Information shocks and provider adaptation: Evidence from interventional cardiology

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Abstract

We study how information diffusion of medical care technology impacts patient outcomes by exploiting physician reactions to a global information shock on the potentially adverse effects of drug-eluting stents (DES). Applying rich micro-data on all percutaneous coronary interventions performed in Swedish hospitals, we define and measure physician adaptability to new treatment information as the rate with which individual cardiologists responded to news about the safety of DES. We find substantial variation in response intensity across physicians. Furthermore, slow-responding cardiologists perform better than quick responders over a range of clinical endpoints. Finally, clear guidelines appear effective in reducing variation in both physician discretion and patient outcomes. Sensitivity checks suggest that these findings cannot be attributed to patient–physician sorting or to heterogeneity in cardiologist skill or treatment method.

Keywords: Provider practice style, adaptability, information diffusion, cardiology, quality of care.

JEL Classifications: H51; I11; I18; J24; O33.

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1 Introduction

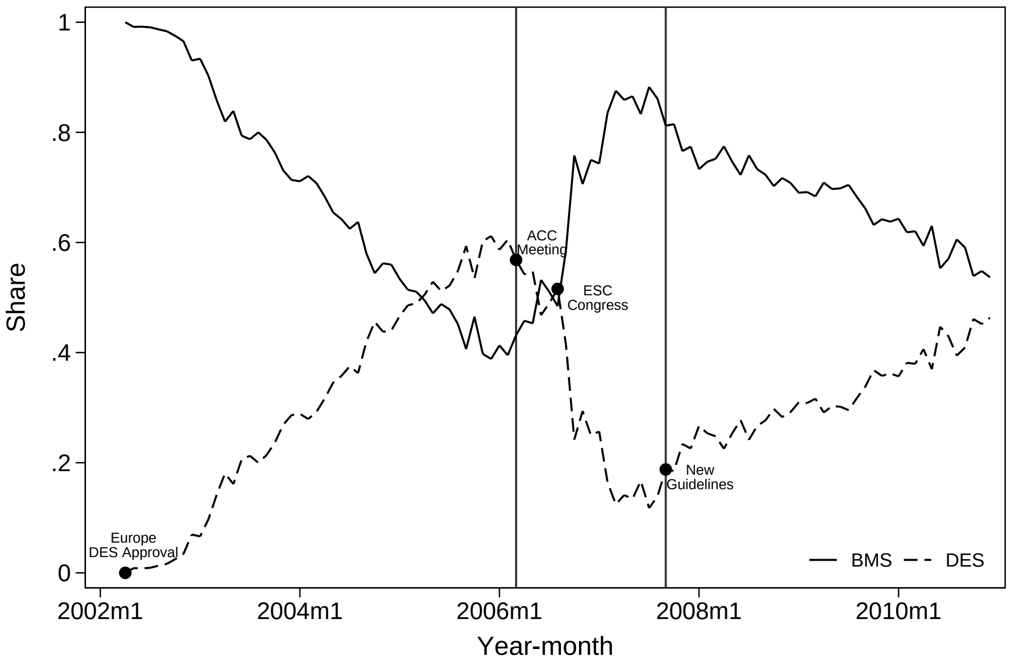
Regional health care expenditures within most OECD countries vary substantially also after adjustment for patient characteristics, prices and consumer demand for health services (Corallo *et al.*, 2014). For example, case-mix adjusted spending from the US Medicare program varies with as much as 70% across hospital regions (Skinner *et al.*, 2011). Furthermore, rates of costly medical activities such as angioplasty, cesarean sections, and MRI/CT scans differ significantly not only across, but also within, OECD (McPherson *et al.*, 2013). However, areas with higher spending do not, in general, have better health outcomes, suggesting that health care resources can be more efficiently allocated to reduce total expenditures without necessarily worsening patient outcomes (Garber and Skinner, 2008).

Using US Medicare claims data from migrating patients, Finkelstein *et al.* (2016) estimate that the majority of regional differences in health care utilization are accounted for by supply-side factors. One such, largely overlooked, factor is discretionary provider treatment decisions (Sutherland *et al.*, 2009). Since aggregate patterns of care arise from the individual decisions of physicians, understanding the underlying factors behind providers' treatment choices may be crucial to achieve cost-effective provision of health care. Health care policy may thus benefit from in-depth knowledge on how new findings on, for example, treatment effectiveness diffuses in the medical community and how the spread of such information may be influenced. This may be particularly important in specialized health care with rapid technological progress where costs are often high and guidelines unclear (see, e.g., CCORT, 2014).

In this article we empirically study how health care specialists respond to new and unexpected information on the effectiveness of a particular medical procedure in an environment initially without clear treatment guidelines. Specifically, our research concerns how cardiologists in Sweden changed their preferred choice of stents (a tube-shaped metal device used to reinforce a blocked artery wall after expansion) when performing percutaneous coronary interventions (PCI) after it was revealed that the newly introduced drug-eluting stents (DES), which had begun to replace the older bare-metal stents (BMS), had potentially severe side-effects. This information shock, intensively debated at cardiologists' meetings in

2006[1], drastically reversed the trend of rapidly increasing popularity of DES, both in Sweden and elsewhere. Figure 1 graphically presents this dramatic shift for Sweden. Between the time of DES approval in early 2002 until the adverse information was publicized in 2006, DES had already become the dominating choice among Swedish cardiologists, covering approximately 65 percent of the Swedish stent market. Only one year later, this share had plummeted below 20 percent. Not until national guidelines, based on extensive follow-up studies which largely dismissed the previous evidence, were introduced in late 2007, DES popularity again began to grow (albeit at a significantly lower rate).[2]

FIGURE 1.
Trends in the use of BMS and DES in Swedish hospitals 2002–2011



NOTE.— The vertical lines indicate the different time periods we analyze as described in detail in the text. The shares sum to one.

The context of interventional cardiology in Sweden approximates an ideal (natural) experimental setting to study information diffusion of medical technology and its impact on medical practice for several reasons: First, it constitutes an advanced medical setting where

[1]This event is often referred to as the DES "firestorm" at the annual congress of European cardiologists (ESC) in Barcelona 2006, where a meta-analysis was presented that suggested that DES was potentially unsafe, sparking intense discussions among the cardiovascular community throughout the following years. See, e.g., https://www.escardio.org/Congresses-&-Events/ESC-Congress/Congress-resources/Congress-news/barcelona-firestorm-2006-killed-initial-enthusiasm-for-drug-eluting-stents.

[2]Sweden is by no means an outlier. Indeed, similar trends in the use of DES are observed in e.g. the United States, Canada, and Scotland (see, e.g., Austin *et al.*, 2009; Epstein *et al.*, 2011)). For example, US trends show a very similar diffusion pattern, where DES was approved by the Food and Drug Administration (FDA) in early 2003 and dominated the market only two years later. A similar drop in its popularity is visible in 2006, following the ACC and ESC conferences (cf., Epstein *et al.*, 2011). Figure A.1 in Appendix A graphically shows the trends observed using US data from Bangalore *et al.* (2014).

rapid technological progress has dramatically improved the quality of care over the last decades and where medical errors are likely to have high stakes consequences on patient health. Indeed, coronary artery disease (CAD) is the leading cause of death globally and PCI has become the gold standard of treating diseases such as acute myocardial infarction (AMI). Second, the magnitude and importance of the information shock regarding the safety of DES and the subsequent provider response is, to our knowledge, almost unparalleled in medical history. In just one month after the ESC congress in Barcelona, DES lost half its market share to the older BMS. This suggests that the information was indeed unanticipated and provides plausibly exogenous variation in order to study high-stakes behavior of medical professionals. Third, the specific treatment alternatives we study (BMS versus DES) are in all relevant aspects equivalent in terms of how they are administered, meaning that we can exclude competing explanations for heterogeneity in decision-making and outcomes based on physical characteristics of the physicians, such as motor skills or visual acuity.[3] This, in combination with the essential lack of guidelines prior to 2008, strengthens our argument that the variation in physician practice styles we observe is exclusively driven by individual discretion originating from individual beliefs. Furthermore, the introduction of DES did not affect the appropriateness of other methods, such as coronary artery bypass grafting (CABG), implying that we may consider the relevant patient population of interest as fixed over time. Finally, examining these issues within the Swedish health care system brings additional advantages. In particular, it allows us to disregard market mechanisms, such as patient selection (patients have a very limited choice of provider in the inpatient sector), competition (hospitals are publicly owned and managed and physicians are salaried) or costs of treatment (the price differential between BMS and DES is largely negligible).

We exploit the DES information shock in our empirical framework by first splitting our sampling time frame into three mutually exclusive information "regimes"; an introduction phase between 2002 and 2006 where the popularity of the DES continuously grew; a period of adverse information between 2006 and 2007 in which the popularity dropped sharply; and a period characterized by the introduction of national guidelines between 2007 and 2011

[3]This is in contrast to, for example, laparoscopic versus open surgery in the treatment of prostate cancer, where any effects on patient outcomes are to some extent related to surgeons' skills, such as motor skills (see e.g., Parsons *et al.*, 2014). Since the medical procedure is essentially the same between the two alternatives in our setting (i.e. DES and BMS), we can effectively disregard from such heterogeneity.

which provided clear information about the appropriate use of DES. In order to study cardiologist responses to each information phase, we subsequently construct an period-specific measure of adaptability to information defined as the relative rate with which each cardiologist adopted (or abandoned) DES. We then apply the resulting distribution of adaptability to explore whether patient outcomes differ by the type of cardiologist they were treated by, conditional on information regime. This approach is similar to that of Currie *et al.* (2016), who estimate specific provider practice styles for heart attack treatments and relate these to patient outcomes.

To estimate our econometric models we use data from the Swedish Coronary Angiography and Angioplasty Register (SCAAR). SCAAR is a Swedish national database that registers all interventional coronary procedures in Swedish hospitals since 2002. The data contain detailed information on all medical procedures each patient received and characteristics of the specific physician who performed it. Furthermore, the SCAAR data is linked to a set of patient clinical outcomes from the Swedish inpatient registry for up to ten years after the procedure was performed. Thus, the data allow us to link individual cardiologist specific treatment choices over time to patient health outcomes.

Several interesting findings emerge from our empirical investigation: First, we find substantial variation in the rate with which cardiologists responded to information in each of the three phases. The magnitude of this dispersion depends crucially on the specific information regime in place. Specifically, the variation in response is significantly less pronounced during the first (introduction) period relative to the second (adverse information) period. This is a striking finding as our setting is a high-stakes context where the adverse information disseminated in 2006 related DES to several severe and life-threatening side effects. Furthermore, the introduction of national guidelines in the final phase, however, restricted physician choice and reduced this variability substantially. Finally, our findings suggest that the speed of response is associated with a number of patient outcomes related to both costs and quality of health care. More specifically, we find that patients treated by "slow" adapters have a lower risk of complications, such as myocardial infarction and revascularization rates, compared to patients treated by "fast" adapters. These effects largely disappear once the guidelines were introduced in the last information phase, suggesting that variation in physician discretion and patient health outcomes are intimately linked. Our results are robust to the inclusion of a set of hospital, cardiologist, treatment and patient characteristics and we find no indication of patient-cardiologist sorting.

Our work is closely linked to the literature exploring the causes and consequences of physician practice styles (see, e.g., Chandra and Staiger, 2007; Epstein and Nicholson, 2009).[4] A few studies have analyzed the relation between provider practice styles, and costs and quality of care by studying how specific traits or the physical environment physicians work in affects treatment decisions. Currie *et al.* (2016) study whether more aggressive (defined as the use of more invasive treatments) or responsive (the tailoring of treatment to patient characteristics) practice styles matter for costs and health outcomes using data on patients suffering from acute myocardial infarction. Molitor (2016) studies how practice styles of cardiologists are affected by their environment by assessing how their behavior changes when they move across health care regions. He finds that migrating physicians are highly malleable and largely change their treatment behavior in line with the prevailing environment, suggesting that hospital characteristics may play a substantial role in shaping practice styles.

Our findings are also related to the literature on the diffusion of innovations, in particular medical technology, and its impact on treatment costs and quality of care. Some authors have argued that the marginal benefit of new treatment technology, such as surgical robots, is lower than the costs due to overenthusiastic practitioners, long learning curves, and industry lobby groups (see, e.g., Parsons *et al.*, 2014). Other studies provide evidence of synergy and spillover effects from the introduction of technology on established treatment procedures, due to economics of scale and increased competition among physicians (see, e.g., Sivarajan *et al.*, 2015). Our present work studies diffusion in an important and high-technology context in which the treatment alternatives follow essentially the same procedures.

The paper proceeds as follows: the next section provides an overview of the Swedish health care system and the clinical context. Section 3 explains our empirical approach and

[4] Chandra *et al.* (2012) provide an overview of potential causes for variations in provider treatment decisions across similar patients. Such reasons include (i) "defensive medicine", where providers perform unnecessary procedures to avoid complaints, bad reputation and possible lawsuits from patients; (ii) financial incentives associated with fee-for-service reimbursement models (McClellan, 2011); (iii) patient preferences and demand for specific procedures (Cutler *et al.*, 2013); and (iv) unobserved heterogeneity across providers (Doyle *et al.*, 2010). The institutional setting we study allows us to essentially disregard from (i)–(iii) in order to focus on (iv).

how we elicit cardiologist adaptation to the new information about DES. Section 4 presents our data and the sample restrictions we apply. Section 5 presents the results from estimation. Section 6 concludes.

2 Institutional Setting

Our empirical analysis uses data on all coronary interventions performed in Swedish hospitals between 2002 and 2011. We start by providing a short summary of the Swedish health care system, followed by general information on the medical procedure we study. Finally, we briefly discuss the event that we exploit as a natural experiment to measure cardiologist adaptability.

