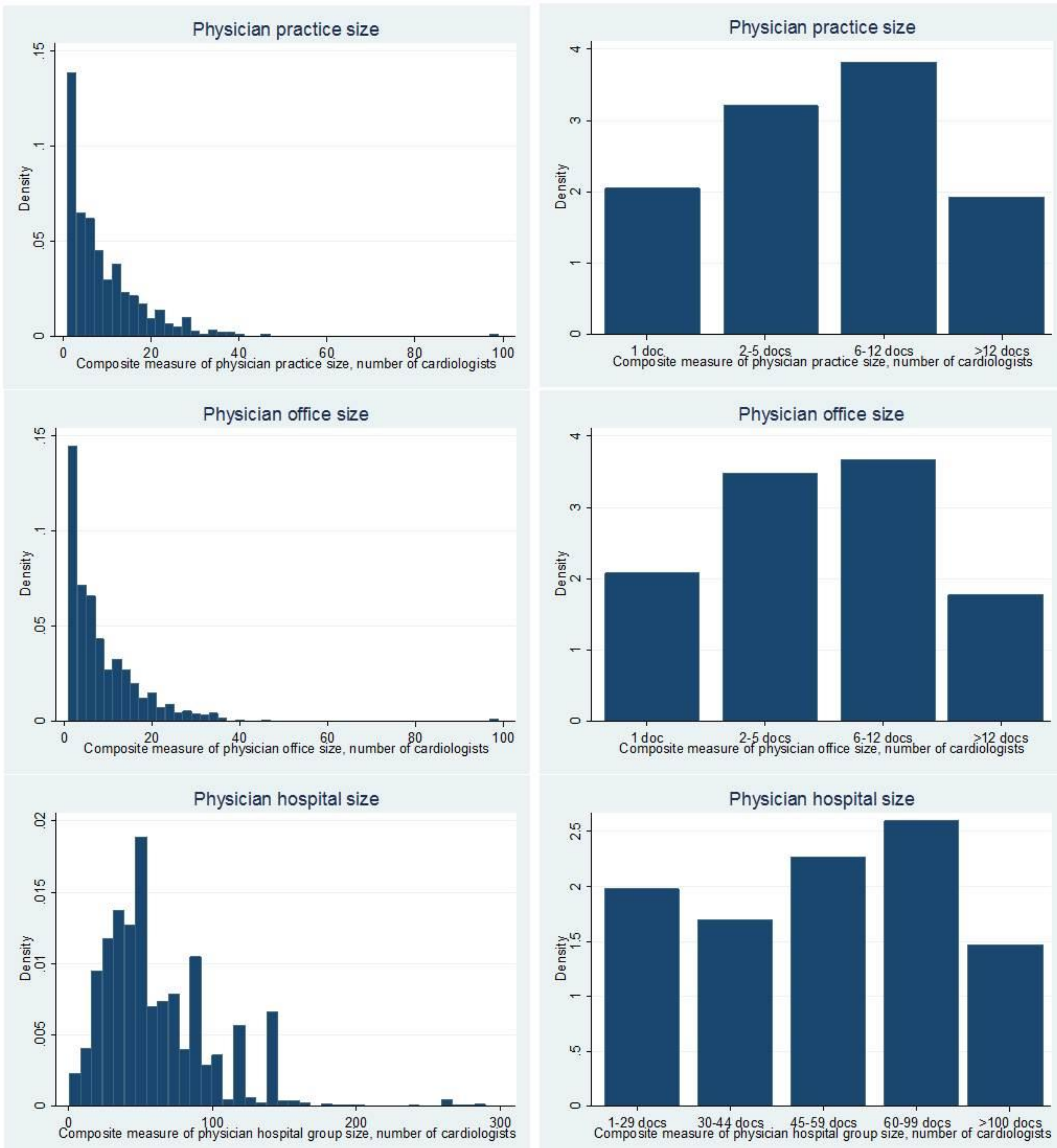



**Figure 6.1**: Observed distribution of physician group size, by each of three different group types

In addition to measuring physician group size with a simple count measure, this variable was also used to generate a categorical variable which grouped physicians into approximately equally sized quantiles based on group size. In the case of practices and offices, this corresponded to group size categories of 1 physician (because there is an inherent interest in solo-physician practices, relative to any multi-physician group), 2-5 physicians, 6-12 physicians, and 13+ physicians. The observed hospital group sizes are, unsurprisingly, much larger than practice or office groups and have there are virtually no physicians in single-physician hospital groups. Thus, the hospital group size quantiles used were 1-29 physicians, 30-44 physicians, 45-59 physicians, 60-99 physicians, and 100+ physicians. The sizes of these quantiles for each group type are also shown in Figure 6.1. Dividing physician group size into quantiles provides the benefit of allowing categorical analysis, rather than assuming a specific functional form (e.g. linear) for the relationship between group size and the various outcome variables (i.e. DES disadoption measures) of interest.

In addition to having choice of which type of organization (office, practice, or hospital) is relevant when measuring physician group size, there is also the issue of which type of physician is relevant. As already noted, I focus specifically on cardiologists here, considering only physicians who have self-identified as specializing in cardiology in the SK&A database. Indeed, we expect each one of these groups (especially hospitals) to contain other physicians, not to mention other medical professionals, who I do not count in these group size measures. As described in the theoretical model, the mechanism through which I suggest that group size influences technology disadoption behavior is the sharing of information. If we are studying the disadoption of DES, the individuals in a group that we would expect to have and share information about coronary stents are the cardiologists. Because it seems unlikely that other physicians (e.g. generalists or specialists in other fields) would gather or share knowledge on coronary stents, I can safely restrict my group size measure to include only cardiologists (and use the label "cardiology-relevant group size" if necessary). But beyond identified specialty (or training), we might be more specifically interested in how these physicians practice. For example, which group of cardiologists is more relevant for this issue of information-sharing: all cardiologists or just cardiologists who implant coronary stents (and should thus logically have more knowledge of the technology)? To address this, I can separately identify and count within groups the cardiologists who implant stents from the general pool of cardiologists. Ultimately, as with the type of organization, I view this question of which type of cardiologist is most relevant to DES disadoption behavior as an empirical question, to which I turn to the data for insight, if not answers.

After identifying which offices, practices, and hospitals each physician is associated with and what type of physicians are of interest, I can simply count the number of physicians who belong to each group, thus giving each group a size. However, this is a group-level measure, but with outcomes that are defined at the physician level, we want a physician-level group size measure. Because, as mentioned above, a single physician can belong to multiple groups (whether offices, practices, or hospitals), we can determine an individual's "composite group size" by simply adding up the size of each of the different same-level groups she belongs to. So, if a physician belongs to three different practices which have 3, 4, and 8 other physicians in them, that physician's "composite" practice size would be 15. With this calculation, I produce the primary explanatory variable of interest in this chapter's analyses.

*Methods*

The analysis methods used here are generally very similar to those used in Chapter 5 (see above for a detailed description and discussion). As the outcome variables of interest (i.e. the different measures of DES disadoption) are continuous, ordinary least squares linear regression is the primary method of analysis. The right-hand-side variables used in these analyses are generally the same as those used in Chapter 5, with a few changes. First, the primary explanatory variable of interest is group size, though physician measures of DES adoption are included as covariates in some models. While the primary interest is in identifying how group size relates to DES disadoption, the adoption measures are included in the interest of controlling for unobserved factors that relate to DES disadoption behavior and may be correlated with DES adoption measures[27].

Second, because the primary explanatory variable is group size and there is relatively little variation in group size within groups (despite the use of "composite group size,"

[27] Of course, Chapter 5 analyzed the relationship between DES disadoption and adoption. Though, as discussed in that chapter, many of the individual DES adoption measures did not have statistically significant relationship with the DES disadoption measures, the interest here is in how the full set of DES adoption measures collectively may relate to any given DES disadoption outcome measure.

described above, because the majority of physicians do not practice in multiple groups), group-level fixed effects cannot be included due to collinearity issues. Because group-level fixed effects cannot be used, but there is concern that other group members may influence an individual's technology use and disadoption behavior (independent of the impact of group size itself), I use the physician-level covariates used before to calculate and include group-level versions of these variables. Specifically, I include measures of the "physician characteristic" and "physician DES use" variables for non-self physicians in a group (i.e. for a given physician, all other physicians who share a group with that physician). These include, for example, the fraction of non-self physicians in a group with cardiology fellowship training and the average number of DES implanted by non-self physicians in a group per quarter after the publicization of DES safety concerns. The self-physician is excluded from these measures because we are interested in how a physician's peers' characteristics and behavior may influence that physician, and because the inclusion of a physician's own characteristics could create collinearity between the different covariates. However, because these group-level measures are defined for non-self physicians, they are missing for single-physician groups. As a result, for the analyses where these group-level covariates are included, I have to exclude single-physician groups, which significantly reduces sample size (at least for group measures focusing on practices and offices).

As in Chapter 5, the primary outcome of interest in these analyses is *time to initial DES disadoption*, and the three other measures of disadoption behavior—i.e. *initial extent of*

*DES disadoption*, *time to minimum DES use*, and *full extent of DES disadoption*—along with the measurement of *area above DES disadoption curve* are secondary outcomes. Though I perform simple OLS regressions for each of these outcome variables, I also convert each of these variables into binary form (as I did in Chapter 5) and perform *logit* analyses, to examine the potential for a more general (i.e. non-linear) relationship between group size and DES disadoption behavior. Furthermore, the fact that the primary outcome variable captures "time to an event" suggests that survival/hazard analysis would be appropriate (if not optimal) in this setting. Thus, I also perform discrete-time hazard analysis, utilizing the *cloglog* link function, to examine the relationship between group size and the primary outcome of interest, *time to initial DES disadoption*.[28]

*Instrumental variable analysis*

One goal in this chapter is to identify a causal relationship between group size and physician DES disadoption behavior. Despite the inclusion of physician- and group-level covariates in the analyses, there are still concerns about the endogeneity of group size. For example, one may be concerned that physicians are selecting into groups of different sizes in accordance with some unobservable characteristics (e.g. affinity for reading scientific literature) that are also correlated with the likelihood of DES disadoption. One potential approach to address this endogeneity concern is to use an instrumental variable

[28] Indeed, because *time to initial DES disadoption* as also the primary outcome variable in Chapter 5, discrete-time hazard analysis should also have been considered there, and it was. However, because such analysis uses the *cloglog* function and the Chapter 5 analyses included many practice- and hospital-level fixed effects, this analysis was very resource intensive and, as such, I was unable to produce estimates for such analyses.

(IV) for group size. After performing simple, non-instrumented regression analyses, I instrument for physician group size by using the ZIP-Code-level mean size of ophthalmology and orthopedic surgery groups (which are also determined in the original SK&A database)[29]. Though this instrument can be used for the size of practices and offices, as those are identified in the SK&A database, which provides addresses for practices and offices, it unfortunately cannot be used for hospital group size because hospitals in the discharge dataset do not have addresses and are labeled with blinded identifiers that cannot be mapped outside of the dataset, making the identity and location of the hospitals unknown. Another limitation to this instrument is the fact that it is not defined for all physicians in the sample, which thus causes a decrease in the analysis sample size.

As with any instrumental variable selection, this choice must satisfy the conditions of exogeneity and relevance. Because we have no reason to think that the size of ophthalmology or orthopedic surgery groups would have any relationship with cardiologists' DES disadoption behavior (except through the size of cardiology groups), we can be comfortable that the instrument is exogenous and the exclusion restriction holds. As for relevance, it is plausible that there are reasons for geographic correlation of

[29] As discussed above, considerable time and effort was spent processing and cleaning the portion of the SK&A dataset that was specific to cardiologists in Florida and New York. Due to the labor-intensity of this process, it was not repeated for ophthalmology or orthopedic surgery practices, which means that the sizes of those practices are unlikely to be determined with the same reliability as the cardiology practices. However, as long as there is no systematic bias in this expected measurement error of ophthalmology and orthopedic surgery practice sizes, there is no reason to be concerned about introducing bias into the instrumental variable analysis. Though the measurement error might weaken the strength of the instruments, the degree of correlation between them and physician group size is a matter of empirical observation, and as long as there is sufficient correlation, the instruments can still be used.

physician group size across different specialties. For example, if patient characteristics are important in determining the optimal physician group size, independent of specialty, and patient characteristics vary by geography, we may observe correlation between group sizes of different specialties. Alternatively, there may be external factors related to business or reimbursement environment that geographically influence physician group size. Ultimately, the question of instrument relevance can be answered empirically, and will be show below, with the results.

## 6.3 – Results

*Primary outcome*

Table 6.1 provides results from the standard OLS regression of the primary outcome, *time to initial DES disadoption*, against physician group size, with different models providing various sets of covariates. Table 6.2 performs generally the same analyses, but includes practice-level covariates (including non-self physician characteristics and DES use measures), which requires removal of solo-physician practices from the sample. Across these two different groups of analyses, we observe comparable results. Most importantly, in the fully-specified models, there is a positive relationship between group size and *time to initial DES disadoption*—indicating that physicians in larger groups begin the disadoption process later—but this coefficient is not statistically significant. Turning to the coefficient estimates on the covariates, we observe that the physician-level variables exhibit relationships with the *time to initial DES disadoption* measure that are very similar to the ones observed in the Chapter 5 analysis, e.g. earlier initial DES disadoption is observed among interventional-cardiology-fellowship-trained physicians and those who implant more DES per quarter after the publicization of safety concerns. Also relating these results to those from Chapter 5, we note that set of DES adoption measures collectively do not provide a statistically significant increase on the predictive power of the model (as determined by the incremental *F*-statistic and its *p*-value), but there is a significant negative relationship between *time to maximum DES use* and *time to initial DES disadoption*, indicating that physicians who were faster to adopt DES (i.e. took less time to reach their maximum DES use rate) generally start disadopting later. The signs of the coefficients on the other individual DES adoption measures are the same here as they were in the Chapter 5 analysis, and the lack of statistical significance is also the same. That is, we observe that physicians who were faster to adopt DES (i.e. took less time to reach their maximum DES use rate) generally start disadopting later, and that physicians who start adopting DES later also start *dis*adopting DES later, though the magnitude of these findings is not statistical significantly different from zero.

In addition to physician-level factors, we can now also observe relationships between the outcome variable and practice-level characteristics. When viewed collectively, the "physician characteristics" of the non-self physicians (e.g. age, experience, and training) in a practice provide significant statistical predictive power in these models of *time to initial DES adoption*, while the "physician DES use measures" (e.g. number of DES implanted before and after safety concern publicization) do not significantly increase the models' predictive power. Interestingly, we see that an increase in the fraction of *interventional*-cardiology-fellowship-trained physicians in a practice is associated with later initial DES disadoption, whereas an increase in the fraction of (non-interventional) cardiology-fellowship-trained physicians in a practice may be related to earlier initial DES disadoption.

Though these analyses provide insight into the relationship between a physician's DES disadoption behavior and that physician's group size, there are still concerns about endogeneity in these analyses, as discussed above. Despite the inclusion of various physician- and practice-level characteristics in the above analyses, one may still be worried that unobserved factors might influence physician selection into practices, thuse confounding the relationship between group size and disadoption behavior. For this reason, I perform an instrumental variable analysis (as detailed above), the results of which are provided in Tables 6.3 and 6.4, repeating the analyses just described. In examining these results, we first consider the performance of the instrument itself. As these tables show, the first stage $F$-statistic for the instrumental variable is less than 10 in each of the model specifications, indicating that it is a relatively weak instrument (i.e. there is weak ZIP-code level correlation between cardiologist group size and the group sizes of the other selected specialties). Instrument weakness aside, the over-identification test gives a $p$-value much greater than 0.05, suggesting that the instruments collectively are valid and not over-identified, i.e. that none of the individual instruments is observably endogenous (assuming that at least one of the instruments is exogenous). However, we also observe a $p$-value on the Durbin-Wu-Hausman test that is greater than 0.05 in all model specifications (and much greater than 0.05 in some specifications), which indicates that observationally there is not a high degree of endogeneity between group size and *time to initial DES disadoption*, indicating that bias generated by unobserved variables may not be too large and the need for an IV analysis is not as great as may have been feared.

Having considered the relevance, strength, and validity of the instruments, we now turn to the estimation results. The primary analysis results, i.e. the effect of group size on *time to initial DES disadoption*, are generally unchanged from the previous simple OLS analysis. In other words, when instrumenting for group size, I again observe a positive relationship between group size and *time to initial DES disadoption,* but the coefficient estimates remain statistically insignificant (compared to zero). Furthermore, the observed relationships with the other covariates are virtually unchanged after instrumenting for group size. Because the instrumental variable analysis decreased the sample size (due to some physicians missing values for the instrumental variables), I also repeated the earlier OLS regression analyses on these reduced samples. These results, which are shown in Tables 6.5 and 6.6 (rather than the results from Tables 6.1 and 6.2), are the ones that should be compared to the instrumental variable analysis results. However, these results (in Tables 6.5 and 6.6) are generally qualitatively unchanged from the results described earlier for the larger samples (in Tables 6.1 and 6.2).

The results in Tables 6.1 – 6.6 are all generated using a continuous measure for group size. However, as described above, I also created a categorical measure of group size to allow a more generalized (i.e. non-linear) examination of the potential relationship between group size and DES disadoption behavior. Repeating each of the above analyses with this categorical group size measure, I provide the results from the fully-specified model from each these analyses in Table 6.7. The single-physician group is the omitted/reference category, except for the analyses which include group-level covariates, where single-physician groups were dropped from the sample, so the next smallest group (2-5 physicians) becomes the omitted/reference category. Across each of these model specifications, we observe no statistically significant relationships between any of the group size categories and *time to initial DES disadoption*, noting also that the coefficient point estimates for some of the groups change sign across model specifications. Otherwise, the relationships between the covariates and the DES disadoption measure are qualitatively similar in these analyses to those observed in the previous analyses.

The analyses presented in Tables 6.1 – 6.7 all use the same outcome variable, a continuous measure of time to initial DES disadoption, with linear regression. However, as discussed above, this variable can be made binary and we can replace OLS regression with *logit* analysis. Tables 6.8 and 6.9 provide results from these binary-outcome analyses, with the tables representing different sets of covariates and treatment of single-group physicians, analogous to the analyses that produced Tables 6.1 and 6.2. In these analyses, the outcome variable is a binary variable indicating early initial DES disadoption, so a negative coefficient estimate on group size would indicate that an increase in group size is associated with a decreased likelihood of early initial disadoption, i.e. larger groups tend to begin the disadoption process later. Indeed, this is the general trend that we observe when examining Tables 6.8 and 6.9 (i.e. larger groups are associated with later initial DES disadoption), though similar to the earlier analyses, the estimated coefficients are not statistically different from zero.

