Innovation and Cross-Market Spillovers in "Big" Firms

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Abstract

Substantial interest has been paid to how increasingly "big" or dominant firms in many sectors of the economy might extend market power or realize economies of scope across product markets that are distinct but share common buyers. Using detailed panel data at the seller-buyer-month level, we quantify the size of and explore the mechanisms underlying these cross-market spillovers in a set of medical device markets serving cardiac catheterization labs. In particular, we show how discrete innovations in one product category induce purchases by the *same buyer* from the *same seller* in a separate product category. These buyer-level spillovers represent nearly 10 percent of market share and one-fifth of all demand spillovers across markets. They also imply significant benefits to innovation for large multiproduct firms relative to single-category ones in this setting. Our exploration of mechanisms are consistent with complementarities in usage or promotion for products that share related features. We find no evidence of spillovers leading to price increases.

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1 Introduction

Firms that produce and sell multiple products or services across related business areas dominate industries as diverse as automobiles, food and beverages, consumer electronics, pharmaceuticals, insurance, and airlines (Borenstein 1991). Various types of economies of scale and scope or firm-specific capabilities can explain the prevalence of this phenomenon, with implications for firm decisions ranging from innovation to sales.[1] Because of this, firm managers, policy makers, and regulators must understand which of these sources contribute to a firm's dominance when determining their actions.[2] The ability of firms to generate spillovers across markets can derive from practices that extend market power or from efficiencies possible only in multiproduct firms. Indeed, this can be thought of as the extension across product markets of two longstanding debates regarding whether profits of big firms are driven by market power or efficiencies (e.g., Clarke et al. 1984; Demsetz 1974; Peltzman 1977) and whether innovation should be expected from big or small firms (e.g., Cohen and Levin 1989; Gans et al. 2002; Schumpeter 1942). However, the endogenous nature of firm decisions, the difficulty of assembling sufficiently detailed data, and the potential for multiple mechanisms to operate simultaneously all make it challenging to empirically estimate and disentangle the sources behind any correlated successes a "big" or dominant firm may experience across its product markets.

In this paper, we use detailed buyer-supplier purchase data and the quasi-exogenous timing of new product innovations to investigate spillovers across product markets in medical devices—an industry increasingly dominated by large multiproduct firms whose "portfolio strategies" have gained attention from regulatory authorities in the EU and share certain similarities with the large tech firms that have come under scrutiny on both sides of the Atlantic.[3] Our detailed data allow us to estimate cross-market, buyer-level spillovers—how changes in purchases in one product market induce changes in purchases by the *same buyer* (hospital) from the *same seller* (device manufacturer) in another product market. As such, we extend prior research relying on more aggregate data to isolate mechanisms that work across versus within buyers and also provide evidence regarding which buyer-level mechanisms are consistent with the data. Understanding these mechanisms is important not only for firm managers deciding how best to target consumers but also for regulators determining whether performance advantages for large firms stem from market power or

[1] Explanations for the prevalence and success of such firms include: superior firm-specific capabilities or supply-side economies of scope in advertising, sales, or R&D (Atalay et al. 2014; Cockburn and Henderson 1994; Panzar and Willig 1981; Teece 1980), cross-selling opportunities or contracting practices that offer buyers a benefit if they concentrate their purchases with a single firm (Cabral and Natividad 2016; Ho et al. 2012; Nalebuff 2000, 2004; Whinston 1990), and reputation effects or other complementarities that may be leveraged across product lines (Cabral 2000; Garthwaite 2014; Gavazza 2011; Hendricks and Sorensen 2009).

[2] For example, recent antitrust rulings in telecommunications (Winkler 2018) and internet software (Satariano 2019) have been driven by concerns about spillovers across product categories and innovation. Cross-market mergers, such as those between hospitals serving geographically distinct regions, or pharmaceutical firms selling products in quite distinct markets, have also been called into question (Dafny et al. 2019).

[3] There is a general belief in the medical device industry that "product range" can be an asset, and the European Commission has included this as a possible factor in at least one medical device merger case. See Commission Decision, Case No COMP/M.3687 – Johnson & Johnson/Guidant (August 25, 2005), available at `http://ec.europa.eu/competition/mergers/cases/decisions/m3687_20050825_20600_en.pdf`.

multiproduct firm efficiencies.

There are multiple potential mechanisms behind such buyer-level spillovers, which in terms of their economics, have analogs to other multiproduct settings. First, a firm's products may have some complementarities in usage due to better integration or similar design across categories. Second, economies of scope may exist in contracting with or coordinating purchases from a few large firms rather than many small firms. Finally, contracts might bundle or otherwise tie purchases across categories. We empirically evaluate for the possibility of these different mechanisms.

Key to this study is a comprehensive seller-buyer-month-level dataset, matching sales data for multiple device categories offered by device manufacturers to the same hospital in the same month. Our data cover a sample of US hospitals' purchases from 2007 through 2012 of the three most important categories of devices in interventional cardiology: coronary stents (stents), balloon catheters (balloons), and guidewires. These devices are used together in angioplasty procedures that treat blockages in the arteries surrounding the heart. The data allow us to measure each manufacturer's prices and market share within each device category in each hospital in each month. The raw data indicate that hospitals purchasing a large share of one of these devices from a given manufacturer tend to also purchase a large share of the other devices from the same manufacturer: Within-firm cross-market correlations in shares range between 51 and 76 percent.

To determine the sources behind this apparent scope advantage, we use difference-in-differences regressions that exploit variation in within-hospital stent shares resulting from the quasi-exogenous timing of new innovations in the stent market during our sample period. Specifically, we document how the introduction of the first few generations of drug-eluting stents (DES), an important technological advance (Burt and Hunter 2006; Htay and Liu 2005), resulted in economically meaningful movements of market share to the innovating manufacturers. The key identification assumption underlying this research design is that changes in stent share at the time of the DES innovations are uncorrelated with contemporaneous changes in balloon or guidewire share, except through those DES innovations.[4] Uncertainty surrounding the timing of regulatory approval (Stern 2017) means that the precise timing of a DES approval is unlikely to be correlated with events in the balloon or guidewire markets (which were also relatively stable technologies during this time period). This is supported by no pre-trends in event studies around these introduction events.

In light of recent advances in the econometrics literature raising concerns about dynamic treatment effect heterogeneity in settings with staggered treatment timing (Goodman-Bacon 2021; Sun and Abraham 2021), we employ a "stacked" difference-in-differences approach (e.g., Gormley and Matsa 2011) that avoids these concerns. We focus on the three DES introductions with the largest immediate impact on the innovating firm's US stent market share during our sample period. For each introduction event, we construct a separate dataset of hospitals actively purchasing devices in interventional cardiology at the time. Each dataset restricts to event windows from three months before through three months after the relevant DES introduction. We then stack these separate

[4]Note that this type of product-specific variation is relatively rare. It is analogous to observing a large shift in a search engine's market share and measuring the ensuing effect on the engine's other consumer products such as email or shopping tools, at the individual consumer level.

datasets together and implement all analyses on the combined, stacked dataset.

Estimating models with progressively richer fixed effects lets us decompose the sources of any spillovers that exist, including whether they operate across or within buyers. Manufacturer-hospital fixed effects control for time-invariant unobservables that impact the sales of a manufacturer's devices at large (such as firm capabilities that might be constant in the short run) and also in a particular hospital (such as heterogeneity in sales quality or brand preferences). Manufacturer-month fixed effects control for time-varying unobservable factors that impact sales of a manufacturer's devices in all hospitals in a month (such as increased advertising). Given our stacked approach, we interact these fixed effects with event indicators so that manufacturer-hospital and manufacturer-month trends are allowed to vary across the different events. With the inclusion of these two sets of fixed effects, our regressions can be interpreted as estimating whether increases in a given hospital's use of a given manufacturer's stents, over and above its average use of that manufacturer's stents surrounding a given DES introduction event, are associated with increases in that (same) hospital's use of that (same) manufacturer's balloons and guidewires, over and above the average increase in that month by other hospitals in the data.

Our analyses deliver three main results: First, we find evidence of economically and statistically significant buyer-level spillovers in this setting. When hospitals increase their use of a manufacturer's stents, they also increase their use of that manufacturer's balloons. In our preferred specification, we find that a 10-percentage-point (about one-third of a standard deviation) increase in a manufacturer's within-hospital stent share is associated with a 1.1-percentage-point increase in its within-hospital balloon share. At the market shares observed in our data, this implies that the average multi-category firm enjoys a 4-percentage-point (10 percent of mean balloon share) advantage in its balloon share at hospitals where it sells stents, relative to the single-category firm selling only balloons. Comparing these magnitudes to those obtained when we estimate less saturated specifications suggests that these buyer-level spillovers encompass nearly one-fifth of all demand spillovers across markets.

Second, while we find that increases in a manufacturer's within-hospital stent share are associated with increases in its within-hospital balloon share, we do not find a similar relationship between stents and guidewires at the hospital level. This is interesting because one would expect many potential buyer-level mechanisms (e.g. economies of scale in sales and distribution or cross-market pricing schemes) to operate similarly across product markets. The only mechanism we hypothesize that is category-specific is the possibility of complementarities in usage. Indeed, stents and balloons share design complementarities such that a physician who is familiar with a given manufacturer's stents will naturally be familiar with that manufacturer's balloons, whereas the same does not hold for stents and guidewires.

