Spillovers Across Product Categories in the Medical Device Industry

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Abstract

We use detailed panel data at the buyer level to understand the size and nature of spillovers across product categories in medical devices. Difference-in-differences regressions identify spillovers in usage (accounting for 21 percent of market share) across categories that share physical features. All categories exhibit spillovers in contracting (accounting for 7 to 18 percent of the probability of contracting). These buyer-level spillovers represent up to half of all potential demand spillovers and one-third of the overall correlation in shares across categories, suggesting meaningful implications for firm strategy and antitrust policy for firms selling in multiple product categories.

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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 management, policy makers, and regulators must understand which of these sources contribute to a firm's dominance when determining their actions.[2] 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 firm may experience across its product lines. In this paper, we investigate the performance of firms across product lines in the medical device industry, a sector increasingly dominated by large multiproduct firms whose "portfolio strategies" have gained attention of regulatory authorities.[3] However, to our knowledge, there is little to no quantitative empirical evidence regarding the nature or extent of such portfolio effects.

Key to this study is a rich panel dataset, matching sales data for multiple device categories offered by sellers (device manufacturers) to the same buyer (hospital) in the same month. The raw data indicate that, for firms selling in multiple categories, their market shares across categories are highly correlated with one another, with correlation coefficients between 0.4 and 0.75. We use panel regressions with increasingly rich sets of fixed effects to decompose the types of mechanisms that underly these correlations. Our richest specification, leveraging a difference-in-differences research design driven by the pseudo-exogenous timing of new product introductions in one product category, allows us to empirically identify buyer-level spillovers, separating them from correlations driven by factors such as firm-specific capabilities or the preferences of a given hospital for a particular device manufacturer. These buyer-level spillovers occur when a buyer's purchases from a given manufacturer in one product category induce purchases by the *same buyer* from the *same manufacturer* in other product categories.

Analyzing spillovers across different device types, combined with detailed information on prices, allows us to deduce two likely mechanisms behind the buyer-level spillovers: First, we observe stronger buyer-level spillovers across devices with shared physical features, suggesting the im-

[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] Indeed, recent antitrust rulings in telecommunications (Winkler 2018) and internet software (Satariano 2019) have been driven by concerns about spillovers across product categories and innovation.

[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 (Aug. 25, 2005), available at http://ec.europa.eu/competition/mergers/cases/decisions/m3687_20050825_20600_en.pdf.

portance of design complementarities at the user (physician) level. Second, we find evidence of economies of scope at the hospital level, likely in contracting or sales, across all devices we consider. The magnitude of these buyer-level spillovers is meaningful, representing up to half of all potential demand spillovers and one third of the overall correlation in shares across categories.

The medical device industry is one in which spillovers across product lines are thought to be important. Many medical procedures involve the use of multiple devices in combination. Sales representatives typically sell multiple related devices, creating the potential for local returns to scale and scope in sales and distribution. Further, manufacturers that produce more than one of the devices used in a given procedure can design physical complementarities into their products such that they work better together than when used with devices from other manufacturers. Even when devices are not actually used together in a procedure, complementarities between a firm's products may arise if the products share usability features that enable a physician who is comfortable with one of them to more easily and successfully use (or, relatedly, be cross-sold on) the others.[4]

Innovation is frequent in the medical device industry, and the life cycle of new devices can be short, especially for relatively new technology areas (e.g., typically about two to three years for the drug-eluting coronary stent devices we study in this paper). Frequent innovation means that market leadership in a given category can shift. To the extent that there are product spillovers, changes in market leadership in one category may result in changes in market share in other product categories, even if product offerings in those other categories remain constant. This can have important implications for antitrust policy in technology-intensive industries where there is concern about dominance in one market foreclosing competition and innovation in related markets. For example, potential entry in a market with relatively low barriers could be limited if having a successful product in a related market is important for sales.[5]

Our data consist of monthly observations from 2005 to 2013 on a sample of US hospitals' purchases of the three most important categories of devices in the area of 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 market share within each device category in each hospital in each month. The raw data indicate that hospitals that purchase 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.

To determine the sources behind this apparent scope advantage, we estimate a series of regressions that measure whether and how a hospital's usage of a given manufacturer's balloons and guidewires changes as its usage of that manufacturer's stents changes. The richness of the data allows us to include both manufacturer-hospital and manufacturer-month fixed effects in our models.

[4]In fact, physicians often collaborate with device manufacturers during the design phase (Chatterji and Fabrizio 2012, 2016; Chatterji et al. 2008).

[5]This is one potential reason for the large degree of concentration, even in low-tech medical device markets. This in turn could contribute to the risk of shortages because a small number of otherwise efficient manufacturers may have difficulty responding quickly to supply or demand shocks. (`https://tradeoffs.org/2020/02/19/season-1-ep-10/`).

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). 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, 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. Estimating models with progressively richer fixed effects allows us to decompose the potential sources of these effects.

In our tightest specification to identify buyer-specific spillovers, we consider difference-in-differences regressions that exploit variation in within-hospital stent shares that results from quasi-exogenous timing of new innovations in the stent market during our sample period. Specifically, several new drug-eluting stents (DES) are introduced during the period we study. DES constitute an important technological advance, improving patient outcomes over previously existing stents (Burt and Hunter 2006; Htay and Liu 2005), and we document how the introduction of the first few generations of DES 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. 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 are also relatively stable technologies during this time period). Furthermore, because stents are the critical and most profitable component of an angioplasty procedure, it is unlikely that manufacturers would adjust the timing of their innovation in the stent market in response to events in the balloon or guidewire markets. Thus, our preferred specification includes both manufacturer-hospital and manufacturer-month fixed effects and focuses on a seven-month window around each of three major DES introductions.[6] We interpret our estimates from this specification as measuring the change in a hospital's usage of a given manufacturer's balloons (or guidewires) that results from the hospital's change in usage of that same manufacturer's stents.[7] We note that since hospitals choose whether to change the share of stents they purchase from a manufacturer, our estimates measure the average effect of the treatment on the treated, which in this case is exactly the "spillover" effect that is relevant for firm strategy and public policy discussions.

[6] Specifically, we focus on the three DES introductions producing the largest immediate impact to the innovating firm's US stent market share during our sample period. 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.

[7] In addition to the argued exogeneity of stent introductions to overall trends in the balloon and guidewire markets, event-study results around these introduction events in Appendix B.1 show no differential pre-trends among manufacturer-hospital pairs with positive, zero, and negative changes in stent usage at the hospital level.

Our empirical analysis delivers four main results. First, we find evidence of economically and statistically significant buyer-level spillovers in the medical device industry. When hospitals increase their use of a manufacturer's stents, they also increase their use of that manufacturer's balloons. In the specification in which we focus on the seven month windows surrounding three major DES introductions, 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 2.5-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 9-percentage-point (21 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 the magnitudes of estimates from our preferred specification to those obtained when we estimate less restrictive specifications suggests that these buyer-level spillovers encompass over one-third of the full set of factors underlying observed correlations in within-firm sales across categories in our setting.

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 important because 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. However, the same does not hold for stents and guidewires. The point estimates from the specifications that use within-hospital guidewire share as the dependent variable are smaller in magnitude and not statistically significant.

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 used from that manufacturer. When we explore the impact of hospitals' changes in stent usage along the extensive margin, we find that hospitals which use a manufacturer's stents are more likely to buy both that manufacturer's balloons and guidewires as well.

Fourth, we incorporate detailed data on the prices paid to each manufacturer by each hospital for all purchased devices. Including balloon (or guidewire) price as an independent variable does not change the estimated coefficient on within-hospital stent share, and we observe a low price sensitivity for both balloons and guidewires. In addition, we find no statistically or economically significant relationship between a hospital's use of a manufacturer's stents and the price it pays for that manufacturer's balloons or guidewires. Combined, these results suggest that price-based incentives are unlikely to be driving the correlated successes multiproduct device manufacturers experience.

These findings help shed light on the possible mechanisms underlying the spillovers that we measure. They indicate that buyer-level spillovers operate in this setting, and they operate over and above any firm-level capabilities that span across products and any economies of scope that operate across buyers (as both of these are captured by our fixed effects). Furthermore, our results show that spillovers operate differently for balloons and guidewires. The extensive margin relationships we find for both balloons and guidewires suggest that economies in contracting at the buyer (hospital) level are a likely source of the multiproduct advantage in this setting. The intensive margin relationship we find for balloons – and lack thereof for guidewires – is most consistent with another source, this one functioning at the user (physician) level – design complementarities across products that share similar physical features.

This paper contributes to several strands of literature. At a broad level, we contribute to the economics of multiproduct industries and the benefits to firm scope (Bailey and Friedlaender 1982; Teece 1982). For instance, 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 second contribution relative to this literature is the detailed nature of our data at the buyer level. These data allow us to examine the degree to which spillovers result when the same buyer uses products in multiple categories produced by the same firm and to separate these from mechanisms operating across buyers. As discussed below, this has different implications for managers and regulators than mechanisms operating at more aggregate level.

Our 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 products. 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.[8] Our price regression results and qualitative interviews with market participants suggest that such incentive-based contracting practices are not a prevalent feature of the markets we study here, or at least not prevalent enough to explain a quantitatively important amount of the spillovers we estimate. Our results do, however, point to frictions in developing new contracts at the buyer-level as playing a role across device types, adding to an emerging literature on buyer-supplier relationships and the frictions to developing new ones (Allen et al. 2019; Grennan and Swanson 2019a; Ho and Lee 2017, 2019; Lee and Fong 2013).

Our paper is also related to the small (again, speaking to the difficulty of empirical work on

[8] 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).

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 – a demand-side information provision mechanism. 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.

Our buyer-level data allow us to speak to additional mechanisms that would be difficult to uncover from the aggregate sales data used in those studies, but several of our results echo theirs. First, 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. There we find that buyer-level spillovers are responsible for about half of these broader spillovers from stents. Among the buyer-level spillovers we measure, both are related to features that may also be at work in this prior literature. The extensive margin effect we estimate is consistent with a mechanism of costly search/contracting costs for adding new manufacturers as suppliers. The intensive margin effect we estimate, 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.[9]

As the links to prior literature suggest, the mechanisms suggested by our analysis are not unique to the medical device industry, or even to business-to-business sales. The mechanisms and managerial and policy implications at work here are of potential interest in any industry where product design decisions and fixed adoption costs can affect spillovers across a manufacturer's product lines at the end-user level. As another (perhaps more familiar) example, consider Apple's resurgence in the personal computer market in the 2000s. Steve Jobs attributed Apple's success in the computer market to an "iPod halo effect" (Stone 2011). Implicit in Jobs's comment is the claim that consumers' experience with the iPod influenced non-Mac users to buy their first Mac computers – a demand spillover not dissimilar from the one we measure here. While many mechanisms could have been operating in the case of Apple, design complementarities between the products (e.g. the Mac-like menu structure in the iPod), shared ease of use, and interoperability have been identified as contributing to the "halo effect" (Godfrey 2016).[10] These were all important strategic product design decisions.