2.1 Health care in Sweden

The Swedish health care system is strongly regulated and the vast majority of health care is owned, managed, and financed by the public sector. The Swedish public sector comprises three tiers; the national, the regional, and the local level. The responsibility for health care, regulated by the Swedish Health Services Act (1982:763), generally takes place at the regional level. The regional county councils are the major financiers and providers of Swedish health care. There are 21 county councils in all, and each council is obliged, by law, to provide its residents with equal access to health services and medical care. Each county council sets its own patient fees, but a national ceiling limits the total amount that a patient has to pay out-of-pocket over a calendar year. The amount paid is very low and consequentially patient fees account for only around three percent of total health care revenues. The county councils are allowed to contract with private providers, but most health care is performed by public agents. This institutional context implies that political representatives of the county councils and local bureaucrats, rather than competition among health care providers, determine the number, size, location, and coverage of hospitals within each region. Furthermore, all Swedish residents, employed and unemployed, are covered by a universal sickness and disability insurance that covers forgone earnings due to health-related work absence up to a cap of 80 percent of earnings. The Swedish Social Insurance Agency is responsible for the benefit payments. The above implies that individuals are generally well-insured against both the direct monetary cost of care and any time off employment.

An additional important feature of the Swedish specialized health care system is that prospective patients have no discretion in their choice of provider. Rather, each hospital is responsible for all specialized care within their respective catchment area, implying that place of residence determines the specific hospital a patient will be admitted to. Furthermore, according to the Swedish Patient Act (2014:821), patients have no legal right to choose treating physician within the inpatient care sector. Instead, patients and physicians are typically quasi-randomly matched based on which physician(s) are on duty on the day of admission. These institutional features hence serve to alleviate potential concerns of sorting between patients and doctors.[5,6]

2.2 Interventional cardiology, angioplasty and PCI[7]

Interventional cardiology is a branch of cardiology that deals with catheter-based treatment of heart disease. Coronary catheterization involves the insertion of a sheath into a major artery (e.g., the femoral artery) and cannulating the heart under X-ray visualization, so-called flouroscopy. The major advantage of using catheter-based methods compared to open surgery in treatment of coronary heart disease lies in their significantly less invasive nature and, as such, avoids scars, pain and long recovery periods. For this reason, interventionist techniques have become the gold standard for treating heart diseases such as acute myocardial infarction (AMI).

The main procedure in interventional cardiology is angioplasty, or percutaneous transluminal angioplasty (PTA). This method entails the insertion of a deflated surgical balloon attached to a catheter, which is passed over a guide-wire into a narrowed or fully obstructed artery. The balloon is then inflated, forcing expansion of the blood vessel and allowing for an improved blood flow. To ensure that the vessel remains open after the balloon dilation, the cardiologist may also insert a stent, a tube-shaped metal device, to reinforce the artery

[5]The situation is very different in the outpatient sector where patients have extended rights in choosing both provider and physician. These treatments do not apply in the context of this paper, however.

[6]In Section 5, we provide complementary empirical evidence that patient-provider selection does not appear to play a major role in the context of our study.

[7]This section is based on Lakhan *et al.* (2009).

wall. This procedure is called percutaneous coronary intervention (PCI) and follows the same steps as other angioplasty procedures with the exception that the cardiologist first injects a contrast medium through the guide catheter to assess the location and estimate the size of the blockage. The cardiologist uses the information from this procedure to decide whether and which type of stent to use to treat the blockage.

The main disadvantage of using stents is that they, because they are objects foreign to the human body, could incite an immune response (neointimal hyperplasia) which may re-occlude the blood vessel and necessitate a new intervention (revascularization). This phenomenon, sometimes referred to as the "Achilles' heel of coronary stenting", is called restenosis and is a very common complication from applications of the first-generation bare-metal stents (BMS) in PCI treatments. To avoid the problems of restenosis, a second-generation of stents that consisted of more biocompatible and anti-inflammatory materials (polymers), so-called drug-eluting stents (DES), were developed. The DES was furthermore designed to prevent fibrosis (the body's reparation process) by slowly releasing anti-proliferative drugs that inhibit cell growth, thereby reducing risk of re-occlusion.

Another problem of coronary stenting is the risk of stent thrombosis (ST). When a blood vessel is injured, the body uses platelets (thrombocytes) and fibrin to form a blood clot to prevent blood loss. ST is the formation of an arterial blood clot caused by the stent itself, due to arterial damage caused by the stent implantation process or to the balloon inflation. ST is a serious complication of PCI resulting in myocardial infarction (MI) or death in up to 80% of patients. Late stent thrombosis and very late stent thrombosis are long-term complications of stents that occur 30+ days and 1+ year after implantation respectively. One particular concern with DES is that the drugs coated on the stent may also inhibit so-called endothelialisation, which is a natural process in the body that prevents thrombus formation. Therefore, anti-platelet drug therapy that reduces the process of thrombus formation is often used in combination with DES when preforming coronary interventions (Kaliyadan *et al.*, 2014).

2.3 The 2006 DES controversy

The market share of DES rose rapidly since its approval in Europe and the US in 2002 and 2003, respectively. Initially, only two versions of the DES, the CYPHER and the TAXUS, were available, differentiated by the active drug coated on the stent (Sirolimus and Paclitaxel, respectively). The main reason for the surge in their popularity was that clinical trials showed that the rate of restenosis was dramatically lowered with as much as 70% compared to implantation of BMS, which thus reduced the incidence of costly follow-up treatments. At the same time, other clinical outcomes, such as risk of death and myocardial infarction, were comparable to the old stents (cf., Morice *et al.*, 2002; Babapulle *et al.*, 2004). In less than two years, DES had become the leading stent used in PCI treatments.

However, the widespread optimism for DES came to an abrupt end in 2006 when an unpublished meta-analysis based on four clinical trials, assessing the safety and efficacy of DES, was presented in a "hot-line" session at the annual congress for European Society of Cardiologists (ESC) in Barcelona (Camenzind, 2006). The, by now, notorious session disclosed a rate of total death and ST-elevated myocardial infarction (STEMI, or Q-wave MI) of 6.3% in the CYPHER DES group versus 3.9% in the BMS group, a statistically significant difference (see Figure A.2). This result initiated a "firestorm" about the potentially unsafe use of DES, reinforced by media, the public and interest groups, questioning their continued application. The reaction among the cardiologist community, public regulatory institutions, and the industry was immediate, calling for further systematic review and reevaluation of available data.[8] Reassuringly, based on the findings in around 18,000 patients, Stettler and colleagues concluded that on key safety measures, such as overall and cardiac mortality, and stent thrombosis, DES and BMS produced comparable event rates. More importantly, patients who received DES experienced an impressive reduction in target lesion revascularization (TLR) rates (cf. Stettler *et al.*, 2007). A special meeting of the US Food and Drug Administration (FDA) in the end of 2006 concluded that DES are safe to use within their approved indications (Daemen and Serruys, 2007).

In retrospect, the response to the adverse information on the safety of DES in 2006 can

[8] At the 2006 World Cardiologist Congress (WCC), a moratorium on DES implantation was called until all existing evidence had been reevaluated. Within one year, the use of DES in the United States fell by nearly 20 percentage points (see Figure A.1).

be considered to be an overreaction for a number of reasons (see, e.g., Serruys and Daemen, 2007a). First, the discouraging results presented at the ESC hot-line session in 2006 was entirely based on aggregate pooled data from the four published trials in different points in time with different follow-up times. Second, only a selection of clinical endpoints were analyzed, STEMI and death. If non-STEMI's would also have been included, the significant difference in outcomes between BMS and the CYPHER stent would have vanished. Third, only the CYPHER results were significantly different from zero, while the difference between the TAXUS stent and its comparison group was not. Finally, when reevaluated using patient-level data from the four CYPHER clinical trials with a uniform follow-up period and a consensus regarding definitions, Spaulding *et al.* (2007) were unable to find a significant difference between the DES and BMS groups. While there were still some concerns about the incidence of very late ST among patients treated with DES, Serruys and Daemen (2007a) conclude that the DES firestorm of 2006 could have been avoided by only base changes in clinical practice on data published in peer reviewed manuscripts together with a more careful evaluation of new techniques.

In the context of this article, the DES controversy of 2006 had an additional impact on medical practice in Sweden due to the presentation and publication of one-to-three-year follow-up results from the Swedish administrative SCAAR registry for about 20,000 patients treated with DES and BMS between 2003–2004. This "landmark" study demonstrated a significantly higher risk of mortality among patients receiving DES (Lagerqvist *et al.*, 2007). However, subsequent extended analyses which also included data from 2005 (James *et al.*, 2009) instead showed improved outcomes for DES-treated patients. The profound impact these results had on Swedish medical practice, as is clear from Figure 1, has been sarcastically coined "the Swedish yo-yo" (Serruys and Daemen, 2007b). Two months after the updated results were publicized in October 2007, the Swedish health authorities enacted national guidelines which stated that DES are safe when used within their licensed indications. As shown in Figure 1 above, this led to a renewed increase in their popularity, albeit at a slower pace then previously.

3 Empirical approach

Our empirical approach is based on exploiting the unexpected adverse safety information about DES in 2006 as a natural experiment. To this end, we separate our data into three time periods indicated by the vertical lines in Figure 1: an introduction period, a negative information period and a positive information period. The introduction period, when the use of DES was licensed in Europe, is defined from the beginning of 2002 until February 2006. The negative information period, when the reports on the risks of DES were first publicized and discussed, is defined from March 2006 until September 2007. The positive information period, when national guidelines were introduced indicating its appropriate use, is defined from October 2007 to the end of our study period in 2011. We empirically model the trends in the use of DES for each of the three time periods, estimating a measure of adaptability for each cardiologist in our data. We then explore the determinants of this adaptability-measure and finally relate this to patient outcomes.

3.1 Defining cardiologist adaptability

Conceptually, we think of adaptability as the rate with which physicians adapt to new information regarding suggested treatment practice. To implement this idea in our setting, we first estimate general trends in the use of DES for each of the three time periods specified above. Specifically, for patient i, treated by cardiologist c in hospital h in year-month time t we estimate the following regression model:

$$DES_{icht} = \sum_{p=1}^{3} \alpha_p \mathbf{I}[P_t = p] + \beta_p(\mathbf{I}[P_t = p] \times M^p) + \epsilon_{icht}, \quad (1)$$

where DES is a binary indicator for whether the patient received a DES; $P = [1, 2, 3]$ indicates the specific information phase[9]; $M^p = (0, 1, ..., m^p_{\max})$ are the monthly linear trends in DES take-up in each period, and $\mathbf{I}[\cdot]$ the indicator function, respectively. The first term on the right-hand side pick up the period-specific intercept (i.e., the initial level of DES take-up in each period). The main coefficients of interest are β_1–β_3, which pick up the average (linear) trend in the use of DES in each of the three periods for our sample of patients.

[9] M^p is superscripted since periods are of different length.

We next estimate *cardiologist-specific* versions of equation (1) to obtain a measure of the relative rate with which each cardiologist's take-up of DES changed in response to new information in each information phase. Subtracting β_1 in equation (1) from the cardiologist-specific β_1^c parameter yields a measure, centered around zero, for the relative speed of a particular cardiologist's DES take-up in the first period compared to the national trend. Subtracting β_2^c and β_3^c from their national averages will yield corresponding cardiologist-specific responses in periods two and three. We denote these centered adaptability measures by $A_c^p = \beta_p^c - \beta_p$. As such, we can estimate period-specific distributions of cardiologists' responses to which we can subsequently relate physician as well as patient characteristics and outcomes.

To explore the robustness of the results, as well as the importance of patient characteristics, hospitals and cardiologists, we also re-estimate equation (1) by including patient case-mix controls and adjusting for hospital and cardiologist fixed effects. Finding little difference in the distributions of adaptability when additional regressors and fixed effects are included in the model suggests that provider and patient characteristics do not play a large role in explaining adaptability. Furthermore, by estimating separate distributions for the three periods of interest allows us to explore whether cardiologists can be grouped by "type" (e.g., cardiologists who respond slow and quickly to new information, respectively).

3.2 Determinants of cardiologist adaptability

Next, we explore the determinants of cardiologist adaptability based on the estimates obtained from equation (1). This allows us to examine whether differences in adaptability are associated with any provider or patient characteristics and, thus, whether we can rule out selection on observables in our analysis. To this end, we run the following regression separately for each of the three time periods:

$$A_c^p = \gamma_0 + \gamma_1 Z_c + \gamma_2 \bar{X}_{c(i)}^p + \nu_c \text{ for } P = p, \tag{2}$$

where A_c^p is the cardiologist- and period-specific adaptability estimate defined above; Z_c are cardiologist characteristics; $\bar{X}_{c(i)}^p$ is a vector of average patient characteristics, where subscript $c(i)$ refers to patient i treated by cardiologist c in period p; and ν_c is the error term.

Hence, γ_1 captures whether, for example, female cardiologists respond faster or slower than male cardiologists, whilst γ_2 picks up whether cardiologists treating, for example, older and unhealthier patients respond faster or slower than cardiologists treating younger and healthier patients. The latter will allow us to explore whether certain patient categories are more or less likely to be treated by cardiologists with different adaptability, shedding light on potential patient and cardiologist selection.

3.3 Modelling patient outcomes

Finally, we apply our measure of cardiologist adaptability to study how it varies with clinical outcomes of patients. We define m^j_{icht}, where $j = 1, \ldots, J$ is the j^{th} outcome for patient i, treated by cardiologist c in hospital h in year-month time t. We estimate the following model for each information phase:

$$m^j_{icht} = \delta_0 + \sum_{k=1}^{4} \delta_k Q^p_k + \zeta_c Z^p_c + \zeta_x X_{it} + \zeta_h H_h + \mu_{icht} \text{ for } P = p, \tag{3}$$

where $Q^p_k = \mathbf{I}[q^p_{k-1} < A^p_c \leq q^p_k]$ is an indicator for the kth quartile $q^p_k \equiv \Pr[A^p < a] \leq k/q$ of the estimated period-specific adaptability distribution cardiologist c belongs to; and H_h, X_{it}, and Z^p_c are vectors of hospital, patient and cardiologist characteristics, respectively. Importantly, Z^p_c includes the same variables as in (2), but in addition also the estimated intercept parameters α^c_p from (1) in order to control for the initial level of DES take-up in each period. Since the adaptability intercepts and slopes are estimated, we perform bootstrap replications to estimate the standard errors of the model parameters.

