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Do responses to news matter? Evidence from interventional cardiology[☆]

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ABSTRACT

We examine physician responses to a global information shock and how these impact their patients. We exploit international news over the safety of an innovation in healthcare, the drug-eluting stent. We use data on interventional cardiologists' use of stents to define and measure cardiologists' responsiveness to the initial positive news and link this to their patients' outcomes. We find substantial heterogeneity in responsiveness to news. Patients treated by cardiologists who respond slowly to the initial positive news have fewer adverse outcomes. This is not due to patient–physician sorting. Instead, our results suggest that the differences are partially driven by slow responders being better at deciding when (not) to use the new technology, which in turn affects their patient outcomes.

1. Introduction

Information is frequently advocated as a tool to improve public services. But some suppliers' responses to information shocks may be objectively better for consumers.[1] In this paper we examine heterogeneity in supplier responses to a frequent type of information shock and explore how this affects their consumers.

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[1] Initiatives such as government websites to aid consumer choice, the publication of "league tables", the provision of information to aid school choice, and policies such as "naming and shaming" of poor suppliers all involve the provision of information to help consumers and improve public services. In this context, much research has drawn attention to the fact that provision of greater information may induce gaming behavior by suppliers with negative consequences for consumers (see,e.g., Dranove et al., 2003).

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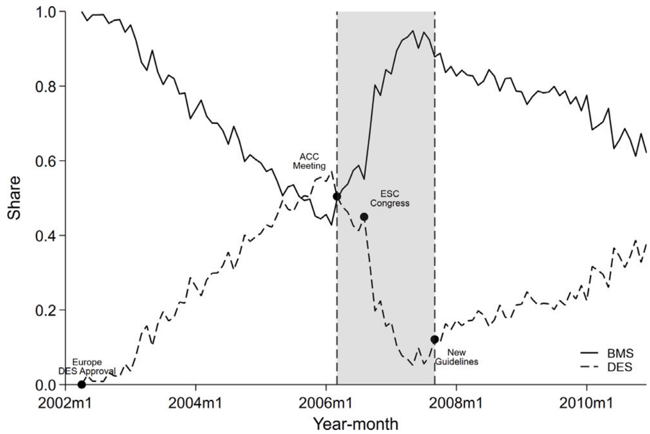

Fig. 1. Trends in the use of BMS and DES in Swedish hospitals, 2002–2011.
Note.— Data from the Swedish Angiography and Angioplasty Register (SCAAR). The vertical axis denotes the share of stents that are DES (vs BMS). Vertical lines indicate different time periods described in the text. Black circles indicate timings of important events with respect to the use of DES.

Our focus is on responses to information in the context of an innovation in healthcare. Information shocks are particularly pertinent in this context. Innovations are generally introduced through clinical trials and successful trials are often based on a relatively homogeneous set of patients. Rolling out the innovation to a wider group of patients often leads to less positive (or negative) effects on patient health than in the initial trial. This can even lead to abandonment of the innovation, known as "medical reversal" (see, e.g., Prasad and Cifu, 2019).[2] In this setting, acting upon or disregarding new information can have a large impact on patient welfare. Since even specialist medical societies appear to be resistant to making medical reversals (suggesting considerable inertia in changing ineffective clinical practice (see, e.g., Wang et al., 2015)), there is a need to investigate physician responses to such common information shocks, whether there is heterogeneity across physicians, and the impact of this heterogeneity on patient outcomes.

To do this we exploit an important innovation in the production technology that interventional cardiologists use in their work: the drug-eluting stent (DES). Starting in 2002 DES was widely heralded as the solution to a key problem in coronary catheterization. As a result it captured over half the market from the older technology (bare-metal stents, henceforth BMS) in only four years after regulatory approval. But in 2006 information was released showing DES caused potentially life threatening side-effects. This second information shock, widely reported internationally, drastically reversed the trend of increasing DES use worldwide. Within just one month, DES lost half its global market share to BMS and the decline continued until extensive re-evaluations of the safety of DES reaffirmed its superiority for certain patient types. This led many national regulatory bodies to issue guidance as to the appropriate use of DES and BMS a year after the negative information shock.[3] After this, DES use rose again.

Fig. 1 shows the effects of these information shocks on the use of DES in our "test-bed" setting, Sweden. Between the date of DES approval in Europe in early 2002 and the release of adverse information in 2006, DES had become the dominant choice of Swedish cardiologists, accounting for approximately 60 percent of the Swedish stent market. Only one year later this share had plummeted to less than 10 percent.[4] This led to a regulatory response with the introduction of new national guidelines in late 2007 providing guidance as to when DES should be used, which led to renewed uptake, albeit at a slower rate than the initial increase.