Such complementarities have also led to cross-product sales and corresponding antitrust concerns in other technology-intensive sectors, including the pharmaceutical, online search, telecommu-

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

[10] Other potential mechanisms include capabilities in engineering and marketing that were leveraged across products or buyer learning about Apple quality after their experience with the iPod.

nications, and computer software industries (Jacobson et al. 2010; Satariano 2019; Winkler 2018). There the concerns are about how spillovers across product lines, no matter their direct welfare impacts, may work to foreclose competition by existing firms or entrants with offerings in a single product line alone. Thus, understanding the potential sources behind the correlated successes of a dominant firm across product lines is important not only for firm strategy, but also for regulators determining the presence of anticompetitive effects.

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

The market for stents, balloons, and guidewires is a differentiated oligopoly. Demand is driven by physicians choosing which devices to use to treat their patients. Prices are typically negotiated between manufacturers and hospitals, hospital systems, or group purchasing organizations. 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. Interventional treatments may offer several advantages over surgical options, for example, in recovery time, patient satisfaction, lower procedural risk, and avoidance of cardio-pulmonary bypass in certain patients (Tobis and Abudayyeh 2015). 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 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.[11] 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.[12]

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 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

[11] 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.

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

catheter lab in the case of stents, will coordinate its own purchasing separately from the rest of the hospital.[13] 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.[14] 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.[15]

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 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

[13]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. Section 5.3 examines price variation in our data and finds our results unaffected.

[14]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.

[15]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.

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.[16]

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.[17]

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 of medical devices by country. Our data include a sample of hospitals in the US, covering about 10 percent of hospitals by revenue from January 2005 through June 2013. 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

[16]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.

[17]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.

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 81,065 manufacturer-hospital-month observations.[18]

Our data verify that it is common for interventional cardiology device manufacturers to operate across categories. Averaging across firm-months in the data, 62 percent of firms which sell devices in one of the three device categories we consider, sell in all three. 37 percent of firms sell in only a single category in a month.[19] Almost 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, averaging about 70 units each per hospital per month. See Appendix Table 5 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.[20] 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 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 3.9 and 5.9 manufacturers active in each device category and between 2 and 3 manufacturers active in each

[18] 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.

[19] Averaging across hospital-month observations, only 15 percent of stent purchases, 29 percent of balloon purchases, and 18 percent of guidewire purchases come from a single manufacturer.

[20] 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. We include in Appendix B.6 robustness checks where we adjust this definition to reflect activity in any of the six or twelve months prior, and our results remain qualitatively and quantitatively similar.

Table 1: Summary statistics

	s^c_{jht}	$\mathbb{1}_{\{s^c_{jht}>0\}}$	$s^c_{jht}\|\mathbb{1}_{\{s^c_{jht}>0\}}$	$\|J^c_m\|$	$\|J^c_h\|$	p^c_{jht}
stents	0.128	0.353	0.362	3.95	2.78	1654.3
	(0.257)	(0.478)	(0.320)	(0.22)	(0.90)	(546.3)
balloons	0.128	0.302	0.423	4.82	2.37	269.6
	(0.281)	(0.459)	(0.369)	(0.39)	(0.96)	(152.6)
guidewires	0.128	0.335	0.381	5.91	2.63	84.3
	(0.261)	(0.472)	(0.327)	(0.96)	(1.02)	(22.1)

Table provides means and standard deviations (in parentheses) for hospital-level shares and prices by category in the typical month. Note that the overall share variable has the same mean across categories due to our inclusion of zero-quantity observations to address censoring. $|J^c_m|$ 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 101.6, with a standard deviation of 4.3. Total number of manufacturer-hospital-month observations is 81,065. Price data is only available when positive quantities are purchased, in which case the total number of manufacturer-hospital-month observations is 26,013 for stents, 21,557 for balloons, and 24,069 for guidewires.

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, 34 percent for guidewires and 35 percent for stents). Conditional on selling to a hospital in a category, a manufacturer accounts for, on average, between 36 and 42 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 \$1,654, than both balloons (\$270) and guidewires (\$84). Appendix Table 6 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 (0.711). We also observe a positive correlation between a manufacturer's within-hospital stent and guidewire shares (0.462) as well as between its balloon and guidewire shares (0.539), 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 and magnitude of buyer-level spillovers in this setting. To do this, we estimate a series of regressions which relate a manufacturer's within-hospital share of either balloons or guidewires to its within-hospital share of stents, controlling for flexible time trends. Our main estimating equation is the following:

$$s^{balloons/gwires}_{jht} = \beta s^{stents}_{jht} + \delta_{jh} + \delta_{jt} + \epsilon_{jht} \tag{1}$$

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 use several strategies to control 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 manufacturer-hospital fixed effects δ_{jh} to control for time-invariant unobservable factors that may influence a manufacturer's sales of all three devices to a given hospital. 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.

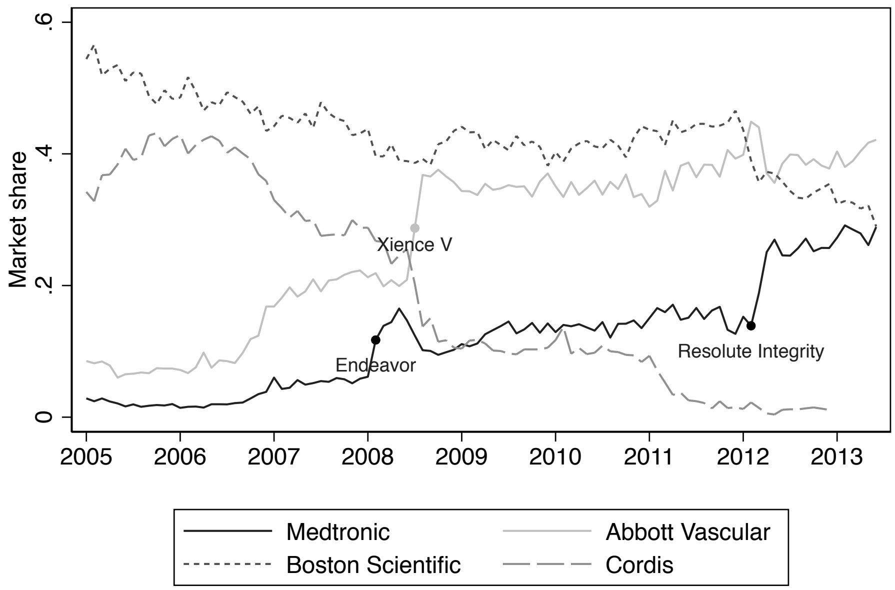
Second, we include manufacturer-month fixed effects δ_{jt} to control for the possibility that, over time, manufacturers may take actions that improve the attractiveness of all of their products simultaneously. A change in a manufacturer's sales across product categories could result, for example, from 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.

Finally, to further mitigate the possibility of time-varying unobservables that impact the within-hospital shares of all of a manufacturer's products simultaneously, we exploit discrete changes to stent shares that result from innovative DES product entry. We employ a difference-in-differences regression by focusing 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. The 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.

The three particular DES events that we focus on – Medtronic Endeavor, Abbott Vascular Xience V, and Medtronic Resolute Integrity – had the largest immediate impact on the innovating firm's US stent market share during our sample period.[21] 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

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

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: Boston Scientific, Abbott Vascular, Cordis, and Medtronic. Appendix Table 7 provides more details on the major manufacturers active across the stent, balloon, and guidewire device categories.

in shares around all three events. Appendix B.3 provides additional evidence that the changes in within-hospital total stent share we see here are driven by changes in DES share. Appendix B.1 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.

We note that while these three DES introductions assist with the identification of an internally valid measure of spillovers, they share challenges of external validity due to the fact that they necessarily limit the analysis to narrow windows around these specific events. Because of this, we estimate spillovers using the panel regression model above first on the full sample. We then zero in on the DES events.

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.

In addition, we run two sets of analyses using detailed price data for stents, balloons, and guidewires at the manufacturer-hospital-month level. If the mechanism enabling spillovers were based on prices, we would expect to see changes in balloon and guidewire prices as stent shares change. We test this by re-running the same specification as in equation (1), but with $p_{jht}^{balloons/gwires}$ as the dependent variable. We also rerun all of our regressions with price added to the right-hand side to provide a measure of how market share responds to price. The parameter on price in these regressions informs the extent to which physician purchasing behavior can be changed with price.

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 margin impacts for balloons and extensive margin impacts for both balloons and guidewires. We then incorporate balloon and guidewire prices into the analysis and confirm that they do not drive our results. Finally, we discuss our collection of results, the possible mechanisms underlying them, and several robustness checks.

5.1 Buyer-level spillovers

Table 2 presents coefficient estimates from regressions of a firm's within-hospital share of either balloons or guidewires on that firm's within-hospital stent share. The first column in the table presents the specification with no fixed effects. Subsequent columns separately add manufacturer, manufacturer-hospital, and manufacturer-month fixed effects. In the final column of each panel, we focus on variation in stent shares resulting from the three DES introductions, restricting to windows three months before and after each event (for seven months total including the introduction month).

Table 2: Spillovers

	Balloons					**Guidewires**				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
s_{jht}^{stents}	0.778***	0.540***	0.224***	0.255***	0.246***	0.469***	0.207***	0.0528**	0.0288	0.0170
	(0.0216)	(0.0273)	(0.0283)	(0.0308)	(0.0377)	(0.0261)	(0.0331)	(0.0208)	(0.0222)	(0.0271)
Observations	81,065	81,065	80,475	80,475	15,803	81,065	81,065	80,475	80,475	15,803
Adj. R^2	0.506	0.627	0.866	0.870	0.902	0.213	0.573	0.893	0.895	0.919
Mfr FE		yes					yes			
Mfr-Hosp FE			yes	yes	yes			yes	yes	yes
Mfr-Month FE				yes	yes				yes	yes

The dependent variable is $s_{jht}^{balloons}$ for balloon specifications and $s_{jht}^{guidewires}$ 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 no fixed effects in Column (1) provides a coefficient estimate of 0.78, 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 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 manufacturer-hospital fixed effects rather than manufacturer fixed effects. The smaller coefficient estimate (0.23 as compared to 0.54) 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 manufacturer-month fixed effects.[22] The fact that the spillover estimate remains statistically identical between these two specifications is consistent with our understanding that there is little independent variation in the balloon market during the time period we study.