In addition to these binary-outcome analyses, we can also use discrete-time hazard analyses to investigate the relationship between group size and the timing of initial DES disadoption. Tables 6.10 and 6.11 provide the results from discrete-time hazard analyses, where “risk of initial DES disadoption” is the dependent variable, and the result are organized analogously to Tables 6.1 and 6.2 (or Tables 6.8 and 6.9). In these analyses, coefficients represent estimated hazard rates, so a negative coefficient estimate on the group size variable would indicate that an increase in group size is associated with decreased “disadoption hazard” and thus later initial disadoption. Though the earlier results might lead us to expect negative coefficients here, interestingly the coefficients on group size in Tables 6.10 and 6.11 are positive, suggesting that larger groups tend to start the disadoption process earlier, though once again these results are not generally statistically significant.

Each of these four new tables uses a continuous measure of physician group size (as was the case in Tables 6.1 – 6.6). Table 6.12 repeats the analyses shown in Tables 6.8 – 6.11, but uses a categorical measure of group size (similar to the approach in Table 6.7). The most notable observation from Table 6.12 is that, once again, there is no statistically significant relationship between group size and the timing of initial DES disadoption, thus making it difficult to draw definitive conclusions about the differential DES disadoption behavior in any of the group size categories.

*Different measures of group size*

Each of the analyses shown in Tables 6.1 – 6.12 defines group size as the number of cardiologists in a physician's practice. However, as discussed above, a physician's group can be identified and measured by using different types of organizations and/or physicians. Tables 6.13 and 6.14 show results from regression analyses that use different measurements of group size, which are determined by a combination of organization type (practice, office, or hospital) and physician type (all cardiologists or only cardiologists who implant stents). In these tables, each cell provides the coefficient estimate (and 95% confidence interval for the coefficient) on physician group size from a fully-specified model that includes group-level covariates and excludes single-physician groups (i.e. Model 6, from Tables 6.2, 6.4, and 6.6) for the analysis of one of the given group size measurements. (For example, in Table 6.13 the cell in the top left-hand corner, corresponding to the "all-cardiologist, practice-level" measure of group size, is taken from Table 6.2—specifically, the group size coefficient for Model 6 in the top right-hand corner of Table 6.2.) Thus, each cell in these tables represents a single cell pulled from a full table of regression analysis results. Table 6.13 presents results from analyses where group size is measured continuously, whereas Table 6.14 contains results from analyses using the categorical measure of group size. Both tables also provide results from both the standard, non-instrumented OLS regressions and the instrumental variable analyses. As noted above, because I cannot identify hospitals' locations and the instruments used here are ZIP-Code-based, I am unable to instrument for hospital group size, so those table entries are left blank.

Starting with Table 6.13, we first notice that none of the coefficient estimates is statistically significantly different from zero. With that said, we observe that most of the point estimates for the relationship between group size and *time to initial DES disadoption* are positive, as we observed in earlier analyses. The one exception to this when groups are measured at physician office level and group size is instrumented for (with ZIP-code-level other specialty practice size). We also observe that, with the exception of the hospital-based group size measures, when group size is determined by counting only cardiologists who implant stents, the coefficient estimates (for the effect of group size on *time to initial DES disadoption*) are of larger magnitude than when group size is determined by counting all cardiologists. In terms of coefficient magnitude, we also notice that the estimates for practice-based group size are comparable to the estimates for office-based group size, whereas the point estimates for hospital-based group size are much smaller, indicating that the marginal increase in hospital size has a smaller impact on *time to initial DES disadoption* than does the marginal increase in practice or group size. Finally, we observe that for each type of group size measurement, the magnitude of coefficient estimates is larger for instrumental variable analysis than for basic OLS analysis (though as already mentioned, in the case of office-based group size, the coefficients change in sign in addition to getting larger).

Table 6.14 is analogous to Table 6.13, but uses categorical group sizes measures instead of continuous measures. Again, the measures of practice- and office-based group sizes show virtually no statistically significant relationship with *time to initial DES disadoption*, but we do observe several significant coefficients for hospital-based group size. Specifically, we see that each group category has a negative coefficient, indicating that each of the group size categories is associated with a shorter *time to initial DES disadoption* than the smallest, omitted hospital-based group category. Otherwise, we observe no obvious relationships across the different group size category measures.

*Secondary outcomes*

We next turn to the secondary outcomes of interest, which are the other three single-dimension measures of DES disadoption—*initial extent of DES disadoption*, *time to minimum DES use*, and *full extent of DES disadoption*—and the one multi-dimensional measure of DES disadoption—*area above the DES disadoption curve*. The results for these outcomes are provided in Tables 6.15 – 6.22, which replicate the format of Tables 6.13 and 6.14, showing the relationship between the given outcome variable and group size as measured by various different variables, both with basic linear regression and instrumental variable analysis. With few exceptions, there are generally no statistically significant relationships between group size and the other measures of DES disadoption behavior, and there are few consistently signed (i.e. positive or negative) relationships. However, it does appear that there may be a weak negative relationship between physician office size (and possibly practice size) and *initial extent of DES disadoption*, suggesting that physicians in larger officers (or practices) may exhibit smaller drops in DES use rates upon initial disadoption.

*Sensitivity analyses*

As was also noted in Chapter 5, the results shown here are all specific to a single DES disadoption definition. To test the sensitivity of these results to the specifications of this definition, the analyses are repeated using multiple different DES disadoption definitions. Figure 6.2 plots coefficient estimates (and their 95% confidence intervals) from analyses of group size and the primary outcome variable, *time to initial DES disadoption*, with a different plot for each combination of the three types of organization (practice, office, and hospital) and two types of physician (all cardiologists and stent-placing cardiologists), analogous to the results shown in Table 6.13, with each point in the plots corresponding to an analysis with an outcome variable based on a different DES disadoption definition. As the plots and calculated coefficient means show, the coefficient estimates are generally positive but lacking statistical significance. These plots were repeated for the secondary outcome variables—i.e. the three other unidimensional measures of DES disadoption and the one multidimensional measure of DES disadoption—and none of the results were statistically significant.

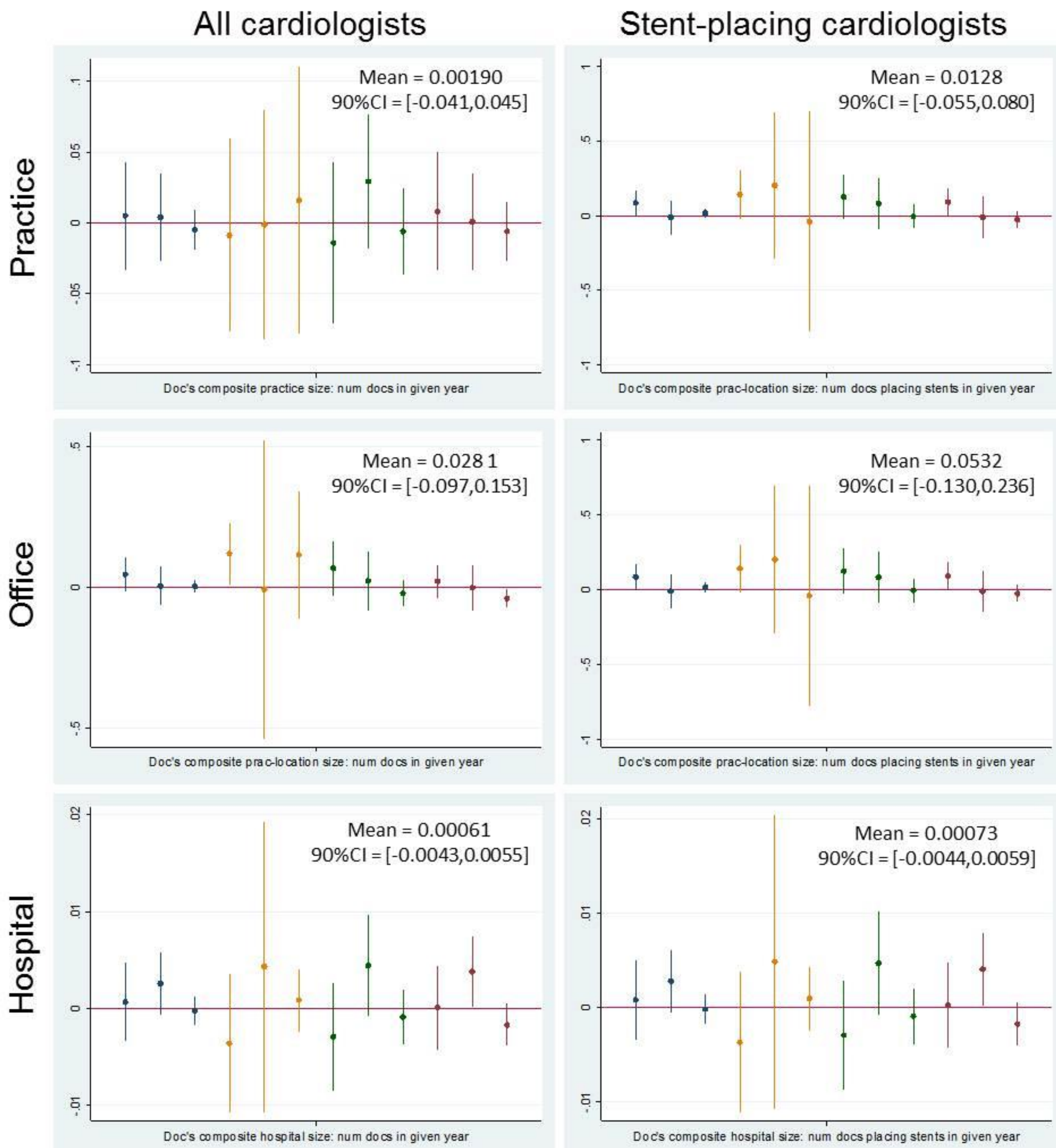



**Figure 6.2**: Coefficient estimates from models relating *time to initial DES disadoption* to group size, with a different plot presented for six different measurements of group size. Each point represents the use of a different DES disadoption definition. Within-plot coefficient means (with 90% confidence intervals) are calculated and shown in text.

## 6.4 – Discussion

The analyses performed here attempt to provide fundamental insight into the determinants of physicians' technology disadoption behavior, choosing to focus specifically on the role of physician group size and the empirical setting of DES use. One of the key results from the above analyses is the observation that physician group size may have a positive relationship with *time to initial DES disadoption*, i.e. physicians in larger groups tend to start the DES disadoption process later. However, while this relationship is observed across multiple different analyses, the coefficient estimates, while generally positive, are generally not significantly different from zero, statistically speaking. Yet, the replication of the result across different analyses and specifications gives some weight to its validity (as compared to a spurious result), despite the lack of conventional statistical significance.

Recalling the theoretical model that I developed in Chapter 4, that theory predicted an ambiguous relationship between group size and time to disadoption, on account of larger groups providing a "benefit" of greater access to information (via more peers), but also introducing the "disadvantage" of an opportunity to free-ride off others' knowledge acquisition, and thus incentivizing the shirking of effort expenditure on own knowledge acquisition. The empirical observation that larger group size may be related to later initial DES disadoption (which I postulate is mediated through decreased effort expenditure toward acquisition of critical information) is suggestive that, in the framework of the theoretical model, the negative effect of free-riding incentive (i.e.

individuals' decrease in effort expenditure on knowledge acquisition) may outweigh the positive effect of increased access to more potential knowledge (via larger group size). Of course, it must be acknowledged again that these results are generally not statistically significant in the conventional sense.

As described above, to address potential concerns over the potentially endogenous relationship between physician group size and DES disadoption behavior, I conducted an instrumental variable analysis aimed at identifying the causal effect of group size on DES disadoption. Though the instrumental variable analyses generally do not produce statistically significant results (like the basic OLS analyses), it is worth commenting on the fact that instrumenting for group size tends to cause an increase in the estimated effect size of group size on *time to initial DES disadoption*. We recall that I was motivated to instrument for group size to address concerns that physicians are selecting into practices of different sizes based on unobserved characteristics that are also related to DES disadoption behavior. Thus, if using an instrumental variable removes this endogeneity of group size and, in so doing, increases the size of the effect, it suggests that there may be an underlying negative relationship between group size and time to disadoption (again with the caveat of no statistical significance). That is, these findings suggest that cardiologists who prefer to select into larger practices may also be more prone to starting the DES disadoption process earlier. Indeed, one potential explanation for this finding is the observation that academic medical groups tend to be very large (e.g. associated with large teaching hospitals), but also attract physicians who are on the forefront of knowledge acquisition, and thus may possibly be the first to learn about safety concerns surrounding DES and begin the disadoption process earlier. However, it is particularly interesting to note that, while instrumentation for group size produces larger, positive coefficient estimates on the practice-based group size measure, the same instrumentation produces negative coefficient estimates on the office-based group size measure. Following the same reasoning discussed above, this relationship suggests that, while cardiologists who select into larger *practices* are more likely to begin DES disadoption earlier, cardiologists who selection into larger *offices* are more likely to begin DES disadoption later. One possible explanation for this could be if physicians who do not want to expend great personal effort on keeping up-to-date with new clinical technologies and guidelines prefer to join larger offices, where they expect to have close contact with a large number of other clinicians, from whom they can hopefully learn new information and with whom they can pool resources to reduce their learning costs. Of course, again, all of these results and potential explanations are considered with the understanding that these results are not statistically significant.

Aside from the estimated coefficients on office-based group size, most of the analyses performed here indicate a positive relationship between group size and *time to initial DES disadoption*, but there is another notable case that appears to disagree with the general trend. Namely, the discrete-time hazard analysis of initial DES disadoption "risk" indicates that larger group size is associated with earlier initial DES disadoption. However, this result may be a mechanical artifact of the data. For example, if a large portion of the sample exhibits early initial DES disadoption and if there is the same distribution of *time to initial DES disadoption* among both large and small groups (i.e. indicating that there is no true difference in initial DES disadoption "risk" by group size), but there are more individuals in large groups than small groups, the result of a discrete-time hazard analysis will indicate a greater initial disadoption hazard for large groups than small groups due to the increased sample prevalence of DES disadoption in large groups. Indeed, we do observe a large portion of the sample having early DES disadoption (see Figure 5.1) and a larger number of big than small groups (see Figure 6.1), so the nature of the sample composition may explain the observed hazard analysis results, rather than a true relationship between increased group size and earlier DES disadoption. Of course, it is worth recalling (yet again) that the other analyses performed in this chapter do not definitively indicate that an increase in group size has a true relationship (either causal or not) with slower initial DES disadoption.

Indeed, there are multiple reasons that the analyses performed here might not provide any significant findings, even if a true relationship does exist between physician group size and technology disadoption behavior. While there are many reasons that DES serves as a strong empirical setting to study technology disadoption (as detailed in Chapter 2), there are also drawbacks specific to this choice. First, there was a relatively large amount of uncertainty surrounding the technology. Though the original publications and research on DES were extremely positive, it did not take long for serious safety concerns to surface and gain attention. Of course, uncertainty is a fundamental component to any example of technology adoption or disadoption, but the hype and publicity surrounding DES, along with the high-stakes (i.e. life-or-death) nature of its application, magnified the potential impact of any given piece of new information regarding the technology, thus making individuals more prone to large and frequent fluctuations in technology use. As I described above, my empirical characterize DES disadoption behavior is based on changes in technology usage rates, so fluctuations in DES rates can create significant noise in the various disadoption measures. Such noise, which is compounded by the relatively small sample size that I study—which I discussed in Chapter 5, and may significantly under-power these analyses, especially given the reduced sample sizes resulting from the use of IV analysis in this chapter—would obviously compromise the ability to identify true functional relationships in the data.

Second, our ability to identify true empirical relationships between physician organization and DES disadoption behavior is inhibited by the relatively brief timeline of global DES adoption and disadoption. Though the short period of combined DES adoption and disadoption is beneficial in that it allows us to observe both types of behavior in a relatively small and accessible amount of data, it is simultaneously detrimental to our research objectives. As described in Chapter 2, DES witnessed very rapid adoption, followed by generalized disadoption, and subsequently re-adoption, all in less than 5 years. While this timeline may not seem short compared to some other technology trajectories (e.g. smart phones or clothing), the fact that data observations are at the quarter level means that the potential window for observable DES adoption and disadoption behaviors is rather small and, as a result, the potential variation in measures of these behaviors is quite limited. Given that the existence of variation is a fundamental requirement for meaningful econometric analysis, it should not be surprising that the coefficient estimates calculated here are not statistically significant.

Despite these empirical limitations, this data analysis still does reveal some potentially interesting relationships, including the examination of different measures of group size. Though the original analysis of group size and *time to initial DES disadoption* focused specifically on physicians' practice size, where "size" is a count of the number of self-identified cardiologists in the practice, there are potentially other group sizes to consider, as discussed and analyzed above. In my investigation of different group size measurements, the primary results for which are shown in Tables 6.13 and 6.14 (along with Tables 6.15 – 6.22, for the secondary outcome variables), I am able to compare the relationships between *time to initial DES disadoption* and practice size, office size, and hospital size. Aside from the interesting difference in sign on the coefficient estimates for practice size and office size that arises with instrumental variable analysis (which I discussed above), we also notice that the magnitude of the coefficients on practice and group size are relatively comparable, while the coefficient estimate for hospital size is considerably smaller. One potential explanation for this observed difference is the fact that hospitals tend to be much larger than practices or offices. In the dataset used here, average hospital size is approximately 6-7 times larger than average practice or office size (54 versus 9 and 7). Given the bigger size, it is expected that the marginal effect of increasing hospital size by 1 physician would have a smaller effect on a physician's DES disadoption behavior than the marginal effect of increasing either practice or office size by 1 physician. Another explanation that would be consistent with these results of different magnitudes of coefficient estimates would be stronger relationships and communications between physicians in practices or offices as opposed to hospitals. This explanation would agree with other research which has found (specifically in the setting of DES use by cardiologists) that peer effects on medical technology selection are greater among physicians within practices than between physicians who work in the same hospital (Huesch 2011 Soc Sci Med). Indeed, such a result would make sense via the influence of knowledge-sharing if practices and offices represent the central organization where cardiologists practice and see patients, and hospitals serve as a simple "workshop" where they operate and place stents. Of course, this is just one theoretical explanation, and we must remember the limited statistical significance of these results, and the fact that other factors may produce such results.

Table 6.13 also compares group size measures that differ in terms of which physicians are counted to determine the given group size. Across all types of organizations (practice, office, and hospital), we observe that effect of an increase in the number of stent-implanting cardiologists has a larger impact on *time to initial DES disadoption* than an increase in the number of general cardiologists. This observation agrees with intuition and an understanding of both the data used here and the institutional details of the clinical situation. The measure of general cardiologists is based on physicians' self-identified specialty and includes physicians' secondary and tertiary specialties. This likely means that some general practitioners are included in the sample because dealing very frequently with cardiac issues (given that heart disease is the leading cause of death in the United States, and conditions such as hypertension, hyperlipidemia, and heart failure are encountered with exceptional regularity in primary care practices) will prompt some general practitioners to consider cardiology to be one of their specialties. However, the measure of cardiologists who implant stents is identified in the discharge data, so it does not have the potential to be inflated to include non-cardiologists. Given that learning is the postulated mechanism through which group size influences DES disadoption, it is logical that physicians who actually implant stents would more reason to quickly acquire critical information regarding DES, and thus we'd expect the second group size measure to have a bigger impact on *time to initial DES disadoption*.