We use this context to examine whether physicians who rapidly embrace a new innovation have better or worse outcomes for their patients. We use the universe of cardiologists in Sweden and data on all their patients from 2002 to 2011. Our setting has several advantages for the study of the impact of information on physician behavior and patient outcomes. First, the initial positive information shock and the subsequent medical reversal were salient, exogenous and the behavioral responses large. Second, the setting is one that affects a relatively large patient population for which the consequences of medical errors can be important.[5] Third, the issuance of national guidelines after the news shocks allows us to use this "guideline period" to define appropriate treatment and to benchmark cardiologist responses and patient outcomes prior to these national guidelines to responses and outcomes in

[2] A recent systematic overview of the clinical evidence supporting US Food and Drug Administration (FDA) "breakthrough approvals" between 2012 and 2017 found that such approvals were often made on the basis of weak evidence. Specifically, the median number of pivotal trials per indication was one, the median number of patients was 222, and only about half of all trials were based on gold standard scientific methods, such as randomization of subjects to treatments (Puthumana et al., 2018).

[3] For example, the American College of Cardiologists/American Heart Association/Task Force on Practice Guidelines (ACC/AHA/SCAI) issued a focused update for PCI guidelines in the end of 2007 (King et al., 2008).

[4] Trends were similar in many countries, including the United States, Canada and Scotland (see, e.g., Austin et al., 2009; Epstein et al., 2011; Bangalore et al., 2014).

[5] Coronary artery disease (CAD) is the global leading cause of death, and angioplasty, performed by interventional cardiologists, has become the gold standard of treating common and severe conditions such as acute myocardial infarction (AMI).

this period.[6] Fourth, the treatment alternatives we study (DES versus BMS) are in all relevant aspects equivalent in how they are clinically administered. Thus we can exclude potential explanations for heterogeneity in behavior and patient outcomes arising from differences in cardiologist motor skills or visual acuity. Furthermore, the introduction of DES did not affect the appropriateness of other treatment options (for example, coronary artery bypass grafting) so the relevant patient population of interest can be considered as fixed over time. Finally, by examining these issues in the context of the Swedish healthcare system, we are able to rule out market mechanisms that may drive decisions about treatment in many healthcare markets. These include patient selection (the treating cardiologist does not generally decide *whether* to stent a patient but only selects the *type* of stent, and patients have virtually no choice of selecting physicians in the Swedish inpatient sector; we explore this empirically below), competition (Swedish hospitals are publicly owned and managed and physicians are salaried) or costs of treatment (the expected price differential between the use of BMS and DES in PCI treatments was relatively small in Sweden).[7] Thus, we may interpret variation in responsiveness to the initial positive news across cardiologists as arising from individual discretion in response to information.

We exploit the three information regimes of ‘‘initial positive news’’ (period one: the period between regulatory approval of DES in 2002 and 2006), ‘‘medical reversal’’ (period two: the period between 2006 and 2007) and the guideline period (period three: the period between 2007 and 2011) for our analysis. To define our measure of responsiveness to positive news about an innovation we construct a cardiologist-specific measure of responsiveness in period one, defined as the speed with which each cardiologist adopted DES relative to the period-specific average across all cardiologists. We use this to categorize whether the cardiologist’s response to the initial positive news was slower than their peers and test whether this is associated with their patient outcomes. We then explore whether the differences that we find are due to patient selection or treatment selection.

We find the following. First, there is less heterogeneity in the speed with which cardiologists take up DES after the guidelines were published compared to the two earlier periods. Hence the guidelines restricted (as they were intended to) individual discretion. They also resulted in improved patient outcomes. We use these findings to justify the use of the guideline period as a period of appropriate practice which we can use as a benchmark for earlier treatment behavior of the cardiologists. We also use the clinical information in the guidelines to define inappropriate (‘‘off-label’’) use of stents. Second, we show that cardiologists’ speed of response to the initial positive news is associated with their patients’ outcomes, with patients treated by slower responders to the positive news having a lower risk of adverse clinical events compared to those treated by their peers. We find no evidence that these differences in patient outcomes are driven by patient–physician sorting. Instead, we find that slower-responding cardiologists make, on average, better choices of which patients to give the new stents to, and they are less likely to use stents inappropriately (i.e., off-label), with such off-label use of stents being strongly associated with an increase in adverse cardiac events. However, despite these differences in the choice of stents and off-label use between slow and other cardiologists and their impacts on patient outcomes, we do not find that this can fully explain the observed differences in outcomes of the two groups of cardiologists. Thus we cannot fully identify the mechanism through which slow responders perform better. Finally, we find that those who respond least to the positive news are more likely to work in teaching hospitals. It is possible that this gives these cardiologists greater access to private information about the innovation, which they use when making clinical decisions.