Our main interest lies in the coefficients δ_1–δ_4, which reflect differences in patient outcomes associated with being treated by cardiologists at different quartiles of the adaptability distribution. Initially, we plot the coefficients to assess any trends in adaptability by patient outcome. Subsequently, we divide our sample of cardiologists into four "types" based on their relative adaptability in the two first periods with a cutoff at the period-specific median. These groups are: slow adapters (in the lower part of the distribution in period one and in the upper part of the distribution in period two), conservative adapters (lower in period one and lower in period two), fast adapters (upper in period one and lower in period two), and enthusiasts (upper in period one and upper in period two). In particular, distinguishing between the relative quality of care provided by fast and slow responders could yield important knowledge about how new treatment information diffuses in the medical community and influences medical practice.

It is important to understand that our measure of adaptability is a function of DES, and therefore that any direct effect of DES on patient outcomes would also be captured by this measure. Based on the background information in Section 2, we have no obvious reason to worry about that patient outcomes should be affected by the type of stent used, except for the risk of restenosis and very late stent thrombosis (which could then function as suitable validity tests). In any case, as a robustness check we also estimate equation (3) with an additional control for the type of stent a patient was treated by.

4 Data

We use data from the Swedish Coronary Angiography and Angioplasty Registry (SCAAR); a Swedish national database that registers all interventional coronary procedures dating back to 2002.[10] SCAAR holds data on patients from all 29 centers that perform coronary interventions in Sweden. The registry is developed and administered by the Uppsala Clinical Research Center (UCR) and sponsored by the Swedish Health Authorities and is independent of commercial funding. All patients undergoing coronary interventions are included in the registry, together with detailed information on the specific procedures performed.

4.1 Sample and variables

Our study population is restricted to all patients in Sweden who received coronary stents between 2002 to 2011 and for whom complete follow-up data were available from other national registries. Since patients may have multiple stenting episodes, we base our investigation on the type of stent implanted at the first recorded procedure and discard all subsequent treatments to keep the sample homogeneous. For the same reason, we also exclude all treatment episodes where multiple-type stents were used. To study the relationship between

[10]The registry dates back to 1991 but does not include the full population of PCI's performed in Sweden until 2002.

cardiologist adaptability and quality of care, we observe a wide range of patient outcomes. We choose to focus on the most common types of complications associated with a PCI: rates of myocardial infarctions (MI), restenosis, stent thrombosis (ST), deaths, and new interventions within three years from the first treatment. We also create a binary variable for the event that one or more of the complications occurred.

Table 1 presents summary statistics of the variables in our sample. The upper panel of the table shows that, of the 29 nation-wide hospitals that perform catheterization, around one-fifth are teaching hospitals. Furthermore, we define a large hospital as a hospital that has a PCI case volume above the 75^{th} percentile of the volume distribution at the start of the analysis period. The middle panel displays characteristics of the 157 cardiologists we observe in the data. About ten percent are female and one-fourth are experienced, measured as being above the 75^{th} percentile of the distribution of cumulatively treated cases at the start of the analysis period. About one-fourth of cardiologists were not observed in the first period of our data but entered at a later stage, and ten percent left the sample before the last period of observation. Finally, the bottom panel of the table displays the different patient characteristics and outcomes that we include in the analysis. The average patient is 66 years old and more likely to be male. About ten percent of the sample of patients had a previous PCI or a coronary artery bypass grafting (CABG) and about on-fourth and half of the sample were diagnosed with diabetes and hypertension, respectively. The majority of sampled patients are hospitalized due to acute conditions, such as an unstable CAD or a ST-elevated myocardial infarction. Most cases concern interventions in the right coronary artery (RCA) or the left anterior descending artery (LCD). While most patients are treated with thrombolytic therapy prior to the PCI, there is quite substantial variation in the length and width of the stent used. Finally, one-fifth of all patients experience some complication after the procedure.

TABLE 1.
Summary statistics of variables in the analysis

	Mean	SD
	Hospital-level characteristics	
Large hospital	0.241	(0.435)
Teaching hospital	0.217	(0.412)
Hospital Region		
North	0.103	(0.310)
Stockholm	0.172	(0.384)
Southeast	0.103	(0.310)
South	0.207	(0.412)
Middle	0.241	(0.435)
West	0.172	(0.384)
No. of hospitals	29	
	Cardiologist-level characteristics	
Cardiologist female	0.096	(0.295)
Cardiologist experienced	0.191	(0.394)
Cardiologist not in period 1	0.236	(0.426)
Cardiologist not in period 2	0.242	(0.430)
Cardiologist not in period 3	0.108	(0.312)
No. of cardiologists	157	
	Patient-level characteristics	
Risk factors		
Patient age	66.21	(10.77)
Patient old	0.222	(0.416)
Patient female	0.289	(0.453)
Previous PCI	0.081	(0.273)
Previous CABG	0.083	(0.276)
Patient has diabetes	0.168	(0.374)
Patient has hypertension	0.474	(0.499)
Smoking status		
Current Smoker	0.215	(0.411)
Former smoker	0.316	(0.465)
Never smoker	0.391	(0.488)
Unknown	0.079	(0.269)
Diagnosed condition		
Unstable CAD	0.465	(0.499)
Stable CAD	0.189	(0.391)
STEMI	0.325	(0.468)
Other	0.021	(0.144)
Angiography result		
Not significant	0.010	(0.101)
1-vessel disease	0.569	(0.495)
2-vessel disease	0.239	(0.426)
3-vessel disease	0.142	(0.349)
LCA disease	0.039	(0.193)
Treatment factors		
Treated segment		
RCA	0.292	(0.455)
LAD	0.452	(0.498)
LCx	0.197	(0.398)
LCA	0.029	(0.168)
CABG	0.030	(0.172)
Clopidogrel before procedure	0.750	(0.433)
Aspirin before procedure	0.904	(0.295)
Number of inserted stents	1.000	(0.000)
Stent width		
<2.5 mm	0.043	(0.203)
2.5 to <3 mm	0.261	(0.439)
3 to <3.5 mm	0.353	(0.478)
3.5 to <4 mm	0.250	(0.433)
> 4 mm	0.093	(0.290)
Stent length		
<10 mm	0.043	(0.203)
10 to 14 mm	0.243	(0.429)
15 to 16 mm	0.259	(0.438)
17 to 19 mm	0.139	(0.346)
20 to 23 mm	0.145	(0.352)
24 to 25 mm	0.090	(0.286)
26 to 30 mm	0.050	(0.218)
> 31 mm	0.030	(0.172)
3 year outcomes		
Any Complication	0.251	(0.434)
Any Myocardial Infarction	0.071	(0.257)
Any Restenosis	0.050	(0.218)
Any Stent Thrombosis	0.011	(0.102)
Any TLR	0.147	(0.354)
Death	0.089	(0.285)
No. of patients	57,513	57,513

NOTE.— Means and standard deviations (in parentheses). Large hospitals and cardiologist experience are defined by the upper quartile of the respective distribution (hospital total case volume, number of performed surgeries) at the start of the analysis period in 2002. Cardiologists not observed in period 1 refers to cardiologists that performed their first PCI after 2006; cardiologists not observed in period 3 refers to those doing their last PCI after September 2007.

Since we are particularly interested in the results underlying the "landmark" study by Lagerqvist *et al.* (2007) that dramatically changed medical practice in the use of stents in Sweden, we compare and validate our sample to this study by an attempt to replicate its main results. Figure A.3 shows the results from this exercise where we have restricted our sample to only include cases between 2003 and 2004 with a follow-up censored at June 30th, 2006. The figure illustrates the cumulative hazard of the composite event of patient death or myocardial infarction over time since the PCI was conducted. Panel (a) shows the overall cumulative hazard for the outcome by stent type until a maximum of three years follow-up, while panel (b) and (c) separately plots the cumulative hazards for the first six months and after six months, respectively. Reassuringly, we obtain the same results as in Lagerqvist *et al.* (2007), with an initial higher hazard from the old BMS and a later reversal with DES underperforming for the longer term outcomes. Hence, we are confident that our sample is comparable to Lagerqvist *et al.* (2007).

5 Results

We begin by presenting the results for the estimation of cardiologist adaptability (i.e., trends in DES take-up) in each of the three information periods. Next, we explore the variation in adaptability across cardiologists and time and whether the trends in DES take-up are related to observable characteristics on the hospital, cardiologist or patient levels. Finally, we relate our estimated adaptability measures to patient outcomes by estimating the effect of different quantiles of the adaptability distribution and cardiologist types on relevant clinical endpoints, including myocardial infarctions, new interventions, and death.

5.1 Cardiologist adaptability

Column (1) of Table 2 presents the results from equation (1), estimating the average cardiologist take-up of DES after its introduction (represented by the period one (P1) trend), after adverse news about the performance of DES (P2 trend), and after the subsequent information which refuted these conclusions through the introduction of national guidelines (P3 trend). The estimated coefficients suggest that the use of DES increased by 1.4 percentage points per month, on average, in the initial period. Period two is characterized by a strong reduction in the use of DES of 3.1 percentage points per month, whilst we see a more modest increase in the use of DES of 0.6 percentage points per month in period three. The estimated trend parameters are all highly statistically significant and correspond well with the descriptive pattern from Figure 1. Finally, the period intercept parameters provides information of the average use of DES in the beginning of each period. As expected, since the first period coincides with the approval of DES use in Europe, the first period intercept cannot be significantly distinguished from zero. The second and third period intercepts suggests that DES was applied to about two-third and one-fourth of all patients at the beginning of period two and three, respectively.

To explore the robustness of our estimates to inclusion of additional patient, cardiologist and hospital characteristics, columns (2)–(6) of Table 2 sequentially include a set of additional covariates. Column (2) includes variables indicating the patient case-mix, whilst columns (3), (4), (5) and (6) include treatment-specific variables, hospital and/or cardiologist fixed effects. This exercise shows that the estimates are very stable across the different specifications, suggesting that the trends and intercepts hold also within hospital, cardiologist, and patient types.[11]

To explore whether the trends in DES take-up can be explained by compositional changes over time in our sample, Table A.1 in Appendix A presents estimates from equation (1), but with additional interactions between the DES take-up period trends and a number of hospital, cardiologist and patient characteristics. Each column reports the estimated coefficients from a regression of the probability of receiving a DES on the period-specific linear monthly trends and intercepts together with interactions and main effects between the trend and the specific characteristic described in the column header. The results suggest a significant negative interaction effect for the size and teaching status of the hospital, as well as for older patients and acute cases, indicating that each of these characteristics is associated with a more conservative treatment method. As a graphical example, Figure A.4 in Appendix A illustrates the average trend in DES uptake across the three periods separately for relatively

[11]For brevity, we do not report the full list of regressors in Table 2. In summary, they show that it is generally less likely that patients with co-morbidities and more severe diagnoses (e.g., STEMI) are treated with DES. Exceptions are diabetes patients and patients with previous PCI treatments who have a higher probability of receiving DES.

older and younger patients. The trend in the use of DES for relatively younger patients is steeper in each of the three periods, consistent with the results from Table A.1. However, while there appears to exist heterogeneity in the *general* trends in DES take-up across patients, hospitals, and cardiologist types, none of these characteristics can explain the variation in DES take-up across *periods*.

TABLE 2.
Determinants of DES use

	(1)	(2)	(3)	(4)	(5)	(6)
Period 1 intercept	-0.023	-0.005	0.203***	0.087	-0.201***	0.072
	(0.016)	(0.018)	(0.041)	(0.044)	(0.019)	(0.059)
Period 2 intercept	0.651***	0.624***	0.561***	0.635***	0.631***	0.580***
	(0.037)	(0.037)	(0.036)	(0.031)	(0.032)	(0.032)
Period 3 intercept	0.231***	0.202***	0.179***	0.216***	0.204***	0.197***
	(0.021)	(0.021)	(0.024)	(0.022)	(0.023)	(0.026)
Period 1 trend	0.015***	0.014***	0.013***	0.014***	0.014***	0.013***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Period 2 trend	-0.032***	-0.031***	-0.028***	-0.032***	-0.032***	-0.029***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Period 3 trend	0.006***	0.006***	0.005***	0.006***	0.006***	0.005***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Patient female		0.019***	0.012***	0.024***	0.024***	0.017***
		(0.003)	(0.003)	(0.003)	(0.003)	(0.002)
Patient old		-0.005	-0.006	-0.010	-0.011	-0.013
		(0.009)	(0.008)	(0.008)	(0.008)	(0.008)
Patient age: 40-44						
Patient age: 45-49		-0.007	-0.013	-0.011	-0.010	-0.017
		(0.011)	(0.010)	(0.010)	(0.010)	(0.009)
Patient age: 50-54		-0.008	-0.021*	-0.018*	-0.018*	-0.032***
		(0.010)	(0.009)	(0.009)	(0.009)	(0.008)
Patient age: 55-59		-0.015	-0.029**	-0.033***	-0.032***	-0.048***
		(0.011)	(0.010)	(0.009)	(0.009)	(0.009)
Patient age: 60-64		-0.024*	-0.037***	-0.045***	-0.043***	-0.059***
		(0.010)	(0.009)	(0.009)	(0.009)	(0.008)
Patient age: 65-69		-0.032**	-0.046***	-0.054***	-0.052***	-0.069***
		(0.011)	(0.010)	(0.009)	(0.009)	(0.008)
Patient age: 70-74		-0.052***	-0.067***	-0.075***	-0.073***	-0.090***
		(0.012)	(0.011)	(0.010)	(0.010)	(0.010)
Patient age: 75-79		-0.068***	-0.080***	-0.090***	-0.088***	-0.102***
		(0.013)	(0.012)	(0.012)	(0.012)	(0.011)
Patient age: 80-84		-0.107***	-0.117***	-0.132***	-0.131***	-0.146***
		(0.015)	(0.014)	(0.013)	(0.013)	(0.012)
Patient age: 85-89		-0.158***	-0.157***	-0.173***	-0.173***	-0.179***
		(0.019)	(0.017)	(0.017)	(0.017)	(0.015)
Patient age: 90+		-0.203***	-0.185***	-0.199***	-0.204***	-0.198***
		(0.024)	(0.023)	(0.020)	(0.020)	(0.020)
Patient characteristics		✓				✓
Treatment characteristics			✓			✓
Hospital FE				✓		✓
Cardiologist FE					✓	✓
No of observations	57,513	57,513	57,513	57,513	57,513	57,513