Third, for both balloons and guidewires, we decompose the effects we measure into their extensive and intensive margins. Specifically, we investigate whether a manufacturer's stent use in a hospital results in the hospital using the manufacturer's other products and/or the hospital increasing its use of those products (conditional on using them). We find that hospitals that increase their

stent usage along the intensive margin also increase the amount of balloons used from the same manufacturer, but not the amount of guidewires from that manufacturer. Similarly, when we explore the impact of hospitals' changes in stent usage along the extensive margin, we find that those hospitals that begin to purchase a manufacturer's stents also tend to purchase its balloons, but not its guidewires. If economies of scope in contracting were driving the spillovers in this setting, we would expect to see extensive-margin impacts across a firm's product markets. The lack of such a finding suggests that while frictions in developing new contracts may exist between buyers and suppliers, and that economies of scope in contracting may faciliate hospitals' purchases of stents and balloons from the same manufacturer, the design complementarities that exist between these two device markets is the driving mechanism behind the buyer-level spillovers we observe.

The results also suggest that the mechanisms driving spillovers in our setting are distinct from previous work that has investigated the role of various types of contracting practices in propagating firm success across product markets. These include Cabral and Natividad (2016) and Ho et al. (2012), which study bundling by wholesalers, and Borenstein (1991) and Lederman (2007, 2008), which consider the effects of customer loyalty programs.[5] Our price regression results and qualitative interviews with market participants suggest that such incentive-based contracting practices are not prevalent enough to explain a quantitatively important amount of the spillovers we estimate.

More broadly, this paper relates to the literature on the economics of multiproduct industries and the benefits to firm scope (Bailey and Friedlaender 1982; Teece 1982), as incumbents may use product line extensions to deter entry by competitors (Schmalensee 1978), to raise market share (Lancaster 1979), or to increase sales and prices (Draganska and Jain 2005; Lederman 2007). Our study builds on this literature in two ways. First, these studies typically explore how changes in firm scope—as measured by discrete changes in the product categories in which a firm operates—impact performance. Our research design, however, holds scope in terms of discrete category presence fixed. Instead, we examine changes in scope as measured by the *extent* of a firm's success in a category; that is, we evaluate how continuous changes in firm market share in one category affect sales in related categories. This helps to clarify that *success* of a firm in other categories, not simply existence of an offering, is an important determinant of scope effects.

Our paper is also related to the small (again, speaking to the difficulty of empirical work on these forces) body of literature that empirically measures the magnitude of and mechanisms behind demand spillovers. Gavazza (2011) evaluates the relationship between firms' product varieties and demand spillovers in the mutual fund industry. Hendricks and Sorensen (2009) show that releasing a new album causes an increase in sales of an artist's old albums, especially if the new release is a hit. Their results are consistent with a model of costly search where consumers discover the artist upon hearing the new release. Garthwaite (2014) finds that advertising in the form of celebrity endorsements raises purchases of non-endorsed titles written by endorsed authors; his results similarly point to information about product quality as a mechanism behind the spillovers.

[5] Theoretical work on tying, bundling, and cross-subsidization of products suggests that these practices can also deter entry by new firms (Baseman 1981; Nalebuff 2000, 2004; Spence 1977; Whinston 1990).

While these studies examine demand spillovers at the aggregate level, our buyer-level data allow us to speak to additional mechanisms that would be difficult to uncover from aggregate sales data, although several of our results echo theirs. Our specification with only manufacturer fixed effects—which allows for spillovers both across and within buyers, but does not control for unobserved heterogeneity in buyer-manufacturer preferences—is more akin to the specifications in those papers. To our knowledge, our study is the first to estimate *buyer-level* spillovers within firms across product markets in any industry. Our results indicate that buyer-level spillovers are responsible for about one-fifth of the broader demand spillovers from stents, which is important because several prominent mechanisms behind both increased market power and also multiproduct efficiencies operate at the buyer level. Indeed, the effects we estimate for balloons, for which the evidence points to similarities in user experience across product categories due to shared physical features, could also have a manifestation in horizontal preferences for aspects of media by the same author, for example.[6]

The remainder of this paper is organized as follows. Section 2 describes our empirical setting and provides relevant institutional background. Section 3 provides details regarding the dataset construction and descriptive patterns. Section 4 presents our empirical approach. Section 5 reports and discusses our results. A final section discusses further implications for multiproduct firm strategy and antitrust policy, as well as directions for future research.

2 Industry background

In this section, we provide relevant institutional background information on the specific medical devices we study and the procedures for which they are used. We discuss the purchasing/sales process underlying the prices and quantities observed in this market as well as the regulatory approval process via which new products enter the market. At each step, we relate the institutions to the broader theoretical mechanisms we seek to test.

2.1 Interventional cardiology

Interventional cardiologists focus on the treatment of coronary and vascular conditions using non-surgical, catheter-based treatments. The size of the global interventional cardiology market makes it an economically meaningful industry for study in its own right. One estimate valued the global market in 2013 at approximately $15 billion and forecasts it to reach more than $25 billion by 2020 (PRNewsire 2018). In our data, we focus on three devices—coronary stents, balloon catheters, and guidewires—that play prominent roles in interventional cardiology's most common procedure, balloon angioplasty.

Balloon angioplasty was introduced in the 1960s to relieve obstruction and narrowing of the coronary artery. From a vascular access point in the arm or leg, a guidewire is maneuvered to

[6] This result also relates to prior theoretical work on firm strategies surrounding product compatibility (Matutes and Regibeau 1988).

locate (using radiographic imaging) and cross a blockage in the arteries surrounding the heart. A balloon catheter (we use the term "balloon" for short throughout the text) is then pushed along the guidewire to the lesion and expanded at high pressure to push open the blockage. After this balloon is removed, a stent—a small, expandable mesh metal tube (a "stent" as purchased from the manufacturer is actually a stenting system, consisting of the stent mounted on its own balloon catheter)—is then guided to the blockage, where the stent is expanded to support the arterial walls. The stent is then left in the artery to prevent it from re-closing.[7] Though the balloons that deploy stents operate under different pressure than those used to push open blockages, they are constructed similarly and have similar control and feel. Consequently, physicians who develop experience with a given manufacturer's stents will naturally be familiar with that manufacturer's balloons. Guidewires are quite different and have control and feel characteristics that are distinct from the catheters that they guide. Because guidewires are the device used to insert and place the other devices, physician familiarity and comfort with a given type of guidewire may be particularly important. These differences between balloons and guidewires and their relation to stents provide an important source of variation as we seek to understand the mechanisms underlying any buyer-level spillovers. Importantly, the core balloon and guidewire technologies (and their relationship to stents) have remained stable over the period we study.[8]

2.2 Hospital purchasing process

Hospitals generate revenue by performing a procedure (such as an angioplasty with a stent), and the price of the device is an input cost the hospital incurs. The physician who performs the procedure—and, importantly, makes the primary decision about what devices to use for a given case—will typically be compensated either as a salaried employee of the hospital or on a fee-for-service basis for the procedure. In either case, the financial benefits to the physician are unrelated to the specific brand of device used. However, physicians typically have strong preferences over which brand to use for a given patient/lesion type because devices are differentiated in physical characteristics of the implanted device itself (for example, stent brands are differentiated on shape, strength, flexibility, and type of drug/polymer) and also characteristics that affect ease of implantation (such as, unexpanded size and flexibility, and the controls and capabilities of the balloons and guidewires used in delivery). In fact, stents are a leading example of a device critical to a procedure, which health care professionals often refer to as "physician preference items."

A given brand is typically purchased directly from its manufacturer via a local sales representative, who is in charge of both sales and distribution, and thus an every week if not every day fixture at the hospital. The manufacturer holds inventory on site at the hospital, and the purchase is

[7] For the reader interested in more details on angioplasty and stenting, the NIH Medline Plus website https://medlineplus.gov/ency/article/007473.htm provides a good place to start, and we found the images at https://vascularsurgeryassociates.net/balloon-angioplasty/ especially clear on the role of the three devices we study in this paper.

[8] We thank Jeff Solomon, MD, MBA, and Robert Li, MD, for sharing the invententionalist's perspectives regarding the relationships between stents, balloons, and guidewires.

made when the physician pulls the product off the shelf and implants it into the patient. Contracts typically specify a linear price for the contract duration, often a year, but are renegotiated more frequently if market conditions change. Most hospitals have materials management or purchasing departments with agents who specialize in negotiations. Sometimes a large business unit, such as a catheter lab in the case of stents, will coordinate its own purchasing separately from the rest of the hospital.[9] In either case, the administrator will play an important role in device pricing and (with input from physicians) in what devices are stocked on the hospital shelves. The administrator will also interact with the same manufacturer across many product categories, creating the potential for spillovers across product categories if some costs of an administrator contracting with a given supplier are fixed.

2.3 Device manufacturers and sales

In the US during the time of our study, there are four manufacturers of coronary stents, all of which also sell balloons and guidewires. There are also manufacturers who sell balloons and/or guidewires, but not stents.[10] These manufacturers all possess integrated R&D and sales/marketing capabilities that may be deployed across all three of these product categories and can potentially serve as a source of economies of scale and scope. The existence of firm capabilities or scope economies that are not buyer-specific make it especially important to have panel data at the buyer level. Further, the fact that firms are not changing whether or not they sell in a given product category over time highlights the importance of instead relying on new product innovation that induces changes in the *extent* of a firm's success in a given category (both across and within buyers) in our identification strategy.[11]

Medical device sales are typically organized to serve needs surrounding related procedures performed by specific groups of physicians, e.g. orthopedic implants or catheter-based interventions. Within these broader areas, there can be even further specialization—for catheter-based interventions this is often split between interventional cardiology (mostly focused on the heart and surrounding vessels) and interventional radiology (mostly focused on peripheral and other vasculature of the body, e.g. surrounding the kidneys). Interventional cardiology sales representatives tend to develop close relationships with physicians and staff of the catheter lab for two reasons. First, the sales representatives have strong technical and clinical knowledge related to the devices

[9] See Schneller (2009) for more qualitative details on pricing in medical devices. Grennan and Swanson (2019b) document a variety of evidence regarding device contracts in a different sample of US hospitals. They also find that the use of quantity, market share, or bundled discounts do not seem to play an empirically important role in pricing for stents, balloons, and guidewires.