The difference-in-differences specification in Column (5), which we consider our most credible specification for identifying buyer-level spillovers, restricts to windows around the three major entry events.[23] We find a coefficient on the within-hospital stent share of 0.25, 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 2.5-percentage-point increase in its balloon market share in that same hospital. This result has nontrivial implications for the performance of multi- vs. 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 25 percent, and thus enjoys an advantage over a single-category firm selling only balloons of more than 6 percentage points ($\beta_1 * (s_{jht}^{stents} * 100) = 0.25 \cdot 25 = 6.25$). Relatedly, with balloon revenues at roughly 16 percent of stent revenues, this spillover provides the average multi-category stent manufacturer the equivalent of an additional 4-percent revenue boost, relative to a single-category stent manufacturer with no such spillovers.[24]

Comparing our preferred specification to those with less fine-grained 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. Note that the spillover estimate from the event windows in (5) is statistically indistinguishable from the estimate from the full sample in (4). This is reassuring in terms of external validity – it suggests that there is not some other important source of variation in stent shares with a dis-

[22] Appendix B.2 includes robustness checks where we do not add manufacturer-month fixed effects but instead explicitly include the leave-out within-market share as a control in the regressions; our conclusions do not change.

[23] Appendix B.1 implements tests for parallel pre-trends at the manufacturer-hospital-category level by discretizing the data into cases with positive, zero, and negative changes in stent shares before and after the event. Consistent with our institutional arguments for the quasi-exogenous timing of new stent introduction, the stent first stage and balloon and guidewire reduced forms all show evidence of no differential pre-trends.

[24] 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 66 units for stents), and the average balloon ($270) priced at roughly 16 percent of the average stent ($1654), we calculate per-hospital balloon revenues to be roughly 16 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). Table 4 also provides results of regressions including price as a control variable, which has no effect on the results, suggesting this back-of-the-envelope calculation that holds prices fixed is likely a good proxy for the actual counterfactual equilibrium.

tinct spillover on balloons that we do not capture in analyzing the entry event time periods. The similarity of Column (5) 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. Further, the magnitude of our estimate in Column (5) relative to the estimate in Column (1) – 0.25 vs. 0.78 – 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 (6) through (10) present the same regressions as in the first five columns but with a manufacturer's within-hospital guidewire share as the dependent variable. As before, with the inclusion of manufacturer and manufacturer-hospital fixed effects in Columns (7) and (8), the coefficient estimates on within-hospital stent share fall relative to the specification with no fixed effects (6). In fact, the magnitude of changes as fixed effects are added are very similar to those in balloons, suggesting that manufacturer-specific capabilities, manufacturer-level scope economies, and hospital preference or sales heterogeneity play similar roles for the two categories, at least quantitatively.

However, the levels of correlation between stents and guidewires differ from those with balloons. 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 0.47 to 0.05. As we add manufacturer-time fixed effects in Column (9) and restrict to windows of time around the three stent entry events in (10), the coefficient on stent share decreases further 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-specific effects and time trends 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 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).

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 begin to decompose the spillovers into their intensive and extensive margins by instead considering an indicator for whether or not manufacturer j is actively selling any stents in hospital h at time t as the independent variable.[25] Interestingly,

[25] 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 (and in Appendix B.6, 7 and 13) 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

in the case of balloons, it returns nearly the same *average* effect of stent spillovers – 7 percentage points vs. 6.25 percentage points for the continuous measure at mean stent share.[26] Of course it does not capture the increasing spillover with increasing stent success implied by the continuous measure.

Column (3) considers both continuous and discrete measures of stent presence at each hospital as independent variables. Once we do so, the continuous overall share measure now captures the effect on the intensive margin and the indicator, the extensive margin. The positive and statistically significant coefficients on both variables indicate that the act of contracting with a manufacturer for its stents and amount of stent usage conditional on contracting both play a role in a hospital's balloon usage from that manufacturer. Comparing the coefficient in Column (3) to that in (1), we see that much of 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**					
	$s_{jht}^{balloons}$			$\mathbb{1}_{\{s_{jht}^{balloons}>0\}}$			$s_{jht}^{guidewires}$			$\mathbb{1}_{\{s_{jht}^{guidewires}>0\}}$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
s_{jht}^{stents}	0.25***		0.24***	0.22***		0.16***	0.02		0.01	-0.00		-0.03
	(0.04)		(0.04)	(0.04)		(0.04)	(0.03)		(0.03)	(0.03)		(0.03)
$\mathbb{1}_{\{s_{jht}^{stents}>0\}}$		0.07***	0.03**		0.18***	0.15***		0.01	0.01		0.05**	0.06**
		(0.01)	(0.01)		(0.03)	(0.03)		(0.01)	(0.01)		(0.03)	(0.03)
Observations	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803
Adj. R^2	0.90	0.89	0.90	0.86	0.86	0.86	0.92	0.92	0.92	0.88	0.88	0.88
Mfr-Hosp FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Mfr-Mth FE	yes	yes	yes	yes	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. The results in (4) indicate that a 10-percentage-point increase in stent share increases the probability of a hospital purchasing balloons by the same manufacturer by 2.2 percentage points. Column (5) looks the extensive margin for both stent and balloon purchases. Hospitals that purchase a manufacturer's stents are 18 percentage points more likely to also purchase its balloons than those that do not purchase the manufacturer's stents.

In Column (6), 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 from a given manufacturer are 15 percentage points more

that category (and, similarly, 1 to 0 as stopping contracting).

[26]This equivalence is consistent with any spillover related to stent share being linear and independent of the stent share level. Appendix B.5 explicitly tests both of these relationships directly, and consistent with this, finds no evidence of a nonlinear effect in stent share.

likely to purchase balloons from that same manufacturer.[27] This is a meaningful increase, equal to about one-third of a standard deviation and almost half the mean hospital propensity to contract with a given balloon manufacturer. 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 over 1.6 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 (7) replicates our preferred specification. Columns (8) and (9) show that neither the stent intensive nor extensive margin seems to affect overall guidewire share. Columns (10) through (12) repeat the same specifications, but with the extensive margin guidewire indicator as the dependent variable. The results in (12) reveal that when a hospital uses a manufacturer's stents, it is 6 percentage points more likely to also use that manufacturer's guidewires. This represents an 18-percent increase in the hospital propensity to contract with a given guidewire supplier. Thus we find that there *is* an economically and statistically significant relationship between stent and guidewire usage at the manufacturer-hospital level, but it operates entirely at the extensive margin.

5.3 Price effects

We have two primary interests in incorporating prices into our analysis: First, price is a natural potential determinant of demand that is left in the unobservable in the previous results.[28] If prices of balloons or guidewires were correlated with stent share (conditional on the fixed effects), then this could bias our spillover estimates. In particular, if balloon or guidewire prices tended to decrease with stent share, this might be evidence for a bundling/tying mechanism driving the observed spillover. To explore these issues, we re-run our main specifications, adding balloon (or guidewire) price as an independent variable. We also explore the correlation between stent share and balloon/guidewire prices directly in regressions with these prices as the dependent variable. Table 4 shows the results.

Column (1) repeats our preferred specification for balloons, restricting to the seven-month windows surrounding our DES events, using only the subsample of the data with nonzero quantities. The coefficient estimate in this subsample is statistically identical to that of the full sample. We add balloon price as an independent variable in Column (2). The effect of balloon price on balloon share is negative, reflecting downward-sloping demand, but it does not substantially change our estimated correlation with stent usage. Repeating this exercise for guidewires in Columns (3) and

[27]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.

[28]Recall that the main reason we did not include price as a regressor in our main analysis is that we only observe the price paid to a manufacturer for devices actually purchased by a hospital, and we are interested in both intensive and extensive margin spillovers. For this analysis with prices, we must restrict to intensive-margin impacts and no longer include the zero-quantity observations in the regressions.

Table 4: Price effects

	Balloons		Guidewires		Price as dep. variable	
	$s_{jht}^{balloons}$		s_{jht}^{gwires}		$p_{jht}^{balloons}$	p_{jht}^{gwires}
	(1)	(2)	(3)	(4)	(5)	(6)
s_{jht}^{stents}	0.251***	0.247***	0.0337	0.0334	-11.28	-0.301
	(0.0398)	(0.0391)	(0.0214)	(0.0214)	(8.724)	(1.326)
$p_{jht}^{balloons}$		-0.000294**				
		(0.000120)				
p_{jht}^{gwires}				-0.000937*		
				(0.000481)		
Observations	3,391	3,391	3,355	3,355	3,391	3,355
Adj. R^2	0.865	0.866	0.897	0.897	0.744	0.730
Mfr-Hosp FE	yes	yes	yes	yes	yes	yes
Mfr-Mth FE	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.

(4) produces similar results. The inclusion of guidewire price does not change the coefficient on stent share.

In the rightmost panel, in Columns (5) and (6), we re-run our analysis with balloon/guidewire prices instead of share as the dependent variable. We do not document any statistically or economically significant change in balloon (or guidewire) price with changes in stent market share.

The second reason we are interested in the price analysis is to explore the possibility that there are stronger brand preferences for guidewires than balloons, and this is why we do not observe an intensive margin spillover for guidewires. Here the magnitudes of the price coefficients offer useful evidence in that stronger brand preferences should correspond to less price sensitivity. The magnitude of the effect of balloon price on balloon share is quite small: A $10 change in balloon price leads only to a 0.29 percentage-point change in balloon market share. The effect of guidewire price on guidewire share is larger, but still rather small: A $10 change in guidewire price corresponds only to a 0.94 percentage-point change in guidewire market share.[29] Thus, while both categories exhibit low sensitivity of demand to price, which may be due to brand preferences, guidewires appear if anything to be slightly more price sensitive than balloons, casting doubt on the hypothesis that different intensities of brand preferences drive the different intensive margin spillovers measured in the two categories.