Aside from this observed relationship between group size and *time to initial DES disadoption*, I also analyze the relationship between group size and the other measures of DES disadoption (*initial extent of DES disadoption*, *time to minimum DES use*, *full extent of DES disadoption*, and *area above the DES disadoption curve*). However, I find virtually no significant association between group size and any of these other DES disadoption measures. Having not developed a theoretical framework that relates group size to these disadoption measures, it cannot be said that this finding is either surprising or expected. Of course, the observed empirical result may also be a result of issues with the data (e.g. noise in the measures, lack of statistical power) instead of fundamental (or theoretical) ambiguity, so further investigation is required to develop deeper understanding of these measures of disadoption. Indeed, one extension of analysis is to consider not just how group size relates to the technology disadoption process—while controlling for the measures of the similar adoption process—but to consider how group size relates *differentially* to the disadoption and adoption processes. It is this topic that I turn to next.

**Table 6.1**: Effect of physician practice size (all cardiologists) on *initial time to DES disadoption*, single-group physicians included, continuous group size measure; basic OLS regression results

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 7 (β/[95%CI]) |
|---|---|---|---|---|
| Physician group size (number of cardiologists) | -0.006 [-0.04,0.02] | -0.005 [-0.03,0.02] | 0.002 [-0.03,0.03] | 0.003 [-0.03,0.03] |
| Physician age (at time of DES safety concern publicization) | | 0.074 [-0.01,0.16] | 0.065 [-0.02,0.15] | 0.063 [-0.02,0.15] |
| Physician years of experience (at time of DES safety concern pub) | | -0.053 [-0.14,0.03] | -0.042 [-0.13,0.04] | -0.044 [-0.13,0.04] |
| Physician has cardiology fellowship training | | -0.446 [-1.47,0.58] | -0.528 [-1.54,0.48] | -0.557 [-1.57,0.46] |
| Physician has interventional cardiology fellowship training | | -0.758 [-1.67,0.16] | -1.058* [-1.97,-0.15] | -1.101* [-2.07,-0.13] |
| Physician total num. DES placed before safety concerns | | | -0.004*** [-0.01,-0.00] | -0.003*** [-0.01,-0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | 0.005** [0.00,0.01] | 0.005* [0.00,0.01] |
| Physician time (quarters) to initial DES adoption | | | | -0.011 [-0.16,0.14] |
| Physician time (quarters) from adoption to max DES use | | | | -0.041* [-0.08,-0.00] |
| Physician initial level DES use (increase) upon adoption | | | | -0.144 [-1.32,1.04] |
| Physician full level DES use (increase) after adoption | | | | 2.223 [-4.56,9.00] |
| r2 | 0.000 | 0.018 | 0.056 | 0.066 |
| F | 0.168 | 1.941 | 4.472 | 3.322 |
| p | 0.682 | 0.086 | 0.000 | 0.000 |
| N | 532.000 | 532.000 | 532.000 | 532.000 |
| Unique docs | 532 | 532 | 532 | 532 |
| Incremental F stat | | 2.383553605 | 10.62192561 | 1.293234336 |
| Prob > incrm F | | 0.050434834 | 3.00617E-05 | 0.271539095 |

**Table 6.2**: Effect of physician practice size (all cardiologists) on *initial time to DES disadoption*, single-group physicians excluded, continuous group size measure; basic OLS regression results

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) |
|---|---|---|---|---|---|---|
| Physician group size (number of cardiologists) | 0.001 [-0.03,0.03] | 0.000 [-0.03,0.03] | 0.005 [-0.03,0.04] | 0.013 [-0.02,0.05] | 0.004 [-0.03,0.04] | 0.005 [-0.03,0.04] |
| Physician age (at time of DES safety concern publicization) | | 0.082 [-0.01,0.18] | 0.074 [-0.02,0.17] | 0.065 [-0.03,0.16] | 0.060 [-0.03,0.15] | 0.059 [-0.04,0.15] |
| Physician years of experience (at time of DES safety concern pub) | | -0.065 [-0.16,0.03] | -0.055 [-0.15,0.04] | -0.034 [-0.12,0.06] | -0.033 [-0.12,0.06] | -0.035 [-0.13,0.06] |
| Physician has cardiology fellowship training | | -0.529 [-1.59,0.53] | -0.602 [-1.65,0.44] | -0.663 [-1.70,0.37] | -0.627 [-1.67,0.41] | -0.660 [-1.70,0.38] |
| Physician has interventional cardiology fellowship training | | -0.769 [-1.72,0.18] | -1.088* [-2.03,-0.14] | -1.104* [-2.04,-0.17] | -1.134* [-2.07,-0.20] | -1.210* [-2.19,-0.23] |
| Physician total num. DES placed before safety concerns | | | -0.004*** [-0.01,-0.00] | -0.003*** [-0.01,-0.00] | -0.003*** [-0.01,-0.00] | -0.003** [-0.01,-0.00] |
| Physician total num. DES placed, from safety concern pub. to 2007 | | | 0.005* [0.00,0.01] | 0.005* [0.00,0.01] | 0.005* [0.00,0.01] | 0.005* [0.00,0.01] |
| Practice average doc age at time of DES safety concern pub. | | | | 0.030 [-0.01,0.07] | 0.019 [-0.02,0.06] | 0.017 [-0.03,0.06] |
| Practice average doc yrs exper. at time of DES safety concern pub | | | | -0.043 [-0.09,0.00] | -0.030 [-0.08,0.02] | -0.028 [-0.08,0.02] |
| Practice fraction of docs with cardiology fellowship training | | | | -1.409* [-2.78,-0.04] | -1.315 [-2.70,0.07] | -1.300 [-2.70,0.09] |
| Practice fraction of docs with intvntl card fellowship training | | | | 1.261* [0.08,2.45] | 1.333* [0.14,2.52] | 1.383* [0.19,2.58] |
| Practice total # DES placed before DES safety concerns | | | | | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] |
| Practice total num. DES placed from safety concern pub. to 2007 | | | | | 0.000 [0.00,0.00] | 0.000 [0.00,0.00] |
| Physician time (quarters) to initial DES adoption | | | | | | 0.016 [-0.14,0.17] |
| Physician time (quarters) from adoption to max DES use | | | | | | -0.043* [-0.08,-0.00] |
| Physician initial level DES use (increase) upon adoption | | | | | | -0.337 [-1.58,0.90] |
| Physician full level DES use (increase) after adoption | | | | | | 5.568 [-1.78,12.9] |
| r2 | 0.000 | 0.018 | 0.057 | 0.091 | 0.093 | 0.107 |
| F | 0.005 | 1.732 | 3.964 | 4.158 | 3.911 | 3.389 |
| p | 0.943 | 0.126 | 0.000 | 0.000 | 0.000 | 0.000 |
| N | 471.000 | 471.000 | 471.000 | 471.000 | 471.000 | 471.000 |
| Unique docs | 471 | 471 | 471 | 471 | 471 | 471 |
| Incremental F stat | | 2.16376855 | 9.38817507 | 4.30018276 | 1.17254722 | 1.74722150 |
| Prob > incrm F | | 0.07209137 | 0.00010075 | 0.00200076 | 0.27944822 | 0.13850694 |

**Table 6.3**: Effect of physician practice size (all cardiologists) on *initial time to DES disadoption*, single-group physicians included, continuous group size measure; instrumental variable regression results

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 7 (β/[95%CI]) |
|---|---|---|---|---|
| Physician group size (number of cardiologists) | 0.065 [-0.07,0.20] | 0.067 [-0.07,0.20] | 0.081 [-0.06,0.22] | 0.093 [-0.04,0.23] |
| Physician age (at time of DES safety concern publicization) | | 0.065 [-0.04,0.17] | 0.053 [-0.05,0.15] | 0.050 [-0.05,0.15] |
| Physician years of experience (at time of DES safety concern pub) | | -0.051 [-0.15,0.05] | -0.038 [-0.13,0.06] | -0.040 [-0.14,0.06] |
| Physician has cardiology fellowship training | | -0.628 [-1.80,0.54] | -0.783 [-1.93,0.37] | -0.775 [-1.94,0.39] |
| Physician has interventional cardiology fellowship training | | -0.799 [-1.85,0.25] | -1.076* [-2.12,-0.03] | -1.054 [-2.17,0.06] |
| Physician total num. DES placed before safety concerns | | | -0.004*** [-0.01,-0.00] | -0.004*** [-0.01,-0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | 0.005* [0.00,0.01] | 0.005* [0.00,0.01] |
| Physician time (quarters) to initial DES adoption | | | | -0.055 [-0.22,0.11] |
| Physician time (quarters) from adoption to max DES use | | | | -0.038 [-0.08,0.01] |
| Physician initial level DES use (increase) upon adoption | | | | 0.161 [-1.18,1.50] |
| Physician full level DES use (increase) after adoption | | | | 1.063 [-8.45,10.57] |
| r2 | . | . | 0.009 | 0.002 |
| F | | | | |
| p | 0.339 | 0.172 | 0.000 | 0.002 |
| N | 452.000 | 452.000 | 452.000 | 452.000 |
| Unique docs | 452 | 452 | 452 | 452 |
| Chi-squared | 0.915050481 | 7.73210558 | 26.31467178 | 29.75563169 |
| Incremental chi2 | 7.026266436 | 6.532713885 | 18.59761003 | 3.748149045 |
| Prob > incrm chi2 | | 0.162740779 | 9.15335E-05 | 0.441161699 |
| IV Hausman p-value | | 0.282509649 | 0.253089586 | 0.193877601 |
| First stage F | | 6.674699106 | 6.710031475 | 6.592914493 |
| IV overid. p-value | | 0.210301053 | 0.272853427 | 0.208809368 |

**Table 6.4**: Effect of physician practice size (all cardiologists) on *initial time to DES disadoption*, single-group physicians excluded, continuous group size measure; instrumental variable regression results

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) |
|---|---|---|---|---|---|---|
| Physician group size (number of cardiologists) | 0.058 [-0.08,0.19] | 0.062 [-0.08,0.20] | 0.075 [-0.06,0.21] | 0.091 [-0.06,0.24] | 0.107 [-0.04,0.26] | 0.138 [-0.02,0.29] |
| Physician age (at time of DES safety concern publicization) | | 0.069 [-0.04,0.18] | 0.057 [-0.05,0.17] | 0.043 [-0.06,0.15] | 0.048 [-0.06,0.16] | 0.044 [-0.07,0.16] |
| Physician years of experience (at time of DES safety concern pub) | | -0.060 [-0.17,0.05] | -0.048 [-0.15,0.06] | -0.033 [-0.14,0.07] | -0.036 [-0.14,0.07] | -0.038 [-0.15,0.07] |
| Physician has cardiology fellowship training | | -0.789 [-1.99,0.42] | -0.936 [-2.13,0.26] | -1.055 [-2.27,0.16] | -1.103 [-2.34,0.13] | -1.169 [-2.44,0.11] |
| Physician has interventional cardiology fellowship training | | -0.750 [-1.85,0.35] | -1.014 [-2.11,0.08] | -0.985 [-2.09,0.12] | -0.953 [-2.06,0.16] | -0.961 [-2.14,0.22] |
| Physician total num. DES placed before safety concerns | | | -0.004*** [-0.01,-0.00] | -0.003*** [-0.01,-0.00] | -0.003** [-0.01,-0.00] | -0.003** [-0.01,-0.00] |
| Physician total num. DES placed from safety concern pub. to 2007 | | | 0.004 [-0.00,0.01] | 0.004 [-0.00,0.01] | 0.004 [-0.00,0.01] | 0.004 [-0.00,0.01] |
| Practice average doc age at time of DES safety concern pub. | | | | 0.029 [-0.02,0.08] | 0.039 [-0.01,0.09] | 0.038 [-0.01,0.09] |
| Practice average doc yrs exper. at time of DES safety concern pub | | | | -0.009 [-0.09,0.07] | -0.017 [-0.08,0.04] | -0.011 [-0.07,0.05] |
| Practice fraction of docs with cardiology fellowship training | | | | -2.465** [-4.20,-0.73] | -2.589** [-4.41,-0.76] | -2.732** [-4.61,-0.85] |
| Practice fraction of docs with intvntl card fellowship training | | | | 1.712* [0.20,3.23] | 1.686* [0.30,3.08] | 1.816* [0.38,3.25] |
| Practice total number DES placed before DES safety concerns | | | | | -0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] |
| Practice total num. DES placed from safety concern pub. to 2007 | | | | | 0.000 [0.00,0.00] | 0.000 [0.00,0.00] |
| Physician time (quarters) to initial DES adoption | | | | | | 0.013 [-0.16,0.19] |
| Physician time (quarters) from adoption to max DES use | | | | | | -0.034 [-0.08,0.01] |
| Physician initial level DES use (increase) upon adoption | | | | | | -0.233 [-1.66,1.20] |
| Physician full level DES use (increase) after adoption | | | | | | 6.888 [-4.84,18.6] |
| r2 | . | . | 0.021 | 0.051 | 0.037 | 0.007 |
| F | | | | | | |
| p | 0.410 | 0.205 | 0.002 | 0.000 | 0.000 | 0.000 |
| N | 400.000 | 400.000 | 400.000 | 400.000 | 400.000 | 400.000 |
| Unique docs | 400 | 400 | 400 | 400 | 400 | 400 |
| Chi-squared | 0.67795974 | 7.21026818 | 22.9934406 | 38.4399506 | 39.8172531 | 42.8781696 |
| Incremental chi2 | 6.86775016 | 5.69330862 | 16.2208832 | 15.7908687 | 0.29251957 | 3.83751880 |
| Prob > incrm chi2 | | 0.22325279 | 0.00030038 | 0.00331301 | 0.58861043 | 0.42844164 |
| IV Hausman p-value | | 0.38103512 | 0.33249003 | 0.29749213 | 0.16268946 | 0.07777907 |
| First stage F | | 6.58383514 | 6.68082938 | 6.41994871 | 8.01560460 | 7.56653347 |
| IV overid. p-value | | 0.20193021 | 0.32268951 | 0.29981937 | 0.33314883 | 0.37037035 |

**Table 6.5**: Effect of physician practice size (all cardiologists) on *initial time to DES disadoption*, single-group physicians included, continuous group size measure; basic OLS regression results, with sample matching instrumental variable analysis (i.e. Table 6.3 results)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 7 (β/[95%CI]) |
|---|---|---|---|---|
| Physician group size (number of cardiologists) | -0.003 [-0.04,0.03] | -0.004 [-0.04,0.03] | 0.005 [-0.03,0.04] | 0.006 [-0.03,0.04] |
| Physician age (at time of DES safety concern publicization) | | 0.052 [-0.04,0.15] | 0.041 [-0.05,0.14] | 0.036 [-0.06,0.13] |
| Physician years of experience (at time of DES safety concern pub) | | -0.039 [-0.13,0.05] | -0.026 [-0.12,0.07] | -0.024 [-0.12,0.07] |
| Physician has cardiology fellowship training | | -0.648 [-1.80,0.51] | -0.766 [-1.90,0.37] | -0.732 [-1.88,0.42] |
| Physician has interventional cardiology fellowship training | | -0.851 [-1.89,0.19] | -1.127* [-2.16,-0.10] | -1.153* [-2.24,-0.06] |
| Physician total num. DES placed before safety concerns | | | -0.004*** [-0.01,-0.00] | -0.004*** [-0.01,-0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | 0.006* [0.00,0.01] | 0.006* [0.00,0.01] |
| Physician time (quarters) to initial DES adoption | | | | -0.031 [-0.19,0.13] |
| Physician time (quarters) from adoption to max DES use | | | | -0.037 [-0.08,0.01] |
| Physician initial level DES use (increase) upon adoption | | | | 0.102 [-1.22,1.42] |
| Physician full level DES use (increase) after adoption | | | | -0.415 [-9.52,8.69] |
| r2 | 0.000 | 0.016 | 0.055 | 0.062 |
| F | 0.042 | 1.410 | 3.685 | 2.647 |
| p | 0.837 | 0.219 | 0.001 | 0.003 |
| N | 452.000 | 452.000 | 452.000 | 452.000 |
| Unique docs | 452 | 452 | 452 | 452 |
| Incremental F stat | | 1.751551877 | 9.24148388 | 0.841025058 |
| Prob > incrm F | | 0.137626603 | 0.000116887 | 0.499653213 |

**Table 6.6**: Effect of physician practice size (all cardiologists) on *initial time to DES disadoption*, single-group physicians excluded, continuous group size measure; basic OLS regression results, with sample matching instrumental variable analysis (i.e. Table 6.4 results)

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) |
|---|---|---|---|---|---|---|
| Physician group size (number of cardiologists) | 0.004 [-0.03,0.04] | 0.002 [-0.03,0.04] | 0.009 [-0.03,0.04] | 0.018 [-0.02,0.06] | 0.011 [-0.03,0.05] | 0.012 [-0.03,0.05] |
| Physician age (at time of DES safety concern publicization) | | 0.061 [-0.05,0.17] | 0.048 [-0.06,0.16] | 0.043 [-0.06,0.15] | 0.038 [-0.07,0.14] | 0.032 [-0.08,0.14] |
| Physician years of experience (at time of DES safety concern pub) | | -0.052 [-0.16,0.05] | -0.038 [-0.14,0.06] | -0.019 [-0.12,0.08] | -0.019 [-0.12,0.08] | -0.015 [-0.12,0.09] |
| Physician has cardiology fellowship training | | -0.747 [-1.94,0.45] | -0.862 [-2.04,0.32] | -0.914 [-2.09,0.26] | -0.886 [-2.06,0.29] | -0.862 [-2.05,0.33] |
| Physician has interventional cardiology fellowship training | | -0.858 [-1.93,0.21] | -1.132* [-2.20,-0.07] | -1.142* [-2.19,-0.09] | -1.156* [-2.21,-0.10] | -1.232* [-2.34,-0.12] |
| Physician total num. DES placed before safety concerns | | | -0.004*** [-0.01,-0.00] | -0.003*** [-0.01,-0.00] | -0.003*** [-0.01,-0.00] | -0.003** [-0.01,-0.00] |
| Physician total num. DES placed from safety concern pub. to 2007 | | | 0.005* [0.00,0.01] | 0.005* [0.00,0.01] | 0.005* [0.00,0.01] | 0.005 [-0.00,0.01] |
| Practice average doc age at time of DES safety concern pub. | | | | 0.046* [0.01,0.09] | 0.036 [-0.01,0.08] | 0.036 [-0.01,0.08] |
| Practice average doc yrs exper. at time of DES safety concern pub | | | | -0.041 [-0.09,0.01] | -0.030 [-0.09,0.03] | -0.029 [-0.09,0.03] |
| Practice fraction of docs with cardiology fellowship training | | | | -2.252** [-3.86,-0.64] | -2.165** [-3.79,-0.54] | -2.165* [-3.82,-0.51] |
| Practice fraction of docs with intvntl card fellowship training | | | | 1.297* [0.01,2.59] | 1.353* [0.06,2.65] | 1.363* [0.05,2.67] |
| Practice total number DES placed before DES safety concerns | | | | | 0.000 [-0.00,0.00] | 0.000 [-0.00,0.00] |
| Practice total num. DES placed from safety concern pub. to 2007 | | | | | 0.000 [0.00,0.00] | 0.000 [0.00,0.00] |
| Physician time (quarters) to initial DES adoption | | | | | | 0.017 [-0.15,0.19] |
| Physician time (quarters) from adoption to max DES use | | | | | | -0.037 [-0.08,0.01] |
| Physician initial level DES use (increase) upon adoption | | | | | | -0.253 [-1.65,1.14] |
| Physician full level DES use (increase) after adoption | | | | | | 3.111 [-7.52,13.7] |
| r2 | 0.000 | 0.016 | 0.054 | 0.093 | 0.095 | 0.103 |
| F | 0.054 | 1.310 | 3.205 | 3.631 | 3.380 | 2.736 |
| p | 0.816 | 0.259 | 0.003 | 0.000 | 0.000 | 0.000 |
| N | 400.000 | 400.000 | 400.000 | 400.000 | 400.000 | 400.000 |
| Unique docs | 400 | 400 | 400 | 400 | 400 | 400 |
| Incremental F stat | | 1.62366742 | 7.83067601 | 4.19257278 | 0.65259984 | 0.82339142 |
| Prob > incrm F | | 0.16745421 | 0.00046276 | 0.00246003 | 0.41968096 | 0.51083096 |