[10] This feature of the market structure seems at least in part related to the large fixed costs associated with regulatory approval for stents in the US, as the EU has many more firms (Grennan and Town 2020). In an earlier working paper version of this manuscript (Grennan et al. 2018), we also examined the EU market and found similar effects to those we report here for the US. We find this reassuring in that it is consistent with the buyer-level spillovers we document persisting in environments with different regulatory and pricing regimes.

[11] As mentioned earlier, all of these firms are also active in selling devices outside of interventional cardiology. We restrict to a single specialty in order to focus on detailed buyer- and user-level spillover effects. For more details see, for example, Medtronic's website for cardiovascular products: https://www.medtronic.com/us-en/healthcare-professionals/products/cardiovascular.html.

and procedures. Because of this, sales representatives are often in the operating room during a procedure. Second, representatives also perform the task of distribution. The salesperson is responsible for making sure that shelves are stocked with the various types and sizes of devices a physician might need and is expected to be responsive within an hour or two (at any time, day or night) if a physician needs an item that is not stocked on the shelf. At a large hospital, the sales representative will stop by the catheter lab at some point nearly every day. Most relevant for our study here, when a new stent is sold, the same sales representative will be providing these services for not only stents, but also balloons and guidewires, offered by the manufacturer.[12]

2.4 Regulatory approval process

Medical device regulation in the US mandates that the FDA determine a device "safe and effective" to grant market access. Devices fall into classes (I, II and III), based on perceived health risk. A Class III device is defined as one used in "supporting or sustaining human life, of substantial importance in preventing impairment of human health, or presents a potential unreasonable risk of illness or injury." Stents are Class III, while balloons and guidewires are Class II. In the US, the approval process for a Class III device generally requires data from randomized clinical trials, involving thousands of patients and costing tens of millions of dollars to complete.[13]

The first coronary stents were approved by the FDA in 1994. Our empirical strategy (discussed in more detail in Section 4) exploits the introduction of drug-eluting stents (DES), stents that are coated with a drug that is slowly released over time to inhibit scar tissue growth. Many large randomized clinical trials showed improved outcomes from DES relative to bare-metal stents (Htay and Liu 2005). The first DES were approved by the FDA in 2003, and successive generations of DES improved to the point that angioplasty has replaced coronary artery bypass graft as the most prevalent treatment for coronary artery disease. In addition to the inherent uncertainty in the timing of regulatory approvals when large clinical trials are involved, Stern (2017) documents that there was also uncertainty in the regulatory process itself for these early DES, affecting the timing of their introduction.

3 Data and descriptive statistics

Our data come from Millennium Research Group's (MRG) *MarketTrack* survey of hospital medical device purchasing patterns. The survey is a key source of market intelligence in the medical device sector and aims to produce representative estimates of the distribution of market shares and prices

[12] Exact representative responsibilities and product portfolios vary somewhat across manufacturers, but our discussions with industry insiders indicate that the three products we study here are always sold by the same person. This was also confirmed via recent searches of firm job postings. For the interested reader, we found Boston Scientific's postings at http://www.bostonscientific.com/content/gwc/en-US/careers.html especially clear. The relevant job was "IC Therapy Consultant," last accessed March 8, 2019.

[13] For more details on FDA device regulation, see https://www.fda.gov/medical-devices/device-advice-comprehensive-regulatory-assistance/overview-device-regulation. See Makower et al. (2010) for a survey on device approval time and costs.

of medical devices by country. Our data include a sample of hospitals in the US, covering about 10 percent of hospitals by revenue from 2007 through 2012. The data contain information on the precise quantities of each interventional cardiology device purchased by a hospital in a month. We limit our sample to the three categories of devices within interventional cardiology (based on MRG's segmentation) that hospitals most often purchase: stents, balloons, and guidewires. Because manufacturers may produce multiple products within the same category (e.g., several different balloon products), we aggregate a hospital's purchases of different products from the same manufacturer in the same category. The resulting dataset includes 60,388 manufacturer-hospital-month observations.[14]

Our data verify that it is common for interventional cardiology device manufacturers to operate across categories. Averaging across firm-months in the data, 57 percent of firms which sell devices in one of the three device categories we consider, sell in all three. Forty-three percent of firms sell in only a single category in a month.[15] No firms sell in two of the three categories. The prevalence of firms selling in multiple categories creates the potential for spillovers to operate. On average, the three devices are used in roughly equal quantities, between 65 and 70 units each per hospital per month. See Appendix Table 4 for more detailed summary statistics on quantities.

Our main variables of interest are within-category shares, s^c_{jht}, measuring the overall share of all devices in category c purchased by hospital h in month t that are produced by manufacturer j. This variable is calculated as the total number of units q manufacturer j sells in category c to hospital h divided by the total number of units of devices in that category that hospital h buys from all manufacturers. Our overall share measure accounts for censoring at zero by explicitly including manufacturer-category-hospital-month observations with zero units purchased ($q^c_{jht} = 0$), provided the hospital is reporting data and the manufacturer has a product available (in any category) during that month. In some specifications, we distinguish changes in hospitals' usage along the intensive and extensive margins. To capture the extensive margin, we construct an indicator $\mathbb{1}_{\{s^c_{jht}>0\}}$ which equals one if manufacturer j is active in category c in hospital h at month t.[16] The intensive margin share variable is then simply the conditional share $s^c_{jht}|\mathbb{1}_{\{s^c_{jht}>0\}}$. We think of these extensive and intensive margin share variables as providing relatively fine measures of a manufacturer's scope at the buyer (hospital) level. Precise variable definitions appear in Appendix A.2.

The first three columns of Table 1 provide means and standard deviations of the hospital-level share variables. The next two columns show the mean number of manufacturers active in a

[14] Because the MRG survey is focused first on collecting data on coronary stents, other product category data is missing in a small number of hospitals. We restrict our sample to hospital-months reporting data on all three of our categories of interest. We also account for censoring at zero by explicitly including zero-unit observations ($q^c_{jht} = 0$), provided the hospital is reporting data and the manufacturer has a product available (in any category) during that month. More details on sample construction are available in Appendix A.1.

[15] Averaging across hospital-month observations, only 15 percent of stent purchases, 29 percent of balloon purchases, and 19 percent of guidewire purchases come from a single manufacturer. Only 3.7 percent of hospital-month purchases come from the same manufacturer for all devices.

[16] We consider a manufacturer as active in a hospital in a given device category if it sold to that hospital in that device category in that month *or* any of the three months prior. This definition thus allows us to smooth any random variation from month to month in whether a hospital purchases from a given manufacturer, and interpret this variable as when a hospital truly starts/stops purchasing from a manufacturer in a given category.

Table 1: Summary statistics

	p^c_{jht}	$\mathbb{1}_{\{s^c_{jht}>0\}}$	$s^c_{jht}\|\mathbb{1}_{\{s^c_{jht}>0\}}$	$\|J^c_m\|$	$\|J^c_h\|$
stents	1,593.5	0.337	0.361	4.00	2.79
	(474.5)	(0.473)	(0.314)	(0.00)	(0.91)
balloons	269.4	0.295	0.414	5.00	2.42
	(164.4)	(0.456)	(0.367)	(0.00)	(0.99)
guidewires	83.5	0.323	0.378	6.20	2.65
	(16.7)	(0.467)	(0.327)	(0.79)	(1.04)

Table provides means and standard deviations (in parentheses) for hospital-level prices and shares by category in the typical month. $|J^c_m|$ gives mean number of manufacturers active in the market by category, and $|J^c_h|$ gives mean number of manufacturers active in a given hospital by category. Mean number of US hospitals in the typical month is 102.2, with a standard deviation of 4.8. Total number of manufacturer-hospital-month observations is 60,388. Price data are only available when positive quantities are purchased, in which case the total number of manufacturer-hospital-month observations is 18,502 for stents, 15,586 for balloons, and 17,169 for guidewires.

category at the overall US market and hospital levels, respectively. The final column gives mean hospital-level prices by category. On average, across months in our data, there are between 4 and 6 manufacturers active in each device category and between 2 and 3 manufacturers active in each hospital, indicating that the market is more concentrated at the hospital level than country level. The means of the indicator variables reveal that, on average, in a given month, a manufacturer will sell its devices to about 30 percent of hospitals in the US market (30 percent for balloons, 32 percent for guidewires, and 34 percent for stents). Conditional on selling to a hospital in a category, a manufacturer accounts for, on average, between 36 and 41 percent of the devices purchased by the hospital in that category. Among these three devices, stents are substantially more expensive, at an average price of $1,594, than both balloons ($269) and guidewires ($84). Appendix Table 5 provides additional summary statistics on prices.

To motivate our analysis, we examine the raw correlation between a manufacturer's within-hospital shares in different categories. We see a strong positive correlation between manufacturers' within-hospital stent shares and within-hospital balloon shares (0.759). We also observe a positive correlation between a manufacturer's within-hospital stent and guidewire shares (0.513) as well as between its balloon and guidewire shares (0.525), though the magnitudes are smaller. Of course, these correlations cannot distinguish spillovers from other unobservable factors that may cause a hospital to concentrate its purchase of devices in different categories with the same manufacturer. The empirical strategy we develop below aims to do this.