The low price sensitivity in device usage that we measure here is consistent with qualitative and quantitative evidence from other studies of medical device demand (Grennan 2013, 2014; Grennan and Swanson 2019a). This makes it unlikely that price-based incentives are driving the correlations in market share changes that we observe. Indeed, this lack of price sensitivity may be a major reason why more complex price-based incentives seem to be relatively rare in medical devices. In sum, prices do not appear to change in a way that might relate to our effects, and even if they did,

[29] At prevailing prices and market shares, these numbers are also small in terms of elasticities with means of -0.19 for balloons and -0.21 for guidewires.

demand is not sensitive enough to price for them to explain the size of spillover we document.

5.4 Discussion of evidence, mechanisms, and robustness

We now turn to a discussion of the results, highlighting noteworthy findings and the underlying economic mechanisms they suggest. First, our preferred difference-in-differences specification clearly indicates the operation of meaningful buyer-level spillovers. The inclusion of 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.[30] The inclusion of 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 demand spillover is large, amounting to $\frac{0.246}{0.778} * 100 = 31.6$ percent of the unconditional relationship between stent and balloon shares at the hospital level.

Second, the decomposition exercise we carry out in Table 3 reveals that buyer-level spillovers 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 a relationship only along the extensive margin of use for both devices. These extensive-on-extensive effects for both balloons and guidewires suggest the presence of buyer-level economies of scope due to a fixed cost, likely in contracting, that is common across the set of products a hospital buys from a manufacturer (but unrelated to the quantity purchased or used).

Third, comparing results across balloons and guidewires indicates that spillovers from stents to these two devices differ on the intensive margin 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

[30] As our fixed effects in our primary specification subsume 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.

that there is either: (1) a mechanism that generates spillovers along the intensive margin of use that operates for balloons but not for guidewires, or (2) a mechanism that generates spillovers along the intensive margin of use that operates 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 an intensive margin relationship 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. Using detailed price data, we provide evidence that our results do not seem be driven by mechanisms related to pricing. In Table 4, we find no statistically or economically significant relationship between a hospital's use of a manufacturer's stents and the price it pays for that manufacturer's balloons or guidewires. We also find that, when we add balloon (guidewire) price to our main regression of balloon (guidewire) share on stent share, we estimate a negative and statistically significant coefficient on the price variable (indicating that demand slopes down), but the inclusion of the price variable does not substantially change the estimated coefficient on the stent share variable. These patterns suggest that 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). While we are not able to measure the size of any switching costs directly in our data, our price analyses suggest it is unlikely that switching costs for guidewires exceed those of balloons on average across physicians. In particular, we find that guidewires exhibit similar (measured as a percentage of price) or even greater (measured in dollars) price sensitivity in the estimated price coefficients, which is not what we would expect if guidewires had higher switching costs.[31]

Ultimately, our results indicate that spillovers operate differently between stents and balloons and stents and guidewires, with guidewires showing no evidence of the intensive margin relationship that balloons exhibit. While we cannot rule out the possibility that there is a common source of spillovers that operates along the intensive margin for both devices and a factor offsetting this for guidewires, we have found no direct evidence for this. Therefore, we believe the 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.

Finally, we note that our results are robust to a number of variations in our modeling assumptions. To summarize those discussed at previous points in the paper, we find quantitatively and qualitatively similar results when we: (1) use aggregate stent share instead of manufacturer-month effects as a control; (2) use DES instead of total stent sales as the independent variable; (3) define extensive margin using various time windows since last observed purchase; or (4) allow for nonlinear effects in s_{jht}^{stents}. In addition, there are three robustness checks of interest that we have not yet discussed: Appendix Table 16 runs our regressions on a subsample of larger hospitals and finds nearly identical results, verifying that our results are not related to measurement error in market shares at smaller hospitals. Appendix Table 17 shows results for a model with a normally distributed random coefficient on s_{jht}^{stents}. The results provide evidence of heterogeneity in spillover effects across hospitals. We find this interesting and intuitive, but because we do not have detailed data on hospital characteristics, we do not pursue this finding further. Finally, Appendix Table 21 reports results for a model that allows effects to differ based on stent share prior to each DES entry event, and finds no quantitatively meaningful heterogeneity on this dimension.[32]

6 Conclusion

We examine 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 dominance across multiple product categories. 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 mechanism (roughly equivalent in magnitude to correlated firm-level capabilities and spillovers that operate across buyers). Our empirical analysis exploits the introduction of early

[31] If switching costs for guidewires are large enough to inhibit spillovers to guidewires when the benefits are small but not when the benefits are large, then we may find an intensive margin effect if we zero in on the hospitals with high stent share for that manufacturer. We examine several specifications that allow for this type of nonlinear spillover effect in Appendix B.5, and we find no economically or statistically significant evidence of such a nonlinearity.

[32] The only statistically significant heterogeneity we find on this dimension is that hospital-manufacturer pairs with low stent usage in this pre-period see a larger effect of stent intensive margin usage on the balloon extensive margin. However, the quantitative magnitude of this effect is small.

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 margin. We also document spillovers from stents to both balloons and guidewires along the extensive margin. Our interpretation is that this collection of results is most consistent with complementarities at the user level between stents and balloons deriving from design similarities and buyer-level economies of scope that impact fixed costs of contracting for all three devices.

Our results point to broader implications for firm strategy, innovation incentives, and antitrust for firms that operate across multiple categories. Our work has shown that a distinct set of multi-product advantages arise when a firm's products are bought by the same buyer, and these mechanisms can be quantitatively important. Multiproduct firms hoping to exploit any such 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. In business-to-consumer settings, the buyer and the user tend to be the same individual, so this distinction may be less relevant, but the relevance of product design strategy for potential spillovers remains.

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). Notably, the potential for buyer-level spillovers can influence innovation incentives for both small and large firms. The spillovers we estimate imply that firms which sell products spanning multiple categories may reap larger rewards to innovation in a focal market than a smaller firm which operates only in that focal market and therefore cannot benefit from the additional revenue generated by such spillovers. Indeed, the 4-percent boost we document from stent spillovers onto balloons is quite large when compared to the 13 percent of sales that top device manufacturers spend on R&D (MassDevice 2012). 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).

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, was recently fined over $9 billion by the EU in three separate antitrust cases, including for requiring third-party websites using Google's search bar to display ads from Google's own advertising services and for favoring its own shopping services in search results (Satariano 2019). News reports suggest that the Department of Justice is preparing for a similar antitrust investigation in the US, the main focus being whether "Google leveraged its power as the world's dominant search engine to gain unfair advantages in other businesses" (Kendall and McKinnon 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. Empirical evidence disentangling supply-side efficiencies from buyer-level spillovers will be important for regulators seeking to understand the sources behind a dominant firm's success across product categories.

Mergers in buyer-supplier settings can also alter the potential for buyer-level spillovers. We discuss here mergers across both hospitals (buyers) and device manufacturers (suppliers); this is a relevant exercise given the high degree of consolidation activity that occurs in both industries (Burns 2005; Dafny 2014). First, consider the merger of two hospitals. The merged hospital's larger size, and possibly, scope (in the case of hospitals with different medical specialties) may reduce the total fixed costs of contracting that would have otherwise been faced by two smaller hospitals pre-merger. As such, a device firm may experience greater spillovers on the extensive margin associated with economies of scope in contracting at the buyer level following hospital mergers. On the intensive margin, individual doctors are not likely to change the degree to which they prefer products that share similar features as a result of the merger. Physicians may change their preference for a given product (or suite of products) post-merger due to exposure to new colleagues with different preferences. To the extent that this type of learning facilitates a change in the purchases of one device type from a given manufacturer, design complementarities then may induce purchasing changes in other device types that share similar features.

Next, suppose a merger occurs between two device manufacturers. Again, we may expect an increase in extensive margin spillovers due to enhanced economies of scope in contracting. Rather than contracting with two separate device manufacturers, a given hospital wanting to try new devices from these manufacturers needs only to contract with one. This is especially relevant if the merger results in extensions into new product categories for the merged firm relative to the scope of the individual firms pre-merger. Spillovers due to design complementarities will depend on the degree to which the two firms' devices in different product lines share interoperability or usability features. That degree of interoperability may be high, for example, in the case of a larger firm buying up smaller firms that make peripheral products designed to work with the dominant firm's devices.[33]

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 would require additional data on product qualities, entry, and exit. Research in this direction would be important in that these welfare questions are at the heart of antitrust concerns regarding multiproduct firms.

References

Allen, J., Clark, R., and Houde, J.-F. (2019). Search frictions and market power in negotiated-price markets. *Journal of Political Economy*, 127(4):1550–1598.

Atalay, E., Hortacsu, A., and Syverson, C. (2014). Vertical integration and input flows. *American Economic Review*, 104(4):1120–1148.

Bailey, E. E. and Friedlaender, A. F. (1982). Market structure and multiproduct industries. *Journal of Economic Literature*, 20(3):1024–1048.

Baseman, K. C. (1981). Open entry and cross-subsidization in regulated markets. In Fromm, G., editor, *Studies in Public Regulation*, pages 329–370. Cambridge: MIT Press.

Borenstein, S. (1991). The dominant-firm advantage in multiproduct industries: Evidence from the U.S. airlines. *Quarterly Journal of Economics*, 106(4):1237–1266.

Burns, L. R., editor (2005). *The Business of Healthcare Innovation.* New York: Cambridge University Press.

[33]An example of this would be a device manufacturer that makes biopsy guns acquiring the manufacturers that make needles used with the biopsy guns.

Burt, H. M. and Hunter, W. L. (2006). Drug-eluting stents: A multidisciplinary success story. *Advanced Drug Delivery Reviews*, 58(3):350–357.

Cabral, L. (2000). Stretching firm and brand reputation. *RAND Journal of Economics*, 31(4):658–673.

Cabral, L. and Natividad, G. (2016). Cross-selling in the US home video industry. *RAND Journal of Economics*, 47(1):29–47.

Chatterji, A. K. and Fabrizio, K. (2012). How do product users influence corporate invention? *Organization Science*, 23(4):971–987.

Chatterji, A. K. and Fabrizio, K. R. (2016). Does the market for ideas influence the rate and direction of innovative activity? Evidence from the medical device industry. *Strategic Management Journal*.

Chatterji, A. K., Fabrizio, K. R., Mitchell, W., and Schulman, K. A. (2008). Physician-industry cooperation in the medical device industry. *Health Affairs*, 27(6):1532–1543.

Cockburn, I. and Henderson, R. (1994). Measuring competence? Exploring firm effects in pharmaceutical research. *Strategic Management Journal*, 15:63–84.