**Table 6.7**: Effect of physician practice size (all cardiologists) on *initial time to DES disadoption*; replication of fully specified models from Tables 6.1 – 6.6, for categorical group size variable (instead of continuous group size measure)

| | Model 7 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 6 (β/[95%CI]) |
|---|---|---|---|---|---|---|
| Physician group size category: 2-5 docs/practice | -0.341 [-1.14,0.46] | Ref | -6.649 [-43.48,30.2] | Ref | -0.408 [-1.30,0.48] | Ref |
| Physician group size category: 6-12 docs/practice | 0.064 [-0.71,0.84] | 0.462 [-0.16,1.09] | -6.216 [-35.3,22.87] | 3.085 [-20.7,26.87] | 0.010 [-0.86,0.88] | 0.428 [-0.26,1.11] |
| Physician group size category: 13+ docs/practice | -0.124 [-0.97,0.73] | 0.249 [-0.57,1.06] | -4.067 [-32.15,24.0] | 3.747 [-9.60,17.09] | 0.072 [-0.90,1.04] | 0.609 [-0.31,1.53] |
| Physician age (at time of DES safety concern publicization) | 0.063 [-0.02,0.15] | 0.058 [-0.04,0.15] | 0.007 [-0.19,0.21] | 0.054 [-0.12,0.23] | 0.038 [-0.06,0.13] | 0.035 [-0.07,0.14] |
| Physician years of experience (at time of DES safety concern pub) | -0.043 [-0.13,0.04] | -0.036 [-0.13,0.06] | -0.014 [-0.17,0.14] | -0.060 [-0.30,0.18] | -0.026 [-0.12,0.07] | -0.021 [-0.12,0.08] |
| Physician has cardiology fellowship training | -0.515 [-1.53,0.50] | -0.596 [-1.64,0.45] | -1.374 [-4.15,1.40] | -0.846 [-4.04,2.35] | -0.709 [-1.86,0.45] | -0.852 [-2.04,0.34] |
| Physician has interventional cardiology fellowship training | -1.102* [-2.08,-0.13] | -1.244* [-2.23,-0.26] | -0.374 [-3.90,3.15] | -1.094 [-2.35,0.16] | -1.129* [-2.22,-0.03] | -1.227* [-2.33,-0.12] |
| Physician total num. DES placed before safety concerns | -0.004*** [-0.01,-0.00] | -0.003** [-0.01,-0.00] | -0.002 [-0.01,0.01] | -0.005 [-0.02,0.01] | -0.004*** [-0.01,-0.00] | -0.003** [-0.01,-0.00] |
| Physician total num. DES placed from safety concern pub. to 2007 | 0.005* [0.00,0.01] | 0.005* [0.00,0.01] | 0.004 [-0.01,0.02] | 0.007 [-0.01,0.02] | 0.006* [0.00,0.01] | 0.005* [0.00,0.01] |
| Practice average doc age at time of DES safety concern pub. | | 0.009 [-0.03,0.05] | | -0.006 [-0.44,0.43] | | 0.031 [-0.02,0.08] |
| Practice average doc yrs exper. at time of DES safety concern pub | | -0.021 [-0.07,0.03] | | 0.025 [-0.38,0.43] | | -0.023 [-0.08,0.04] |
| Practice fraction of docs with cardiology fellowship training | | -1.189 [-2.58,0.20] | | -1.942 [-8.29,4.41] | | -2.128* [-3.80,-0.46] |
| Practice fraction of docs with intvntl card fellowship training | | 1.384* [0.20,2.57] | | 1.637* [0.19,3.08] | | 1.375* [0.07,2.68] |
| Practice total # DES placed before DES safety concerns | | 0.000 [-0.00,0.00] | | -0.000 [-0.00,0.00] | | 0.000 [-0.00,0.00] |
| Practice total num. DES placed from safety concern pub. to 2007 | | 0.000 [0.00,0.00] | | 0.000 [0.00,0.00] | | 0.000 [0.00,0.00] |
| Physician time (quarters) to initial DES adoption | -0.016 [-0.16,0.13] | 0.012 [-0.14,0.16] | -0.007 [-0.32,0.30] | -0.025 [-0.42,0.37] | -0.038 [-0.20,0.12] | 0.012 [-0.16,0.18] |
| Physician time (quarters) from adoption to max DES use | -0.039* [-0.08,-0.00] | -0.041* [-0.08,-0.00] | -0.022 [-0.15,0.11] | -0.025 [-0.15,0.10] | -0.036 [-0.08,0.01] | -0.036 [-0.08,0.01] |
| Physician initial level DES use (increase) upon adoption | -0.069 [-1.25,1.12] | -0.250 [-1.49,0.99] | 0.741 [-4.61,6.10] | 0.236 [-4.98,5.45] | 0.193 [-1.13,1.52] | -0.195 [-1.60,1.21] |
| Physician full level DES use (increase) after adoption | 2.206 [-4.58,8.99] | 5.598 [-1.75,12.94] | 4.772 [-19.7,29.24] | 8.094 [-11.8,27.97] | 0.013 [-9.11,9.14] | 3.588 [-7.04,14.22] |
| r2 | 0.069 | 0.111 | . | . | 0.067 | 0.107 |
| F | 2.971 | 3.324 | | | 2.409 | 2.685 |
| p | 0.000 | 0.000 | 0.081 | 0.002 | 0.004 | 0.000 |
| N | 532.000 | 471.000 | 452.000 | 400.000 | 452.000 | 400.000 |
| Unique docs | 532 | 471 | 452 | 400 | 452 | 400 |
| Chi-squared | 1.208503586 | 1.645510969 | 20.60859566 | 39.26394931 | 0.819781812 | 0.80297695 |
| Incremental chi2 | 0.306175936 | 0.161724345 | 2.403863705 | 3.333784352 | 0.513005083 | 0.523827499 |
| Prob > incrm chi2 | | | 0.661929143 | 0.503597289 | | |
| IV Hausman p-value | | | 0.872827023 | 0.60268869 | | |
| First stage F | | | | | | |
| IV overid. p-value | | | 0.068646826 | 0.16134496 | | |

**Table 6.8**: Effect of physician practice size (all cardiologists) on binary (early) *initial time to DES disadoption*, single-group physicians included, continuous group size measure; logit regression results

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 7 (β/[95%CI]) |
|---|---|---|---|---|
| Physician group size (number of cardiologists) | 0.004 [-0.02,0.03] | 0.004 [-0.02,0.03] | -0.000 [-0.02,0.02] | -0.000 [-0.02,0.02] |
| Physician age (at time of DES safety concern publicization) | | -0.028 [-0.10,0.04] | -0.024 [-0.10,0.05] | -0.022 [-0.09,0.05] |
| Physician years of experience (at time of DES safety concern pub) | | 0.009 [-0.06,0.08] | 0.002 [-0.07,0.07] | 0.001 [-0.07,0.07] |
| Physician has cardiology fellowship training | | 0.447 [-0.33,1.23] | 0.508 [-0.29,1.30] | 0.515 [-0.29,1.32] |
| Physician has interventional cardiology fellowship training | | 0.733 [-0.17,1.64] | 0.984* [0.05,1.92] | 1.075* [0.07,2.08] |
| Physician total num. DES placed before safety concerns | | | 0.003*** [0.00,0.00] | 0.003** [0.00,0.00] |
| Physician total num. DES placed from safety concern pub. thru 2007 | | | -0.005** [-0.01,-0.00] | -0.005* [-0.01,-0.00] |
| Physician time (quarters) to initial DES adoption | | | | 0.001 [-0.13,0.13] |
| Physician time (quarters) from adoption to max DES use | | | | 0.028 [-0.01,0.06] |
| Physician initial level DES use (increase) upon adoption | | | | -0.032 [-1.04,0.97] |
| Physician full level DES use (increase) after adoption | | | | -2.358 [-8.74,4.03] |
| chi2 | 0.094 | 10.537 | 24.338 | 27.903 |
| p | 0.759 | 0.061 | 0.001 | 0.003 |
| N | 532.000 | 532.000 | 532.000 | 532.000 |
| Unique docs | 532 | 532 | 532 | 532 |
| Incremental LR chi2 | | 10.44319408 | 13.80083301 | 3.565239077 |
| Prob > incrm chi2 | | 0.033588538 | 0.001007366 | 0.468028179 |

**Table 6.9**: Effect of physician practice size (all cardiologists) on binary (early) *initial time to DES disadoption*, single-group physicians excluded, continuous group size measure; logit regression results

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) |
|---|---|---|---|---|---|---|
| Physician group size (number of cardiologists) | -0.009 [-0.03,0.02] | -0.008 [-0.03,0.02] | -0.010 [-0.04,0.02] | -0.025 [-0.06,0.00] | -0.018 [-0.05,0.02] | -0.019 [-0.05,0.01] |
| Physician age (at time of DES safety concern publicization) | | -0.032 [-0.11,0.05] | -0.029 [-0.11,0.05] | -0.022 [-0.10,0.06] | -0.016 [-0.10,0.07] | -0.011 [-0.10,0.07] |
| Physician years of experience (at time of DES safety concern pub) | | 0.013 [-0.06,0.09] | 0.006 [-0.07,0.08] | -0.006 [-0.09,0.07] | -0.007 [-0.09,0.07] | -0.011 [-0.09,0.07] |
| Physician has cardiology fellowship training | | 0.468 [-0.34,1.28] | 0.515 [-0.31,1.34] | 0.604 [-0.25,1.46] | 0.570 [-0.28,1.42] | 0.551 [-0.31,1.42] |
| Physician has interventional cardiology fellowship training | | 0.640 [-0.29,1.57] | 0.935 [-0.03,1.90] | 0.963 [-0.02,1.94] | 1.005* [0.02,1.99] | 1.218* [0.15,2.29] |
| Physician total num. DES placed before safety concerns | | | 0.003*** [0.00,0.00] | 0.003*** [0.00,0.00] | 0.003*** [0.00,0.00] | 0.003** [0.00,0.00] |
| Physician total num. DES placed from safety concern pub. to 2007 | | | -0.006** [-0.01,-0.00] | -0.006** [-0.01,-0.00] | -0.005** [-0.01,-0.00] | -0.005* [-0.01,-0.00] |
| Practice average doc age at time of DES safety concern pub. | | | | -0.011 [-0.04,0.02] | -0.001 [-0.04,0.04] | 0.002 [-0.04,0.04] |
| Practice average doc yrs exper. at time of DES safety concern pub | | | | 0.015 [-0.03,0.06] | 0.003 [-0.04,0.05] | 0.000 [-0.05,0.05] |
| Practice fraction of docs with cardiology fellowship training | | | | 1.156 [-0.08,2.39] | 1.094 [-0.16,2.34] | 1.068 [-0.20,2.33] |
| Practice fraction of docs with intvntl card fellowship training | | | | -1.162* [-2.18,-0.15] | -1.240* [-2.27,-0.21] | -1.300* [-2.33,-0.27] |
| Practice total # DES placed before DES safety concerns | | | | | -0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] |
| Practice total num. DES placed from safety concern pub. to 2007 | | | | | 0.000 [0.00,0.00] | 0.000 [0.00,0.00] |
| Physician time (quarters) to initial DES adoption | | | | | | -0.038 [-0.18,0.10] |
| Physician time (quarters) from adoption to max DES use | | | | | | 0.021 [-0.02,0.06] |
| Physician initial level DES use (increase) upon adoption | | | | | | -0.025 [-1.14,1.09] |
| Physician full level DES use (increase) after adoption | | | | | | -5.204 [-13.3,2.90] |
| chi2 | 0.475 | 9.212 | 22.931 | 38.127 | 39.283 | 43.420 |
| p | 0.491 | 0.101 | 0.002 | 0.000 | 0.000 | 0.000 |
| N | 471.000 | 471.000 | 471.000 | 471.000 | 471.000 | 471.000 |
| Unique docs | 471 | 471 | 471 | 471 | 471 | 471 |
| Incremental LR chi2 | | 8.73742231 | 13.7183799 | 15.1967016 | 1.15625831 | 4.13624416 |
| Prob > incrm chi2 | | 0.06800845 | 0.00104976 | 0.00431015 | 0.28224288 | 0.38788110 |

**Table 6.10**: Effect of physician practice size (all cardiologists) on *risk of initial DES disadoption*, single-group physicians included, continuous group size measure; discrete-time hazard analysis

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 7 (β/[95%CI]) |
|---|---|---|---|---|
| Physician group size (number of cardiologists) | 0.015* [0.00,0.03] | 0.013 [-0.00,0.03] | 0.010 [-0.00,0.02] | 0.008 [-0.00,0.02] |
| Physician age (years) | | -0.074*** [-0.12,-0.03] | -0.060** [-0.10,-0.02] | -0.062** [-0.10,-0.02] |
| Physician years of experience | | 0.053** [0.01,0.09] | 0.037 [-0.00,0.07] | 0.041* [0.00,0.08] |
| Physician has cardiology fellowship training | | 0.175 [-0.28,0.63] | 0.148 [-0.27,0.56] | 0.228 [-0.20,0.65] |
| Physician has interventional cardiology fellowship training | | 0.181 [-0.26,0.62] | 0.334 [-0.09,0.76] | 0.225 [-0.21,0.66] |
| Physician total num. DES placed before safety concerns | | | 0.001*** [0.00,0.00] | 0.002*** [0.00,0.00] |
| Physician cumulative total number of DES implanted | | | -0.001* [-0.00,-0.00] | -0.001** [-0.00,-0.00] |
| Physician time (quarters) to initial DES adoption | | | | 0.050 [-0.00,0.10] |
| Physician time (quarters) from adoption to max DES use | | | | 0.005 [-0.01,0.02] |
| Physician initial level DES use (increase) upon adoption | | | | -0.005 [-0.54,0.53] |
| Physician full level DES use (increase) after adoption | | | | -0.670 [-3.70,2.36] |
| chi2 | 4.980 | 23.414 | 56.829 | 59.470 |
| p | 0.026 | 0.000 | 0.000 | 0.000 |
| N | 2440.000 | 2440.000 | 2440.000 | 2440.000 |
| Unique docs | 630 | 630 | 630 | 630 |

**Table 6.11**: Effect of physician practice size (all cardiologists) on *risk of initial DES disadoption*, single-group physicians excluded, continuous group size measure; discrete-time hazard analysis

| | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) | Model 4 (β/[95%CI]) | Model 5 (β/[95%CI]) | Model 6 (β/[95%CI]) |
|---|---|---|---|---|---|---|
| Physician group size (number of cardiologists) | 0.011 [-0.00,0.03] | 0.010 [-0.00,0.02] | 0.009 [-0.00,0.02] | 0.005 [-0.01,0.02] | 0.002 [-0.01,0.02] | 0.002 [-0.01,0.02] |
| Physician age (years) | | -0.064* [-0.11,-0.01] | -0.050* [-0.10,-0.01] | -0.050* [-0.10,-0.01] | -0.049* [-0.09,-0.00] | -0.052* [-0.10,-0.01] |
| Physician years of experience | | 0.048* [0.00,0.09] | 0.033 [-0.01,0.07] | 0.033 [-0.01,0.07] | 0.032 [-0.01,0.07] | 0.037 [-0.00,0.08] |
| Physician has cardiology fellowship training | | 0.104 [-0.43,0.64] | 0.116 [-0.35,0.58] | 0.159 [-0.30,0.62] | 0.120 [-0.32,0.56] | 0.176 [-0.27,0.62] |
| Physician has interventional cardiology fellowship training | | 0.331 [-0.13,0.80] | 0.526* [0.10,0.95] | 0.485* [0.06,0.91] | 0.438* [0.02,0.86] | 0.315 [-0.12,0.75] |
| Physician total num. DES placed before safety concerns | | | 0.002*** [0.00,0.00] | 0.001*** [0.00,0.00] | 0.001* [0.00,0.00] | 0.001* [0.00,0.00] |
| Physician cumulative total number of DES implanted | | | -0.002** [-0.00,-0.00] | -0.001** [-0.00,-0.00] | -0.001 [-0.00,0.00] | -0.001 [-0.00,0.00] |
| Practice average doc age (among non-self physicians) | | | | 0.005 [-0.01,0.03] | 0.005 [-0.01,0.02] | 0.005 [-0.01,0.02] |
| Practice average doc yrs exper. (among non-self physicians) | | | | -0.020 [-0.06,0.02] | -0.020 [-0.06,0.02] | -0.020 [-0.06,0.02] |
| Practice fraction of docs with cardiology fellowship training | | | | 0.339 [-0.29,0.96] | 0.311 [-0.30,0.93] | 0.303 [-0.31,0.92] |
| Practice fraction of docs with intvntl card fellowship training | | | | -0.230 [-0.77,0.31] | -0.143 [-0.67,0.39] | -0.163 [-0.70,0.38] |
| Practice total # DES placed pre-DES safety pub (non-self docs) | | | | | 0.000* [0.00,0.00] | 0.000* [0.00,0.00] |
| Practice total cumulative # DES placed (by non-self physicians) | | | | | -0.000* [-0.00,-0.00] | -0.000* [-0.00,-0.00] |
| Physician time (quarters) to initial DES adoption | | | | | | 0.045 [-0.01,0.10] |
| Physician time (quarters) from adoption to max DES use | | | | | | -0.003 [-0.02,0.02] |
| Physician initial level DES use (increase) upon adoption | | | | | | -0.026 [-0.60,0.54] |
| Physician full level DES use (increase) after adoption | | | | | | -0.919 [-4.39,2.55] |
| chi2 | 1.917 | 14.001 | 43.256 | 49.869 | 61.802 | 61.417 |
| P | 0.166 | 0.016 | 0.000 | 0.000 | 0.000 | 0.000 |
| N | 1912.000 | 1912.000 | 1912.000 | 1912.000 | 1912.000 | 1912.000 |
| Unique docs | 523 | 523 | 523 | 523 | 523 | 523 |