4 Empirical approach

The goal of our empirical analysis is to identify the presence, magnitude, and potential mechanisms of buyer-level spillovers in this setting. To do this, we exploit discrete changes to stent shares that result from innovative DES product entry. We employ stacked difference-in-differences regressions

that focus on seven-month windows surrounding three major DES introductions. Uncertainty in the precise timing of regulatory approval discussed previously allows us to consider the stent share changes that result as plausibly exogenous with respect to balloon and guidewire market trends, especially within the narrow time windows we study in this specification.[17] Our main estimating equation is the following, where e indexes introduction events:

$$s_{jhte}^{balloons/gwires} = \beta s_{jhte}^{stents} + \delta_{jhe} + \delta_{jte} + \epsilon_{jhte} \tag{1}$$

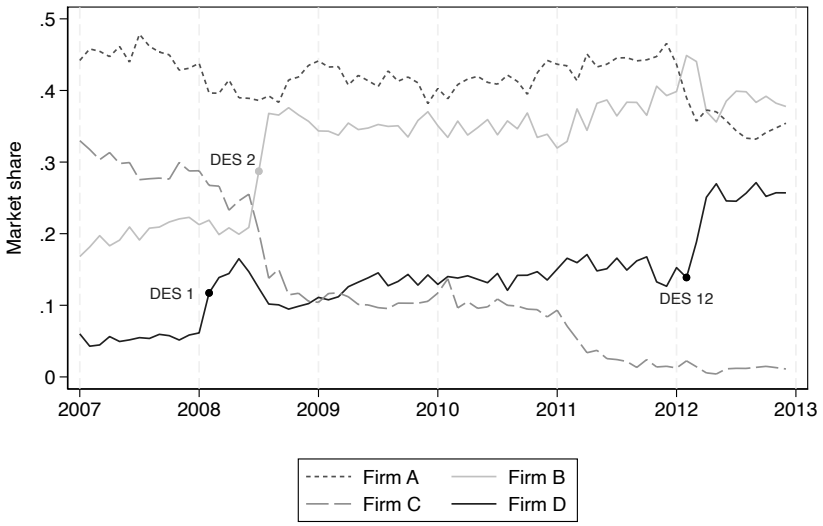
The key parameter of interest is β which captures how a manufacturer's within-hospital balloon (or guidewire) share changes as its within-hospital stent share changes. The primary challenge in estimating this equation is distinguishing buyer-level spillovers from other factors that would generate a positive correlation across a manufacturer's within-hospital shares in different device categories. For example, manufacturers that produce higher quality products may sell more of all of their products to particular hospitals. Alternatively, firms that initiate a marketing campaign may experience increases in the sales of all of their devices.

We address this by controlling for unobservable factors that may result in a correlation in the within-hospital shares of a manufacturer's different products in a given month. First, we include event-manufacturer-hospital fixed effects δ_{jhe} to control for time-invariant unobservable factors that may influence a manufacturer's sales of all three devices to a given hospital in the time surrounding the DES entry events. With the inclusion of these fixed effects, our estimates are identified by changes in the shares of products that a hospital purchases from a manufacturer, rather than differences in shares across hospitals, thus controlling for the possibility that some hospitals prefer devices from particular manufacturers.

Second, we include event-manufacturer-month fixed effects δ_{jte} to control for the possibility that, over time, manufacturers may take actions that improve the attractiveness of all of their products simultaneously. A change in a manufacturer's sales across product categories could result, for example, from a new advertising campaign or from positive or negative press coverage. By including these effects, we control for such changes, and we only identify spillovers from changes in a manufacturer's sales to a particular hospital, over and above any sales changes that manufacturer has in the market overall in that month. This ensures that we are estimating a hospital-level (buyer-level) relationship.

[17] DES introductions may be correlated with actions by the introducing firms which, in turn, impact balloon and guidewire sales such as increased sales effort. Because these actions would not have happened but for the introduction of the new stents, they are part of the spillovers we are trying to measure.

Figure 1: Three major DES introductions and stent market shares



Markers indicate the three major DES introductions of interest; lines give overall market share in stents. We plot market share for the four manufacturers active in the US stent market. Appendix Table 6 provides more details on the manufacturers active across the stent, balloon, and guidewire device categories.

The three particular DES events that we focus on had the largest immediate impact on the innovating firm's US stent market share during our sample period.[18] These product introductions induce changes in the stent shares of both the introducing firms and competing firms, both of which serve to identify our coefficient of interest. Figure 1 demonstrates this first stage—we see immediate changes in shares around all three events. Appendix B verifies no differential pre-trends at the manufacturer-hospital level in this first stage and the reduced forms for balloon and guidewire shares by discretizing our continuous treatment of stent share into positive, zero, and negative groups.

After obtaining estimates of spillovers using the major DES introductions, we decompose those spillovers into changes in the intensive and extensive margins. That is, we look at spillovers in terms of both the intensity of balloon (or guidewire) use and the probability of using that manufacturer's balloons (or guidewires) at all. Characterizing the pattern of spillovers along these different margins helps shed light on which mechanisms may be causing the spillovers to exist.

5 Results

In this section, we present the results of our analysis. First, we document evidence of economically and statistically significant buyer-level spillovers in the interventional cardiology device space. Next, we decompose these spillovers into their intensive and extensive margins, finding intensive- and extensive-margin impacts for balloons but not for guidewires. Finally, we discuss our collection of

[18] Appendix A.5 shows the changes in market share for innovating firms with DES product entries.

results and the possible mechanisms underlying them.

5.1 Buyer-level spillovers

Table 2 presents coefficient estimates from stacked difference-in-differences regressions of a firm's within-hospital share of either balloons or guidewires on that firm's within-hospital stent share at the time of three DES introductions. We focus on variation in stent shares resulting from these introductions, restricting to windows three months before and after each event (for seven months total including the introduction month). The first column in the table presents the specification with only event fixed effects. Subsequent columns separately add event-manufacturer, event-manufacturer-hospital, and event-manufacturer-month fixed effects.

Table 2: Spillovers

	Balloons				**Guidewires**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
s_{jhte}^{stents}	0.831***	0.614***	0.0938***	0.106***	0.534***	0.238***	0.0248**	0.0232
	(0.0241)	(0.0340)	(0.0288)	(0.0309)	(0.0281)	(0.0408)	(0.0124)	(0.0141)
Observations	18,200	18,200	17,460	17,460	18,200	18,200	17,460	17,460
Adj. R^2	0.530	0.654	0.943	0.943	0.256	0.595	0.947	0.947
Event FE	yes				yes			
Event-Mfr FE		yes				yes		
Event-Mfr-Hosp FE			yes	yes			yes	yes
Event-Mfr-Month FE				yes				yes

The dependent variable is $s_{jhte}^{balloons}$ for balloon specifications and $s_{jhte}^{guidewires}$ for guidewire specifications. Robust standard errors clustered at the hospital level are in parentheses. *** p<0.01, ** p<0.05, and * p<0.1.

We begin our discussion by looking at the relationship between stent and balloon shares in the left panel. The specification with only event fixed effects in Column (1) provides a coefficient estimate of 0.83, suggesting that a hospital's purchase of a manufacturer's stents in given month is highly correlated with its purchases of that manufacturer's balloons. Columns (2) through (4) build up our fixed effects. The positive difference between (1) and the specification with event-manufacturer fixed effects in (2) provides indirect evidence that there are unobserved manufacturer-specific attributes (potentially R&D or sales capabilities) which result in some manufacturers having higher shares of both stents and balloons. Column (3) differs from (2) in that it includes event-manufacturer-hospital fixed effects rather than event-manufacturer fixed effects. The smaller coefficient estimate (0.09 as compared to 0.61) indicates that there are unobserved factors at the manufacturer-hospital level (potentially physician preferences or effort by a sales representative) that are positively correlated across stents and balloons for the same manufacturer-hospital pair. Column (4) differs from (3) in that it adds event-manufacturer-month fixed effects.

Column (4) is our preferred specification. We find a coefficient on the within-hospital stent share of 0.11, indicating that a 10-percentage-point increase (about one-third of a standard deviation) in a manufacturer's stent share in a hospital generates a 1.1-percentage-point increase in its balloon

market share in that same hospital. This result has nontrivial implications for the performance of multi- versus single-category firms. To quantify this, consider that the average multi-category device manufacturer offering stents and balloons has a within-hospital stent share of 36 percent, and thus enjoys an advantage over a single-category firm selling only balloons of nearly 4 percentage points ($\beta_1 \cdot s_{jht}^{stents} \cdot 100 = 0.11 \cdot 36 = 4$). Relatedly, with balloon revenues at roughly 17 percent of stent revenues, this spillover provides the average multi-category stent manufacturer the equivalent of an additional 2-percent revenue boost, relative to a single-category stent manufacturer with no such spillovers.[19]

Comparing our preferred specification to those with coarser fixed effects provides insight into the robustness of our main buyer-level spillover estimate as well as its magnitude relative to firm-specific capabilities or other firm-level scope economies that are encompassed in the fixed effects. The similarity of Column (4) to Column (3) demonstrates that our preferred estimate of hospital-level spillovers represents a substantial portion of all factors that drive the correlations across categories within a manufacturer-hospital pair during these introduction events. Further, the magnitude of our estimate in Column (4) relative to the estimate in Column (1)—0.11 versus 0.83—suggests that within the broad class of all potential explanations of why sales might be correlated across categories within a manufacturer, the buyer-level spillovers we identify are quantitatively important.

Columns (5) through (8) present the same regressions as in the first four columns but with a manufacturer's within-hospital guidewire share as the dependent variable. As before, with the inclusion of event-manufacturer and event-manufacturer-hospital fixed effects in Columns (6) and (7), the coefficient estimates on within-hospital stent share fall relative to the specification with only event fixed effects (5). Moving from the specification with no fixed effects to one which includes manufacturer-hospital fixed effects decreases the coefficient on US within-hospital stent share from 0.53 to 0.025. As we add manufacturer-time fixed effects in Column (8), the coefficient on stent share declines slightly and is no longer statistically significant at conventional levels. Thus, in contrast to the case of balloons, we find limited evidence of buyer-level spillovers in guidewires. Manufacturer- and manufacturer-hospital-specific effects appear to explain most of the relationship between stent and guidewire shares.