Cohen, W. M. and Levin, R. C. (1989). Empirical studies of innovation and market structure. *Handbook of Industrial Organization*, 2:1059–1107.

Dafny, L. (2014). Hospital industry consolidation—Still more to come? *New England Journal of Medicine*, 370(3):198–199.

Draganska, M. and Jain, D. C. (2005). Product-line length as a competitive tool. *Journal of Economics & Management Strategy*, 14(1):1–28.

Federico, G., Morton, F. S., and Shapiro, C. (2019). Antitrust and innovation: Welcoming and protecting disruption. In Lerner, J. and Stern, S., editors, *NBER Innovation Policy and the Economy, Volume 20*. Chicago: University of Chicago Press.

Galasso, A. and Luo, H. (2017). Tort reform and innovation. *Journal of Law and Economics*, 60(3):385–412.

Galasso, A. and Luo, H. (2019a). Risk-mitigating technologies? The case of radiation diagnostic devices. Harvard Business School Working Paper No. 19-106.

Galasso, A. and Luo, H. (2019b). When does product liability risk chill innovation? Evidence from medical implants. Harvard Business School Working Paper No. 19-002.

Garthwaite, C. L. (2014). Demand spillovers, combative advertising, and celebrity endorsements. *American Economic Journal: Applied Economics*, 6(2):76–104.

Gavazza, A. (2011). Demand spillovers and market outcomes in the mutual fund industry. *RAND Journal of Economics*, 42(4):776–804.

Godfrey, R. (2016). *Strategic Management: A Critical Introduction*. New York: Routledge.

Grennan, M. (2013). Price discrimination and bargaining: Empirical evidence from medical devices. *American Economic Review*, 103(1):145–177.

Grennan, M. (2014). Bargaining ability and competitive advantage: Empirical evidence from medical devices. *Management Science*, 60(12):3011–3025.

Grennan, M., Gupta, C., and Lederman, M. (2018). Firm scope and spillovers from new product innovation: Evidence from medical devices. NBER Working Paper 25183.

Grennan, M. and Swanson, A. (2019a). Diagnosing price dispersion: Demand, bargaining, and search in hospital-supplier contracting. Working paper.

Grennan, M. and Swanson, A. (2019b). Transparency and negotiated prices: The value of information in hospital-supplier bargaining. *Journal of Political Economy*. Forthcoming.

Grennan, M. and Town, R. J. (2020). Regulating innovation with uncertain quality: Information, risk, and access in medical devices. *American Economic Review*, 110(1):120–61.

Hendricks, K. and Sorensen, A. (2009). Information and the skewness of music sales. *Journal of Political Economy*, 117(2):324–369.

Ho, J., Ho, K., and Mortimer, J. (2012). The use of full-line forcing contracts in the video rental industry. *American Economic Review*, 102(2):686–719.

Ho, K. and Lee, R. S. (2017). Insurer competition in health care markets. *Econometrica*, 85(2):379–417.

Ho, K. and Lee, R. S. (2019). Equilibrium provider networks: Bargaining and exclusion in health care markets. *American Economic Review*, 109(2):473–522.

Htay, T. and Liu, M. W. (2005). Drug-eluting stent: A review and update. *Vascular Health and Risk Management*, 1(4):263.

Jacobson, J., Sher, S., and Holman, E. (2010). Predatory innovation: An analysis of Allied Orthopedic v. Tyco in the context of Section 2 jurisprudence. *Loyola Consumer Law Review*, 23:1.

Kendall, B. and McKinnon, J. (2019). Justice Department is preparing antitrust investigation of Google. *Wall Street Journal*.

Lancaster, K. (1979). *Variety, Equity, and Efficiency: Product Variety in an Industrial Society*, volume 10. New York: Columbia University Press.

Lederman, M. (2007). Do enhancements to loyalty programs affect demand? The impact of international frequent flyer partnerships on domestic airline demand. *RAND Journal of Economics*, 38(4):1134–1158.

Lederman, M. (2008). Are frequent flyer programs a cause of the "hub premium"? *Journal of Economics and Management Strategy*, 17(1):35–66.

Lee, R. S. and Fong, K. (2013). Markov-perfect network formation: An applied framework for bilateral oligopoly and bargaining in buyer-seller networks. Working paper.

Makower, J., Meer, A., and Denend, L. (2010). FDA impact on U.S. medical technology innovation: A survey of over 200 medical technology companies. `https://www.advamed.org/sites/default/files/resource/30_10_11_10_2010_Study_CAgenda_makowerreportfinal.pdf`. Accessed June 23, 2019.

MassDevice (2012). Medical device companies: Who spends the most on R&D? `https://www.massdevice.com/medical-device-companies-who-spends-most-rd/`. Accessed June 28, 2019.

Matutes, C. and Regibeau, P. (1988). "Mix and match": Product compatibility without network externalities. *RAND Journal of Economics*, 19(2):221–234.

MRG, M. R. G. (2013). Marketrack: Us ic devices 2004-13. Available for purchase www.mrg.net.

Nalebuff, B. (2000). Competing against bundles. In Hammond, P. J. and Myles, G. D., editors, *Incentives, Organization, and Public Economics: Papers in Honour of Sir James Mirrlees*, chapter 17, pages 323–336. New York: Oxford University Press.

Nalebuff, B. (2004). Bundling as an entry barrier. *Quarterly Journal of Economics*, 119(1):159–187.

Newman, J. M. (2011). Anticompetitive product design in the new economy. *Florida State University Law Review*, 39:681.

Panzar, J. C. and Willig, R. D. (1981). Economies of scope. *American Economic Review*, 71(2):268–72.

PRNewsire (2018). Interventional cardiology devices market size to grow swiftly, expected to surpass $25 billion by 2020. `https://www.prnewswire.com/news-releases/interventional-cardiology-devices-market-size-to-grow-swiftly-expected-to-surpass-25-billion-by-2020--million-insights-681905181.html`. Accessed July 29, 2018.

Satariano, A. (2019). Google fined $1.7 billion by E.U. for unfair advertising rules. *New York Times*. `https://www.nytimes.com/2019/03/20/business/google-fine-advertising.html`. Accessed September 17, 2019.

Schlesinger, J., Kendall, B., and McKinnon, J. (2019). Tech giants Google, Facebook and Amazon intensify antitrust debate. *Wall Street Journal*.

Schmalensee, R. (1978). Entry deterrence in the ready-to-eat breakfast cereal industry. *Bell Journal of Economics*, 9:305–327.

Schneller, E. S. (2009). The value of group purchasing – 2009: Meeting the need for strategic savings. Report of Health Care Sector Advances, Inc.

Schumpeter, J. A. (1942). *Socialism, Capitalism and Democracy*. New York: Harper and Brothers.

Shapiro, C. (2019). Protecting competition in the American economy: Merger control, tech titans, labor markets. *Journal of Economic Perspectives*, 33(3):69–93.

Spence, A. M. (1977). Entry, capacity, investment and oligopolistic pricing. *Bell Journal of Economics*, pages 534–544.

Stern, A. D. (2017). Innovation under regulatory uncertainty: Evidence from medical technology. *Journal of Public Economics*, 145:181–200.

Stone, B. (2011). Steve Jobs: The return, 1997 - 2011. *Bloomberg*. `https://www.bloomberg.com/news/articles/2011-10-06/steve-jobs-the-return-1997-2011`. Accessed Mar. 17, 2018.

Sutton, J. (1989). Endogenous sunk costs and the structure of advertising intensive industries. *European Economic Review*, 33(2-3):335–344.

Teece, D. J. (1980). Economies of scope and the scope of the enterprise. *Journal of Economic Behavior & Organization*, 1(3):223–247.

Teece, D. J. (1982). Towards an economic theory of the multiproduct firm. *Journal of Economic Behavior & Organization*, 3(1):39–63.

Teece, D. J. (1986). Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, 15(6):285–305.

Tobis, J. M. and Abudayyeh, I. (2015). New devices and technology in interventional cardiology. *Journal of Cardiology*, 65(1):5–16.

Waller, S. W. and Sag, M. (2014). Promoting innovation. *Iowa Law Review*, 100:2223–2247.

Whinston, M. D. (1990). Tying, foreclosure, and exclusion. *American Economic Review*, 837(852-54):856.

Winkler, E. (2018). AT&T not out of the legal woods yet. *Wall Street Journal*. `https://www.wsj.com/articles/at-t-not-out-of-the-legal-woods-yet-1533549600`. Accessed August 28, 2018.

Data Availability Statement

The data used in this research comes from Millennium Research Group's Marketrack annual survey of hospitals (MRG 2013). This proprietary data is available for purchase 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 January 2005 through June 2013. 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. For instance, we correct purchases of the DES "Sprint" from Medtronic to be "Endeavor Sprint," as Medtronic does not have a stent by the name Sprint. We also see numerous records of "Promus 2.25" in our US data; "2.25" is not part of the stent name but rather its 2.25-mm diameter. We recode these observations to "Promus" before November 2011 and to "Promus Element" from November 2011 and on, as the FDA approved Promus Element in November 2011 and the first US purchases of "Promus Element" appear then in our data. We similarly clean the few instances where manufacturer names are recorded inconsistently. We also recode "Guidant" as "Abbott Vascular" to account for Abbott's 2006 purchase of Guidant's vascular intervention business.

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. We include in Appendix B.6 robustness checks where we adjust this definition to reflect activity in any of the six or twelve months prior, and our results remain qualitatively and quantitatively similar.

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 $j \in \mathcal{J}_{ht}^{c}$ and our within-market intensive share, for all manufacturers $j \in \mathcal{J}_{mt}^{c}$.

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):

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

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:

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

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:

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

$$= \frac{\sum_{h \in H_{mt}} q_{jht}^{c} - q_{jlt}^{c}}{\sum_{h \in H_{mt}} \sum_{k \in J_{mt}^{c}} q_{kht}^{c} - \sum_{k \in J_{mt}^{c}} q_{klt}^{c}} \tag{11}$$

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 5 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 (about 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 5: 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	26.44	(30.45)	26,013	66.43	(52.39)	2.5	1711.22	(1134.90)	4.0
balloons	32.87	(39.78)	21,557	68.42	(60.64)	2.3	1451.80	(1529.70)	4.8
guidewires	31.20	(35.26)	24,069	72.52	(61.54)	2.1	1264.23	(1559.67)	6.0

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. Mean number of US hospitals in the sample in the typical month is 101.7, with a standard deviation of 4.5. N_{jht} gives total number of manufacturer-hospital-month observations by category.