**Table 6.12**: Effect of physician practice size (all cardiologists) on *early initial DES disadoption* (logit analysis) and *risk of initial DES disadoption* (hazard analysis), with categorical group size measure

| **BINARY OUTCOME, LOGIT ANALYSIS** | | | **DISCRETE-TIME HAZARD ANALYSIS** | | |
|---|---|---|---|---|---|
| | Model 7 (β/[95%CI]) | Model 6 (β/[95%CI]) | Model 7 (β/[95%CI]) | Model 6 (β/[95%CI]) | |
| Physician group size category: 2-5 docs/practice | 0.602 [-0.04,1.24] | Ref | 0.195 [-0.11,0.50] | Ref | Physician group size category: 2-5 docs/practice |
| Physician group size category: 6-12 docs/practice | 0.507 [-0.12,1.13] | -0.284 [-0.86,0.29] | 0.166 [-0.14,0.47] | -0.065 [-0.34,0.21] | Physician group size category: 6-12 docs/practice |
| Physician group size category: 13+ docs/practice | 0.404 [-0.28,1.09] | -0.370 [-1.10,0.36] | 0.306 [-0.03,0.64] | 0.068 [-0.29,0.42] | Physician group size category: 13+ docs/practice |
| Physician age (at time of DES safety concern publicization) | -0.019 [-0.09,0.05] | -0.011 [-0.10,0.07] | -0.060** [-0.1,-0.02] | -0.051* [-0.1,-0.01] | Physician age (years) |
| Physician years of experience (at time of DES safety concern pub) | -0.001 [-0.07,0.07] | -0.010 [-0.09,0.07] | 0.039* [0.00,0.08] | 0.036 [-0.00,0.08] | Physician years of experience |
| Physician has cardiology fellowship training | 0.564 [-0.25,1.38] | 0.522 [-0.35,1.39] | 0.214 [-0.21,0.64] | 0.160 [-0.29,0.61] | Physician has cardiology fellowship training |
| Physician has interventional cardiology fellowship training | 1.004 [-0.00,2.01] | 1.245* [0.17,2.32] | 0.210 [-0.22,0.64] | 0.328 [-0.10,0.75] | Physician has interventional cardiology fellowship training |
| Physician total num. DES placed before safety concerns | 0.002** [0.00,0.00] | 0.003** [0.00,0.00] | 0.001*** [0.00,0.00] | 0.001* [0.00,0.00] | Physician total num. DES placed before safety concerns |
| Physician total #. DES placed from safety concern pub to 2007 | -0.004* [-0.01,-0.0] | -0.005* [-0.01,-0.0] | -0.001* [-0.00,-0.0] | -0.001 [-0.00,0.00] | Physician cumulative total number of DES implanted |
| Practice average doc age at time of DES safety concern pub. | | 0.006 [-0.03,0.05] | | 0.006 [-0.01,0.03] | Practice average doc age (among non-self physicians) |
| Practice average doc yrs exper at time of DES safety concern pub | | -0.003 [-0.05,0.05] | | -0.021 [-0.06,0.02] | Practice average doc yrs exper. (among non-self physicians) |
| Practice fraction of docs with cardiology fellowship training | | 0.973 [-0.30,2.24] | | 0.277 [-0.34,0.90] | Practice fraction of docs with cardiology fellowship training |
| Practice fraction of docs with intvntl card fellowship training | | -1.270* [-2.3,-0.24] | | -0.154 [-0.68,0.37] | Practice fraction of docs with intvntl card fellowship training |
| Practice total # DES placed before DES safety concerns | | -0.000 [-0.00,0.00] | | 0.000* [0.00,0.00] | Practice total #. DES placed pre-DES safety pub (non-self docs) |
| Practice total # DES placed from safety concern pub. to 2007 | | 0.000 [0.00,0.00] | | -0.000* [-0.00,-0.0] | Practice total cumulative #. DES placed (by non-self physicians) |
| Physician time (quarters) to initial DES adoption | -0.005 [-0.13,0.12] | -0.035 [-0.17,0.10] | 0.050 [-0.00,0.10] | 0.046 [-0.01,0.10] | Physician time (quarters) to initial DES adoption |
| Physician time (quarters) from adoption to max DES use | 0.027 [-0.01,0.06] | 0.020 [-0.02,0.06] | 0.005 [-0.01,0.02] | -0.003 [-0.02,0.02] | Physician time (quarters) from adoption to max DES use |
| Physician initial level DES use (increase) upon adoption | -0.061 [-1.08,0.95] | -0.065 [-1.18,1.05] | -0.028 [-0.56,0.51] | -0.049 [-0.62,0.52] | Physician initial level DES use (increase) upon adoption |
| Physician full level DES use (increase) after adoption | -2.474 [-8.94,3.99] | -5.209 [-13.3,2.89] | -0.791 [-3.68,2.09] | -0.805 [-4.34,2.73] | Physician full level DES use (increase) after adoption |
| chi2 | 31.463 | 43.443 | 59.755 | 60.358 | chi2 |
| p | 0.003 | 0.000 | 0.000 | 0.000 | p |
| N | 532.000 | 471.000 | 2440.000 | 1912.000 | N |
| Unique docs | 532 | 471 | 630 | 523 | Unique docs |
| Incremental LR chi2 | 3.56704358 | 4.08428673 | | | |
| Prob > incrm chi2 | 0.46775770 | 0.39471904 | | | |

**Table 6.13**: Effect of physician group size, continuous measures, on *time to initial DES disadoption*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Time to initial DES disadoption | | | Organization type: Practice β/[95%CI] | Office β/[95%CI] | Hospital β/[95%CI] | |
|---|---|---|---|---|---|---|
| Physician type | All docs | Physician group size (continuous count) | 0.005 [-0.03,0.04] | 0.047 [-0.01,0.11] | 0.001 [-0.00,0.00] | OLS analysis (non-IV) |
| | Stent docs | Physician group size (continuous count) | 0.014 [-0.05,0.08] | 0.083 [-0.01,0.17] | 0.001 [-0.00,0.00] | |
| | All docs | Physician group size (continuous count) | 0.138 [-0.02,0.29] | -0.100 [-0.31,0.11] | X | IV analysis (2SLS) |
| | Stent docs | Physician group size (continuous count) | 0.246 [-0.04,0.53] | -0.206 [-0.49,0.07] | X | |

**Table 6.14**: Effect of physician group size, categorical measures, on *time to initial DES disadoption*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Time to initial DES disadoption | | | Organization type: Practice β/[95%CI] | Office β/[95%CI] | Hospital β/[95%CI] | |
|---|---|---|---|---|---|---|
| Physician type | All docs | Physician group category #2 | Ref | Ref | Ref | OLS analysis (non-IV) |
| | | Physician group category #3 | 0.462 [-0.16,1.09] | -0.056 [-1.15,1.04] | -0.319 [-1.10,0.46] | |
| | | Physician group category #4 | 0.249 [-0.57,1.06] | 0.887 [-0.46,2.23] | -0.953** [-1.67,-0.24] | |
| | | Physician group category #5 | X | X | -0.358 [-1.12,0.40] | |
| | Stent docs | Physician group category #2 | Ref | Ref | Ref | |
| | | Physician group category #3 | -0.109 [-0.79,0.57] | -0.708 [-1.78,0.36] | -1.209** [-1.97,-0.45] | |
| | | Physician group category #4 | 0.524 [-0.72,1.77] | 1.682 [-0.17,3.53] | -1.413*** [-2.08,-0.74] | |
| | | Physician group category #5 | X | X | -0.779* [-1.51,-0.04] | |
| | All docs | Physician group category #2 | Ref | Ref | X | IV analysis (2SLS) |
| | | Physician group category #3 | 3.085 [-20.70,26.87] | 0.569 [-8.19,9.33] | X | |
| | | Physician group category #4 | 3.747 [-9.60,17.09] | -1.981 [-6.48,2.52] | X | |
| | Stent docs | Physician group category #2 | Ref | Ref | X | |
| | | Physician group category #3 | -1.897 [-13.00,9.20] | -3.192 [-8.26,1.87] | X | |
| | | Physician group category #4 | 5.693 [-1.29,12.68] | -2.983 [-8.07,2.10] | X | |

For practice and office groups: category#1 = 1 doc; category#2 = 2-5 docs; category#3 = 6-12 docs; category #4 = 13+ docs; For hospital groups: category#1 = 1-29 docs; category #2=30-44 docs; category#3 = 45-59 docs; category#4 = 60-99; category#5 = 100+ docs

**Table 6.15**: Effect of physician group size, continuous measures, on *initial extent of DES disadoption*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Initial extent of DES disadoption | | | Organization type: Practice β/[95%CI] | Office β/[95%CI] | Hospital β/[95%CI] | |
|---|---|---|---|---|---|---|
| Physician type | All docs | Physician group size (continuous count) | 0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | OLS analysis (non-IV) |
| | Stent docs | Physician group size (continuous count) | -0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | |
| | All docs | Physician group size (continuous count) | 0.001 [-0.00,0.01] | -0.013* [-0.03,-0.00] | X | IV analysis (2SLS) |
| | Stent docs | Physician group size (continuous count) | -0.000 [-0.01,0.01] | -0.010 [-0.02,0.00] | X | |

**Table 6.16**: Effect of physician group size, categorical measures, on *initial extent of DES disadoption*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Initial extent of DES disadoption | | | Organization type: Practice β/[95%CI] | Office β/[95%CI] | Hospital β/[95%CI] | |
|---|---|---|---|---|---|---|
| Physician type | All docs | Physician group category #2 | Ref | Ref | Ref | OLS analysis (non-IV) |
| | | Physician group category #3 | -0.027* [-0.05,-0.00] | 0.001 [-0.04,0.05] | -0.000 [-0.03,0.03] | |
| | | Physician group category #4 | -0.026 [-0.06,0.01] | -0.008 [-0.06,0.05] | 0.010 [-0.02,0.04] | |
| | | Physician group category #5 | X | X | -0.002 [-0.03,0.03] | |
| | Stent docs | Physician group category #2 | Ref | Ref | Ref | |
| | | Physician group category #3 | -0.031* [-0.06,-0.00] | -0.026 [-0.07,0.02] | 0.004 [-0.03,0.03] | |
| | | Physician group category #4 | 0.014 [-0.03,0.06] | 0.004 [-0.07,0.08] | 0.009 [-0.02,0.04] | |
| | | Physician group category #5 | X | X | -0.005 [-0.03,0.02] | |
| | All docs | Physician group category #2 | Ref | Ref | X | IV analysis (2SLS) |
| | | Physician group category #3 | 0.170 [-0.88,1.22] | -0.317 [-0.83,0.19] | X | |
| | | Physician group category #4 | 0.129 [-0.46,0.72] | -0.189 [-0.45,0.07] | X | |
| | Stent docs | Physician group category #2 | Ref | Ref | X | |
| | | Physician group category #3 | 0.118 [-0.31,0.55] | -0.153 [-0.41,0.10] | X | |
| | | Physician group category #4 | -0.038 [-0.31,0.23] | -0.221 [-0.48,0.04] | X | |

For practice and office groups: category#1 = 1 doc; category#2 = 2-5 docs; category#3 = 6-12 docs; category #4 = 13+ docs; For hospital groups: category#1 = 1-29 docs; category #2=30-44 docs; category#3 = 45-59 docs; category#4 = 60-99; category#5 = 100+ docs

**Table 6.17**: Effect of physician group size, continuous measures, on *time to minimum DES use*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Time to minimum DES use | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| | | | β/[95%CI] | β/[95%CI] | β/[95%CI] | |
| Physician type | All docs | Physician group size (continuous count) | -0.052 [-0.13,0.03] | -0.077 [-0.20,0.05] | 0.003 [-0.01,0.01] | OLS analysis (non-IV) |
| | Stent docs | Physician group size (continuous count) | -0.073 [-0.21,0.07] | -0.007 [-0.20,0.18] | 0.003 [-0.01,0.01] | |
| | All docs | Physician group size (continuous count) | -0.043 [-0.34,0.26] | 0.191 [-0.32,0.70] | X | IV analysis (2SLS) |
| | Stent docs | Physician group size (continuous count) | -0.114 [-0.66,0.43] | 0.110 [-0.51,0.73] | X | |

**Table 6.18**: Effect of physician group size, categorical measures, on *time to minimum DES use*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Time to minimum DES use | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| | | | β/[95%CI] | β/[95%CI] | β/[95%CI] | |
| Physician type | All docs | Physician group category #2 | Ref | Ref | Ref | OLS analysis (non-IV) |
| | | Physician group category #3 | -0.995 [-2.30,0.31] | -1.477 [-3.84,0.88] | 0.813 [-0.82,2.44] | |
| | | Physician group category #4 | -0.879 [-2.59,0.83] | -1.963 [-4.86,0.94] | 1.281 [-0.21,2.77] | |
| | | Physician group category #5 | X | X | 1.227 [-0.36,2.82] | |
| | Stent docs | Physician group category #2 | Ref | Ref | Ref | |
| | | Physician group category #3 | -0.187 [-1.63,1.26] | 1.533 [-0.80,3.86] | 1.215 [-0.38,2.81] | |
| | | Physician group category #4 | -0.622 [-3.27,2.03] | -0.468 [-4.50,3.56] | 1.726* [0.32,3.13] | |
| | | Physician group category #5 | X | X | 1.584* [0.04,3.12] | |
| | All docs | Physician group category #2 | Ref | Ref | X | IV analysis (2SLS) |
| | | Physician group category #3 | 1.453 [-43.43,46.33] | 16.678 [-16.77,50.13] | X | |
| | | Physician group category #4 | 0.671 [-24.50,25.85] | -2.387 [-19.57,14.80] | X | |
| | Stent docs | Physician group category #2 | Ref | Ref | X | |
| | | Physician group category #3 | 5.872 [-15.71,27.45] | 5.272 [-6.73,17.27] | X | |
| | | Physician group category #4 | -2.649 [-16.24,10.94] | -2.570 [-14.62,9.48] | X | |

For practice and office groups: category#1 = 1 doc; category#2 = 2-5 docs; category#3 = 6-12 docs; category #4 = 13+ docs; For hospital groups: category#1 = 1-29 docs; category #2=30-44 docs; category#3 = 45-59 docs; category#4 = 60-99; category#5 = 100+ docs

**Table 6.19**: Effect of physician group size, continuous measures, on *full extent of DES disadoption*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Full extent of DES disadoption | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| | | | β/[95%CI] | β/[95%CI] | β/[95%CI] | |
| Physician type | All docs | Physician group size (continuous count) | 0.002 [-0.00,0.00] | -0.004 [-0.01,0.00] | -0.000 [-0.00,0.00] | OLS analysis (non-IV) |
| | Stent docs | Physician group size (continuous count) | 0.000 [-0.00,0.00] | -0.003 [-0.01,0.00] | -0.000 [-0.00,0.00] | |
| | All docs | Physician group size (continuous count) | -0.006 [-0.02,0.00] | -0.014 [-0.03,0.00] | X | IV analysis (2SLS) |
| | Stent docs | Physician group size (continuous count) | -0.015 [-0.04,0.00] | -0.016 [-0.04,0.00] | X | |

**Table 6.20**: Effect of physician group size, categorical measures, on *full extent of DES disadoption*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Full extent of DES disadoption | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| | | | β/[95%CI] | β/[95%CI] | β/[95%CI] | |
| Physician type | All docs | Physician group category #2 | Ref | Ref | Ref | OLS analysis (non-IV) |
| | | Physician group category #3 | -0.032 [-0.08,0.01] | 0.049 [-0.03,0.13] | 0.008 [-0.05,0.07] | |
| | | Physician group category #4 | 0.008 [-0.05,0.07] | -0.025 [-0.12,0.07] | 0.023 [-0.03,0.08] | |
| | | Physician group category #5 | X | X | -0.012 [-0.07,0.04] | |
| | Stent docs | Physician group category #2 | Ref | Ref | Ref | |
| | | Physician group category #3 | -0.010 [-0.06,0.04] | 0.034 [-0.04,0.11] | 0.034 [-0.02,0.09] | |
| | | Physician group category #4 | 0.015 [-0.07,0.10] | -0.075 [-0.21,0.06] | 0.045 [-0.00,0.09] | |
| | | Physician group category #5 | X | X | 0.019 [-0.03,0.07] | |
| | All docs | Physician group category #2 | Ref | Ref | X | IV analysis (2SLS) |
| | | Physician group category #3 | 1.136 [-2.97,5.24] | -0.036 [-0.66,0.59] | X | |
| | | Physician group category #4 | 0.585 [-1.72,2.89] | -0.279 [-0.60,0.04] | X | |
| | Stent docs | Physician group category #2 | Ref | Ref | X | |
| | | Physician group category #3 | 0.502 [-0.69,1.69] | -0.304 [-0.77,0.16] | X | |
| | | Physician group category #4 | -0.500 [-1.25,0.25] | -0.276 [-0.75,0.19] | X | |

For practice and office groups: category#1 = 1 doc; category#2 = 2-5 docs; category#3 = 6-12 docs; category #4 = 13+ docs; For hospital groups: category#1 = 1-29 docs; category #2=30-44 docs; category#3 = 45-59 docs; category#4 = 60-99; category#5 = 100+ docs

**Table 6.21**: Effect of physician group size, continuous measures, on *area above DES disadoption curve*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Full extent of DES disadoption | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| | | | β/[95%CI] | β/[95%CI] | β/[95%CI] | |
| Physician type | All docs | Physician group size (continuous count) | 0.002 [-0.02,0.03] | -0.021 [-0.07,0.02] | -0.001 [-0.00,0.00] | OLS analysis (non-IV) |
| | Stent docs | Physician group size (continuous count) | -0.006 [-0.05,0.04] | -0.006 [-0.08,0.06] | -0.001 [-0.00,0.00] | |
| | All docs | Physician group size (continuous count) | -0.005 [-0.10,0.11] | -0.037 [-0.16,0.09] | X | IV analysis (2SLS) |
| | Stent docs | Physician group size (continuous count) | -0.039 [-0.25,0.17] | -0.088 [-0.26,0.08] | X | |

**Table 6.22**: Effect of physician group size, categorical measures, on *area above of DES disadoption curve*, using different group measures (organization and physician type) and analysis methods (OLS and IV)

| Full extent of DES disadoption | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| | | | β/[95%CI] | β/[95%CI] | β/[95%CI] | |
| Physician type | All docs | Physician group category #2 | Ref | Ref | Ref | OLS analysis (non-IV) |
| | | Physician group category #3 | -0.479* [-0.92,-0.04] | -0.290 [-1.09,0.51] | -0.163 [-0.73,0.40] | |
| | | Physician group category #4 | -0.059 [-0.64,0.52] | -0.216 [-1.20,0.77] | 0.011 [-0.50,0.53] | |
| | | Physician group category #5 | X | X | -0.227 [-0.77,0.32] | |
| | Stent docs | Physician group category #2 | Ref | Ref | Ref | |
| | | Physician group category #3 | -0.075 [-0.56,0.41] | 0.177 [-0.69,1.05] | 0.133 [-0.41,0.67] | |
| | | Physician group category #4 | 0.225 [-0.66,1.11] | 0.144 [-1.25,1.54] | 0.239 [-0.24,0.72] | |
| | | Physician group category #5 | X | X | 0.019 [-0.50,0.54] | |
| | All docs | Physician group category #2 | Ref | Ref | X | IV analysis (2SLS) |
| | | Physician group category #3 | 17.578 [-44.55,79.7] | -0.082 [-3.87,3.71] | X | |
| | | Physician group category #4 | 10.362 [-25.14,45.9] | -0.076 [-4.29,4.14] | X | |
| | Stent docs | Physician group category #2 | Ref | Ref | X | |
| | | Physician group category #3 | 5.217 [-3.37,13.80] | -2.424 [-7.22,2.38] | X | |
| | | Physician group category #4 | -2.367 [-8.82,4.09] | -1.378 [-6.41,3.65] | X | |

For practice and office groups: category#1 = 1 doc; category#2 = 2-5 docs; category#3 = 6-12 docs; category #4 = 13+ docs; For hospital groups: category#1 = 1-29 docs; category #2=30-44 docs; category#3 = 45-59 docs; category#4 = 60-99; category#5 = 100+ docs

## CHAPTER 7: Differential relationships of disadoption and adoption to physician group size

In the previous chapters, I investigated the relationship between physician group size and technology disadoption behavior, from both theoretical and empirical perspectives. In this chapter, I extend that investigation by performing another type of analysis. As discussed multiple times above (e.g. in Chapters 2 and 3), many parallels can and should be drawn between technology adoption and disadoption due to the many similarities between the two processes. In Chapter 5, I used the empirical setting of cardiologists' DES use to explore the relationships between these two related phenomena, and in Chapter 6 I studied the relationship between cardiologist group size and DES disadoption, while controlling for adoption behavior as a potential explanatory factor of disadoption. However, following these analyses, we now come to another natural question by extension: how is the relationship between physician group size and disadoption different from the relationship between physician group size and adoption? That is, if we believe the two processes are similar and we observe that group size influences physician behavior for one of the processes (disadoption), how does group size differentially influence the other process? In this chapter, I will explore this question.