5.2 Decomposition into extensive and intensive margins

Table 3 provides results that decompose extensive- and intensive-margin effects at the hospital level. This decomposition directly tests the extent to which the spillover mechanism is related to the amount of usage conditional on contracting (intensive margin) or to the contracting process itself (extensive margin). These results both help shed light on the mechanisms at work in our

[19] Appendix A.4.3 provides summary statistics by multi- and single-category status. Appendix Table A.3 provides descriptives on monthly quantities sold and prices paid. With balloons and stents used in almost equal quantities per hospital per month (68 units for balloons and 64 units for stents), and the average balloon ($269) priced at roughly 17 percent of the average stent ($1,594), we calculate per-hospital balloon revenues to be roughly 17 percent of stent revenues. Marginal costs in these medical device markets are typically thought to be very low relative to prices, with margins of 80 percent or more, making revenue a good proxy for profits (Burns 2005).

setting and contribute to a growing body of literature documenting evidence regarding the value of buyer-supplier relationships and the frictions to adding more suppliers (Allen et al. 2019; Grennan and Swanson 2019a; Ho and Lee 2017, 2019; Lee and Fong 2013). Understanding the mechanisms at play also allow us to begin to infer whether the buyer-level spillovers following new DES innovation appear to be more consistent with anticompetitive practices or efficiencies only possible within multiproduct firms.

Looking first at spillovers from stents to balloons, Column (1) of Table 3 replicates our preferred specification from the previous table. In Column (2), we decompose the spillovers into their intensive and extensive margins by adding as an independent variable an indicator for whether or not manufacturer j is actively selling any stents in hospital h at time t as the independent variable.[20] In doing so, the continuous overall stent share measure now captures the effect on the intensive margin and the indicator, the extensive margin. Comparing the coefficients in Column (2) to that in (1), we see that the increase in balloon share measured in our main specification is driven by changes in the intensive margin of stent usage.

Table 3: Decomposition

	Balloons				**Guidewires**			
	$s_{jhte}^{balloons}$		$\mathbb{1}_{\{s_{jhte}^{balloons}>0\}}$		$s_{jhte}^{guidewires}$		$\mathbb{1}_{\{s_{jhte}^{guidewires}>0\}}$	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
s_{jhte}^{stents}	0.11***	0.10***		0.06**	0.02	0.02		0.02
	(0.03)	(0.03)		(0.03)	(0.01)	(0.01)		(0.02)
$\mathbb{1}_{\{s_{jhte}^{stents}>0\}}$		0.01	0.07**	0.06**		0.00	0.03	0.03
		(0.01)	(0.03)	(0.03)		(0.01)	(0.02)	(0.02)
Observations	17,460	17,460	17,460	17,460	17,460	17,460	17,460	17,460
Adj. R^2	0.94	0.94	0.93	0.93	0.95	0.95	0.93	0.93
Event-Mfr-Hosp FE	yes	yes	yes	yes	yes	yes	yes	yes
Event-Mfr-Mth FE	yes	yes	yes	yes	yes	yes	yes	yes

Robust standard errors clustered at the hospital level are in parentheses. *** p<0.01, ** p<0.05, and * p<0.1.

Next, we explore whether changes in a hospital's stent purchases influence the probability that it purchases balloons at all from the same manufacturer. We change the dependent variable to an indicator for whether a hospital purchases a non-zero number of balloons from a given manufacturer in a month. Column (3) looks at the extensive margin for both stent and balloon purchases. Hospitals that purchase a manufacturer's stents are 7 percentage points more likely to also purchase its balloons than those that do not purchase the manufacturer's stents. In Column (4), we evaluate both the intensive and extensive stent margin impacts on the probability of contracting for balloons. In the months surrounding the major DES introductions, hospitals that begin purchasing stents

[20] As noted in the data section, we smooth random variation from month to month in whether a hospital purchases from a given manufacturer by defining this indicator as zero only when a hospital has not purchased from a manufacturer in a given category for 4 consecutive months. We interpret a change in this variable from 0 to 1 as reflecting a decision by a hospital to begin contracting with a given manufacturer in that category (and, similarly, 1 to 0 as stopping contracting).

from a given manufacturer are 6 percentage points more likely to purchase balloons from that same manufacturer.[21] Conditional on using a manufacturer's stents, a 10-percentage-point increase in the share of stents purchased increases the probability of balloon purchases by 0.6 percentage points. Thus changes in the probability of purchasing balloons from a given manufacturer are driven by changes in stent purchasing on both the intensive and extensive margins.

The remainder of Table 3 decomposes the stent-to-guidewire spillovers. As before, Column (5) replicates our preferred specification. Column (6) shows that neither the stent intensive nor extensive margin seems to affect overall guidewire share. Columns (7) and (8) use the extensive margin guidewire indicator as the dependent variable. The results reveal no intensive- or extensive-margin impacts of stent usage on the probability of guidewire usage at the hospital level.

5.3 Discussion

We now turn to a discussion of the results, highlighting noteworthy findings and the underlying economic mechanisms they suggest. First, our stacked difference-in-differences results clearly indicate the operation of meaningful buyer-level spillovers. The inclusion of event-manufacturer-hospital fixed effects rules out the possibility that our estimate results from hospitals simply preferring certain manufacturers or manufacturers having lower costs of serving certain hospitals.[22] The inclusion of event-manufacturer-month fixed effects rules out the possibility that our estimated effect is the result of unobservable actions by a manufacturer over time that impact its sales in multiple product categories. Thus, with the inclusion of these fixed effects and by focusing on short windows around the DES entry events, we feel confident that we are indeed uncovering a true spillover in the sense that the remaining estimated relationship between stent sales and balloon or guidewire sales at the hospital level must be due to a common response—by the hospital buyer—to the stent entry event. For balloons, the magnitude of this buyer-level spillover is large, amounting to roughly one-fifth of all demand spillovers across markets.

Second, the decomposition exercise we carry out in Table 3 reveals that buyer-level spillovers from stents onto balloons can be driven by changes along both the intensive and extensive margins. In particular, a manufacturer's within-hospital balloon share is closely related to its within-hospital stent share, with the extensive margin indicator for whether a manufacturer sells stents to a hospital having minimal additional explanatory power. However, the likelihood of a hospital using a manufacturer's balloons depends on both the indicator of stent usage and the continuous measure of stent share—though the indicator matters more at typical levels of stent purchases in the data. When we look at spillovers between stents and guidewires, we find no relationship along either the

[21] Recall that we smooth our contracting measure to consider manufacturers as active in a hospital if they sold devices in that category to that hospital in that month or any of the three months prior. Because our specifications include manufacturer-hospital fixed effects, this relationship is identified off of hospital-manufacturer pairs with a *change* in contracting status. It would also be correct to frame this effect in terms of stopping contracting instead of beginning.

[22] As our fixed effects in our primary specification subsume event-manufacturer fixed effects, they also rule out the possibility that the hospital-level relationship in our main results derives from manufacturer-specific capabilities that are fixed over time, such as superior R&D or marketing capabilities.

intensive or extensive margin of use for either device.

Third, comparing results across balloons and guidewires indicates that spillovers from stents to these two devices differ on both the intensive and extensive margins where balloons show a large effect and guidewires show none. On the surface, this seems surprising. Both balloons and guidewires are used together with stents in angioplasty procedures. They are used by the same physicians and sold by the same salespeople. In addition, the descriptive statistics for the two product markets in Table 1 are quite similar, and the relationship between the within-hospital share of each and the within-hospital stent share changes in a similar fashion as fixed effects are added to the specifications in Table 2. In spite of these apparent similarities, the estimated difference in buyer-level spillovers from stents indicates that there is either: (1) a mechanism that generates spillovers operating for balloons but not for guidewires, or (2) a mechanism that generates spillovers operating for both devices but is offset by some other factor in the case of guidewires. We address each of these in turn.

As discussed above, a key difference between balloons and guidewires is that balloons share physical features with stents because stents themselves are mounted on, and inserted using, a balloon. These design similarities between stents and balloons can give rise to usage complementarities such that a physician who uses more of a given manufacturer's stents (for example, due to the introduction of a new DES) would become more comfortable using that same manufacturer's balloons. Or relatedly, these design similarities could enable a cross-selling sales pitch from stents to balloons. This could explain our finding of a buyer-level spillover for stents and balloons but not for stents and guidewires.

There are two other potential mechanisms that could give rise to spillovers along the intensive margin, both of which would be expected to impact balloons and guidewires similarly. The first is some form of price discount that links prices for balloons and guidewires to stent usage. However, prior research has found that the use of quantity, market share, or bundled discounts do not drive pricing for stents, balloons, and guidewires (Grennan and Swanson 2019b). Further, other estimates of demand for medical devices have suggested that a low price sensitivity in this space is due to physician preferences and is one reason that bundling-type pricing schemes are infrequently found in implantable devices (Grennan 2013, 2014; Grennan and Swanson 2019a). As such, it is unlikely that price-based incentives could drive the correlations in market share changes that we observe.

The second possible mechanism that could generate spillovers along the intensive margin is hospitals learning about quality. If hospitals learn about the quality of a manufacturer's balloons and guidewires based on the quality of its DES and/or their interactions with the manufacturer with respect to its DES, this would generate a relationship between stent use and use of these other devices along both the extensive and intensive margins (e.g. a hospital starts using a manufacturer's balloons and uses them for a larger share of their procedures). Because such a mechanism should impact both balloons and guidewires, if it is present in our setting, there must be something offsetting this mechanism for guidewires. Our qualitative interviews with interventional cardiologists suggest one possible offsetting factor—higher switching costs for guidewires. Because guidewires

are the device used to place the other devices, and proper and accurate placement is critical to the success of the procedure, the physicians we interviewed indicated that comfort and familiarity with guidewires is essential (and that this could create a reluctance to switch guidewire manufacturers).