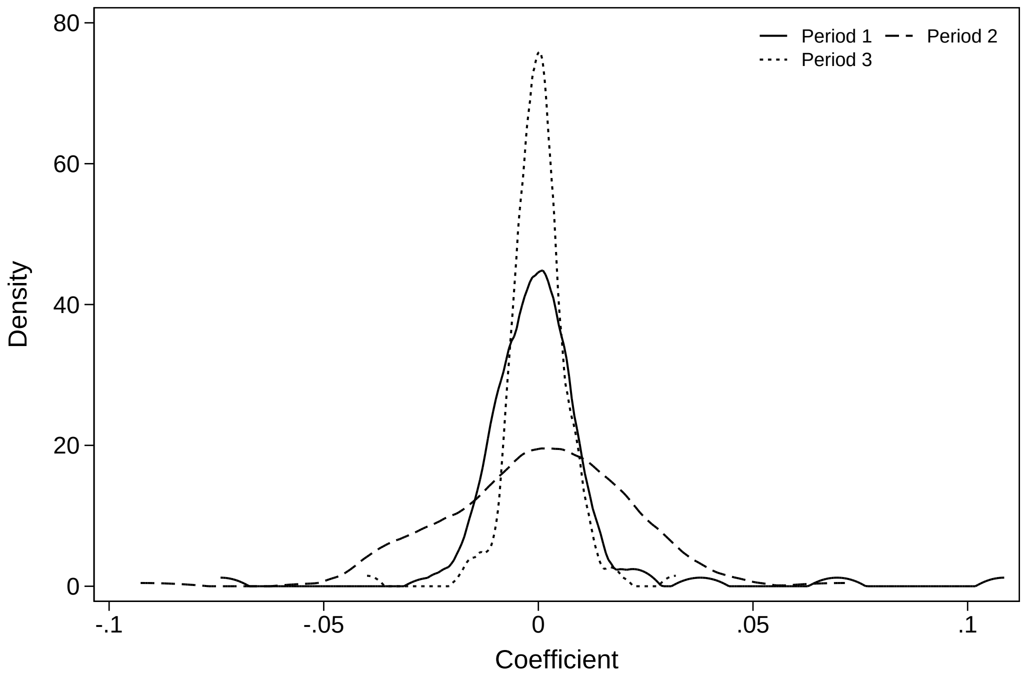
NOTE.— OLS estimates where the dependent variable is a binary indicator whether the patient received a DES (vs. BMS). The regressions additionally control for 12 different patient diagnosis codes and additional co-morbidities. Robust standard errors clustered by cardiologist in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Next, we study the variation in adaptability across individual cardiologists. Figure 2 plots the centered period-specific adaptability distributions based on the deviation between the estimated trends from the cardiologist-specific regressions of equation (1) and the sample average[12]. Interestingly, the figure shows that the adaptability dispersion varies depending

[12] Figure A.5 in Appendix A shows the corresponding uncentered adaptability distributions. Furthermore,

on the type of information currently in place. In particular, there is substantially more heterogeneity in cardiologist adaptability in the period with adverse news (period two), compared to the two periods where the use of DES was increasing. In other words, while most cardiologists do reduce their use of DES in response to reports that they may do harm, some are doing this at a slower pace while others are very quick at returning to BMS. Nevertheless, Figure 2 shows that the introduction of national guidelines in period three substantially reduced cardiologist discretion and led to a highly concentrated adaptability distribution.[13]

FIGURE 2.
Cardiologist adaptability in the three periods (centered)



NOTE.— Adaptability estimates are centered around zero (i.e. the cardiologist-level estimate minus the overall mean shown in column 1 of Table 2. Densities are based on the number of cardiologists observed in each period: 120, 119, and 140 respectively.

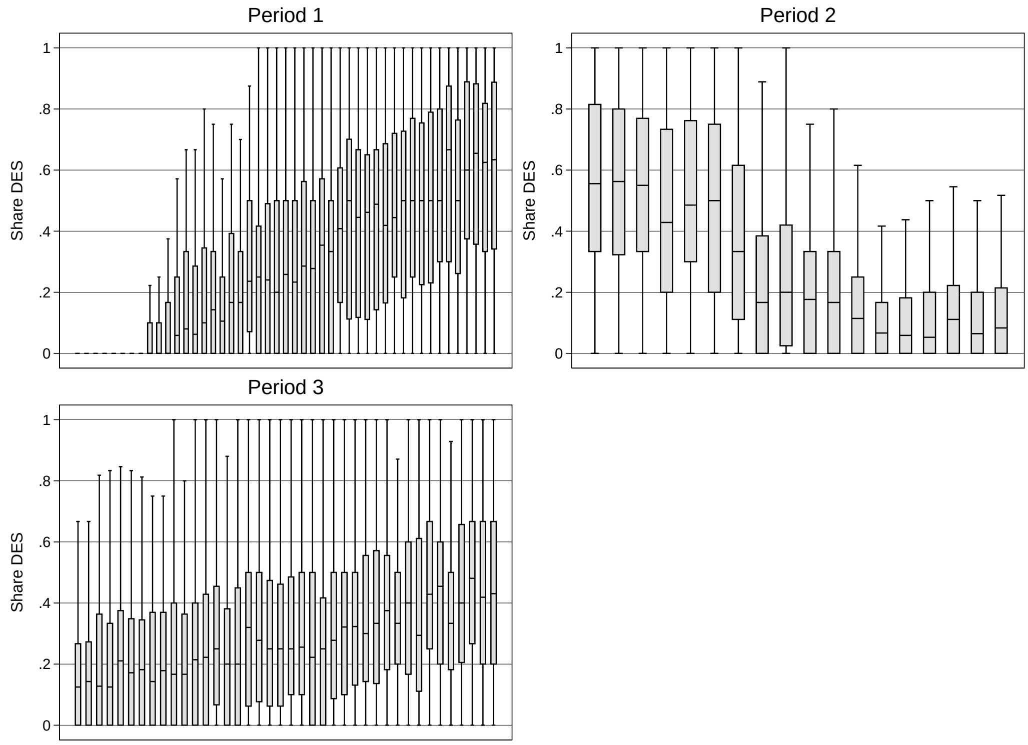
Our estimated adaptability measure may give misleading implications if the observed variation in DES is derived from only a few cardiologists who deterministically switch back and forth between the old and new stents across periods. We explore this potential issue by estimating the distribution of the cardiologist-specific use of DES for each month over the observation period. Figure 3 presents these distributions in monthly box plots for each of

Figure A.6 compares the distributions of period-specific cardiologists' adaptability that do and do not control for patient, cardiologist, and hospital characteristics. This shows identical distributions in all cases, once again indicating that cardiologist adaptability is not affected by observed patient, cardiologist or hospital characteristics.

[13]One potential concern is that the pattern in Figure 2 simply rises from sampling variation since the second period is substantially shorter than the other two periods. Figure A.7 of Appendix A shows the equivalent distributions when the first and third periods have been shortened to the length of the second period. These distributions look very similar to the distributions from using the full sample.

the three periods. Although there exists a group of cardiologists who only one stent type, the majority use a combination of both in a given month. Furthermore, the figure indicates a general increase in the share of DES used over time in period one and three, and a general decrease in period two. This suggests that the average trend in DES popularity over time reflects a general trend among all cardiologists with varying intensity, rather than being completely driven by a small group of cardiologists.

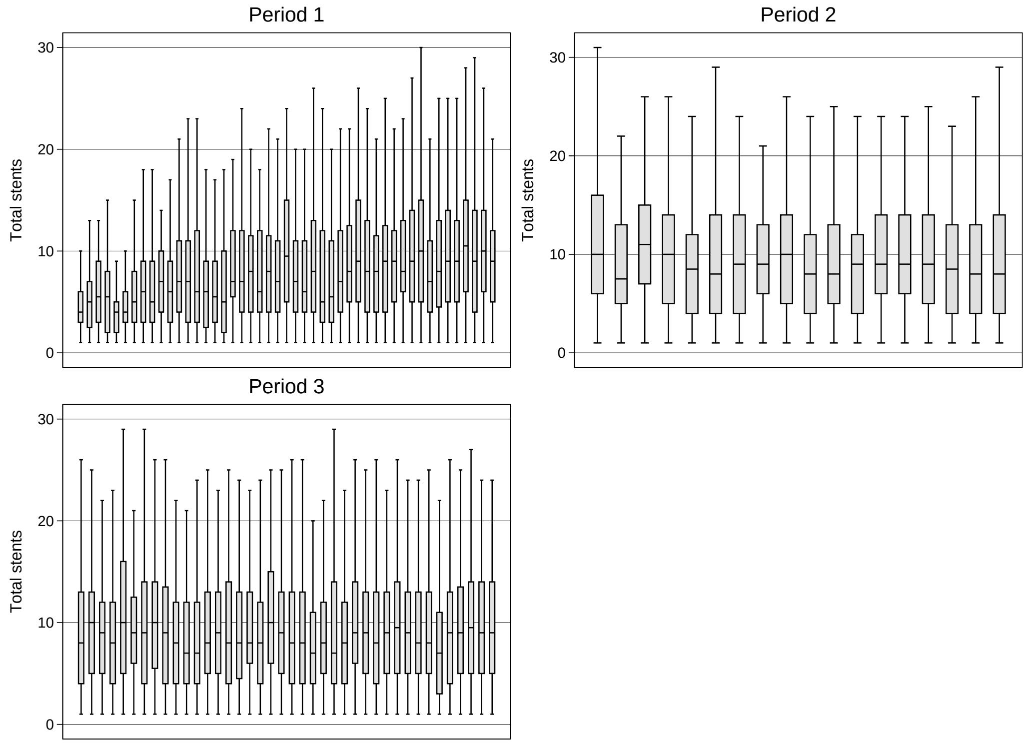
FIGURE 3.
Monthly cardiologist distributions of share DES used



NOTE.— The box and whiskers indicates the interquartile range and the maximum and minimum of the monthly cardiologist adaptability distributions, respectively.

Another potential issue with the interpretation of the adaptability distributions is that cardiologists reduced or entirely ceased using any type of stent when the adverse news about DES was publicized. Alternative treatments to PCI are thrombolytic drug treatment, using anti-clot agents, or surgical treatment, such as coronary artery bypass grafting (CABG), which could be seen as more or less salient alternatives if the faith in the efficacy of using stents varied in the medical community over time. To study whether the overall use of stents in the treatment of patients with coronary artery disease varied over time, Figure 4 explores the distributions of the monthly number of stents used by cardiologists for each of the three information periods. The figure clearly shows that the application of stents (DES or BMS) varied very little over the analysis period, hence suggesting that the changes in the popularity of DES was entirely attributed to switching to (or from) BMS.[14]

FIGURE 4.
Cardiologist distribution of total stents applied by month



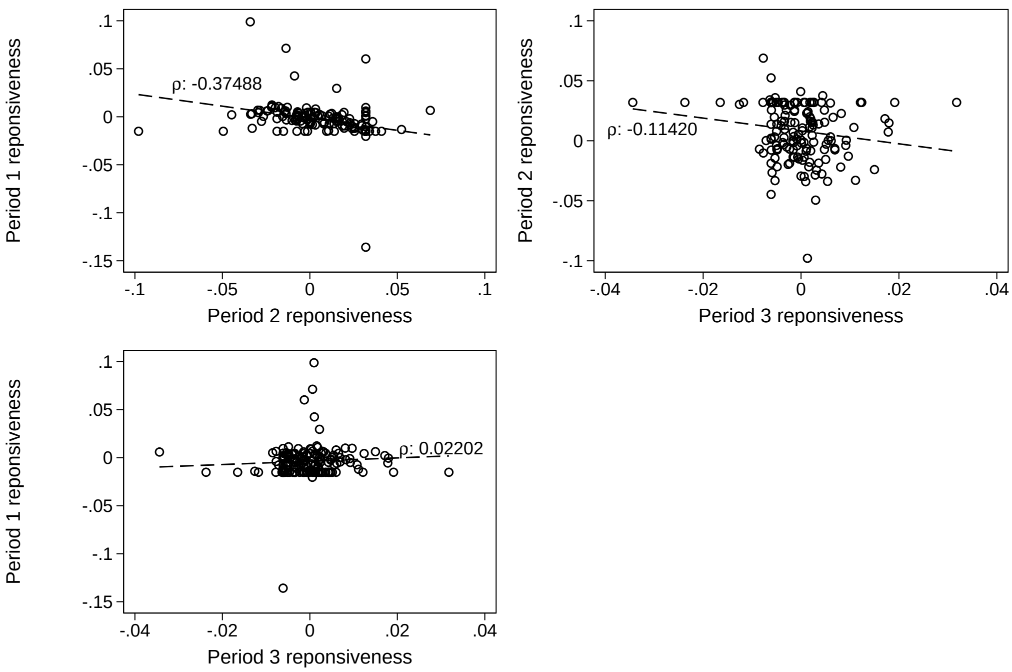
NOTE.— The box and whiskers indicates the interquartile range and the maximum and minimum of the monthly cardiologist adaptability distributions, respectively.

Finally, we examine the extent to which adaptability correlates *within* cardiologists. This allows us to investigate the existence of cardiologist types. For example, a positive correlation between period one and period two would suggest that cardiologists are predominantly either enthusiasts (eager to adopt new technology but reluctant in abandoning it despite adverse information) or conservative (hesitant to adopt new technology and quick in abandoning it when adverse news arrive). On the other hand, a negative correlation would imply that cardiologists are predominantly either slow or fast adopters (either react quickly or slowly to new information, irrespective of whether it is positive or negative). Figure 5 presents the results from correlating the within-cardiologist adaptability across the three periods. As can be seen from the upper-left panel of the figure, the within-cardiologist correlation between period one and period two is strongly negative with a correlation coefficient of -0.38. In other words, the larger the estimate is in period one (i.e. the faster the response), the smaller (more negative) the estimate is in period two (i.e. the faster the response) and vice

[14]For completeness, we also plot a graph of quarterly trends in individual cardiologists' use of DES over time in Figure A.8 in Appendix A. As expected, the figure shows substantial variation in the use of DES both across and within cardiologists in all three periods.

versa, suggesting that the cardiologists in our sample are either fast or slow adopters, irrespective of whether the information is positive or negative. In contrast, within-cardiologist correlations in adaptability between period one and two and period three are much smaller in magnitude, -0.11 and 0.02, respectively, suggesting that all cardiologists react similarly to news in period three irrespective of their reaction in the two previous periods. This is consistent with the observation from Figure 2 that the introduction of national guidelines in period three reduced physician discretion in stent choice when performing a PCI.