Table 6 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 (\$1654) is substantially more expensive than the average balloon (\$270) 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 6: Prices

	Full sample			Around DES events		
	mean	SD	N_{jht}	mean	SD	N_{jht}
p_{jht}^{stents}	1654.3	(546.3)	26,013	1589.9	(499.7)	4,920
$p_{jht}^{balloons}$	269.6	(152.6)	21,557	269.7	(157.3)	4,074
p_{jht}^{gwires}	84.3	(22.1)	24,069	84.0	(17.9)	4,519

Table provides average monthly prices 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 Largest manufacturers by market share

Table 7: Largest firms by market share

Category	Manufacturer	$s_m \mid \mathbb{1}_m$	$\mathbb{1}_h$	$s_h \mid \mathbb{1}_h$
stents	Boston Scientific	.430	.895	.505
	Abbott Vascular	.269	.821	.322
	Cordis	.187	.510	.292
	Medtronic	.114	.540	.192
balloons	Boston Scientific	.578	.914	.624
	Abbott Vascular	.293	.656	.437
	Medtronic	.095	.459	.218
	Cordis	.027	.189	.206
	Angioscore	.009	.188	.037
guidewires	Abbott Vascular	.578	.934	.606
	Boston Scientific	.283	.866	.350
	Medtronic	.070	.313	.197
	Cordis	.039	.314	.121
	Terumo	.033	.212	.119
	Argon Medical	.007	.007	.405
	Vascular Solutions	.004	.010	.150

Table gives the largest firms in terms of mean intensive within-market share by device category from January 2005 through June 2013. 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 81,065.

Table 7 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: Boston Scientific, Abbott Vascular, Cordis, and Medtronic. 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 8 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 53 percentage points (stents) and 72 percentage points (balloons). Robustness checks in Appendix B.7 make use of the stent share 75th percentile (0.614) as a cutoff when defining a hospital's low versus high pre-period stent usage from a given manufacturer.

Table 8: Within-hospital shares across all manufacturers (with detailed intensive share distribution)

	s^c_{jht}	$\mathbb{1}_{\{s^c_{jht}>0\}}$	$s^c_{jht}\vert\mathbb{1}_{\{s^c_{jht}>0\}}$			
	mean	mean	mean	p25	p50	p75
stents	0.128 (0.257)	0.353 (0.478)	0.362 (0.320)	0.080	0.265	0.614
balloons	0.128 (0.281)	0.302 (0.459)	0.423 (0.369)	0.064	0.327	0.788
guidewires	0.128 (0.261)	0.335 (0.472)	0.381 (0.327)	0.082	0.303	0.643

Total number of manufacturer-hospital-month observations is 81,065.

A.4.3 Multi- and single-category manufacturers

Tables 9 and 10 provide mean within-hospital shares for multi- and single-category manufacturers, respectively. Table 9 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 Boston Scientific, Medtronic, Cordis, and Abbott Vascular. Overall within-hospital shares are about 0.25 across all three categories, with each of these firms possessing one-fourth of the interventional cardiology market. Conditional on selling in a hospital in a given category, the typical multi-category manufacturer provides that hospital between 36 and 45 percent of its devices in that category although there is substantial dispersion in these metrics.

While Table 9 explores multi-category manufacturers, Table 10 looks at the single-category

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

	s^c_{jht}	$\mathbb{1}_{\{s^c_{jht}>0\}}$	$s^c_{jht} \vert \mathbb{1}_{\{s^c_{jht}>0\}}$			
	mean	mean	mean	p25	p50	p75
stents	0.250 (0.314)	0.691 (0.462)	0.362 (0.320)	0.080	0.265	0.614
balloons	0.248 (0.353)	0.554 (0.497)	0.448 (0.367)	0.091	0.379	0.815
guidewires	0.243 (0.322)	0.606 (0.489)	0.400 (0.328)	0.098	0.333	0.667

Total number of manufacturer-hospital-month observations is 41,420.

Table 10: Within-hospital shares for single-category manufacturers

	s^c_{jht}	$\mathbb{1}_{\{s^c_{jht}>0\}}$	$s^c_{jht} \vert \mathbb{1}_{\{s^c_{jht}>0\}}$			
	mean	mean	mean	p25	p50	p75
balloons	0.008 (0.031)	0.189 (0.391)	0.041 (0.061)	0.000	0.020	0.055
guidewires	0.016 (0.080)	0.108 (0.310)	0.151 (0.198)	0.000	0.079	0.222

Total number of manufacturer-hospital-month observations is 8,156 for balloons and 18,909 for guidewires.

manufacturers in our sample. As such, each panel of Table 10 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. Single-category manufacturers in both balloons and guidewires have low within-hospital overall shares (from less than one to 1.1 percent). Conditional on selling balloons to a hospital, a balloon manufacturer will provide roughly 4.1 percent of that hospital's balloon devices in a given month. For guidewire manufacturers, this figure is higher, at 15.1 percent.

A.5 DES entry events

Table 11 gives all DES introductions in the US during our sample period, January 2005 through June 2013, 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: Medtronic Endeavor, Abbott Vascular Xience V, and Medtronic Resolute Integrity. 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 11: DES entry events

Date	Manufacturer	Product	Pre-s_{jht}^{stent}	Post-s_{jht}^{stent}	Diff
2008-Feb*	Medtronic	Endeavor	.057	.149	.092
2008-July*	Abbott Vascular	Xience V	.205	.370	.164
2008-July	Boston Scientific	Promus	.398	.397	-.001
2008-Oct	Boston Scientific	Taxus Express Atom	.387	.432	.044
2008-Nov	Medtronic	Endeavor Sprint	.099	.107	.008
2008-Nov	Boston Scientific	Taxus Liberte	.397	.436	.039
2009-June	Boston Scientific	Taxus Liberte Atom	.421	.415	-.005
2011-Apr	Boston Scientific	Ion	.428	.438	.010
2011-June	Abbott Vascular	Xience Nano	.367	.377	.010
2011-Nov	Abbott Vascular	Xience Prime	.377	.413	.036
2011-Nov	Boston Scientific	Promus Element	.443	.431	-.013
2012-Feb*	Medtronic	Resolute Integrity	.137	.236	.099
2013-Jan	Abbott Vascular	Xience Xpedition	.384	.391	.007

Table gives DES introductions in the US during our sample period; the three focal DES entry events (producing the largest immediate impact to the innovating firm's stent market share) are starred. Date refers to first instance product appears in our data.

B Robustness checks

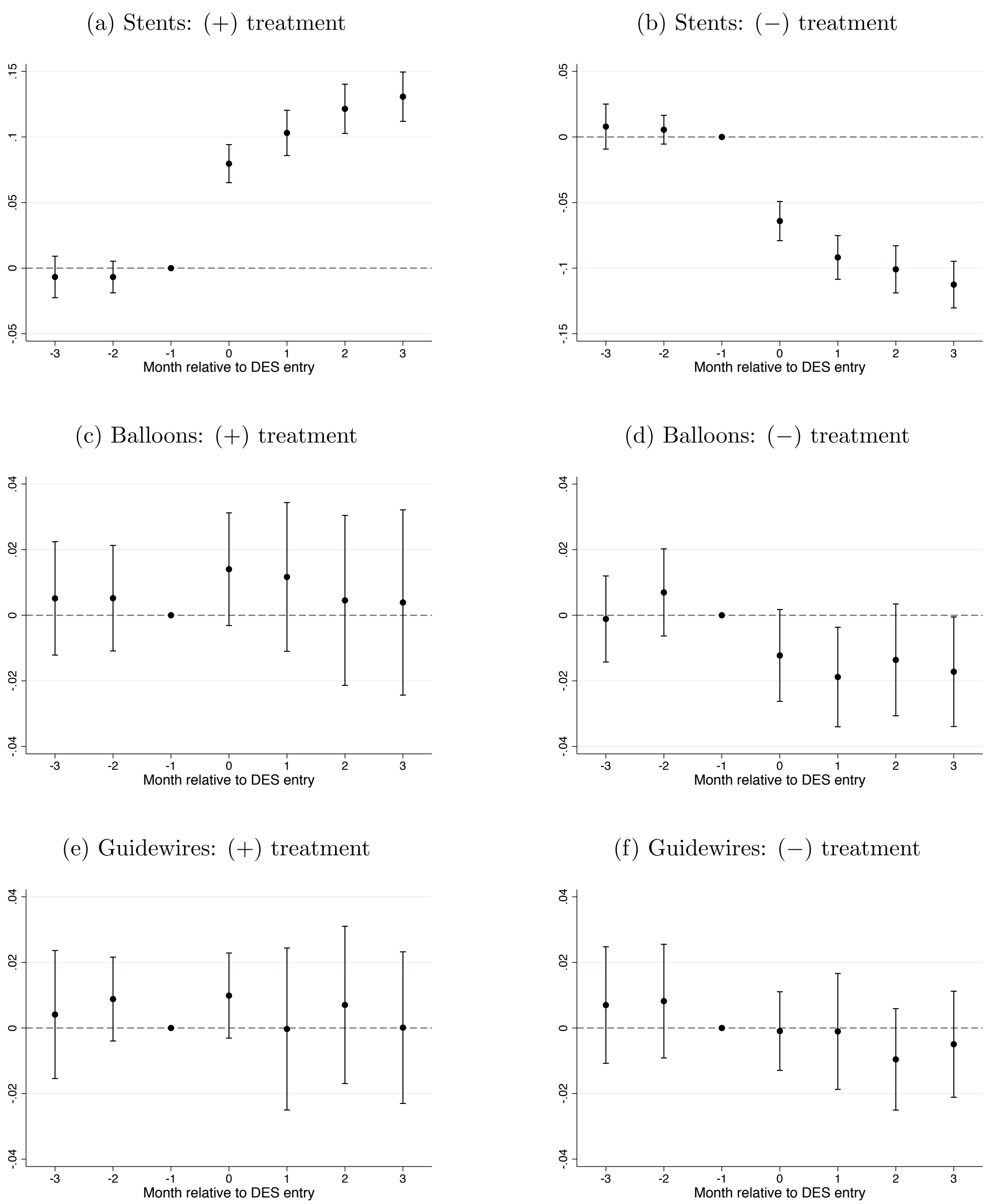
B.1 Event-study examination of parallel pre-trends