## 7.1 – Research questions

1) What is the observed empirical differential relationship between a physician’s group size and that physician’s *time to initial disadoption* and *time to initial adoption*, as studied in the setting of cardiologist use of drug-eluting stents?
2) What are the observed empirical differential relationships between a physician’s group size and the other measures of physician’s adoption and disadoption of DES (namely, *time to maximum/minimum use*, *initial extent of adoption/disadoption*, and *full extent of adoption/disadoption*)?
3) Can empirical analysis identify a causal differential relationship between a physician’s group size and that physician’s DES adoption and disadoption behaviors, by using an instrumental variable for physician group size?
5) Given that a physician can belong to multiple different groups (e.g. office, practice, and hospital), how do the sizes of those different groups relate differentially to that physician’s DES adoption and disadoption behavior, as measured with the various different measures?

## 7.2 – Data and methods

*Data processing*

The data used for empirical analyses in this chapter are the same as those used in Chapters 5 and 6, so those chapters can be referenced for details of the original data and basic data processing steps. However, for the analyses planned here, additional data processing is necessary.

In order to perform the desired analyses for this chapter, a significant restructuring of the data is required. For many of the analyses above, the dataset was ultimately reduced to either the physician-quarter level (with one observation per physician-quarter) or the physician level (one observation per physician). However, for this chapter, I restructure the data so that it is instead at the physician-phase-quarter level or physician-phase level, where "phase" represents a larger time period, which is either the "DES adoption phase" or the "DES disadoption phase." The beginning and end dates of each phase are a function of the conditions used for the DES disadoption definition that is used for the given analysis (because these conditions determine, among other things, how early DES disadoption is possible, as discussed in Chapter 5), but for the most commonly used DES disadoption definition (for which physicians become "at risk" for disadoption after the publicization of DES safety concerns in September 2006), the "DES adoption phase" runs from 2003Q2 to 2005Q2, and the "DES disadoption phase" runs from 2006Q3 to 2008Q1[30]. In transforming the data to be organized at the phase-level, I combine the DES adoption measures with their analogous DES disadoption measures to make single "DES change" measures. For example, *time to initial DES adoption* is combined with *time to initial DES disadoption* to create a single *time to initial DES change* variable, with the two different outcomes distinguished by a separate "phase" variable, which takes

[30] One can observe here that the adoption and disadoption phases are not perfectly adjacent, which is intentional. The gap between these phases represents the time when global DES use was generally high and not changing, i.e. after most physicians had fully adopted DES, but had not yet started the disadoption process.

on a different (binary) value for adoption and disadoption outcomes[31]. The relevance and value of this data transformation will be discussed in more detail below, when the methods used for analyses in this chapter will be described.

Another important data processing step required here involves physician group size. As described in Chapter 6, physician group size can be measured at (at least) 3 levels: office, practice, and hospital. Whereas hospital group size information comes from the same source as the coronary stent placement information (i.e. the discharge datasets), the office and practice group size information comes from a separate source: the SK&A database. As a result, when studying how a physician's office or practice size relates to that physician's DES adoption behavior, we face an issue: the SK&A dataset only dates back to 2005 (as mentioned in Chapter 5), whereas DES were approved by the FDA in 2003 and many physicians started using the technology in 2003 and 2004. Thus, if I want to relate office or practice size to a physician's DES adoption behavior, I need to make some assumptions and impute, or "back-fill," physicians' office and practice size in 2003 and 2004. To do this, I simply take a physician's group size in 2005 (or her earliest year of observation) and carry that group size measurement back into the preceding years for which it is missing. Of course, doing this assumes that physicians' office and practice sizes did not change from 2003 to 2005 (or later, if a physician first appears in the data later), which we don't believe to be strictly true. However, even if this assumption is not globally true, as long as it is equally valid for all individuals and there are not systematic

[31] In the terminology or syntax of Stata (the statistical software package used for the majority of data processing and analysis performed in this dissertation), this basically amounts to using the "reshape" function to reshape the data from wide form to long form.

differences between individuals for whom the assumption is more or less valid, then this assumption will not introduce systematic bias into the subsequent analyses.

To further address potential concerns about this imputation assumption, it is also worth noting here that for many analyses, the dataset will be organized at the physician-phase level, so each physician will have one observation each for the DES adoption and disadoption phases. When organized as such, the variables defined at the quarter- or year-level, which include group size, are averaged to take a single, phase-specific value. In this case, for the most common DES disadoption definitions, the adoption phase includes not only 2003 and 2004, but also 2005, for which office and practice size measures were originally found in the data and not back-filled. Of course, concerns about data extrapolation and imputation of values still exist, but they are mitigated by the fact that the final average values of interest include as inputs the "true," non-extrapolated values (as opposed to having average values that are based *only* on extrapolated or imputed values).

*Methods*

Though the appearance of the data is much different after the above processing, with observations now at the phase-level (whether physician-phase or physician-phase-quarter) and variables now combining previously separate measures (i.e. DES adoption and disadoption measures), the outcome variables are still continuous and of the same general appearance and magnitude as before, so the same types of analyses as were used in Chapter 6 can be used here. Of course, there are some basic changes, though. Whereas the primary outcome variable of interest in the preceding two chapters was *time to initial DES disadoption*, after data transformation described above, that outcome variable becomes *time to initial DES change*, with similar changes for each of the secondary outcome variables[32]. The data transformation also changes the potential explanatory variables. Though I was able to control for all four DES adoption measures in analyses in the past two chapters, those adoption measures have now been combined with the disadoption measures. As a result, the only adoption/disadoption relevant covariates that can be included in analyses here are, for a given "DES change" measure, the three other combined "DES change" measures. For example, when the outcome variable is *time to initial DES change*, I can control for *time to max/min DES use*, *initial extent of DES change*, and *full extent of DES change*.

Regardless of the outcome variable, the primary explanatory variable of interest here is physician group size. Of course, given that the outcome variable now represents a combined DES adoption and disadoption measure, the interpretation of the regression coefficient on this explanatory variable will now be different. However, as said above, one of my core interests in this chapter is identifying the differential relationship between group size and DES adoption and disadoption. This can be accomplished due to the data transformation, which produced an "adoption phase" indicator variable, which has a

[32] To specifically address the other adoption/disadoption measure along the time dimension: though this measure was previously referred to as *time to maximum DES use* for the adoption phase and *time to minimum DES use* for the disadoption phase, I will refer to the combined outcome as *time to maximum DES change*, because in fact, the maximum and minimum DES use points were really chosen to measure the biggest change in DES use after the adoption/disadoption processes began.

value of 1 for the disadoption phase and 0 for the adoption phase. The interaction of this phase indicator variable with group size in the regression analysis produces a coefficient that indicates the relationship (magnitude and sign) between an increase in group size and the DES disadoption outcome measure, relative to the same increase in group size effect and the analogous DES adoption outcome measure. Thus, the coefficient on this interaction term quantifies empirically the differential relationship that I seek to determine here, allowing a measurement of the difference between the two processes that are related and seem generally very similar.

Another advantage allowed by the above data transformation also shows up in the right-hand-side of the regression analyses to be performed here. Whereas in the previous chapters, the outcome variables (i.e. DES disadoption measures) were determined at the physician level, the outcome variables used in this chapter are determined at the physician-phase level. As a result, there is within-physician variation of the outcome variable, which allows the use of physician-level fixed effects in these analyses. In the previous analyses, I could only control for sets of specified physician characteristics (e.g. training and DES use) because physician-level fixed effects would have been perfectly collinear with the outcomes. The use of physician-level fixed effects here, though, is preferable because they can identify as much variation as the individual physician-level characteristic variables, while also controlling for unobserved physician-level characteristics that are time-invariant. Thus, the use of physician-level fixed effects helps address endogeneity issues, including the concern that physicians may select into practices of different sizes according to unobserved characteristics that ultimately also relate to technology disadoption (and/or adoption) behavior. Admittedly, one downside to the inclusion of physician-level fixed effects is that we cannot simultaneously determine the relationship between the various previously-studied physician-level factors and the outcome variable of interest. However, as those other variables were generally intended as covariates and were not the primary explanatory variable of interest, the tradeoff is deemed to be worthwhile.

## 7.3 – Results

Table 7.1 provides the results from the standard OLS regression analysis of the new primary outcome variable, *time to initial DES change*, against group size. First, we observe a positive and statistically significant coefficient on the non-interacted group size term, indicating that an increase in group size is associated with a physician starting the DES change process (which views adoption and disadoption together) later. Next, we see that there is a negative and statistically significant coefficient on the term that interacts group size with an indicator for the disadoption phase. Furthermore, the coefficient on the interaction terms is larger in magnitude than the coefficient on group size, indicating that the impact of group size on disadoption is opposite and greater than its impact on adoption. We also observe that the covariates—physician-level fixed effects and the other three measures of DES behavior change—provide significant predictive power, with each of the DES adoption/disadoption measures having a statistically significant coefficient.

Unlike in the previous chapters, where analyses of the three secondary disadoption outcomes rarely (if ever) provided noteworthy results, the analyses of *initial extent of DES change*, *time to maximum DES change*, and *full extent of DES change* provide results (which are given in Tables 7.2 – 7.4) with statistically significant, non-zero values. The analysis of each of these three outcomes, like the analysis of the primary outcome, produces a positive coefficient estimate on the group size term and a negative coefficient estimate on the interaction term. Furthermore, the individual coefficients on each of the DES adoption/disadoption behavior covariates are also all statistically significant.

Due to concerns about the endogeneity of physician group size (as discussed above and in Chapter 6), I repeat the analysis for each of the DES behavior outcome variables, instrumenting for physician group size. Unfortunately, the results for these IV analyses, which are shown in Tables 7.5 – 7.8, find generally no statistically significant results between either group size or the interaction term and any of the DES adoption/disadoption outcomes (with the possible exception of *full extent of DES change*), with most of the coefficients of interest being statistically indistinguishable from zero.

Repeating the same general approach that was used in Chapter 6, I also investigate different measurements of group size and how those different measurements relate to

DES disadoption behavior. Table 7.9 shows the results from the set of analyses with *time to initial DES change* as the dependent variable and group size (along with its interaction with a disadoption phase indicator) is the independent variable, and with variation in the method for measuring group size across analyses, i.e. with alteration of the type of organization (practice, office, or hospital) and type of cardiologist (general or excluding those who do not implant stents) that are considered when counting physicians. We first notice that, regardless of which type of organization or physicians are considered when measuring group size, the signs on the coefficient estimates are the same: the coefficient estimate on group size is positive, whereas the coefficient on the interaction term (of group size and disadoption phase) is negative. Next, as was the case in Chapter 6, we observe that the coefficients are of similar magnitude for the practice-based group size and office-based group size, while the coefficients for hospital-based group size measurements are of considerably smaller. Also repeating a previously observed trend, we can see that when group size measurements only count cardiologists who place stents, as opposed to all cardiologists, the magnitude of the coefficient estimates is again larger. Interestingly, whereas instrumenting for practice-based group size increases the magnitude of the coefficient estimates but eliminates the statistical significance, instrumenting for office-based group size does not eliminate the observed statistical significance of coefficients, yet increases the magnitude of the estimates.

The results for the examination of how different group size measurements relate to the secondary outcomes of interest (*initial extent of DES change*, *time to maximum DES* *change*, and *full extent of DES change*) are provided in Tables 7.10 – 7.12. Of note, we see that in all cases the observed pattern in coefficient signs remains: there is positive sign on the coefficient estimate for group size, but a negative sign on the coefficient estimate for the interaction term. However, in most cases, the results are not statistically significant. One set of exceptions, though, are the coefficients from the analysis of effect of hospital-based group size on *initial extent of DES change*, seen in Table 7.10. Also, the results in Table 7.12 show strong significant relationship between group size and *full extent of DES change*, both for the group size and interaction coefficients, regardless of which organization and physician type were used to measure group size. Generally speaking, these coefficients relating group size to secondary DES behavior outcomes also exhibit many of the trends observed in the analysis of *time to initial DES change*, e.g. smaller magnitude for hospital-based group measurement, larger magnitude for stent-implanting cardiologist measurements, and (where there is sufficient statistical significance to differentiate the point estimates from 0) larger magnitude for IV analyses.

## 7.4 – Discussion

As described above, the purpose of the analyses performed in this chapter is to identify the difference in how group size influences DES disadoption behavior relative to how it influences DES adoption behavior. Though the approach used here addresses this goal, it comes with caveats. One major challenge is the interpretation of coefficients on variables that now represent a combination of DES adoption and disadoption behavior. For example, the coefficient on group size in these analyses indicates the relationship between group size and both adoption and disadoption together. If these processes are separate and different, they are conflated into a single measure here, thus losing their distinction. However, the interaction of group size with the disadoption phase indicator variable separates out the effect of group size on disadoption. So, to determine the net effect of group size on DES disadoption, these two coefficients need to be added together. If group size has an identical impact on DES adoption and disadoption, the coefficient estimate on the interaction term should be indistinguishable from zero.

Thus, it is interesting to observe that, in the analysis of *time to initial DES change* (in Tables 7.1, 7.5, and 7.9), we observe a positive coefficient estimate on group size but a larger negative coefficient on the interaction term, indicating that an increase in group size is associated with an decrease in *time to DES disadoption*, but an increase in *time to DES adoption*. Interestingly, this observation indicates that the two processes are not symmetric, disagreeing with the theoretical model established in Chapter 4, but agreeing with the empirical results noted in both Chapters 5 and 6. Despite belief that the technology adoption and disadoption processes are theoretically similar in many ways, the empirical results, now estimated three different ways, all indicate that along the dimensions measured here, these two processes are notably different.

The observed difference in the effect of group size on adoption and disadoption is also interesting in its own right, but it is also somewhat confusing that the estimated net effect of group size on *time to initial disadoption* is of the opposite sign as was observed in

Chapter 6 analyses. One major difference between these analyses and those performed in Chapter 6 is the difference in covariates used in the analyses. Whereas Chapter 6 used a long list of physician- and practice-level characteristics, along with DES adoption measures, the analyses performed here replace physician- and practice-level characteristics with physician-level fixed effects and DES adoption measures with the combined adoption/disadoption measures. Though these combined adoption/disadoption covariates have statistically significant coefficient estimates in many of the analyses here, these coefficients are both complicated and confusing to interpret. For example, because DES disadoption behaviors are included in both the covariate and outcome variable, the observed relationship may be the result of correlation of different disadoption behaviors, unlike the relationships between adoption and disadoption measures that were studied in Chapters 5 and 6.

It should be noted in this discussion that (as described above), in order to study the relationship between group size and technology adoption, I need to impute practice and office size measures in 2003 and 2004. Though, as discussed above, we do not expect there to be systematic within-sample bias in these imputed group size measures, there is still a concern regarding global trends in group size over time. Namely, as discussed earlier, physician practice have been systematically increasing in size (on average) over recent years, which may mean that my backward imputation of group size overestimates practice sizes in 2003 and 2004. If this is true, it may indicate that the coefficient estimates on the group size variable are underestimates, which could partially explain the observed net negative effect of group size on *time to initial DES disadoption*.

Ultimately, the analyses performed here provide some insight into how group size differentially relates to DES adoption behavior and DES disadoption behavior, but these insights are somewhat limited and are counterbalanced by a series of new questions. More investigation into this topic is required to develop a complete understanding of this topic.