FIGURE 5.
Correlation within cardiologist adaptability across periods



NOTE.— Adaptability estimates are centered around zero (i.e. the cardiologist-level estimate minus the overall mean shown in column 1 of Table 2. Densities are based on the number of cardiologists observed in each period: 120, 119, and 140 respectively. Each data point corresponds to the relationship of a cardiologist's adaptability between two periods.

5.2 Determinants of cardiologist adaptability

Table 3 explores the determinants of cardiologist adaptability from estimating equation (2) separately for each of the three information periods. In general, cardiologist and average patient characteristics do not perform well in explaining adaptability as can be seen by the mostly small and insignificant parameter estimates. Although some estimates are significantly different from zero, there is no clear pattern across the three periods, suggesting that these results are artefacts of multiple testing. The estimates reported in Table 3 also shed light on the importance of patient selection. For example, if fast-responding cardiologists prefer to treat patients with certain characteristics (e.g., without co-morbidities), or if patients with certain characteristics (e.g., older patients) prefer to be treated by certain cardiologists (e.g., fast adopters), the estimates would show a correlation between adaptability and such characteristics. We do not find this. Rather, the included regressors explain very little of the variation in adaptability as can be seen from the adjusted R^2 and a F-test of the joint significance of the coefficients of the included variables reported at the bottom of the table.

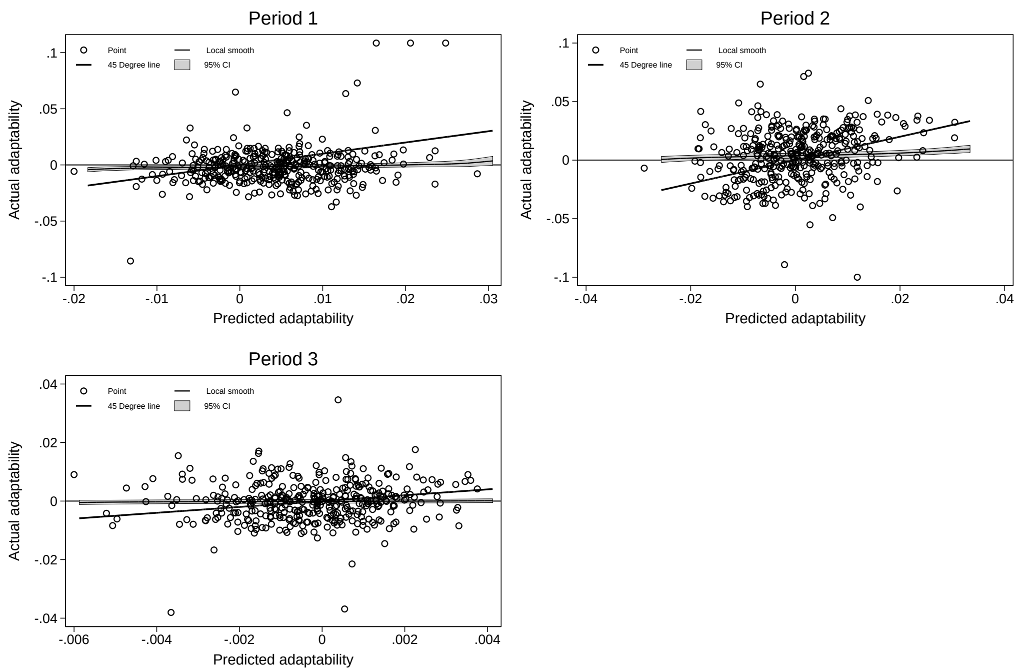
TABLE 3.
Determinants of cardiologist adaptability

	(1) Period 1	(2) Period 2	(3) Period 3
Cardiologist female	0.000	-0.004	-0.003*
	(0.004)	(0.008)	(0.001)
Cardiologist experienced	-0.002	-0.005	-0.000
	(0.002)	(0.005)	(0.001)
Cardiologist not in period 1		-0.001	0.000
		(0.009)	(0.001)
Cardiologist not in period 2	0.005		-0.002
	(0.003)		(0.002)
Cardiologist not in period 3	-0.004	-0.007	
	(0.002)	(0.009)	
Mean patient female	-0.018	-0.021	-0.001
	(0.022)	(0.040)	(0.014)
Mean patient previous PCI	0.006	-0.118	-0.006
	(0.020)	(0.065)	(0.022)
Mean patient previous CABG	-0.013	0.016	-0.016
	(0.033)	(0.060)	(0.020)
Mean patient diabetes	0.020	-0.069	0.019
	(0.030)	(0.063)	(0.020)
Mean patient hypertension	-0.010	0.053	-0.002
	(0.010)	(0.028)	(0.009)
Mean patient age	0.002	-0.004	0.000
	(0.001)	(0.003)	(0.001)
Mean patient old	0.000	0.103	0.018
	(0.037)	(0.068)	(0.035)
Mean patient never smoked	-0.006	0.080**	0.016
	(0.018)	(0.030)	(0.017)
Mean patient quit smoking	-0.030	0.061	0.003
	(0.023)	(0.054)	(0.020)
Mean patient smoker	-0.034*	0.054	0.009
	(0.016)	(0.029)	(0.014)
Constant	-0.101	0.225	-0.015
	(0.078)	(0.172)	(0.066)
No. of observations	120	119	140
Adjusted R^2	0.147	0.038	0.065
F-stat	1.418	1.536	0.969
p-value	0.156	0.106	0.492

NOTE.— The table presents the estimates from a regression of adaptability on cardiologist and average treated patient characteristics as described in equation (2).

Table 3 uses a continuous measure of adaptability and, by virtue of the OLS estimator, only explores determinants at the (conditional) mean of this distribution. However, it may be that associations between cardiologist adaptability and observable patient characteristics only show up in certain parts of the adaptability distribution, which will be important for our analysis on patient outcomes below. Figure 6 evaluates this concern by relating the prediction from estimation of equation (2) to actual cardiologist adaptability using the variables reported in Table 3 for each period. Specifically, the figure plots the dependent variable in equation (2) on the vertical axis as a function of the prediction from equation (2) on the horizontal axis and assessing the relation between the measures by fitting a local linear regression line with corresponding confidence intervals. If the prediction is able to capture (parts of) cardiologist adaptability, we would expect the smoothed line to be closer to the 45 degree line (corresponding to a perfect fit) and further away from the horizontal line at zero (corresponding to pure randomness). The estimated slope is close to and statistically indistinguishable the horizontal line, hence providing additional evidence that non-trivial patient-cardiologist sorting is unlikely to occur in our sample. Note that this is not unexpected, given that the hospital market in Sweden is heavily regulated with essentially no room for competition and choice of provider.

FIGURE 6.
Relationship between predicted and true cardiologist adaptability



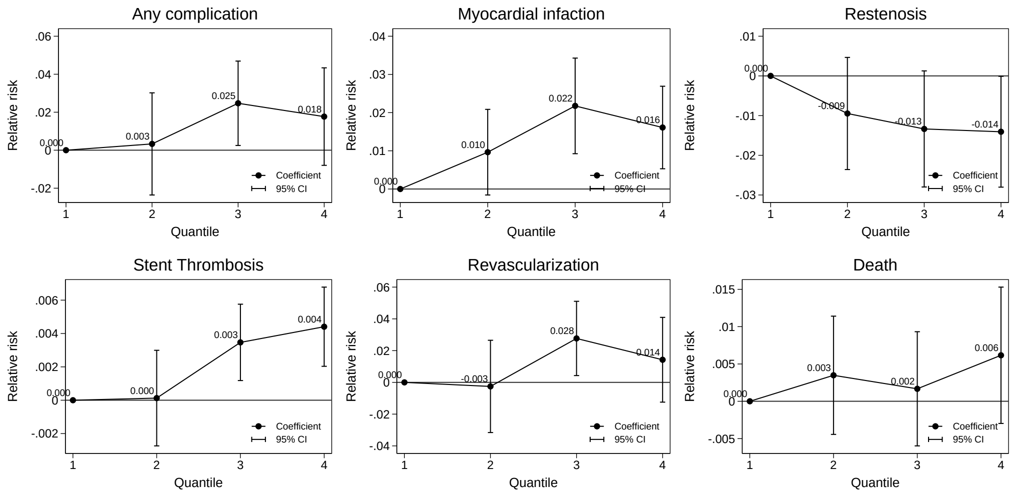
NOTE.— The figure illustrates the relation between actual cardiologist adaptability and predicted adaptability using the same set of regressors as in Table 3. The solid 45 degree line corresponds to a perfect fit and the zero line to pure randomness. The local linear regression and its corresponding confidence interval is estimated using a rectangular kernel with a bandwidth of 0.01.

5.3 The impact on patient outcomes

We next study the relationship between adaptability and patient outcomes. Given that cardiologist adaptability is unrelated to (observable) patient-cardiologist sorting, we attribute any impact of adaptability on our chosen clinical outcome as a causal effect on quality of care. For each patient outcome and period, we study how patient treatment by a cardiologist in the upper three quantiles of the adaptability distribution relates to treatment by a cardiologist in the lowest quartile, after adjustment for our hospital, cardiologist, treatment, and patient characteristics as described in equation (3) and reported in Table 1.

Figure 7 presents the results for the first (introduction) period, whilst Figure 8 and Figure 9 present the results for the subsequent (adverse news and guidelines) two periods. The figures are plotted by outcome and presents the ordered quartile-specific coefficients together with corresponding 95 % confidence intervals. The upper left panel of Figure 7 shows that the risk of any type of complication within three years from the date of the procedure was substantially higher among cardiologists who were fast in adapting to the new stents (i.e., with the steepest slopes). Relative to the baseline complication risk of about .25, the figure suggests an increase of about ten percent from being treated by a cardiologist above compared to below median adaption. Studying the specified clinical endpoints, we see that the higher risk of complication stems from, in particular, an increase in the risk of MI and ST among patients treated by fast adapting cardiologists in the first period while the risk of restenosis is lower. These results thus correspond well with the main result and conclusion from the landmark study by Lagerqvist *et al.* (2007): cardiologists that were fast in adapting to the new stents once they were introduced did also have generally worse patient outcomes.

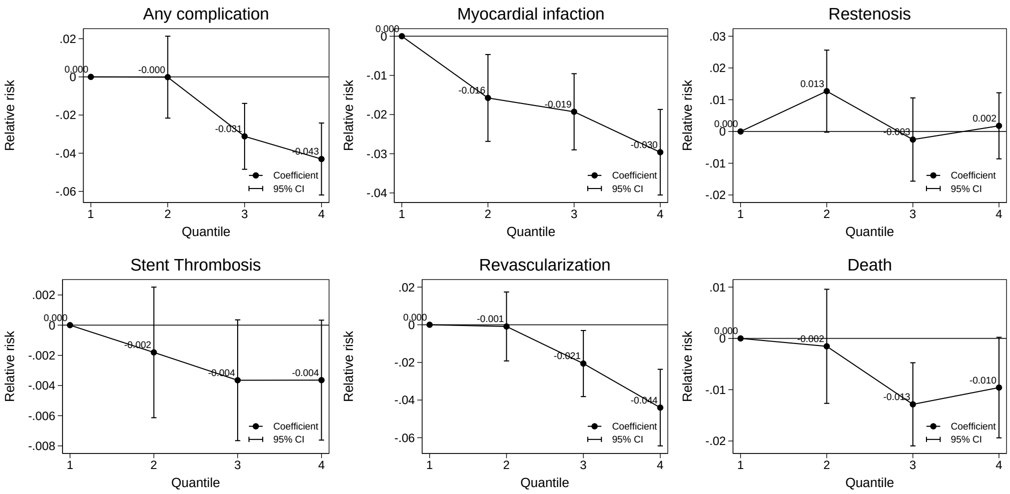
FIGURE 7.
Effect of cardiologist adaptability on patient outcomes in period one



NOTE.— The figure presents OLS estimates from a regression of patient outcomes on a set of dummy variables for being treated by a cardiologist at different quartiles of the period-specific adaptability distribution adjusted for hospital, cardiologist, and patient characteristics as described in equation (3). Robust 95% confidence intervals, clustered by cardiologist, presented as vertical lines around each point estimate.

Turning next to the results from the second (adverse news) period, displayed in Figure 8, we see a drastically reversed pattern compared to Figure 7 in which cardiologists at the top of the adaptability distribution are now associated with the best patient outcomes. Note, however, that the first quartile in the adaptability distribution (the reference category) now corresponds to the fastest adapting cardiologists (i.e., those fastest in *reducing* their use of DES). Thus, Figure 8 suggests that quickly reverting back to the old technology generally resulted in worse patient outcomes. The magnitude of these effects is also substantial with an estimated 20% relative difference in the risk of any complication between the lowest and the highest quartile of the distribution. This effect is mainly driven by a relative reduction in the risk of a MI and revascularization among cardiologists that did not immediately revert back to BMS, but also to some extent in the risk of patient death. Thus, combining the estimated results from the two first periods, it appears that the cardiologists that did not strongly react to the new information (irrespective if it was positive or negative) had the overall best outcomes. We will return to this below when we categorize and study different cardiologist types separately.