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:

$$s_{jhte}^{balloons/gwires} = \sum_{k=-3}^{k=3} \lambda_k \big(treated_{jhe} \cdot \mathbb{1}_{t=k}\big) + \sum_{k=-3}^{k=3} \gamma_k \big(negative_{jhe} \cdot \mathbb{1}_{t=k}\big) + \delta_{jhe} + \delta_{jte} + \epsilon_{jhte} \quad (16)$$

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

B.2 Inclusion of leave-out within-market share as a control

Table 12: Spillovers (leave-out within-market stent share as a control)

	Balloons					Guidewires				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
s_{jht}^{stents}	0.778***	0.540***	0.224***	0.258***	0.252***	0.469***	0.207***	0.0528**	0.0314	0.0203
	(0.0216)	(0.0273)	(0.0283)	(0.0306)	(0.0377)	(0.0261)	(0.0331)	(0.0208)	(0.0224)	(0.0275)
$s_{jm_{-l}t}^{stents}$				-0.164***	-0.160***				0.106***	0.0895**
				(0.0465)	(0.0559)				(0.0365)	(0.0429)
Observations	81,065	81,065	80,475	80,475	15,803	81,065	81,065	80,475	80,475	15,803
Adj. R^2	0.506	0.627	0.866	0.867	0.900	0.213	0.573	0.893	0.894	0.919
Mfr FE		yes					yes			
Mfr-Hosp FE			yes	yes	yes			yes	yes	yes

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

Tables 12 and 13 replicate our prior analyses but exclude manufacturer-month fixed effects in order to explicitly include the leave-out within-market stent share as a control. Doing so does not change our conclusions, as the coefficient estimates on within-hospital stent share remain quantitatively similar. The first three columns of each panel of Table 12, i.e. Columns (1) through (3) for balloons and (6) through (8) for guidewires, replicate spillover specifications from the paper text for reference. Columns (4) and (9) add the leave-out within-market stent share in place of the manufacturer-month fixed effects for the balloon and guidewire specifications, respectively. For both balloons and guidewires, we see statistically significant coefficients on the within-market stent share. The opposing signs and relative magnitudes of the coefficients for balloons versus guidewires indicate that market-level time trends play a greater role in a manufacturer's guidewire sales than hospital-level factors, while the reverse is true for balloons. Columns (5) and (10) narrow our sample to the windows surrounding the DES introductions; the same conclusions continue to hold.

Table 13: Decomposition (leave-out within-market stent share as a control)

	Balloons						Guidewires					
	$s_{jht}^{balloons}$			$\mathbb{1}_{\{s_{jht}^{balloons}>0\}}$			$s_{jht}^{guidewires}$			$\mathbb{1}_{\{s_{jht}^{guidewires}>0\}}$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
s_{jht}^{stents}	0.25***		0.24***	0.22***		0.15***	0.02		0.01	0.00		-0.03
	(0.04)		(0.04)	(0.04)		(0.03)	(0.03)		(0.03)	(0.03)		(0.03)
$\mathbb{1}_{\{s_{jht}^{stents}>0\}}$		0.07***	0.03***		0.20***	0.18***		0.02*	0.01*		0.08***	0.08***
		(0.01)	(0.01)		(0.03)	(0.03)		(0.01)	(0.01)		(0.03)	(0.03)
$s_{jm_{-l}t}^{stents}$	-0.16***	-0.03	-0.19***	0.14	0.05	-0.05	0.09**	0.08*	0.07	0.28***	0.17*	0.19**
	(0.06)	(0.05)	(0.06)	(0.11)	(0.11)	(0.10)	(0.04)	(0.04)	(0.05)	(0.09)	(0.10)	(0.09)
Observations	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803
Adj. R^2	0.90	0.89	0.90	0.85	0.86	0.86	0.92	0.92	0.92	0.88	0.88	0.88
Mfr-Hosp FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Mfr-Mth FE	yes	yes	yes	yes	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.

Including the leave-out within-market share as a control also does not change the conclusions of our decomposition analysis (Table 13). The act of contracting with a manufacturer for its stents and the amount of stent usage conditional on contracting both play a role in whether a hospital uses that manufacturer's balloons in Column (6), and if so, how much of them (3). In contrast, Columns (9) and (12) show that changes to guidewire usage along both the intensive and extensive margins are driven by changes in stent purchasing on the extensive margin only. Market-level trends play a much greater role in the probability of purchasing a manufacturer's guidewires and in the intensity of guidewire usage than hospital-level factors.

B.3 DES share as independent variable

Our empirical strategy exploits three DES introductions as plausibly exogenous shocks. DES usage accounts for 87 percent of total stent usage, on average, across all our data; when we restrict to windows surrounding the major introductions, that figure rises to 93 percent. To further demonstrate that the changes to stent share are driven by DES, we (1) repeat our spillovers analysis using within-hospital share of DES as the independent variable and (2) implement a two-stage least squares regression analysis incorporating DES share as an instrument for total stent share.

Table 14 presents the results of our spillover analysis restricting to within-hospital DES share as the independent variable in place of total stent share. As expected, the coefficients are quantitatively smaller than those of our main results but qualitative interpretations remain the same.

Table 14: Spillovers (DES share as independent variable)

	Balloons					**Guidewires**				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
s_{jht}^{DES}	0.642***	0.405***	0.161***	0.185***	0.149***	0.330***	0.138***	0.0439**	0.0213	0.00618
	(0.0244)	(0.0259)	(0.0228)	(0.0251)	(0.0275)	(0.0242)	(0.0284)	(0.0183)	(0.0194)	(0.0229)
Observations	81,065	81,065	80,475	80,475	15,803	81,065	81,065	80,475	80,475	15,803
Adj. R^2	0.410	0.577	0.862	0.866	0.898	0.125	0.561	0.893	0.895	0.919
Mfr FE		yes					yes			
Mfr-Hosp FE			yes	yes	yes			yes	yes	yes
Mfr-Month FE				yes	yes				yes	yes

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

Table 15 incorporates DES share into a 2SLS analysis. Column (1) shows the first stage in which we regress within-hospital stent share on within-hospital DES share for the windows surrounding our DES introductions, including both manufacturer-hospital and manufacturer-month fixed effects. The adjusted R^2 tells us that 94.5 percent of the total variation in within-hospital stent share is explained by the variation in within-hospital DES share, manufacturer-hospital factors, and manufacturer-month factors. The within R^2 (not reported in the table) of 0.720 says that 72.0 percent of the total variation in a manufacturer's within-hospital stent share (de-meaned for both its average share in that hospital over time and its average across all hospitals in a given month) is explained by its within-hospital DES share. Columns (2) and (5) repeat our preferred specifications for the balloon and guidewire spillovers analysis. Columns (3) and (6) give the reduced form regression in which we regress within-hospital balloon (guidewire) share directly on within-hospital DES share. A 10-percentage-point increase in a manufacturer's within-hospital DES share is associated with a 1.5-percentage point increase in within-hospital balloon share (3), but there is no effect for guidewires (6). Lastly, Columns (4) and (7) show the 2SLS results where we have used DES share as an instrument for stent share. Notably, the coefficient estimate on within-hospital stent share in the 2SLS specification is statistically identical to the OLS specification for both balloons and guidewires.

Table 15: Spillovers (2SLS incorporating DES share)

	First stage	**Balloons**			**Guidewires**		
	(1) s_{jht}^{stents}	(2) OLS $s_{jht}^{balloons}$	(3) RF $s_{jht}^{balloons}$	(4) 2SLS $s_{jht}^{balloons}$	(5) OLS s_{jht}^{gwires}	(6) RF s_{jht}^{gwires}	(7) 2SLS s_{jht}^{gwires}
s_{jht}^{stents}		0.246***		0.212***	0.0170		0.00879
		(0.0377)		(0.0370)	(0.0271)		(0.0326)
s_{jht}^{DES}	0.703***		0.149***			0.00618	
	(0.0259)		(0.0275)			(0.0229)	
Observations	15,803	15,803	15,803	15,803	15,803	15,803	15,803
Adj. R^2	0.945	0.902	0.898		0.919	0.919	
Mfr-Hosp FE	yes	yes	yes	yes	yes	yes	yes
Mfr-Mth FE	yes	yes	yes	yes	yes	yes	yes

The dependent variable for each specification is listed below column number. Robust standard errors clustered at the hospital level are in parentheses. *** p<0.01, ** p<0.05, and * p<0.1.

B.4 Excluding small-quantity hospitals

To confirm that our share measures are not noisily measured by hospitals purchasing just a few units of each device, we repeat our spillovers analysis excluding small-quantity hospitals. Specifically, we drop hospitals with an average monthly purchase of fewer than 20 units in any of our three device categories. Figure 3 shows how this restriction relates to the distributions of average monthly product usage across the hospitals in our sample. In particular, this takes us from the full sample of 337 to a subsample of 270 hospitals. The similarity of coefficients in Table 16 with our main results suggests that these outlier hospitals are not driving the results.

Figure 3: Average monthly quantity purchased per hospital

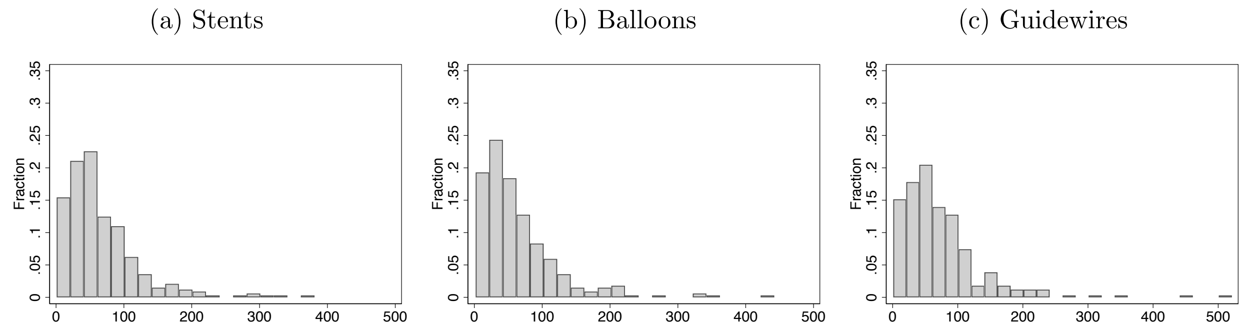


Table 16: Spillovers (subsample excluding small hospitals)