Our work contributes to several strands of literature. The first explores causes and consequences of physician practice styles (see, e.g., Chandra and Staiger, 2007; Epstein and Nicholson, 2009). Chandra et al. (2012) provide an overview of potential causes for variations in provider treatment decisions across similar patients. These 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., 2019); and (iv) unobserved heterogeneity across providers (Doyle et al., 2010). Our institutional setting allows us to focus on variation in the behavior of providers, abstracting from the first three potential drivers of variation. In particular, we contribute to a small set of recent studies which analyze the relationship between provider practice styles and costs and quality of care. 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 of patients with acute myocardial infarction. Currie and MacLeod (2020) explore whether physician experimentation with anti-depressant drugs is associated with better patient health outcomes. Molitor (2018) examines how cardiologists’ practice styles are affected by their environment by assessing how their behavior changes when they move across healthcare 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. Cutler et al. (2019) examine physician behavior using responses to vignettes (hypothetical medical cases) and identify types of behavior from these responses. Although they do not study the association with patient outcomes, they find that these types of behavior explain a relatively large share of variance in medical expenditures.

While information is likely to play a role in these decisions, none of these papers focus on responses to information. There is a large literature on prescribing responses to warnings by regulatory authorities concerning risk which shows that drug safety warnings may not be optimally received. A review of 20 years of US Federal Drug Administration communications of risk concluded that although some communications had immediate and strong impacts, many had either delayed or had no impact on health care

[6] We show below that cardiologists followed this guidance, reducing the probability of serious complications in the patient population.

[7] See, e.g., Ekman et al. (2006) who estimates that the expected one-year cost of a PCI with a Taxus DES in 2004 amounted to SEK 72,000 (USD 7900) versus SEK 67,000 (USD 7400) for BMS. Both direct and indirect (i.e., repeat revascularization) treatment costs are included as Swedish hospitals are paid on a capitation basis. This contrasts, for example, with much larger cost differences in the US (see, e.g., Karaca-Mandic et al., 2017). In addition, we can rule out large incentives for adoption from lobbying by the medical devices industry as this is much more muted in the Swedish centralized healthcare system compared to more market-oriented systems.

utilization or health behaviors (Dusetzina et al., 2012). In a healthcare context closer to the Swedish setting, a meta analysis of 25 UK medicine risk communications relating to prescribing concluded that risk communications were associated with significant changes in both intended and unintended (detrimental) changes in health outcomes (Weatherburn et al., 2020). In the explicit context of a medical reversal, Everhart et al. (2021) examine physician-level deadoption of a combination of diabetes medications following evidence that they were not effective when taken together. They find on average physicians decreased prescribing following the release of public information but many physicians also increased prescribing.

Closest to our research, Staats et al. (2017) study the negative news shock for DES. They examine how physician experience (defined as volume of activity) affects the speed of response to this news in a US context. They find that more experienced cardiologists respond more sluggishly to the negative news shock. Our focus is on heterogeneity in response to the early good news about the innovation and, importantly, and in contrast to Staats et al. (2017) (and most other studies in this field), we link the speed of response to patient outcomes. Our Swedish setting also allows us to close down avenues relating to behavior that is a response to the financial incentives present in the US context.

We also contribute to the literature on responses to information and their impacts outside the medical setting. This literature shows that individuals may over- or under-react to news (see, e.g., Daniel et al., 1998), and that individuals respond differently to positive and negative news (e.g., in psychology (Baumeister et al., 2001), empirical finance (De Bondt and Thaler, 1985, 1987; Veronesi, 1999; Hong et al., 2000; Hong and Stein, 2007; Kacperczyk et al., 2015), and politics (Soroka, 2006)). There is a growing interest in ideas of differential responses to common information driven by salience and limited attention, whereby cognitively overloaded individuals rationally pay attention to only a subset of information (see, e.g., Maćkowiak et al., 2018). Our study shows that heterogeneity in responses to common information shocks also affect physician behavior and, importantly, the health of their patients.