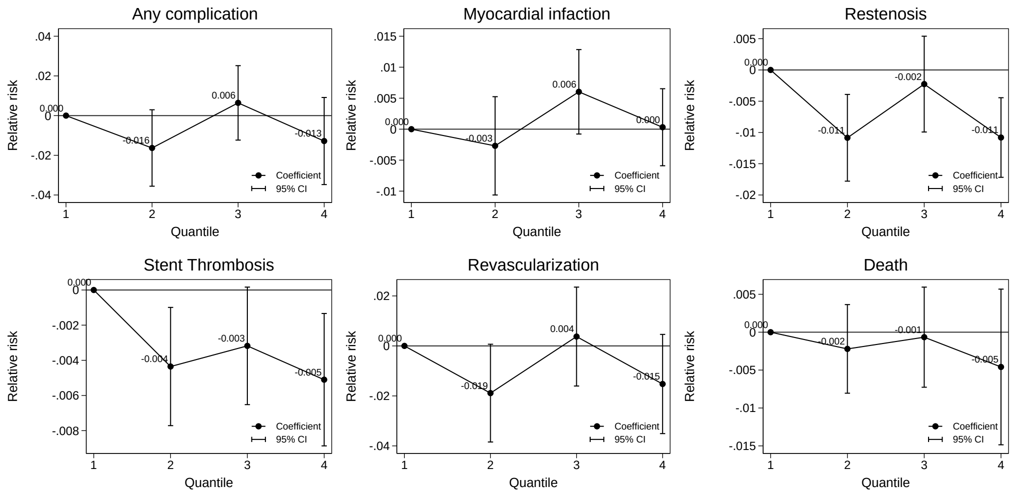
FIGURE 8.
Effect of cardiologist adaptability on patient outcomes in period two



NOTE.— The figure presents OLS estimates from a regression of patient outcomes on a set of dummy variables for being treated by a cardiologist at different quartiles of the period-specific adaptability distribution adjusted for hospital, cardiologist, and patient characteristics as described in equation (3). Robust 95% confidence intervals, clustered by cardiologist, presented as vertical lines around each point estimate.

Finally, Figure 9 shows the estimated association between patient outcome and cardiologist adaptability in the last period in which new national guidelines were introduced. Interestingly, the relative risk of any type of complication is now indistinguishable from zero across all four quartiles of the adaptability distribution. Except for a slight reduction in the relative risk of restenosis and ST for faster adapters (i.e., cardiologists that were quick in returning back to DES), no clear pattern in patient outcomes can be discerned. This suggests, in combination with the evidence on the reduction in response dispersion from Figure 2, that the introduction of the guidelines meant a lower degree of cardiologist discretion which also served to reduce variation in quality of care received by patients.

FIGURE 9.
Effect of cardiologist adaptability on patient outcomes in period three



NOTE.— The figure presents OLS estimates from a regression of patient outcomes on a set of dummy variables for being treated by a cardiologist at different quartiles of the period-specific adaptability distribution adjusted for hospital, cardiologist, and patient characteristics as described in equation (3). Robust 95% confidence intervals, clustered by cardiologist, presented as vertical lines around each point estimate.

One argument against the interpretation of Figure 7–Figure 9 is based on the fact that we do not control for the type of stent used in our models. Clearly, if DES by itself has better or worse effects on patients' outcomes we would expect this to account for at least part of the estimated patterns. However, we think that there are at least two arguments against adding the stent type as an additional control in the models: First, since we are studying the choices made by cardiologists in an uncertain information environment, including a dummy for the stent used is a "bad" control in the sense that we would then control for part of the effect that we are interested in. Second, from reviewing the literature surrounding the DES controversy, there is no clear reason to believe that the adverse information regarding the safety of DES was correct. Nevertheless, in order to compare the results with and without the stent type included as a control, Figure A.9–Figure A.11 in Appendix A show overlaid plots of the results without a stent type indicator (in blue) and with a stent type indicator (in red). Quite strikingly we see that the results are nearly always very similar, irrespective of specification, expect for the risk of restenosis and ST, in which the results including the stent type dummy are always slightly attenuated. This is exactly what we would expect, given the prior information regarding the superiority. Note, though, that for all other outcomes including the type of stent used does not change the interpretation that fast adapters have generally worse patient outcomes than slow adapters.

To further study the relationship between cardiologist adaptability and patient outcomes, we define cardiologists as one of four types, based on their adaptability in the first two periods. More specifically, we group cardiologists in "fast" and "slow" adapter categories depending on whether they were above or below the period-specific median adaptability. For this, we only include cardiologists observed in all three periods, which reduces our sample to 50,014 patients treated by 105 cardiologists.[15] As such, we obtain four different categories, shown in Figure 10.

FIGURE 10.
Definition and sample size of cardiologist types

Period 1 \ **Period 2**	*Slow*	*Fast*
Slow	Slow adapters ($n = 39$)	Conservative adapter ($n = 14$)
Fast	Enthusiastic adapter ($n = 13$)	Fast adapters ($n = 39$)

NOTE.— The figure displays the four categories of cardiologists used in the analysis according to the combination of normalized adaptability estimates in the two initial periods (introduction and adverse news). A slow (fast) adapter is defined as being below (above) the median of the distribution in each period. The number in parenthesis reports the number of cardiologists belonging to each group.

The top left corner of Figure 10 contains "slow adapters"; i.e., cardiologists who adapted slowly to information irrespective of whether it was positive or negative. They did not jump to using the new stents when they were introduced in 2002, but they were also slow to reduce their use of DES when the news of the negative side effects was published. In contrast to these cardiologists, those in the bottom right hand corner are "fast adapters" who quickly changed their treatment choice in both periods. In other words, they were quick to take up the new stents, but also quick in reverting back to the old stents in 2006.

In the bottom left hand corner are "enthusiastic adapters" who were fast in adapting in the first period when DES was introduced, but slow to respond to the news of negative side effects in the second period. Hence, despite the messages in period two that they should

[15] To ensure that this selection does not affect our earlier estimates,we have estimated the analyses of Table 2 on the reduced sample. The estimates are quantitatively and qualitatively similar.

reduce the use of DES, their strongly held beliefs about the appropriateness of this treatment led them to sustain their high use. Finally, "conservative adapters", shown in the upper right hand corner, were slow in the first period, preferring to stick to the well-known BMS rather than innovate to using DES, but fast in the second period, quickly reverting back to the older technology. As can be seen from Figure 10, slow and fast adapters are relatively more common than conservative and enthusiasts. Furthermore, Figure A.12 in Appendix A shows the type- and period-specific adaptability distributions for the four cardiologist types we consider.

We use the four types of cardiologists in a regression model similar to (3), but where we replace the adaptability measure by the mutually exclusive indicator variables for each cardiologist type. The results for all periods are reported in Panel A of Table 4 and largely confirm our previous findings that patient outcomes are best for those treated by slow adapters. More specifically, column (1) reports that patients treated by conservative adapters are 3.8 percentage points more likely to experience complications, whilst patients treated by quick and enthusiastic adapters have an increased risk of 2.1 and 1.7 percentage points, respectively. With an average of .25 of patients experiencing any complications, these correspond to a 7–15% increase overall. Studying the separate clinical endpoints in columns (2)–(6), we see that the results for conservative and enthusiastic adapters are driven by single increases in the risk of revascularization and myocardial infarction, respectively, while quick adapters have significantly worse results for three out of five outcomes.

Finally, panels B–D of Table 4 reports relative complication rates by period, once again showing the relative superiority of slow adapters for the first two periods. However, comparing the point estimates from the first two periods to the third period, in which national guidelines were introduced, there is a clear attenuation of the relative outcome differences across types. Thus, together with the suggestive evidence of reduced dispersion from Figure 2 and Figure 5, it appears that the new guidelines reduced treatment discretion among cardiologists and thereby also variation in clinical outcomes.

TABLE 4.
Effect of cardiologist type on patient outcomes

	(1) Any complication	(2) Myocardial Infarction	(3) Restenosis	(4) Stent Thrombosis	(5) Revascularization	(6) Death
A. All periods						
Slow adapter [*ref.*]						
Conservative	0.038***	0.000	0.002	0.002	0.044***	0.001
	(0.014)	(0.004)	(0.005)	(0.002)	(0.016)	(0.006)
Enthusiast	0.017*	0.013**	-0.005	0.001	0.017	0.001
	(0.009)	(0.005)	(0.005)	(0.001)	(0.010)	(0.004)
Quick adapter	0.021*	0.006*	-0.002	0.003***	0.024**	0.001
	(0.011)	(0.003)	(0.003)	(0.001)	(0.011)	(0.004)
Controls	✓	✓	✓	✓	✓	✓
Observations	50,014	50,014	50,014	50,014	50,014	50,014
Mean of outcome	0.250	0.071	0.050	0.011	0.150	0.089
B. Only period 1						
Slow adapter [*ref.*]						
Conservative	0.038***	0.009	0.005	0.004**	0.040***	0.001
	(0.012)	(0.006)	(0.005)	(0.002)	(0.014)	(0.009)
Enthusiast	0.033***	0.022***	-0.001	0.005***	0.035***	0.001
	(0.011)	(0.008)	(0.008)	(0.001)	(0.011)	(0.005)
Quick adapter	0.029**	0.013**	-0.008*	0.004***	0.036***	0.002
	(0.012)	(0.005)	(0.004)	(0.001)	(0.012)	(0.004)
Controls	✓	✓	✓	✓	✓	✓
Observations	19,330	19,330	19,330	19,330	19,330	19,330
Mean	0.250	0.073	0.043	0.007	0.150	0.082
C. Only period 2						
Slow adapter [*ref.*]						
Conservative	0.045***	0.001	0.001	-0.001	0.047***	0.009
	(0.012)	(0.006)	(0.005)	(0.002)	(0.016)	(0.010)
Enthusiast	0.006	0.007	-0.008	-0.002	0.018**	-0.003
	(0.011)	(0.007)	(0.009)	(0.003)	(0.008)	(0.006)
Quick adapter	0.040***	0.024***	0.005	0.002	0.037***	0.011**
	(0.010)	(0.005)	(0.006)	(0.002)	(0.009)	(0.005)
Controls	✓	✓	✓	✓	✓	✓
Observations	10,763	10,763	10,763	10,763	10,763	10,763
Mean	0.250	0.069	0.056	0.013	0.140	0.091
D. Only period 3						
Slow adapter [*ref.*]						
Conservative	0.037*	-0.006	0.001	0.001	0.047**	0.000
	(0.019)	(0.004)	(0.007)	(0.002)	(0.021)	(0.006)
Enthusiast	-0.015	-0.003	-0.016**	-0.001	-0.017	-0.001
	(0.016)	(0.004)	(0.006)	(0.002)	(0.014)	(0.006)
Quick adapter	0.011	-0.001	0.000	0.004**	0.013	-0.000
	(0.014)	(0.004)	(0.005)	(0.001)	(0.013)	(0.005)
Controls	✓	✓	✓	✓	✓	✓
Observations	19,921	19,921	19,921	19,921	19,921	19,921
Mean	0.260	0.070	0.054	0.013	0.150	0.095

NOTE.— The table presents the OLS estimates from a regression of patient outcomes on hospital, cardiologist, treatment, and patient characteristics. Robust standard errors, clustered by cardiologist, presented in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6 Conclusion

This paper studies how physicians adapt to new treatment information, how this response relates to patient outcomes, and how the introduction of national guidelines regarding the appropriate use of treatment influences physician behaviour and patient health outcomes. We exploit the publication of unexpected information, suggesting there were safety concerns relating to the recently introduced drug-eluting stents (DES). We apply detailed micro-level data on all PCI's performed in Swedish hospitals between 2002–2011 and study how cardiologists adapted to changes in treatment recommendations during different information regimes.

Our results suggest substantial heterogeneity in treatment decisions of physicians in this high-stakes context. The largest variation in medical practice occurred during the phase with adverse information when the safety concerns regarding DES arose, suggesting that, despite relatively unambiguous information regarding treatment side effects, this led to significant uncertainty as to the appropriateness of DES. The introduction of guidelines, however, restricted physician choice and substantially reduced this variability.

Relating cardiologist adaptability to patient outcomes, our estimates indicate that more slow-adapting cardiologists, on average, have better patient outcomes along a range of clinical factors, including the risk of myocardial infarction and revascularization. However, with the introduction of treatment guidelines, these effects disappear, suggesting that guidelines, in addition to restricting cardiologist discretion, improve patient outcomes. We do not find any evidence suggesting that our results are driven by patient selection to cardiologist type.

Our findings suggest that imposing guidelines could be superior to discretionary treatments in contexts where patient heterogeneity is relatively limited. However, at the same time, it is possible that these guidelines may not have been proposed without the evidence based on the eagerness of enthusiastic adapters' treatment decisions. Indeed, without early adapters, any potential side-effects of new treatments and how to avoid such may have never been discovered, suggesting a crucial trade-off in the policy discussion on restricting medical practice.