Ultimately, our results indicate that spillovers operate differently between stents and balloons relative to stents and guidewires,Taken together, we believe design complementarities offer the most plausible explanation for the intensive margin relationship between stents and balloons (and lack thereof in guidewires). Perhaps most interestingly, our results indicate that buyer-level spillovers can be quite nuanced and operate differently between seemingly similar pairs of related products.

6 Conclusion

Firm dominance across product markets may be attributable to either practices that solely extend market power without offering consumer benefit or to efficiencies inherent in multiproduct firms, such as economies of scope in advertising and R&D. Empirical evidence disentangling market power from efficiencies in product line spillovers is thus important for regulators seeking to understand the sources behind a dominant firm's success, and further, many of the potential mechanisms operate at the buyer level. This paper examines the sources of spillovers across product lines in medical devices used in interventional cardiology, where raw correlations in the data indicate large diversified firms enjoy such dominance across multiple product markets. Leveraging detailed data at the seller-buyer-month level and a novel empirical strategy, we identify economically and statistically significant buyer-level spillovers as an important factor. We offer the first empirical evidence quantifying buyer-level spillovers in any industry and are able speak to the mechanisms behind these spillovers.

Our empirical analysis exploits the introduction of early generations of DES, a new class of stents, which generated large movements in manufacturers' overall and within-hospital stent shares. We estimate how these changes in stent shares impact hospitals' usage of firms' other interventional cardiology devices, namely balloons and guidewires. Our analysis finds evidence of spillovers from stents to balloons along the intensive and extensive margins but not from stents to guidewires. Our interpretation is that these results are most consistent with complementarities at the user level between stents and balloons deriving from design similarities. The fact that we observe these spillovers in usage onto one related product market, but not the other, points to multiproduct firm efficiencies following innovation in stents as driving the spillovers. If we thought they were driven by anticompetitive practices, then we might expect to see them occur for both balloons and guidewires.

While empirical magnitudes may vary across settings, the phenomenon we explore here has implications for firm strategy, innovation incentives, and antitrust for firms that operate across multiple categories. Firms hoping to exploit any buyer-level spillovers must first understand whether they require a common user or only a common purchaser. This distinction is relevant in our setting (some of the mechanisms we have considered require devices to be used by the same doctors while others do not) and is likely to be important in other business-to-business settings as well. For

example, firms selling a number of related software applications for use by enterprise customers can take advantage of buyer-level economies of scope in contracting, as long as there is a common purchaser, even if the applications are used by different departments or employees. On the other hand, to benefit from design similarities across different software products (e.g., a common menu structure or common commands), the applications must be used by the same users.

Our identification of buyer-level spillovers for large multiproduct device firms contributes empirical evidence to the debate about whether and how innovative activity relates to firm size and scope (Cohen and Levin 1989; Schumpeter 1942; Teece 1986), as well as to the growing body of research on innovation incentives in medical technology (Chatterji and Fabrizio 2012, 2016; Galasso and Luo 2017, 2019a,b; Grennan and Town 2020; Stern 2017). The spillovers we estimate imply that multiproduct firms may reap larger rewards to innovation than a smaller firm operating only in a single market. Indeed, the 2-percent boost we document from stent spillovers onto balloons is significant when compared to the 13 percent of sales that top device manufacturers spend on R&D overall (MassDevice 2012). While our mechanisms indicate the presence of cross-market firm efficiencies in this setting, that does not necessarily mean that spillovers leveraged from new product innovation by the multiproduct firm are welfare enhancing. To the extent that dominant firms are able to exploit buyer-level spillovers, smaller firms may be at a greater disadvantage in entry or capturing market share even when they have created truly innovative products. Dominant firms may also be able to exploit "predatory innovation" by incorporating design complementarities that create a similar user experience or greater interoperability across product lines but provide no or minimal innovative benefits; rather than improving a product or promoting supply-side efficiencies, such design choices instead lead to the exclusion of rivals (Jacobson et al. 2010). Thus, the overall long-run welfare implications of within-firm, cross-market spillovers will be complex and ultimately depend on their short-run effects as well as their effects on innovation incentives for large and small firms (Cabral 2021).

As such, our results also relate to antitrust debates in technology-intensive sectors where there is concern about market power in one product category affecting competition and innovation in related product categories (Federico et al. 2019). The types of buyer-level spillovers we consider here are particularly relevant to current antitrust inquiries into the "Tech Giants"—Apple, Amazon, Facebook, and Google (Schlesinger et al. 2019; Shapiro 2019). Google, for example, has been fined billions of dollars by EU regulators and faces lawsuits by numerous state attorney generals and the Department of Justice for anticompetitive practices, including leveraging its position as the dominant online search engine to favor its own advertising and shopping services (Molla and Estes 2020; Satariano 2019). Google has argued that many design choices, such as prioritizing links to its own services in search results (facilitating a buyer-level spillover), provide value to consumers. While courts have previously been deferential to firms' product design decisions (Newman 2011; Waller and Sag 2014), these inquiries suggest there may be limits to the extent that regulators will allow such strategies.

Our paper points to several avenues for future research. While dominant multiproduct firms

are common across many industries, better understanding of the mechanisms behind these correlated effects is important for firm managers, economic researchers, and antitrust regulators alike. Some mechanisms—such as buyer-level economies of scope due to fixed costs of contracting—will increase the likelihood of a buyer using a firm's second product if it purchases the firm's first product, but will not generate incremental sales of the second product as use of the first increases. Other mechanisms—such as design complementarities—will generate a positive relationship between products along the intensive margin of use. As more buyer-level data linked across categories (like the data used in this study) become available, researchers will be able to further ascertain the presence, magnitude, and sources of buyer-level spillovers in other industries. To the extent that these spillovers enhance the production of new products that provide value, consumers likely benefit. The reverse may be true if these spillovers stifle competition or innovative activity in an industry by adding yet another "endogenous sunk cost" of entry (Sutton 1989). Disentangling these types of welfare implications requires additional data on product qualities, entry, and exit. Further research in this direction is important, as it will inform public policy and firm strategy as more industries are dominated by "big" firms selling a portfolio of products across different categories.

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Data availability statement

The data used in this research comes from Millennium Research Group's (MRG) *Market-Track* annual survey of hospitals (MRG 2013). This proprietary data is available for purchase at www.mrg.net.

Appendices

A Data appendix

A.1 Data construction

Our data come from Millennium Research Group's (MRG) *MarketTrack* survey of hospitals, tracking their medical device usage at the product-hospital-month level. The data in this paper cover a random sample of US hospitals from 2007 through 2012. We limit our analysis to the three categories (based on MRG's segmentation) of interventional cardiology devices most frequently purchased by these hospitals: stents, balloon catheters, and guidewires. Because manufacturers may produce multiple products within the same category (e.g., several different balloon catheters), we aggregate a hospital's purchases of different products by the same manufacturer in the same category. Because the MRG survey is focused first on collecting data on coronary stents, other product category data is missing in a small number of hospitals. We restrict our sample for analysis to hospital-months reporting data on all three of our categories of interest. We also account for censoring at zero by explicitly including zero-unit observations ($q^c_{jht} = 0$), provided the hospital is reporting data and the manufacturer has a product available (in any category) during that month. The resulting dataset is at the manufacturer-hospital-month level and includes 81,065 manufacturer-hospital-month observations.

One challenge in the data is identifying DES products that may be recorded under different names by different hospitals but are in fact the same product. To address this issue, we first employ standard text regularization methods. We correct for capitalization inconsistencies; remove common expressions that appear in some entries and not in others; and remove excess spaces between words and leading and trailing spaces. For more complex cases, we search for information online and make deductions based on approval dates and product descriptions. We similarly clean the few instances where manufacturer names are recorded inconsistently. In the case of major acquisitions, we attach observations associated with the acquired firm to the new parent company.

A.2 Variable definitions

Our share measures incorporate manufacturer-hospital-month observations with no units sold in that category ($q^c_{jht} = 0$), provided the hospital is reporting data and the manufacturer has a product available (in any category) in the overall US market during that month. That is, we calculate these shares for every hospital $h \in \mathcal{H}_{mt}$, the set of all hospitals purchasing devices in stents, balloons, AND guidewires in market m in month t, and for every manufacturer $j \in \mathcal{J}_{mt}$, the set of all manufacturers active in market m in month t (where market m represents the overall US market).

A.2.1 Overall share measures

Within-hospital share. Share of manufacturer j in category c in hospital h in month t (where hospital h is located in market m):

$$s^c_{jht} = \frac{q^c_{jht}}{\sum_{k \in \mathcal{J}_{mt}} q^c_{kht}} \tag{2}$$

Within-market share. Share of manufacturer j in category c in market m in month t:

$$s^c_{jmt} = \frac{q^c_{jmt}}{\sum_{k \in \mathcal{J}_{mt}} q^c_{kmt}} = \frac{\sum_{h \in \mathcal{H}_{mt}} q^c_{jht}}{\sum_{h \in \mathcal{H}_{mt}} \sum_{k \in \mathcal{J}_{mt}} q^c_{kht}} \tag{3}$$

Leave-out within-market share. Share of manufacturer j in market m excluding hospital l in month t:

$$s^c_{jm_{-l}t} = \frac{q^c_{jm_{-l}t}}{\sum_{k \in \mathcal{J}_{mt}} q^c_{km_{-l}t}} = \frac{\sum_{h \neq l \in \mathcal{H}_{mt}} q^c_{jht}}{\sum_{h \neq l \in \mathcal{H}_{mt}} \sum_{k \in \mathcal{J}_{m_{-l}t}} q^c_{kht}} \tag{4}$$

$$= \frac{\sum_{h \in \mathcal{H}_{mt}} q^c_{jht} - q^c_{jlt}}{\sum_{h \in \mathcal{H}_{mt}} \sum_{k \in J_{mt}} q^c_{kht} - \sum_{k \in J_{mt}} q^c_{klt}} \tag{5}$$

A.2.2 Extensive share measures

Whether active in hospital:

$$\mathbb{1}_{\{s^c_{jht} > 0\}} = \begin{cases} 1, & \text{if manufacturer } j \text{ is actively selling in category } c \text{ in hospital } h \text{ in month } t \\ 0, & \text{otherwise} \end{cases} \tag{6}$$

where $h \in \mathcal{H}^c_{mt}$ and $j \in \mathcal{J}_{mt}$.