**Table 7.1**: Effect of practice size (all cardiologists) on *time to initial DES change*, basic OLS regression results

| Physician time (quarters) to initial DES change | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) |
|---|---|---|---|
| Practice size (number of cardiologists) | 0.044** [0.02,0.07] | 0.059* [0.00,0.12] | 0.062* [0.01,0.11] |
| Interaction: practice size X disadoption indicator | -0.116*** [-0.14,-0.09] | -0.121*** [-0.15,-0.09] | -0.114*** [-0.15,-0.08] |
| Physician time (quarters) to maximum DES change | | | -0.033* [-0.07,-0.00] |
| Physician initial extent (size) of DES change | | | 6.050*** [5.13,6.97] |
| Physician full extent (size) of DES change | | | -3.176*** [-4.00,-2.35] |
| r2 | 0.044 | 0.502 | 0.599 |
| F | 34.335 | 1.350 | 1.988 |
| p | 0.000 | 0.000 | 0.000 |
| N | 1500.000 | 1500.000 | 1500.000 |
| Unique docs | 639 | 639 | 639 |
| Physician FEs | | X | X |
| Incremental F stata | | 1.236083228 | 69.2882838 |
| Prob > incrm F | | 0.001972238 | 4.04986E-40 |

**Table 7.2**: Effect of practice size (all cardiologists) on *initial extent of DES change*, basic OLS regression results

| Physician initial extent (size) of DES change | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) |
|---|---|---|---|
| Practice size (number of cardiologists) | 0.010*** [0.01,0.01] | 0.009*** [0.00,0.01] | 0.000 [-0.00,0.00] |
| Interaction: practice size X disadoption indicator | -0.021*** [-0.02,-0.02] | -0.021*** [-0.02,-0.02] | -0.002 [-0.00,0.00] |
| Physician time (quarters) to initial DES change | | | 0.027*** [0.02,0.03] |
| Physician time (quarters) to maximum DES change | | | -0.008*** [-0.01,-0.01] |
| Physician full extent (size) of DES change | | | 0.475*** [0.43,0.52] |
| r2 | 0.200 | 0.548 | 0.735 |
| F | 186.614 | 1.627 | 3.695 |
| p | 0.000 | 0.000 | 0.000 |
| N | 1500.000 | 1500.000 | 1500.000 |
| Unique docs | 639 | 639 | 639 |
| Physician FEs | | X | X |
| Incremental F stata | | 1.037940405 | 201.6159992 |
| Prob > incrm F | | 0.305820911 | 6.6928E-99 |

**Table 7.3**: Effect of practice size (all cardiologists) on *time to maximum DES change*, basic OLS regression results

| Physician time (quarters) to maximum DES change | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) |
|---|---|---|---|
| Practice size (number of cardiologists) | 0.138*** [0.08,0.19] | 0.119* [0.01,0.23] | 0.096 [-0.01,0.20] |
| Interaction: practice size X disadoption indicator | -0.135*** [-0.19,-0.08] | -0.134*** [-0.19,-0.08] | -0.094* [-0.17,-0.02] |
| Physician time (quarters) to initial DES change | | | -0.139* [-0.28,-0.00] |
| Physician initial extent (size) of DES change | | | -7.685*** [-9.68,-5.69] |
| Physician full extent (size) of DES change | | | 5.988*** [4.29,7.69] |
| r2 | 0.018 | 0.518 | 0.570 |
| F | 14.051 | 1.440 | 1.767 |
| p | 0.000 | 0.000 | 0.000 |
| N | 1500.000 | 1500.000 | 1500.000 |
| Unique docs | 639 | 639 | 639 |
| Physician FEs | | X | X |
| Incremental F stata | | 1.392915325 | 35.04898756 |
| Prob > incrm F | | 3.2058E-06 | 2.27438E-21 |

**Table 7.4**: Effect of practice size (all cardiologists) on *full extent of DES change*, basic OLS regression results

| Physician full extent (size) of DES change | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) |
|---|---|---|---|
| Practice size (number of cardiologists) | 0.018*** [0.02,0.02] | 0.017*** [0.01,0.02] | 0.011*** [0.01,0.02] |
| Interaction: practice size X disadoption indicator | -0.036*** [-0.04,-0.03] | -0.036*** [-0.04,-0.03] | -0.024*** [-0.03,-0.02] |
| Physician time (quarters) to initial DES change | | | -0.020*** [-0.02,-0.01] |
| Physician time (quarters) to maximum DES change | | | 0.009*** [0.01,0.01] |
| Physician initial extent (size) of DES change | | | 0.661*** [0.60,0.73] |
| r2 | 0.448 | 0.591 | 0.723 |
| F | 606.496 | 1.938 | 3.483 |
| p | 0.000 | 0.000 | 0.000 |
| N | 1500.000 | 1500.000 | 1500.000 |
| Unique docs | 639 | 639 | 639 |
| Physician FEs | | X | X |
| Incremental F stata | | 0.471012944 | 136.9062509 |
| Prob > incrm F | | 1 | 1.89098E-72 |

**Table 7.5**: Effect of practice size (all cardiologists) on *time to initial DES change*, instrumental variable regression results

| Physician time (quarters) to initial DES change | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) |
|---|---|---|---|
| Practice size (number of cardiologists) | -0.947 [-3.98,2.08] | 0.034 [-0.42,0.48] | 0.107 [-0.16,0.38] |
| Interaction: practice size X disadoption indicator | 1.945 [-4.42,8.31] | 0.549 [-0.55,1.65] | -0.094 [-0.40,0.21] |
| Physician time (quarters) to maximum DES change | | | -0.020 [-0.06,0.02] |
| Physician initial extent (size) of DES change | | | 6.494*** [5.59,7.40] |
| Physician full extent (size) of DES change | | | -2.873 [-6.97,1.22] |
| r2 | . | . | 0.611 |
| F | | | |
| p | 0.828 | 1.000 | 0.000 |
| N | 1096.000 | 1096.000 | 1096.000 |
| Unique docs | 484 | 484 | 484 |
| Physician FEs | | X | X |
| Chi-squared | 0.377923035 | 242.1580658 | 1655.033333 |
| First stage F | 0.109261804 | 0.27789886 | 1.851239779 |
| Incremental chi2 | | 240.2876918 | 302.7038498 |
| Prob > incrm chi2 | | 1 | 2.58566E-65 |

**Table 7.6**: Effect of practice size (all cardiologists) on *initial extent of DES change*, instrumental variable regression results

| Physician initial extent (size) of DES change | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) |
|---|---|---|---|
| Practice size (number of cardiologists) | -0.056 [-0.27,0.16] | 0.017 [-0.00,0.03] | -0.017 [-0.04,0.00] |
| Interaction: practice size X disadoption indicator | 0.124 [-0.33,0.57] | -0.027 [-0.07,0.02] | 0.021 [-0.00,0.04] |
| Physician time (quarters) to initial DES change | | | 0.038*** [0.03,0.05] |
| Physician time (quarters) to maximum DES change | | | -0.005** [-0.01,-0.00] |
| Physician full extent (size) of DES change | | | 0.774*** [0.47,1.08] |
| r2 | . | 0.509 | 0.675 |
| F | | | |
| p | 0.853 | 0.000 | 0.000 |
| N | 1096.000 | 1096.000 | 1096.000 |
| Unique docs | 484 | 484 | 484 |
| Physician FEs | | X | X |
| Chi-squared | 0.318986698 | 741.1423124 | 2473.218788 |
| First stage F | 0.109261804 | 0.27789886 | 2.032953926 |
| Incremental chi2 | | 735.8059979 | 205.9633879 |
| Prob > incrm chi2 | | 8.60796E-13 | 2.17044E-44 |

**Table 7.7**: Effect of practice size (all cardiologists) on *time to maximum DES change*, instrumental variable regression results

| Physician time (quarters) to maximum DES change | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) |
|---|---|---|---|
| Practice size (number of cardiologists) | 0.359<br>[-1.28,2.00] | 0.344<br>[-0.09,0.77] | 0.030<br>[-0.58,0.64] |
| Interaction: practice size X disadoption indicator | -0.382<br>[-3.82,3.06] | -0.164<br>[-1.22,0.89] | 0.202<br>[-0.50,0.90] |
| Physician time (quarters) to initial DES change | | | 0.049<br>[-0.29,0.39] |
| Physician initial extent (size) of DES change | | | -7.399***<br>[-9.77,-5.03] |
| Physician full extent (size) of DES change | | | 10.441*<br>[0.17,20.71] |
| r2 | 0.002 | 0.527 | 0.537 |
| F | | | |
| p | 0.279 | 0.000 | 0.000 |
| N | 1096.000 | 1096.000 | 1096.000 |
| Unique docs | 484 | 484 | 484 |
| Physician FEs | | X | X |
| Chi-squared | 2.550577445 | 1181.907294 | 1341.303877 |
| First stage F | 0.109261804 | 0.27789886 | 1.824113705 |
| Incremental chi2 | | 1165.080759 | 88.26645945 |
| Prob > incrm chi2 | | 3.14089E-58 | 5.16249E-19 |

**Table 7.8**: Effect of practice size (all cardiologists) on *full extent of DES change*, instrumental variable regression results

| Physician full extent (size) of DES change | Model 1 (β/[95%CI]) | Model 2 (β/[95%CI]) | Model 3 (β/[95%CI]) |
|---|---|---|---|
| Practice size (number of cardiologists) | 0.052<br>[-0.04,0.14] | 0.043***<br>[0.02,0.07] | 0.024*<br>[0.00,0.04] |
| Interaction: practice size X disadoption indicator | -0.091<br>[-0.28,0.10] | -0.073*<br>[-0.14,-0.01] | -0.013<br>[-0.04,0.01] |
| Physician time (quarters) to initial DES change | | | -0.018***<br>[-0.03,-0.01] |
| Physician time (quarters) to maximum DES change | | | 0.011**<br>[0.00,0.02] |
| Physician initial extent (size) of DES change | | | 0.843***<br>[0.53,1.16] |
| r2 | . | 0.286 | 0.682 |
| F | | | |
| p | 0.248 | 1.000 | 0.000 |
| N | 1096.000 | 1096.000 | 1096.000 |
| Unique docs | 484 | 484 | 484 |
| Physician FEs | | X | X |
| Chi-squared | 2.791709401 | 223.004581 | 2082.174851 |
| First stage F | 0.109261804 | 0.27789886 | 1.301719839 |
| Incremental chi2 | | 215.8092308 | 175.3442844 |
| Prob > incrm chi2 | | 1 | 8.92923E-38 |

**Table 7.9**: Effect of physician group size on *time to initial DES change*, using different group measures (organization and physician type) and analysis methods (standard and IV)

| Time to initial DES change | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| Physician type | All docs | Group size | 0.062* [0.01,0.11] | 0.078** [0.02,0.13] | 0.003 [-0.00,0.01] | Standard (non-IV) analysis |
| | | Interaction | -0.114*** [-0.15,-0.08] | -0.148*** [-0.19,-0.10] | -0.006** [-0.01,-0.00] | |
| | Stent docs | Group size | 0.086* [0.00,0.17] | 0.128** [0.04,0.22] | 0.003 [-0.00,0.01] | |
| | | Interaction | -0.198*** [-0.26,-0.14] | -0.211*** [-0.28,-0.14] | -0.006** [-0.01,-0.00] | |
| | All docs | Group size | 0.107 [-0.16,0.38] | 0.335* [0.00,0.67] | X | Instrumental variable analysis |
| | | Interaction | -0.094 [-0.40,0.21] | -0.397** [-0.66,-0.14] | | |
| | Stent docs | Group size | 0.306 [-0.81,1.42] | 0.314 [-0.13,0.76] | X | |
| | | Interaction | -0.422 [-2.05,1.20] | -0.599** [-1.05,-0.15] | | |

See tables 7.1 and 7.5

**Table 7.10**: Effect of physician group size on *initial extent of DES change*, using different group measures (organization and physician type) and analysis methods (standard and IV)

| Initial extent of DES change | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| Physician type | All docs | Group size | 0.000 [-0.00,0.00] | -0.000 [-0.00,0.00] | 0.001*** [0.00,0.00] | Standard (non-IV) analysis |
| | | Interaction | -0.002 [-0.00,0.00] | -0.003* [-0.01,-0.00] | -0.001*** [-0.00,-0.00] | |
| | Stent docs | Group size | -0.001 [-0.01,0.00] | -0.002 [-0.01,0.00] | 0.001*** [0.00,0.00] | |
| | | Interaction | -0.001 [-0.01,0.00] | -0.004 [-0.01,0.00] | -0.001*** [-0.00,-0.00] | |
| | All docs | Group size | -0.017 [-0.04,0.00] | -0.010 [-0.03,0.01] | X | Instrumental variable analysis |
| | | Interaction | 0.021 [-0.00,0.04] | -0.002 [-0.02,0.02] | | |
| | Stent docs | Group size | -0.047 [-0.14,0.05] | 0.003 [-0.03,0.03] | X | |
| | | Interaction | 0.075 [-0.06,0.21] | -0.023 [-0.06,0.01] | | |

See tables 7.2 and 7.6

**Table 7.11**: Effect of physician group size on *time to maximum DES change*, using different group measures (organization and physician type) and analysis methods (standard and IV)

| Time to max. DES change | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| Physician type | All docs | Group size | 0.096 [-0.01,0.20] | 0.067 [-0.04,0.17] | 0.001 [-0.01,0.01] | Standard (non-IV) analysis |
| | | Interaction | -0.094* [-0.17,-0.02] | -0.082 [-0.17,0.00] | -0.003 [-0.01,0.00] | |
| | Stent docs | Group size | 0.107 [-0.06,0.27] | 0.075 [-0.09,0.24] | 0.002 [-0.01,0.01] | |
| | | Interaction | -0.127 [-0.26,0.00] | -0.080 [-0.21,0.05] | -0.003 [-0.01,0.01] | |
| | All docs | Group size | 0.030 [-0.58,0.64] | 0.556 [-0.11,1.22] | X | Instrumental variable analysis |
| | | Interaction | 0.202 [-0.50,0.90] | -0.556 [-1.12,0.01] | | |
| | Stent docs | Group size | -0.266 [-2.71,2.18] | 0.312 [-0.53,1.16] | X | |
| | | Interaction | 0.825 [-2.77,4.42] | -0.469 [-1.40,0.46] | | |

See tables 7.3 and 7.7

**Table 7.12**: Effect of physician group size on *full extent of DES change*, using different group measures (organization and physician type) and analysis methods (standard and IV)

| Full extent of DES change | | | Organization type | | | |
|---|---|---|---|---|---|---|
| | | | Practice | Office | Hospital | |
| zPhysician type | All docs | Group size | 0.011*** [0.01,0.02] | 0.014*** [0.01,0.02] | 0.002*** [0.00,0.00] | Standard (non-IV) analysis |
| | | Interaction | -0.024*** [-0.03,-0.02] | -0.031*** [-0.03,-0.03] | -0.005*** [-0.01,-0.00] | |
| | Stent docs | Group size | 0.020*** [0.01,0.03] | 0.025*** [0.02,0.03] | 0.003*** [0.00,0.00] | |
| | | Interaction | -0.042*** [-0.05,-0.04] | -0.050*** [-0.05,-0.05] | -0.005*** [-0.01,-0.00] | |
| | All docs | Group size | 0.024* [0.00,0.04] | 0.022 [-0.01,0.05] | X | Instrumental variable analysis |
| | | Interaction | -0.013 [-0.04,0.01] | -0.006 [-0.03,0.02] | | |
| | Stent docs | Group size | 0.060** [0.02,0.10] | 0.038* [0.00,0.07] | X | |
| | | Interaction | -0.079* [-0.14,-0.02] | -0.007 [-0.05,0.04] | | |

See tables 7.4 and 7.8

# CHAPTER 8: Conclusions

The topic of medical technology disadoption is one that has been rarely studied in the existing health economics and health services research literatures. However, given the importance of medical technology in driving both the overall US health care system expenditure and the annual growth rate of that expenditure, there is a large and growing need for an in-depth understanding of the technology disadoption process. Indeed, partially motivated by the understanding of the critical role of medical technology, there is a well-established high level of academic interest in the technology adoption process, resulting in a vast literature on medical technology diffusion. Nevertheless, as supported by the growing popularity of the Choosing Wisely campaign, it has become increasingly clear that the disadoption of medical technologies is an integral part of health system operations designed to improve the efficacy and value of clinical medicine. Thus, there is real value to improving our understanding and evaluation of the medical disadoption process, including our knowledge of factors that influence that process.

The framework that I develop in this dissertation to characterize the disadoption process provides a reproducible, quantitative means to evaluate changes in technology use. The complexity of this framework highlights some of the intricacies of the disadoption process and may provide some insight into why relatively little published research has previously examined medical technology disadoption; though academically interesting and practically important, technology disadoption is more nuanced and less intuitive than technology adoption, thus more challenging to study theoretically or empirically. Along with the characterization framework, I also develop a decision-theoretic model, which helps incorporate physician organizational features—specifically, group size—into our understanding of the technology change behavior, generating insight and predictions to be tested empirically. The technology of coronary drug-eluting stents (DES)—which underwent rapid diffusion in the US in 2003-04, followed by widespread abandonment in 2006-07—provides a convenient setting for empirical investigation of technology disadoption.

Among the interesting empirical results described in the preceding chapters is the finding that there may be a negative relationship between physician group size and time to initiation of the technology disadoption process, indicating that physicians in larger groups begin to disadopt DES later. Though the results are not statistically significant, point estimates of the coefficients are consistently negatively signed in various analyses throughout Chapter 6. Interpreted in the context of the theoretical model I developed in Chapter 4, these results suggest the possibility that, in the current setting of DES disadoption, the balance between the opposing forces of collective benefit (through intra-group information sharing via shared efforts) and collective cost (through effort-shirking incentivized by the possibility of free-loading on group members' efforts) that comes with increasing group size may weigh in favor of the communal cost and detriment. If true, this result should give pause to researchers and policy-makers who promote the virtues of increasing physician group sizes, offering the possibility that larger groups may contribute to delayed technology disadoption and its corresponding detriments. Even if not true, the potential for these results should be sufficient to raise concerns about one potential implication of the ongoing trend toward larger physician groups.

Of course, we must again note that these results are not statistically significant, so the above interpretation is only suggestive. Furthermore, the findings from Chapter 7 point toward an opposite relationship between group size and time to initial DES disadoption, further highlighting the complexity of this issue and underlines the need for future research. For such future work to build on the current research it would ideally include a larger dataset, with more observation and variables, to provide additional statistical power and process insight. However, even with such data improvements, it is likely that concern for enodgeneity issues would remain, as it is hard to imagine an exogenous variation in group size, i.e. a change in group size occurring without a simultaneous change in physician practice environment in ways that would, independent of group size, influence technology use decisions (or more specifically, in ways *less* concerning than those already discussed in this dissertation). For these reasons, we must keep the current results in perspective and, despite their weaknesses, appreciate the value that they add to the current understanding and discussion of these issues.

Aside from these potential findings relating group size to timing of the disadoption process, this dissertation also investigates the relationship between disadoption and the preceding adoption of the same technology. One of the few empirical relationships observed between these two processes was a weak (likely statistically insignificant) negative relationship between speed of technology adoption and timing of the initiation of the disadoption process, i.e. physicians who took less time (were faster) to fully adopt DES were more likely to take more time (be slower) to start disadopting DES (or conversely, those who were slower to reach full adoption tended to be quicker to start the disadoption process). As discussed above, this observation would be consistent with physician behavior being shaped by, among other possible factors, product loyalty or risk aversion. This theorized effect of these factors is also consistent with the observation that higher levels of maximum technology use were associated with increased time to reach minimum technology use post-disadoption, i.e. physicians with higher maximum levels of DES use tended to take longer to reach their minimum DES use levels (or conversely, physicians with lower maximum DES use levels tended to reach their post-disadoption minimum DES use level more quickly). Of course, noting that these adoption and disadoption behaviors are consistent with behavioral factors does not mean that those factors cause the observed behaviors. Unfortunately, given the both the inherent connection between adoption and disadoption, along with the complexity of these behaviors, it is difficult to imagine a situation in which exogenous variation of technology adoption behavior could be identified, allowing us to determine its independent causal influence on the disadoption process.