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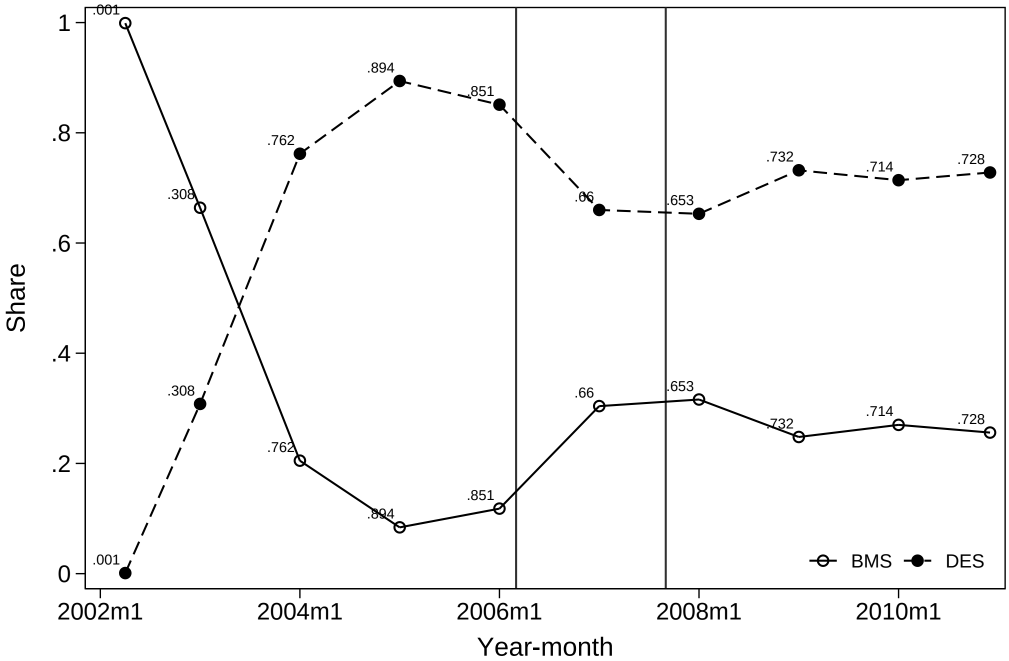
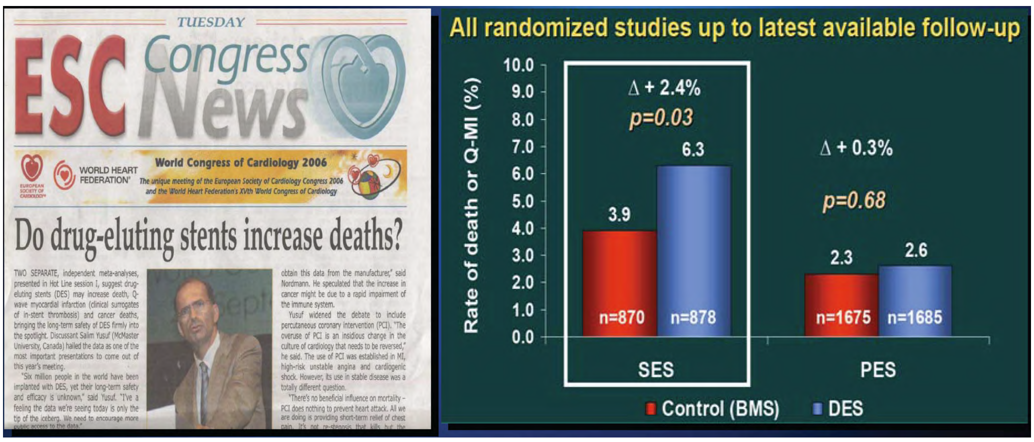
Appendix A Additional Tables and Figures

FIGURE A.1.
US trends in BMS and DES take-up



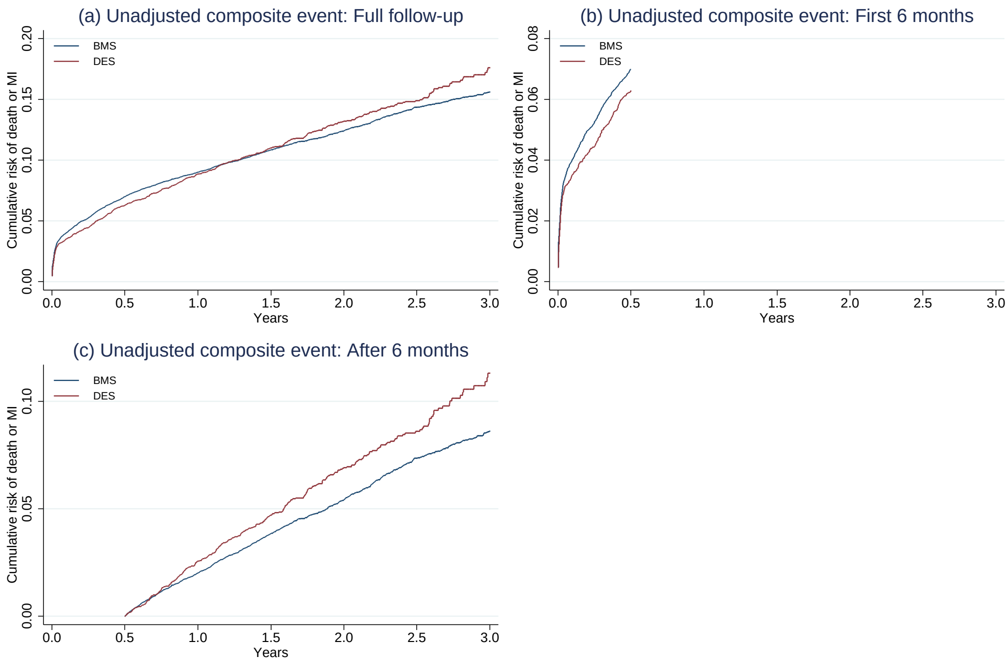
NOTE.— The vertical lines indicate the different time periods we analyze as described in detail in the text. The shares sum to one.

FIGURE A.2.
Headline from the 2006 ESC DES firestorm in Barcelona



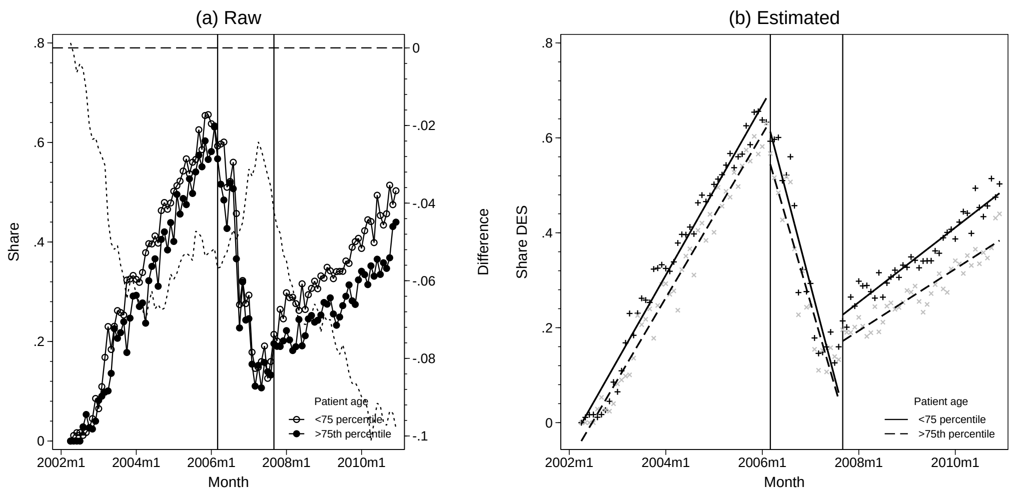
NOTE.— Information flyer and presentation slide taken from the presentation by Dr. Edourdo Camenzind at the 2006 annual congress of the European Society of Cardiologists in Barcelona.

FIGURE A.3.
Estimated hazards to death and myocardial infarction by stent type using 2003-2004 SCAAR data



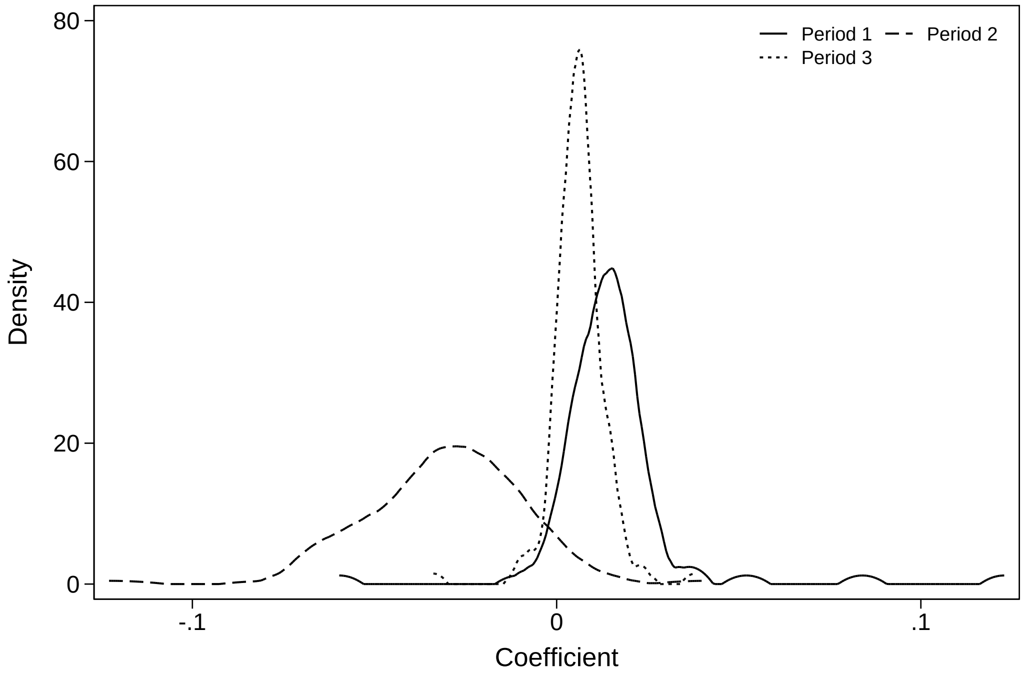
NOTE.— Own calculations based on replications of Figures 1 (a) and 2 (a) in Lagerqvist *et al.* (2007). Data is based on sampled cases between 2003 and 2004 with a follow-up censored at June 30th, 2006. Outcome is measure as the composite event of death or myocardial infarction. All definitions are otherwise the same as in the main analysis sample.

FIGURE A.4.
Trends in DES take-up by patient age



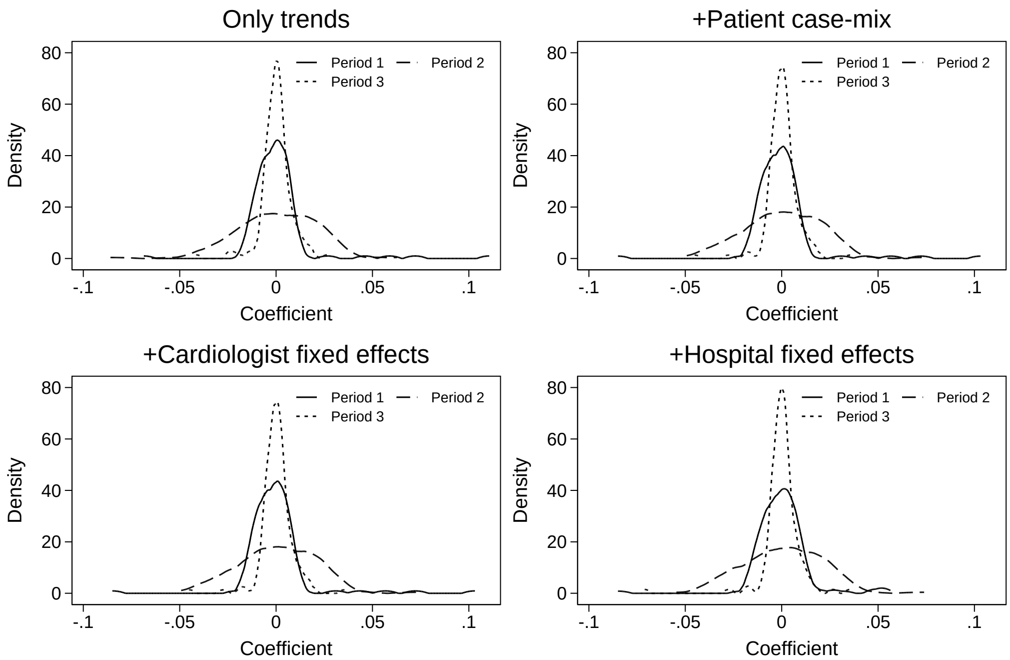
NOTE.— The figure shows the raw (panel a) and estimated (panel b) trends in DES take-up by time period and patient age. The dotted line measured on the right *y*-axis in panel (a) indicates the average group difference over time. The trends in panel (b) are estimated with a piece-wise linear spline defined by the three time periods separately for old and young patients.

FIGURE A.5.
Cardiologist adaptability in the three periods (uncentered)



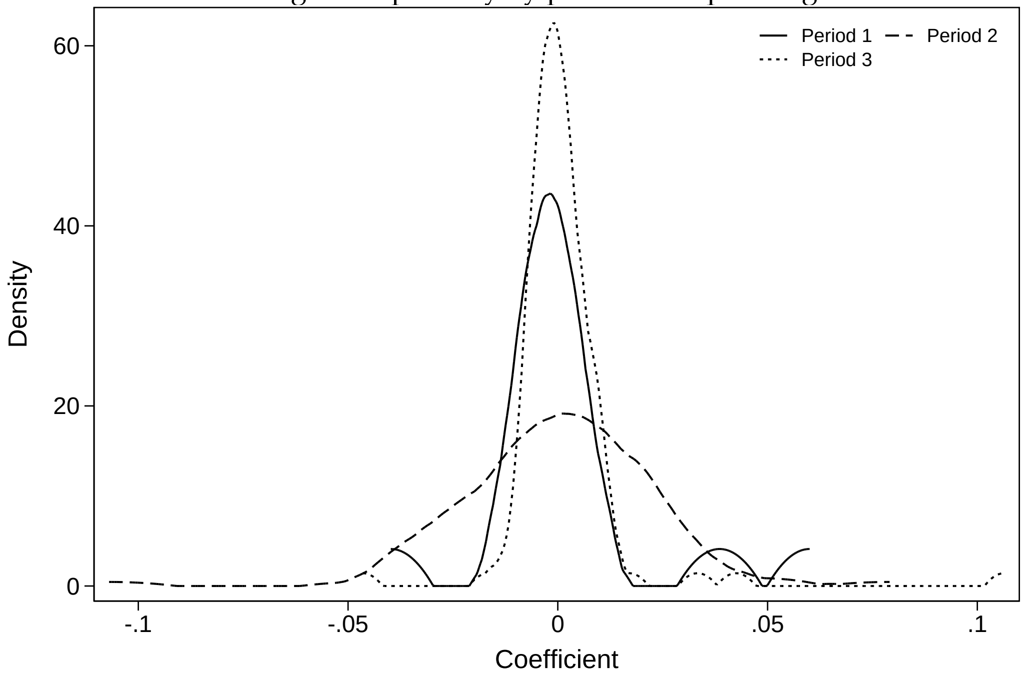
NOTE.— Densities are based on the number of cardiologists observed in each period: 120, 119, and 140 respectively.