The paper proceeds as follows. The next section provides an overview of the Swedish healthcare system and the clinical context. Section 3 explains our empirical approach, how we estimate cardiologist responsiveness to news shocks, the effect on patient outcomes, and explores potential mechanisms that may be driving these differences. Section 4 presents the data, Section 5 the results and Section 6 concludes.

2. Institutional setting

We first provide a short summary of the relevant parts of the Swedish healthcare system for our subsequent analysis. This is followed by information on the medical context of interventional cardiology. Finally, we provide details on the DES controversy.

2.1. Healthcare in Sweden

Virtually all healthcare in Sweden is provided and financed by the public sector. The Swedish public sector comprises three tiers; the national, the regional, and the local level. The responsibility for delivery of healthcare takes place primarily at the regional level where there are 21 county councils. Each council is required by law to provide its residents with equal access to health services and medical care. The county councils are allowed to contract with private providers but most healthcare is managed by public organizations. This institutional setting implies that political representatives of the county councils and local bureaucrats, rather than competition among healthcare providers, determine the number, size, location, and coverage of hospitals within each region. Patient fees are nominal and subject to national caps, and 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. This means that individuals are generally well-insured against both the direct monetary cost of care and any time off work.

Patients do not choose their hospital or their physician in that hospital. Each hospital is responsible for all specialized care within their respective catchment area and the place of residence therefore determines the specific hospital a patient will be admitted to. Patients and physicians are quasi-randomly matched based on which physician(s) are on duty on the day of admission. Patients have no legal right to choose the treating physician within the inpatient care sector (Swedish Patient Act 2014:821). These institutional features limit sorting between patients and doctors (we also explore this empirically below). Hospital physicians are paid on a salaried basis and have no financial links with referring primary care physicians.

2.2. Interventional cardiology, angioplasty and PCI

Interventional cardiology is a branch of cardiology that deals with catheter-based treatment of heart disease. Interventionist techniques have become the gold standard for treating heart diseases such as acute myocardial infarction (AMI). The main procedure in interventional cardiology is percutaneous transluminal coronary angioplasty (PTCA). This 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 wall. This is known as 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, because they are objects foreign to the human body, they can result in an immune response that may re-occlude the blood vessel and necessitate a new intervention. This is known as restenosis. It is a common adverse clinical event associated with use of first-generation bare-metal stents (BMS) in PCI treatments. To reduce the risk of restenosis, a second-generation of stents consisting of more bio-compatible and anti-inflammatory materials, drug-eluting stents (DES), were developed. Procedurally, however, inserting a DES is equivalent to inserting a BMS.

Coronary stenting is also associated with stent thrombosis (ST), the formation of an arterial blood clot caused by the stent itself due to arterial damage from the stent implantation process or balloon inflation. This is a serious clinical outcome resulting in myocardial infarction (a heart attack, MI) or death in up to 80 percent of affected patients. This adverse outcome may occur some time after treatment (late and very late ST occur 30+ days and 1+ year after implantation, respectively). The drugs coated on the DES can inhibit the natural process in the body that prevents thrombus formation and thus DES are potentially associated with increased risk of ST. When considering clinical severity of the different outcomes, they are generally ranked in the medical literature as follows: death, MI, ST, and restenosis.

2.3. The 2006 DES controversy

The market share of DES rose very rapidly following its approval in Europe and the US in 2002 and 2003, respectively. This increase in popularity was driven by results from initial clinical trials that showed a substantial reduction in the rate of restenosis, with no effects on other clinical outcomes, such as death and myocardial infarction (see, e.g., Morice et al., 2002; Babapulle et al., 2004). In less than two years, DES became the leading stent used in PCI treatment. But the widespread optimism about DES came to an abrupt end in 2006 after the European Society of Cardiologists (ESC) annual congress, at which an (unpublished) meta-analysis showed an increased rate of death and ST-elevated myocardial infarction (STEMI, or Q-wave MI) in those treated with DES compared to BMS. This result initiated a "firestorm" about the potentially unsafe use of DES, reinforced by the media, the public and other stakeholders in the healthcare system. The reaction among the cardiologist community, public regulatory institutions, and the industry was immediate, calling for further systematic review and reevaluation of available data. Within one year, the use of DES in the United States fell by nearly 20 percentage points. In Sweden, the DES controversy of 2006 was even more salient due to the relatively small physician community and the publication of a further (Swedish) study demonstrating a significantly higher risk of mortality among patients receiving DES up to three years after receipt (Lagerqvist et al., 2007). In December 2006, the Swedish Medical Products Agency, the National Board for Health and Welfare and the National College of Cardiologists issued a joint statement to practitioners to be "restrictive" in their use of DES until further notice.