Whether active in market:

$$\mathbb{1}_{\{s^c_{jmt} > 0\}} = \begin{cases} 1, & \text{if manufacturer } j \text{ is actively selling in category } c \text{ in market } m \text{ in month } t \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

where $j \in \mathcal{J}_{mt}$. We consider a manufacturer to be "actively selling" in a hospital in a given device category if it sold to that hospital in that device category in that month *or* any of the three months prior. This definition thus allows us to smooth any random variation from month to month in whether a hospital purchases from a given manufacturer, and we interpret a change in this variable from 0 to 1 as reflecting a decision by a hospital to begin contracting with a given manufacturer.

A.2.3 Intensive (conditional) share measures

Our intensive share measures differ from the overall and extensive metrics in that we restrict the universe of manufacturers to only those manufacturers actively selling within a given category c in either hospital h or market m in month t. That is, our within-hospital intensive share is calculated for all manufacturers $j \in \mathcal{J}^c_{ht}$ and our within-market intensive share, for all manufacturers $j \in \mathcal{J}^c_{mt}$.

Within-hospital share conditional on active in hospital. Share of manufacturer j in category c in hospital h in month t, conditional on manufacturer j actively selling in category c in hospital h (where hospital h is located in market m):

$$s^c_{jht} | \left[\mathbb{1}_{\{s^c_{jht} > 0\}} = 1 \right] = \frac{q^c_{jht}}{\sum_{k \in \mathcal{J}^c_{ht}} q^c_{kht}} \tag{8}$$

Within-market share conditional on active in market. Share of manufacturer j in category c in market m in month t, conditional on manufacturer j actively selling in category c in market m:

$$s^c_{jmt} | \left[\mathbb{1}_{\{s^c_{jmt} > 0\}} = 1 \right] = \frac{q^c_{jmt}}{\sum_{k \in \mathcal{J}^c_{mt}} q^c_{kmt}} = \frac{\sum_{h \in H_{mt}} q^c_{jht}}{\sum_{h \in H_{mt}} \sum_{k \in \mathcal{J}^c_{mt}} q^c_{kht}} \tag{9}$$

Leave-out within-market share conditional on active in market. Share of manufacturer j in market m excluding hospital l in month t, conditional on manufacturer j actively selling in category c in market m:

$$s^c_{jm_{-l}t} | \left[\mathbb{1}_{\{s^c_{jmt} > 0\}} = 1 \right] = \frac{q^c_{jm_{-l}t}}{\sum_{k \in \mathcal{J}^c_{mt}} q^c_{km_{-l}t}} = \frac{\sum_{h \neq l \in H_{mt}} q^c_{jht}}{\sum_{h \neq l \in H_{mt}} \sum_{k \in \mathcal{J}^c_{m_{-l}t}} q^c_{kht}} \tag{10}$$

$$= \frac{\sum_{h \in H_{mt}} q^c_{jht} - q^c_{jlt}}{\sum_{h \in H_{mt}} \sum_{k \in J^c_{mt}} q^c_{kht} - \sum_{k \in J^c_{mt}} q^c_{klt}} \tag{11}$$

A.2.4 Decomposition of overall within-market share

Below we decompose the overall within-market share into functions of the within-hospital share and the leave-out within-market share. For simplicity, the category c superscript is omitted.

$$s_{jmt} = \frac{q_{jmt}}{\sum_{k\in\mathcal{J}_{mt}} q_{kmt}} = \frac{\sum_{h\in H_{mt}} q_{jht}}{\sum_{h\in H_{mt}}\sum_{k\in\mathcal{J}_{mt}} q_{kht}} \tag{12}$$

$$= \frac{q_{jlt} + \sum_{h\in H_{mt}} q_{jht} - q_{jlt}}{\sum_{h\in H_{mt}}\sum_{k\in\mathcal{J}_{mt}} q_{kht}} \tag{13}$$

$$= \frac{q_{jlt}}{\sum_{h\in H_{mt}}\sum_{k\in\mathcal{J}_{mt}} q_{kht}} + \frac{\sum_{h\in H_{mt}} q_{jht} - q_{jlt}}{\sum_{h\in H_{mt}}\sum_{k\in\mathcal{J}_{mt}} q_{kht}} \tag{14}$$

$$= s_{jht}\frac{\sum_{k\in\mathcal{J}_{mt}} q_{kht}}{\sum_{h\in H_{mt}}\sum_{k\in\mathcal{J}_{mt}} q_{kht}} + s_{jm_{-l}t}\frac{\sum_{h\in H_{mt}}\sum_{k\in\mathcal{J}_{mt}} q_{kht} - \sum_{k\in\mathcal{J}_{mt}} q_{kht}}{\sum_{h\in H_{mt}}\sum_{k\in\mathcal{J}_{mt}} q_{kht}} \tag{15}$$

A.3 Device quantities and prices

Table 4 looks at average quantities of devices (1) purchased by a hospital from a manufacturer in a month; (2) purchased by a hospital from *all* manufacturers in a month; and (3) sold by a manufacturer to *all* hospitals in a month. From the leftmost panel, we note that a manufacturer active in a device category sells, on average, about 30 units of that device to each hospital with which it actively contracts in that category per month. We see from the middle panel that hospitals are purchasing the three devices—stents, balloons, and guidewires—in roughly equal quantities in a given month (between 60 and 70 units each per hospital per month). The rightmost panel shows that the stent market is most concentrated of our three device categories, followed by the balloon and then guidewire markets.

Table 4: Quantities

	Quantity per manu-hosp			Quantity per hospital			Quantity per manufacturer		
	mean	SD	N_{jht}	mean	SD	$\lvert J_h^c\rvert$	mean	SD	$\lvert J_m^c\rvert$
stents	25.24	(28.14)	24,544	63.48	(49.30)	102.4	1621.77	(921.70)	4.0
balloons	31.88	(38.03)	24,544	67.53	(58.41)	102.4	1380.14	(1468.88)	5.0
guidewires	30.08	(33.93)	24,544	70.19	(59.33)	102.4	1165.85	(1502.49)	6.2

Table provides average monthly quantities with standard deviations in parentheses. Quantities based on sample where we have *not* adjusted for censoring at zero. $|J_h^c|$ gives mean number of manufacturers active in a given hospital by category, and $|J_m^c|$ gives mean number of manufacturers active in the market by category. N_{jht} gives total number of manufacturer-hospital-month observations by category.

Table 5 presents summary statistics on hospital-level prices, observed in product-hospital-months with positive quantities purchased. The left panel considers the full sample while the right panel focuses on the 7-month windows surrounding our DES events. We calculate a manufacturer's monthly price for a device category in a hospital as a weighted average of all products they sell to that hospital in that category. Using data from the full sample, we see that the average

stent ($1,594) is substantially more expensive than the average balloon ($269) or guidewire ($84). Looking at the subsample around our DES entry events, the average stent price declines modestly to $1590, but remains considerably higher than the average balloon and guidewire prices, which are unchanged.

Table 5: Prices

	Full sample			Around DES events		
	mean	SD	N_{jht}	mean	SD	N_{jht}
stents	1593.5	(474.5)	18,502	1589.9	(499.7)	4,920
balloons	269.4	(164.4)	15,586	269.7	(157.3)	4,074
guidewires	83.5	(16.7)	17,169	84	(17.9)	4,519

Table provides average monthly prices p_{jht} with standard deviations in parentheses. Prices based on sample where we have *not* adjusted for censoring at zero. N_{jht} gives total number of manufacturer-hospital-month observations by category.

A.4 Manufacturer heterogeneity

A.4.1 Market shares of largest manufacturers

Table 6: Market shares of largest manufacturers

Category	Manufacturer	$s_m\|\mathbb{1}_m$	$\mathbb{1}_h$	$s_h\|\mathbb{1}$
stents	Firm A	.413	.881	.49
	Firm B	.321	.827	.38
	Firm C	.133	.483	.242
	Firm D	.133	.582	.223
balloons	Firm A	.565	.906	.614
	Firm B	.294	.64	.453
	Firm D	.098	.481	.216
	Firm C	.032	.203	.225
	Firm E	.01	.189	.039
guidewires	Firm B	.589	.935	.62
	Firm A	.264	.855	.338
	Firm D	.075	.316	.198
	Firm C	.036	.301	.115
	Firm F	.033	.218	.115
	Firm G	.007	.007	.405
	Firm H	.004	.01	.15

Table gives the market shares of the largest firms in terms of mean intensive within-market share by device category from 2007 through 2012. Using a shorthand notation, $s_m|\mathbb{1}_m$ gives mean intensive within-market share in each category, $\mathbb{1}_h$ gives the mean proportion of hospitals the manufacturer is active in (in that category), and $s_h|\mathbb{1}$ is the manufacturer's mean share conditional on being active in a hospital (in that category). Total number of manufacturer-hospital-month observations is 60,388.

Table 6 shows that the interventional cardiology medical device market exhibits typical features of multiproduct industries. The table provides mean within-market and within-hospital shares by

category for each of the four firms active in the US stent market: Firms A, B, C, and D. Each category is ordered in terms of largest mean US market share. We notice a few key details regarding market structure. First, the interventional cardiology device market very highly concentrated. The four firms active in the US stent market account for nearly all of the US balloon and guidewire markets as well. Second, success across product categories is correlated. Third, concentration is greater at the hospital level than the market level.