FIGURE A.6.
Adjusted cardiologist adaptability in the three periods



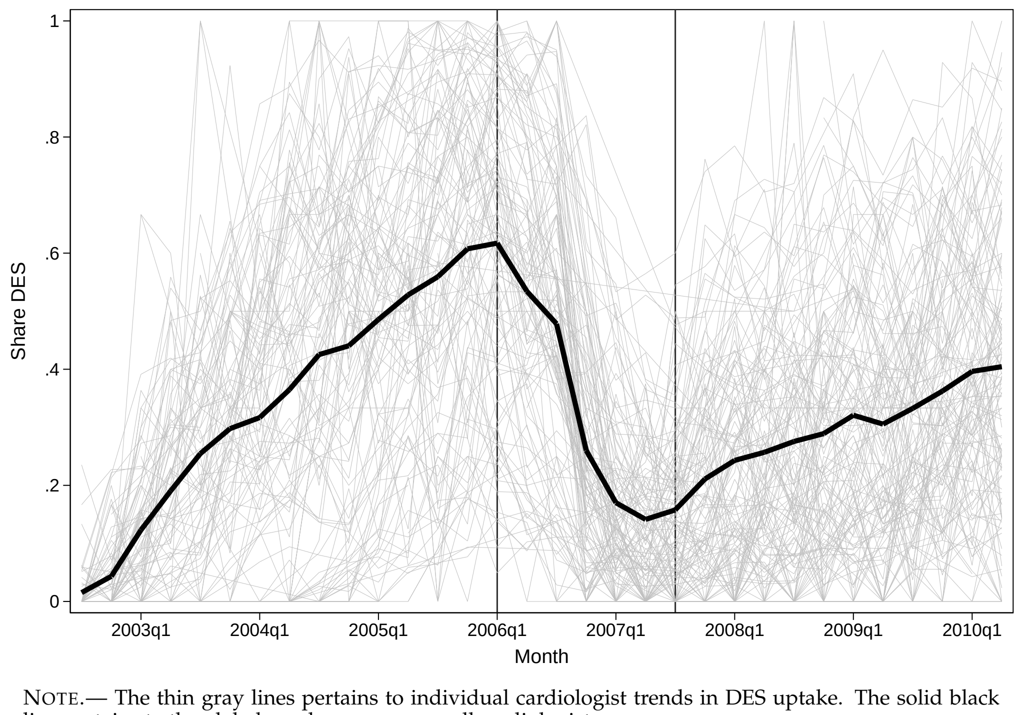
NOTE.— Adaptability estimates are centered around zero (i.e. the cardiologist-level estimate minus the overall mean shown in column 1 of Table 2. Densities are based on the number of cardiologists observed in each period: 120, 119, and 140 respectively. The top-left figure is identical to Figure 2; the top-right figure does not control for patient case-mix; the bottom left figure accounts for surgeon fixed effects; the bottom-right figure accounts for hospital fixed effects.

FIGURE A.7.
Cardiologist adaptability by periods of equal length



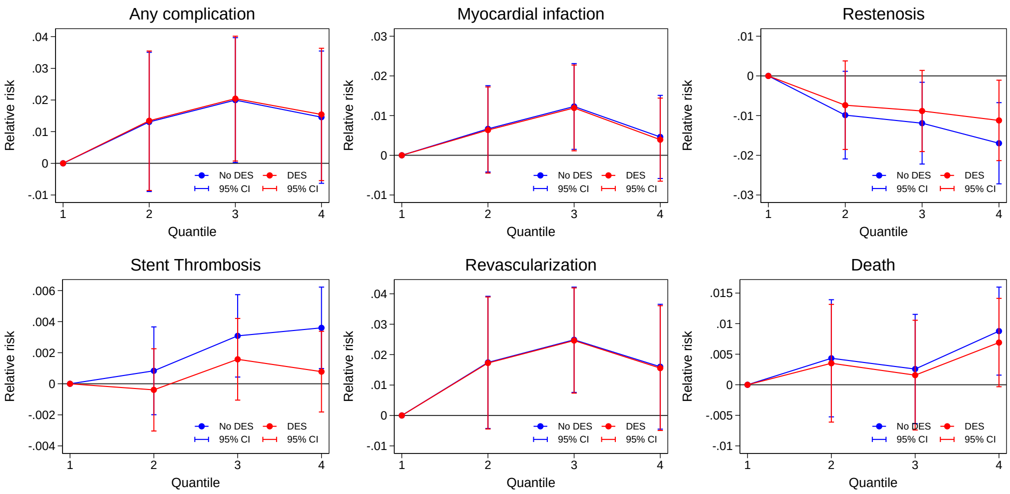
NOTE.— Adaptability estimates are centered around zero (i.e. the cardiologist-level estimate minus the overall mean shown in column 1 of Table 2. Each density is based on periods of 18 months (the original length of period 2).

FIGURE A.8.
Individual cardiologist trends across periods



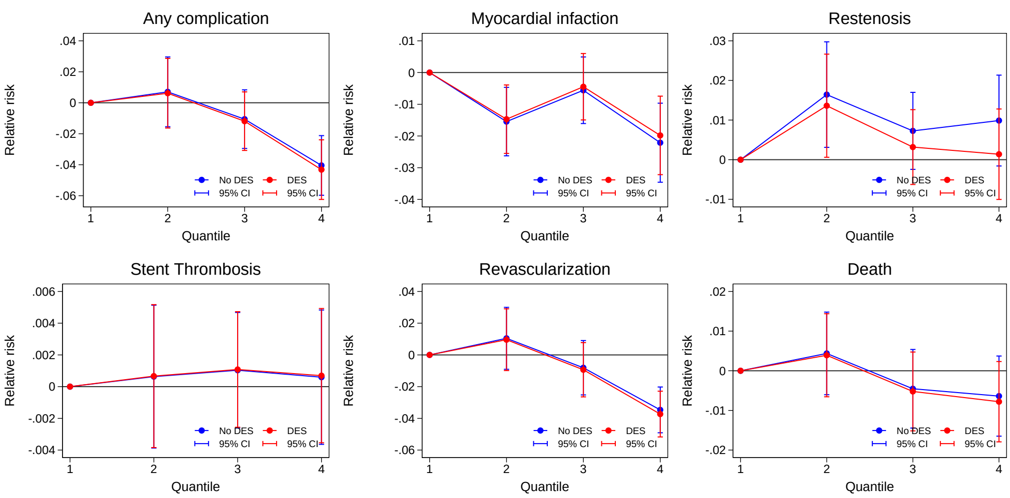
NOTE.— The thin gray lines pertains to individual cardiologist trends in DES uptake. The solid black line pertains to the global yearly mean across all cardiologists.

FIGURE A.9.
Effect of cardiologist adaptability on patient outcomes in period 1



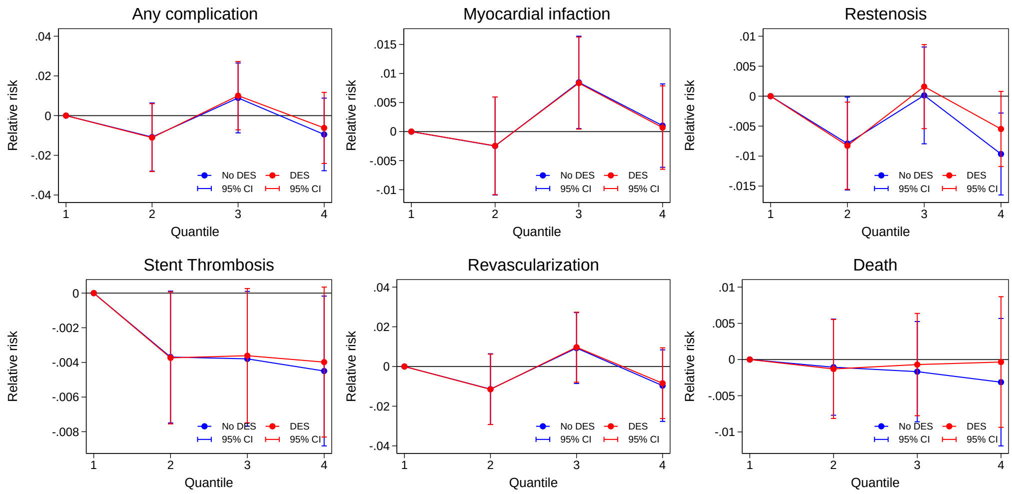
NOTE.— The figure presents OLS estimates from a regression of patient outcomes on a set of dummy variables for being treated by a cardiologist at different quartiles of the period-specific adaptability distribution adjusted for hospital, cardiologist, and patient characteristics as described in equation (3). Robust 95% confidence intervals, clustered by cardiologist, presented as vertical lines around each point estimate.

FIGURE A.10.
Effect of cardiologist adaptability on patient outcomes in period 2



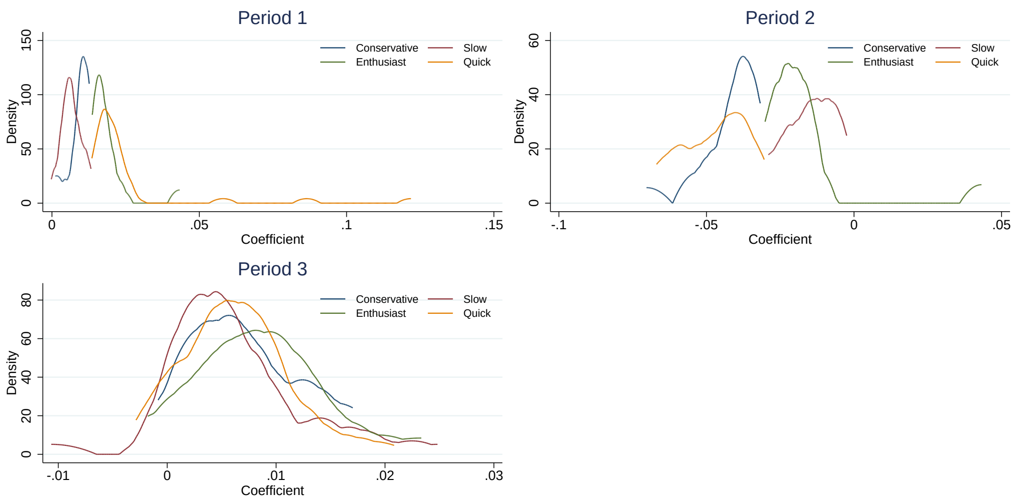
NOTE.— The figure presents OLS estimates from a regression of patient outcomes on a set of dummy variables for being treated by a cardiologist at different quartiles of the period-specific adaptability distribution adjusted for hospital, cardiologist, and patient characteristics as described in equation (3). Robust 95% confidence intervals, clustered by cardiologist, presented as vertical lines around each point estimate.

FIGURE A.11.
Effect of cardiologist adaptability on patient outcomes in period 3



NOTE.— The figure presents OLS estimates from a regression of patient outcomes on a set of dummy variables for being treated by a cardiologist at different quartiles of the period-specific adaptability distribution adjusted for hospital, cardiologist, and patient characteristics as described in equation (3). Robust 95% confidence intervals, clustered by cardiologist, presented as vertical lines around each point estimate.

FIGURE A.12.
Cardiologist adaptability by period and cardiologist type



NOTE.— Densities are based on the number of cardiologists observed in each period: 120, 119, and 140 respectively.

TABLE A.1.
Trends in DES take-up

	(1) Trends only	(2) Large hospital	(3) Teaching hospital	(4) Surgeon female	(5) Surgeon experienced	(6) Patient not in period 1	(7) Patient over 75	(8) Patient female	(9) Same gender	(10) Acute (unplanned)
P1 trend	0.014***	0.015***	0.015***	0.014***	0.014***	0.014***	0.014***	0.014***	0.014***	0.017***
	(0.000)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
P2 trend	-0.030***	-0.029***	-0.029***	-0.030***	-0.030***	-0.030***	-0.030***	-0.030***	-0.030***	-0.029***
	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
P3 trend	0.006***	0.007***	0.007***	0.006***	0.006***	0.006***	0.006***	0.006***	0.006***	0.007***
	(0.000)	(0.001)	(0.001)	(0.000)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)	(0.001)
P1 trend interacted		-0.002*	-0.004***	-0.001	0.000	0.000	-0.001**	0.000	0.000	-0.003***
		(0.001)	(0.001)	(0.001)	(0.001)	(.)	(0.000)	(0.000)	(0.000)	(0.001)
P2 trend interacted		-0.002*	-0.004***	-0.001	0.000	-0.001	-0.001**	0.000	0.000	-0.003***
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
P3 trend interacted		-0.002*	-0.003***	-0.001	0.000	-0.001	-0.001**	0.000	0.000	-0.003***
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)	(0.000)	(0.001)
Large hospital		0.931*								
		(0.488)								
Teaching hospital			1.921***							
			(0.396)							
Cardiologist female				0.424						
				(0.581)						
Cardiologist experienced					-0.196					
					(0.434)					
Cardiologist not in P1						0.335				
						(0.641)				
Patient over 75							0.283*			
							(0.161)			
Patient female								-0.076		
								(0.146)		
Patient/cardiologist same gender									-0.072	
									(0.158)	
Acute case										1.253***
										(0.390)
P2	24.227***	24.251***	24.272***	24.218***	24.305***	24.196***	24.298***	24.229***	24.228***	25.851***
	(0.354)	(1.445)	(1.384)	(1.472)	(1.474)	(1.457)	(1.482)	(1.474)	(1.474)	(1.503)
P3	3.793***	3.844***	3.860***	3.808***	3.810***	3.683***	3.812***	3.793***	3.800***	5.065***
	(0.145)	(0.447)	(0.416)	(0.477)	(0.489)	(0.491)	(0.480)	(0.475)	(0.475)	(0.725)
Constant	-7.128***	-7.528***	-7.668***	-7.157***	-7.096***	-7.128***	-7.223***	-7.104***	-7.078***	-8.860***
	(0.100)	(0.357)	(0.363)	(0.399)	(0.437)	(0.393)	(0.395)	(0.388)	(0.414)	(0.568)
p-value		0.021	0.000	0.664	0.792	0.570	0.414	0.058	0.243	0.207
No. of observations	94,366	94,366	94,366	94,366	94,366	94,366	94,366	94,366	94,366	94,366

NOTE.— The table presents OLS estimates where the dependent variable is a binary indicator whether the patient received a DES (vs. BMS). Column 1 models only trends; column 2-11 interact the trend with the variable indicated in the column heading (e.g. large hospital, teaching hopsital, female cardiologist, etc. Robust standard errors clustered by cardiologist in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.