At the end of 2007 the American College of Cardiologists/American Heart Association/Task Force on Practice Guidelines (ACC/AHA/SCAI) jointly issued new angioplasty guidelines that indicated which patients were appropriate recipients of DES. This reversed the downward trend in DES use (King et al., 2008). In Sweden, results from an additional year of follow-up of patients, presented at the subsequent ESC conference in September 2007, showed that the association between mortality and DES was no longer present in the data (James et al., 2009). At the same time, the Swedish National Board of Health and Welfare issued new national guidelines for cardiac care in line with the ACC/AHA/SCAI recommendations (Socialstyrelsen, 2008). These state that cardiologists should limit "off-label" use of DES,[8] and not give DES to patients who are prone to bleed and/or unlikely to follow prescriptions of blood thinning drugs. As shown in Fig. 1 above, the publication of these guidelines led to renewed use of DES.[9]

3. Empirical approach

Our empirical approach exploits the exogenous shocks in DES safety information to identify cardiologists' speed of response in the initial positive news period (period one). The period starts when the use of DES was licensed in Europe in 2002 and ends in February 2006, denoted by the first vertical line in Fig. 1, just before the reports on the risks of DES were first publicized and discussed. The period of medical reversal runs from March 2006 until September 2007. The guideline period starts in October 2007, when the guidelines were first issued and runs through to the end of our study window in 2011.

3.1. Defining cardiologist responsiveness

We seek to characterize each cardiologist's responses to the new innovation relative to their peers. Although we are only interested in the speed of response in period one, we model cardiologists' use of DES in all three periods for two reasons. First, as shown in Fig. 1, the trends in the use of DES are characterized by three very distinct time windows, which should be modeled as such. Second, further analysis – discussed in Section 3.3 – also exploits the use of DES in the guideline period to define (a) patients' suitability for a DES, (b) decision error, and (c) the inappropriate use of DES. We are therefore also interested in cardiologists' responses in this period.[10]

[8] This includes the use of DES in (i) lesions over 30 mm and outside of 2.5–3.75 width; (ii) lesions in bypass graft, left main coronary artery and complex lesions covering three or more vessels; (iii) left ventricular ejection function below 30 percent; (iv) history of previous myocardial infarction; and (v) ostial, bifurcated or occluded lesions and in-stent restenosis (see also Marroquin et al., 2008).

[9] Appendix A provides more detail about the 2006 DES controversy and the trends in DES use. Appendix B shows that cardiologists changed their behavior in response to the guidelines and that this led to a reduction in the probability of patients experiencing adverse clinical events.

[10] Modeling all three periods or restricting the data to only period one does not affect our trend estimates for period one. Results available upon request.

For patient i treated by cardiologist $c \in C$ in hospital $h \in H$ in year-month t_p of period p ($p \in 1, 2, 3$) we estimate a two-level mixed-effects model[11] separately for each period, allowing us to capture physician-specific intercepts and trends in the use of DES. Specifically, for each information period we separately estimate:

$$DES_{icht_p} = \alpha_c^p + \beta_c^p \times m_{t_p} + \epsilon_{icht_p}^p, \tag{1}$$

where DES is a binary indicator that equals 1 if the patient received a DES and 0 if the patient received a BMS and $m_{t_p} = \{0, 1, \dots, M_{t_p}\}$ is defined as the total number of months from the start of period p, respectively. The physician heterogeneity is modeled as $\alpha_c^p = \alpha^p + a_c^p$ and $\beta_c^p = \beta^p + b_c^p$ where the random coefficients, a_c^p and b_c^p, are normally distributed with zero mean. The latter captures the cardiologist-specific responsiveness relative to the mean in each of the three periods.

One important advantage of the mixed-effects model in Eq. (1) is that it implicitly includes an Empirical Bayes Shrinkage (EBS) algorithm to estimate the parameters adjusting for statistical uncertainty in the estimated physician response. We also drop physicians who have done less than 25 stenting procedures at the start of the observation period in 2002 which deals with the fact that some cardiologists may have treated few cases.

Our specification implicitly assumes that cardiologists are the decision makers in terms of which stent to use, rather than, for example, hospital or regional boards. In the Swedish set up the purchasing manager at the coronary care unit, in consultation with the cardiologists, is responsible for stent purchases. During our period of observation, both BMS and DES have been simultaneously available to cardiologists, with no evidence of unavailability of either stent type driving cardiologists' treatment decision.