A.4.2 Intensive share distribution

Table 7 repeats the within-hospital shares presented in Table 1, adding the 25th percentile, median, and 75th percentile for the intensive share across categories. The intensive share measures vary substantially across manufacturer-hospital-month observations for all three device categories, with the interquartile ranges spanning between 51 percentage points (stents) and 72 percentage points (balloons).

Table 7: Within-hospital shares across all manufacturers (with detailed intensive share distribution)

	$\mathbb{1}_{\{s^c_{jht}>0\}}$	$s^c_{jht} \mid \mathbb{1}_{\{s^c_{jht}>0\}}$			
	mean	mean	p25	p50	p75
stents	0.337 (0.473)	0.361 (0.314)	0.088	0.270	0.600
balloons	0.295 (0.456)	0.414 (0.367)	0.062	0.308	0.769
guidewires	0.323 (0.467)	0.378 (0.327)	0.080	0.296	0.637

Total number of manufacturer-hospital-month observations is 60,388.

A.4.3 Multi- and single-category manufacturers

Tables 8 and 9 provide mean within-hospital shares for multi- and single-category manufacturers, respectively. Table 8 restricts to those manufacturer-months where the manufacturer is actively selling in *more than one* category. Shares are higher here relative to those seen with our full data sample for two reasons: the first being a mechanical result of our incorporating zero shares to account for censoring, and the second, that these multi-category manufacturers include the largest manufacturers, i.e., Firms A, B, C, and D.

While Table 8 explores multi-category manufacturers, Table 9 looks at the single-category manufacturers in our sample. As such, each panel of Table 9 encompasses a different set of manufacturers. Our data do not include any manufacturers selling only stents in the US. All three within-hospital share metrics are substantially lower for the single-category firms relative to the multi-category manufacturers.

Table 8: Within-hospital shares for multi-category manufacturers

	$\mathbb{1}_{\{s^c_{jht}>0\}}$	$s^c_{jht}\|\mathbb{1}_{\{s^c_{jht}>0\}}$			
	mean	mean	p25	p50	p75
stents	0.692	0.361	0.088	0.270	0.600
	(0.461)	(0.314)			
balloons	0.557	0.445	0.094	0.373	0.800
	(0.497)	(0.365)			
guidewires	0.601	0.402	0.099	0.335	0.667
	(0.490)	(0.329)			

Table 9: Within-hospital shares for single-category manufacturers

	$\mathbb{1}_{\{s^c_{jht}>0\}}$	$s^c_{jht}\|\mathbb{1}_{\{s^c_{jht}>0\}}$			
	mean	mean	p25	p50	p75
balloons	0.190	0.042	0.000	0.021	0.056
	(0.392)	(0.062)			
guidewires	0.111	0.138	0.000	0.073	0.202
	(0.315)	(0.178)			

A.5 DES entry events

Table 10 gives all DES introductions in the US during our sample period, 2007 through 2012, and corresponding within-hospital stent shares in the three months before and after the introductions for the innovating firm. In our empirical approach, we exploit the three entry events with the largest change to the innovating firm's stent market share: DES 1, DES 2, and DES 12. These events induce changes in within-hospital stent share for the innovating firm ranging from 9 to 16 percentage points. It is important to note that our approach makes use of corresponding variation in competitors' stent shares as well.

Table 10: DES entry events

Date	Manufacturer	Product	Pre-s_{jht}^{stent}	Post-s_{jht}^{stent}	Diff
2008-Feb*	Firm D	DES 1	.057	.149	.092
2008-July*	Firm B	DES 2	.205	.37	.164
2008-July	Firm A	DES 3	.398	.397	-.001
2008-Oct	Firm A	DES 4	.387	.432	.044
2008-Nov	Firm D	DES 5	.099	.107	.008
2008-Nov	Firm A	DES 6	.397	.436	.039
2009-June	Firm A	DES 7	.421	.415	-.005
2011-Apr	Firm A	DES 8	.428	.438	.01
2011-June	Firm B	DES 9	.367	.377	.01
2011-Nov	Firm B	DES 10	.377	.413	.036
2011-Nov	Firm A	DES 11	.443	.431	-.013
2012-Feb*	Firm D	DES 12	.137	.236	.099

B Event-study examination of parallel pre-trends

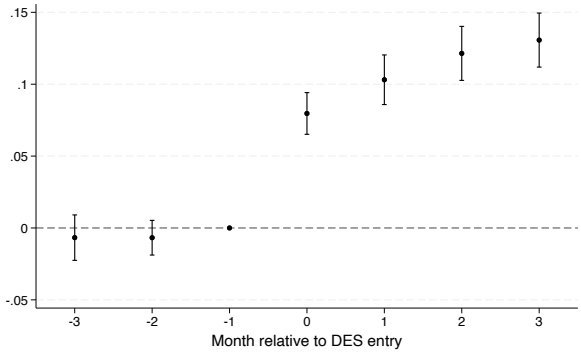
The parallel trends assumption for difference-in-differences analyses requires that trends in within-hospital balloon (guidewire) share for manufacturer-hospital pairs with greater intensity of treatment (i.e., larger changes in stent share surrounding the DES introductions) would be the same as for those manufacturer-hospital pairs with lower intensity of treatment, in the absence of the DES events. There is no standard way to implement this test with a continuous treatment variable like our stent market share. To assess this assumption, we plot the treatment effect over time for manufacturer-hospital pairs of different treatment intensities. We separate manufacturer-hospital pairs into three groups based on their change in average pre- to post-event stent share: "(+) treatment" being those with a positive change, "control" being those with no change, and "(−) treatment" being those with a negative change. We plot the coefficients from the following "stacked" regression, where e indexes each DES event and k indexes month relative to the introduction month:

$$s_{jhte} = \sum_{k=-3}^{k=3} \lambda_k(positive_{jhe} \cdot \mathbb{1}_{t=k}) + \sum_{k=-3}^{k=3} \gamma_k(negative_{jhe} \cdot \mathbb{1}_{t=k}) + \delta_{jhe} + \delta_{jte} + \epsilon_{jhte} \tag{16}$$

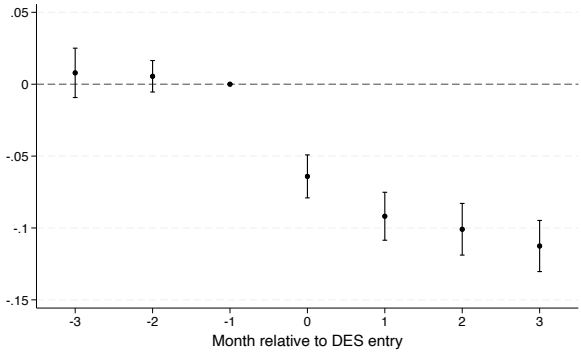
Figure 2 plots these coefficients for the stent first stage and balloon and guidewire reduced forms. The excluded group is the no-change "control", and the left and right panels plot the positive and negative "treatment" groups, respectively. Pre-trends appear parallel in all specifications. The discretization does add some noise, particularly in the reduced forms. However, the plots are in line with our main results, showing an effect of changes to stent share on balloon share, but lack of an effect for guidewires. The parallel trends evidence in the stent first stages are especially precise, reassuring that there does not appear to be any difference in trends of hospitals that see different stent share changes around the DES entry events.

Figure 2: Event studies examining parallel trends

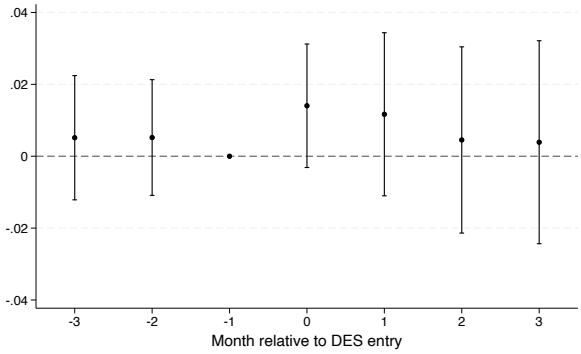
(a) Stents: (+) treatment



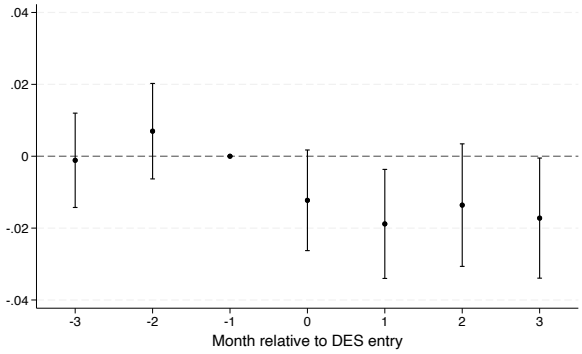
(b) Stents: (−) treatment



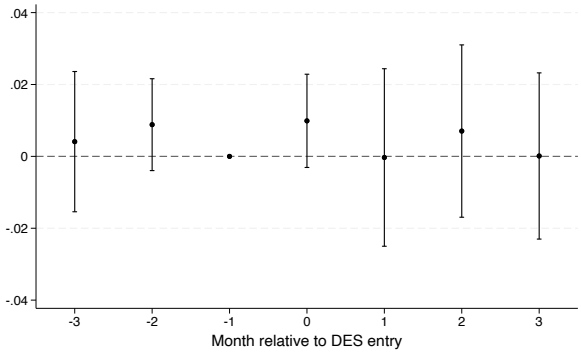
(c) Balloons: (+) treatment



(d) Balloons: (−) treatment



(e) Guidewires: (+) treatment



(f) Guidewires: (−) treatment