	Balloons					Guidewires				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
s_{jht}^{stents}	0.765***	0.516***	0.209***	0.242***	0.254***	0.455***	0.191***	0.0531**	0.0274	0.0184
	(0.0251)	(0.0306)	(0.0281)	(0.0318)	(0.0419)	(0.0290)	(0.0369)	(0.0242)	(0.0269)	(0.0300)
Observations	69,481	69,481	69,029	69,029	13,922	69,481	69,481	69,029	69,029	13,922
Adj. R^2	0.483	0.621	0.869	0.874	0.902	0.199	0.590	0.900	0.901	0.922
Mfr FE		yes					yes			
Mfr-Hosp FE			yes	yes	yes			yes	yes	yes
Mfr-Month FE				yes	yes				yes	yes

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

B.5 Flexible specifications

We carry out a series of flexible model specifications for our spillovers analysis. Under concerns that the relationship between within-hospital stent and within-hospital balloon (guidewire) share may be nonlinear, we add squared and cubic terms, respectively:

$$s_{jht}^{balloons/gwires} = \beta_1 s_{jht}^{stents} + \beta_2 (s_{jht}^{stents})^2 + \delta_{jt} + \delta_{jh} + \epsilon_{jht} \quad (17)$$

$$s_{jht}^{balloons/gwires} = \beta_1 s_{jht}^{stents} + \beta_2 (s_{jht}^{stents})^2 + \beta_3 (s_{jht}^{stents})^3 + \delta_{jt} + \delta_{jh} + \epsilon_{jht} \quad (18)$$

We also fit a linear mixed model, containing both fixed effects and random slope terms. That is, we estimate the following regression:

$$s_{jht}^{balloons/gwires} = (\beta_1 + \alpha_{1jh}) s_{jht}^{stents} + \delta_{jt} + \delta_{jh} + \epsilon_{jht} \quad (19)$$

where $\alpha_{1jh} \sim N(0, \sigma^2_{a_1})$. With this specification, we allow for the effect of within-hospital stent share to vary across manufacturer-hospital observations.

Table 17: Spillovers (flexible specifications)

	Balloons				**Guidewires**			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_1	0.246***	0.243***	0.236***	0.174***	0.0170	0.0603*	0.0440	0.0116
	(0.0377)	(0.0488)	(0.0891)	(0.0313)	(0.0271)	(0.0329)	(0.0581)	(0.0185)
β_2		0.00303	0.0251			-0.0504	0.000276	
		(0.0525)	(0.263)			(0.0394)	(0.174)	
β_3			-0.0160				-0.0367	
			(0.203)				(0.136)	
σ_{a_1}				0.281***				0.182***
				(0.116)				(0.073)
Observations	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803
Adj. R^2	0.902	0.902	0.902		0.919	0.919	0.919	
Mfr-Hosp FE	yes	yes	yes	yes	yes	yes	yes	yes
Mfr-Mth FE	yes	yes	yes	yes	yes	yes	yes	yes

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

The results of these specifications are shown in Table 17. Columns (1) and (5) repeat our preferred specification for balloons and guidewires, focused on the windows surrounding our three DES introductions. Columns (2) and (6) add the squared term, and Columns (3) and (7) add the cubic term. The squared and cubic terms are insignificant in all specifications, for both balloons and guidewires. We conclude that a linear relationship best fits the relationship between a manufacturer's within-hospital stent and balloon (guidewire) shares.

This is interesting not only in terms of robustness, but also as an indirect test of the idea that perhaps guidewires have higher switching costs than balloons. In a model where guidewires do experience spillovers, but switching costs exceed spillover benefits at low levels of spillovers, we might expect an attenuated linear effect. However, if higher levels of spillovers do exceed switching costs, then we might see this relationship in the nonlinear specifications. The fact that we do not provides another piece of evidence casting doubt on such a mechanism (or any model in which guidewires and balloons differ on the functional form of spillovers).

Columns (4) and (8) provide the mixed model specification results; the estimates for β_1 (for both balloons and guidewires) become smaller. While β_1 gives the average effect across all manufacturer-hospital observations, the random parameter estimate σ_{a_1} indicates the marginal effect of within-hospital stent share at the manufacturer-hospital level. The economically and statistically significant σ_{a_1} estimates suggest a nontrivial amount of variation across manufacturer-hospital observations. Because we have little in the way of hospital characteristics to explain this variation, and the mean effects are similar to our main specifications, we do not pursue this further.

B.6 Extensive share definition

We repeat our decomposition analysis using alternative definitions of the within-hospital extensive share variable. Recall that a manufacturer is considered 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. Table 18 alters this definition by considering a manufacturer as active only if it sold to a hospital in that device category *in that month*. Tables 19 and 20 further smooth the contracting measure by allowing a manufacturer to be active if it sold in any of the six or twelve months prior, respectively. Our conclusions do not change with these alternative definitions.

Table 18: Decomposition (extensive share zero requires zero in that month)

	Balloons						**Guidewires**					
	$s_{jht}^{balloons}$			$\mathbb{1}_{\{s_{jht}^{balloons}>0\}}$			$s_{jht}^{guidewires}$			$\mathbb{1}_{\{s_{jht}^{guidewires}>0\}}$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
s_{jht}^{stents}	0.25***		0.24***	0.24***		0.15***	0.02		0.01	0.04		0.00
	(0.04)		(0.04)	(0.03)		(0.03)	(0.03)		(0.03)	(0.03)		(0.04)
$\mathbb{1}_{\{s_{jht}^{stents}>0\}}$		0.07***	0.01		0.16***	0.12***		0.01	0.01		0.05***	0.05**
		(0.01)	(0.01)		(0.02)	(0.02)		(0.01)	(0.01)		(0.02)	(0.02)
Observations	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803
Adj. R^2	0.90	0.90	0.90	0.82	0.82	0.82	0.92	0.92	0.92	0.84	0.84	0.84
Mfr-Hosp FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Mfr-Mth FE	yes	yes	yes	yes	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.

Table 19: Decomposition (extensive share zero requires zero for six months prior)

	Balloons						**Guidewires**					
	$s_{jht}^{balloons}$			$\mathbb{1}_{\{s_{jht}^{balloons}>0\}}$			$s_{jht}^{guidewires}$			$\mathbb{1}_{\{s_{jht}^{guidewires}>0\}}$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
s_{jht}^{stents}	0.25***		0.24***	0.21***		0.16***	0.02		0.01	-0.02		-0.03
	(0.04)		(0.04)	(0.04)		(0.04)	(0.03)		(0.03)	(0.03)		(0.04)
$\mathbb{1}_{\{s_{jht}^{stents}>0\}}$		0.07***	0.03**		0.18***	0.16***		0.01	0.01		0.04	0.05
		(0.02)	(0.01)		(0.04)	(0.04)		(0.01)	(0.01)		(0.04)	(0.04)
Observations	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803
Adj. R^2	0.90	0.89	0.90	0.87	0.88	0.88	0.92	0.92	0.92	0.89	0.89	0.89
Mfr-Hosp FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Mfr-Mth FE	yes	yes	yes	yes	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.

Table 20: Decomposition (extensive share zero requires zero for twelve months prior)

	Balloons						**Guidewires**					
	$s_{jht}^{balloons}$			$\mathbb{1}_{\{s_{jht}^{balloons}>0\}}$			$s_{jht}^{guidewires}$			$\mathbb{1}_{\{s_{jht}^{guidewires}>0\}}$		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
s_{jht}^{stents}	0.25***		0.24***	0.17***		0.15***	0.02		0.02	-0.01		-0.02
	(0.04)		(0.04)	(0.04)		(0.04)	(0.03)		(0.03)	(0.04)		(0.04)
$\mathbb{1}_{\{s_{jht}^{stents}>0\}}$		0.05***	0.02*		0.16***	0.14***		0.00	0.00		0.06	0.06
		(0.02)	(0.01)		(0.05)	(0.04)		(0.01)	(0.01)		(0.04)	(0.04)
Observations	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803	15,803
Adj. R^2	0.90	0.89	0.90	0.89	0.89	0.89	0.92	0.92	0.92	0.90	0.90	0.90
Mfr-Hosp FE	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes
Mfr-Mth FE	yes	yes	yes	yes	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.

B.7 Heterogeneity in pre-period stent share

We repeat our decomposition analysis accounting for heterogeneity in pre-period stent share. We interact the intensive stent share in the post-event period with indicators for whether the manufacturer had, on average, a low or high pre-period stent share in that hospital. We distinguish low and high pre-period stent shares using as a cutoff the 75th percentile of intensive stent share across the sample period (0.614; see Appendix Table 8).

Table 21: Decomposition (separating low and high pre-period stent shares)

	Balloons		**Guidewires**	
	$s_{jht}^{balloons}$	$\mathbb{1}_{\{s_{jht}^{balloons}>0\}}$	$s_{jht}^{guidewires}$	$\mathbb{1}_{\{s_{jht}^{guidewires}>0\}}$
	(1)	(2)	(3)	(4)
$\mathbb{1}_{\{low\,pre\}} \times \mathbb{1}_{\{post\}} \times s_{jht}^{stents}$	0.0984***	0.139***	0.0157	0.0366
	(0.0260)	(0.0447)	(0.0179)	(0.0286)
$\mathbb{1}_{\{high\,pre\}} \times \mathbb{1}_{\{post\}} \times s_{jht}^{stents}$	0.0912***	0.0394**	0.0232	-0.0150
	(0.0255)	(0.0196)	(0.0209)	(0.0247)
$\mathbb{1}_{\{s_{jht}^{stents}>0\}}$	0.0617***	0.169***	0.0121	0.0507*
	(0.0138)	(0.0332)	(0.00990)	(0.0263)
Observations	15,803	15,803	15,803	15,803
Adj. R^2	0.896	0.860	0.919	0.879
Mfr-Hosp FE	yes	yes	yes	yes
Mfr-Mth FE	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.

Table 21 shows no quantitatively meaningful heterogeneity based on pre-period stent share. The impact on intensive margin balloon share in Column (1) derives about equally from changes in stent share for manufacturer-hospital pairs with low pre-period stent usage versus high. On the extensive margin for balloons in (2), changes in stent share for manufacturer-hospital pairs with low pre-period usage do induce a larger effect than those with high, but the quantitative magnitude of this effect is small. In Column (3), we see no effect on intensive margin guidewire share, irrespective of stent usage in the pre-period. Column (4) shows that we also see no effect on extensive margin guidewire usage from intensive stent usage, with changes in probability of guidewire usage coming entirely from changes in contracting with a manufacturer for its stents.