Beyond this potentially weak relationship between timing of disadoption and rate of adoption, I find empirically—across multiple different analytic approaches with multiple different specifications—that there is not strong evidence of symmetry between the adoption and disadoption processes. This is one of the relatively few instances in academic research where a null finding is just as interesting as, if not more than, a statistically significant quantitative result, whether positive or negative. Indeed, one major takeaway from this dissertation is that despite extensive investigation, there is little empirical evidence of significant associations between a physician's technology adoption behavior and her disadoption behavior. This indicates that, despite the theoretic similarities between these two processes, they appear to be empirically disparate and unrelated. Of course, as discussed above, there are some setting-specific factors that may contribute to or increase the possibility of these null results, including limited statistical power and a relatively brief period of study. However, this null finding, if valid, should enhance our motivation—already heightened by the inherent importance of the topic—for further research into technology disadoption because it indicates that we may not be able to draw much inference or insight into the disadoption process from the existing vast literature on technology adoption. That is to say, these empirical results indicate that researchers and policy-makers may possibly know even less than they think they do about technology disadoption, with relatively little work currently available to guide their evaluation and assessment of this high-value topic. Thus, the need for future research on medical technology disadoption is even greater.

# APPENDIX 3: Illustrations of adoption/disadoption framework

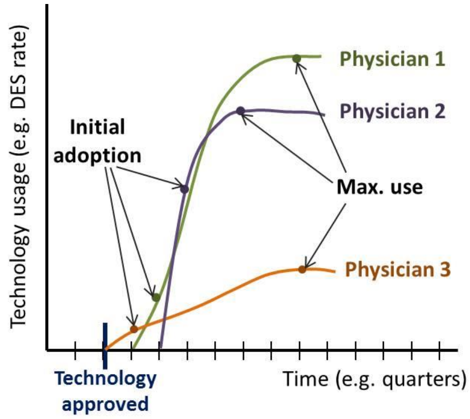



**Figure 3A.1**: Three physicians' technology use during adoption

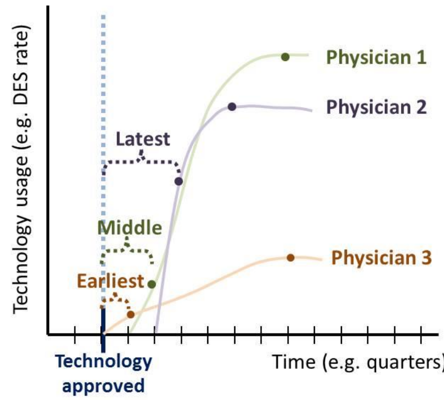



**Figure 3A.2**: Time to initial adoption

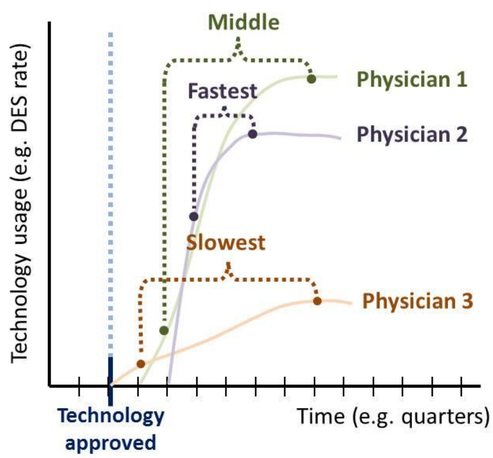



**Figure 3A.3**: Time from initial to maximum use ("speed" of adoption)

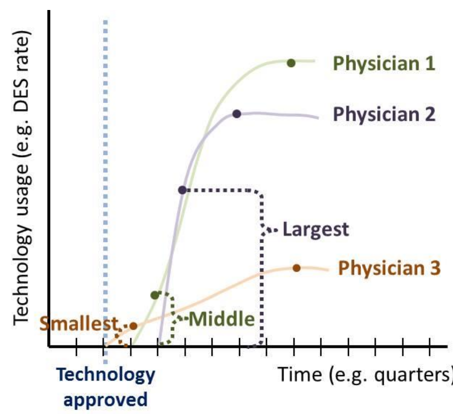



**Figure 3A.4**: Initial extent of adoption

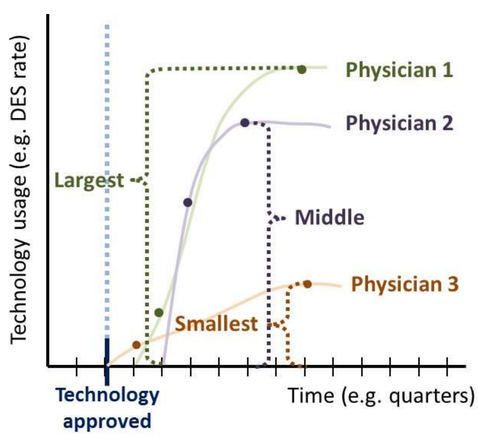



**Figure 3A.5**: Full extent of adoption

| Adoption dimension | Physician 1 | Physician 2 | Physician 3 |
|---|---|---|---|
| Time to initial | Middle | Latest | Earliest |
| Speed of | Middle | Fastest | Slowest |
| Initial extent | Middle | Largest | Smallest |
| Full extent | Largest | Middle | Smallest |

**Table 3A.1**: Summary of Figures 3A.1 – 3A.5

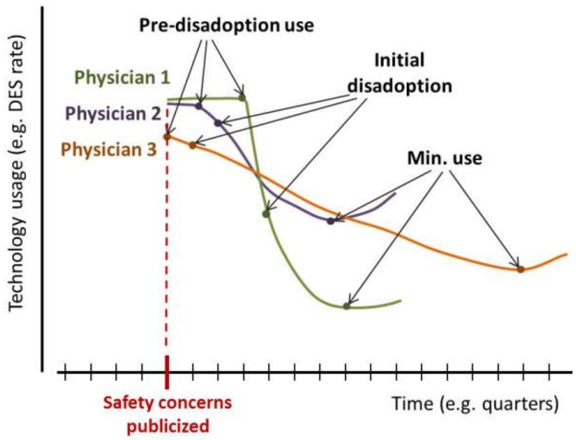



**Figure 3A.6**: Three physicians' technology use during disadoption

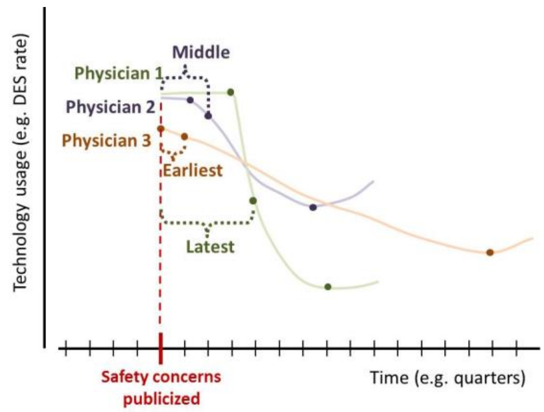



**Figure 3A.7** Time to initial disadoption

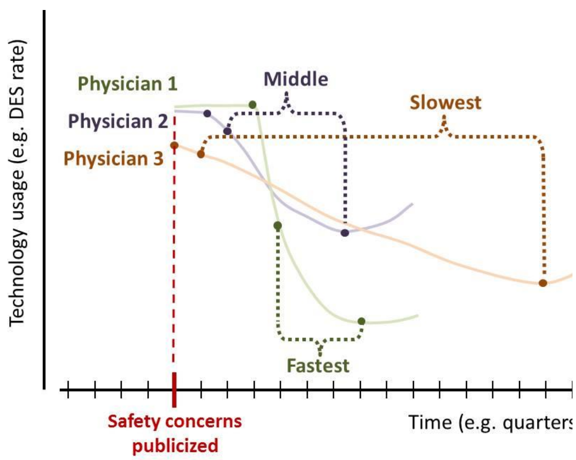



**Figure 3A.8**: Time from initial to maximum use ("speed" of disadoption)

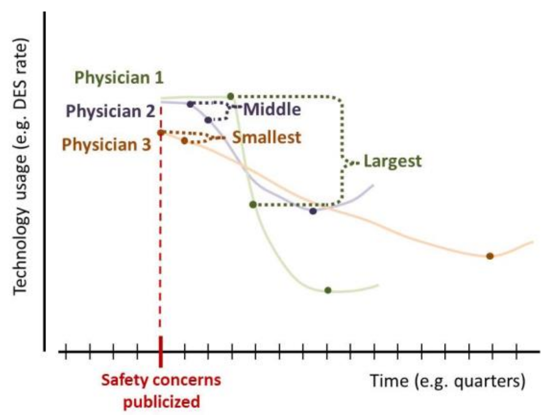



**Figure 3A.9**: Initial extent of disadoption

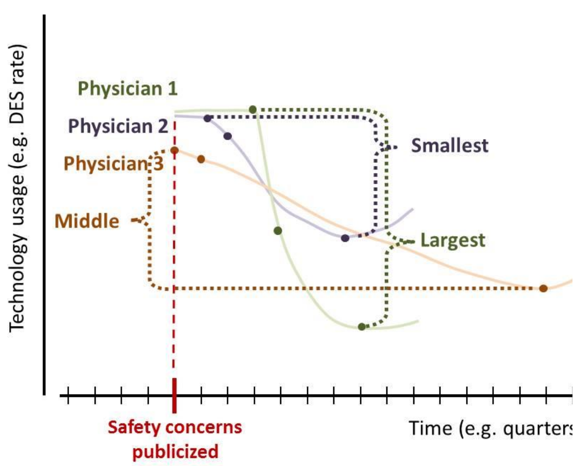



**Figure 3A.10**: Full extent of disadoption

| Disadoption dimension | Physician 1 | Physician 2 | Physician 3 |
|---|---|---|---|
| Time to initial | Latest | Middle | Earliest |
| Speed of | Fastest | Middle | Slowest |
| Initial extent | Largest | Middle | Smallest |
| Full extent | Largest | Smallest | Middle |

**Table 3A.2**: Summary of Figures 3A.6 – 3A.10

## APPENDIX 4: Theoretical model calculations

Restating the first-order condition from equation (4) and applying equation (3) to solve for $\partial\kappa/\partial e$:

$$\frac{dU}{de} = \frac{\partial U}{\partial \kappa}\frac{\partial \kappa}{\partial e} + \frac{\partial U}{\partial e} = \frac{\partial U}{\partial \kappa}\frac{\partial}{\partial e}\left\{1 - \left[(1-\theta)\big(1-g(e)\big)\right]^{nt}\right\} + \frac{\partial U}{\partial e}$$

$$= \frac{\partial U}{\partial \kappa}(1-\theta)^{nt} nt\big(1-g(e)\big)^{nt-1}\frac{\partial g}{\partial e} + \frac{\partial U}{\partial e} = 0$$

Next, because one of our interests is examining the relationship between group size and time (to disadoption), we can choose to express this equation as an explicit function of $n$ and $t$, and apply the implicit function theorem to determine $dt/dn$. That is, we have:

$$F(n,t) = \frac{\partial U}{\partial \kappa}(1-\theta)^{nt} nt\big(1-g(e)\big)^{nt-1}\frac{\partial g}{\partial e} + \frac{\partial U}{\partial e} = 0$$

and we want to solve for:

$$\frac{dt}{dn} = -\frac{\partial F/\partial n}{\partial F/\partial t}$$

We start by solving for the numerator, using the convenient substitution $y = nt - 1$:

$$\frac{\partial F}{\partial n} = \frac{\partial F}{\partial y}\frac{\partial y}{\partial n} = \frac{\partial}{\partial y}\left\{\frac{\partial U}{\partial \kappa}(1-\theta)^{y+1}(y+1)\big(1-g(e)\big)^{y}\frac{\partial g}{\partial e} + \frac{\partial U}{\partial e}\right\}\frac{\partial y}{\partial n}$$

$$= \frac{\partial U}{\partial \kappa}(1-\theta)\frac{\partial g}{\partial e}\frac{\partial y}{\partial n}\frac{\partial}{\partial y}\left\{(y+1)\left[(1-\theta)\big(1-g(e)\big)\right]^{y}\right\}$$

$$= \frac{\partial U}{\partial \kappa}(1-\theta)\frac{\partial g}{\partial e}t\left[(y+1)\ln\big(f(e)\big)\,(f(e))^{y} + (f(e))^{y}\right]$$

$$= \frac{\partial U}{\partial \kappa}(1-\theta)\frac{\partial g}{\partial e}t\left[nt\ln\big(f(e)\big) + 1\right](f(e))^{nt-1}$$

where $f(e) = (1-\theta)\big(1-g(e)\big)$. Solving for the denominator ($\partial F/\partial t$) is slightly more complicated because time, $t$, is a function of effort, $e$. That is, for a given value of $\kappa$, the likelihood of critical knowledge acquisition, the amount of time $t$ required to reach that likelihood will depend on the knowledge acquisition effort expenditure $e$. So, what we need to calculate here is:

$$\frac{\partial F}{\partial t} = \frac{\partial F}{\partial e}\frac{\partial e}{\partial t}$$

The calculation of $\partial e/\partial t$ will require us to revisit equation (3), which we rewrite here:

$$G(e,t) = 1 - \kappa - \left[(1-\theta)\big(1 - g(e)\big)\right]^{nt} = 0$$

so that we can again apply the implicit function theorem:

$$\frac{\partial e}{\partial t} = -\frac{\partial G/\partial t}{\partial G/\partial e}$$

Again, we start by solving for the numerator of this new expression, and we use the substitution $x = nt$:

$$\frac{\partial G}{\partial t} = \frac{\partial G}{\partial x}\frac{\partial x}{\partial t} = \frac{\partial}{\partial x}\left\{1 - \kappa - \left[(1-\theta)\big(1-g(e)\big)\right]^{x}\right\}\frac{\partial x}{\partial t}$$

$$= -\ln\big(f(e)\big)\big(f(e)\big)^{x}\frac{\partial x}{\partial t} = -nt\ln\big(f(e)\big)\big(f(e)\big)^{nt}n$$

Now for the denominator:

$$\frac{\partial G}{\partial e} = (1-\theta)^{nt}nt\left[\big(1-g(e)\big)\right]^{nt-1}\frac{\partial g}{\partial e}$$

$$= (1-\theta)nt\big(f(e)\big)^{nt-1}\frac{\partial g}{\partial e}$$

Combining the two, we have:

$$\frac{\partial e}{\partial t} = -\frac{\partial G/\partial t}{\partial G/\partial e} = \frac{nt\ln\big(f(e)\big)\big(f(e)\big)^{nt}n}{(1-\theta)nt\big(f(e)\big)^{nt-1}\frac{\partial g}{\partial e}} = \frac{\ln\big(f(e)\big)f(e)n}{(1-\theta)\frac{\partial g}{\partial e}}$$

Returning our attention to the previous expression, we can next calculate $\partial F/\partial e$:

$$\frac{\partial F}{\partial e} = \frac{\partial}{\partial e}\left\{\frac{\partial U}{\partial \kappa}(1-\theta)^{nt} nt\big(1-g(e)\big)^{nt-1}\frac{\partial g}{\partial e} + \frac{\partial U}{\partial e}\right\}$$

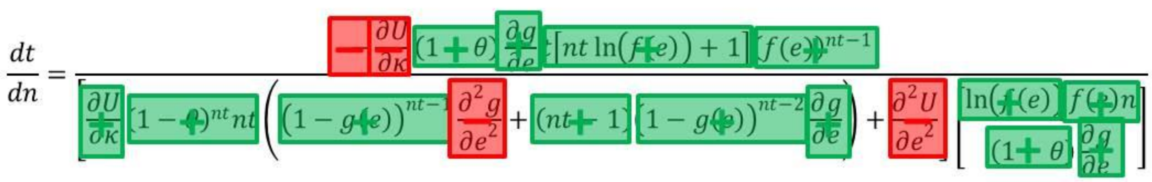
$$= \frac{\partial U}{\partial \kappa}(1-\theta)^{nt} nt\left[\big(1-g(e)\big)^{nt-1}\frac{\partial^2 g}{\partial e^2} + (nt-1)\big(1-g(e)\big)^{nt-2}\frac{\partial g}{\partial e}\right] + \frac{\partial^2 U}{\partial e^2}$$

Finally, we can combine all of the pieces:

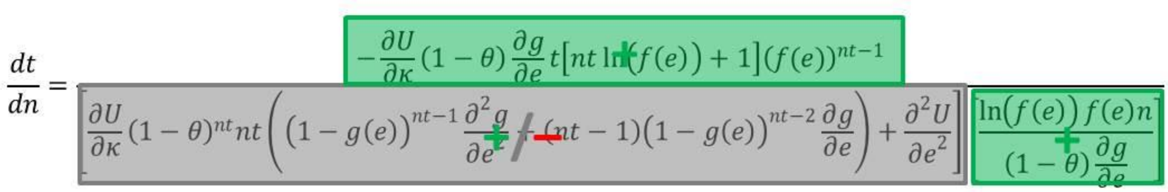
$$\frac{dt}{dn} = -\frac{\partial F/\partial n}{\partial F/\partial t} = -\frac{\partial F/\partial n}{\frac{\partial F}{\partial e}\frac{\partial e}{\partial t}}$$

$$= \frac{-\frac{\partial U}{\partial \kappa}(1-\theta)\frac{\partial g}{\partial e}t\left[nt\ln\big(f(e)\big)+1\right](f(e))^{nt-1}}{\left[\frac{\partial U}{\partial \kappa}(1-\theta)^{nt} nt\left(\big(1-g(e)\big)^{nt-1}\frac{\partial^2 g}{\partial e^2} + (nt-1)\big(1-g(e)\big)^{nt-2}\frac{\partial g}{\partial e}\right) + \frac{\partial^2 U}{\partial e^2}\right]\left[\frac{\ln\big(f(e)\big)f(e)n}{(1-\theta)\frac{\partial g}{\partial e}}\right]}$$

As described in the text of the chapter, one of my primary interests is identifying the sign of the above expression. Working through the individual components, utilizing the assumptions about the functions $U(e,\kappa)$ and $g(e)$ that were listed above, and using green to label positively signed terms and red to label negatively signed terms, we have the following:



in which the signs reduce to:



In total, we can see that the sign of $dt/dn$ as ambiguous, i.e. time to acquisition of critical information, which triggers disadoption, may either increase or decrease with group size. Examination reveals that the sign of the above expression depends on the relative magnitudes of the different factors that appear in the first large term of the denominator, including physician utility from knowledge and disutility from effort; time (i.e. number of periods) and group size; and both the effort-based and effort-independent likelihoods of acquiring critical knowledge.

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