3.2. Cardiologist responsiveness and patient outcomes

We focus on responses to the initial good news period, period one. To define a slow responder to the initial positive news about the innovation, we create a dummy variable with value one if the cardiologist's use of DES in the first period is in the bottom quartile of the b_c^1 distribution from Eq. (1), and zero otherwise. Our analysis compares these slow responders to all other cardiologists.[12]

We start by examining the association between being a slow responder in period one and a set of patient outcomes. We define outcomes o_{icht}^j, where $j = 1, \dots, J$ is the jth outcome for patient i, treated by cardiologist c in hospital h in year-month t. For each outcome of interest, we pool data across all periods and estimate:

$$o_{icht}^j = \delta^j Slow_c + \zeta_c^j Z_c + \zeta_x^j X_{it} + \zeta_h^j H_h + \mu_{icht}^j, \tag{2}$$

where $Slow_c$ is a binary indicator for whether the cardiologist is a slow responder to the period one news, and Z_c, X_{it}, and H_h are vectors of cardiologist, patient and hospital characteristics, respectively. Our focus is the outcome-specific δ^j coefficients, which reflect differences in patient outcomes associated with being treated by a slow responder to news, relative to all others. We then repeat this analysis for each period separately.

3.3. Exploring potential mechanisms

Finding differences in patient outcomes between slow and other responders raises the question of what may be driving such variation. We examine four potential mechanisms.

First, differences in patient outcomes between those treated by slow responders and all others could arise because of non-random allocation of patients to cardiologists. Even in the Swedish setting, patients who differ in their suitability for a DES stent could be non-randomly allocated across cardiologists. We explore this in two ways.

First, we reestimate Eq. (1) including patient and cardiologist controls and hospital fixed effects. If the distribution of responsiveness is unchanged when additional regressors are included, this suggests that selection of patients by cardiologists is unlikely to affect our estimates of responsiveness to news. We find that the inclusion of these controls does not change the distribution of responsiveness in any of the three periods (results available upon request from authors.)

Second, we examine whether patients treated by slow responders differ in their suitability for a DES relative to patients of other cardiologists. To do this, we use data from the guideline period to estimate the probability of being given a DES stent as a function of observed patient characteristics. This uses the assumption that cardiologists' behavior in the guideline period reflects best practice after the issuance of detailed guidance. We provide empirical support for this assumption in Appendix B.[13]

We estimate the logistic regression model:

$$p(X_i) = \Pr(DES_i = 1 | X_i) = \frac{\exp(X_i'\beta)}{1 + \exp(X_i'\beta)}, \tag{3}$$

[11] A mixed model, mixed-effects model or mixed error-component model is a statistical model containing both fixed effects and random effects. See, e.g., Baltagi (2008) for an overview.

[12] Appendix C tests robustness to our use of quartiles of the distribution by examining non-linearities between patient outcomes and the different quartiles of the period one responsiveness distribution, conditional on hospital, patient, and cardiologist characteristics. To further test this, we model the relationship between patient outcomes and cardiologists' speed of response as linear (Section 5). Our results are robust to these tests.

[13] The patient characteristics we use are reported under the heading "risk factors" in Table D.1, including e.g. age, gender, median income of patients' postcode of residence, comorbidities, smoking status and diagnosis.

where X is the vector of patient characteristics and the data is from the guideline period only. We then use the parameters from Eq. (3) to define a suitability score for each patient in the two pre-guideline periods: $s_i \equiv \hat{p}(X_i) \in \{0, 1\}$. To test for differences between the slow responders and the other cardiologists we compare the marginal distributions of s_i for slow and other responders. A finding of a significant difference in the suitability distribution between the two groups would indicate selection of patients to cardiologists.

A second mechanism for finding that slow and other responders have systematically different patient outcomes is that cardiologists select different types of stents for similar patients, which in turn may affect outcomes. To understand the extent to which slow responders differentially take into account patient suitability for DES in their treatment decisions, we explore whether slow responders are more or less likely to choose the appropriate stent type, based on use of stents in the guideline period, for a given patient. We define the decision error for each patient as the difference between the stent used (coding a 0 for BMS and a 1 for DES) and the predicted suitability score for a DES (i.e., s_i as defined above where a higher score indicates higher suitability for DES).[14] To examine whether slow and other responders differ in decision errors, we compare their decision error distributions.

A third mechanism for finding that patients of slow responders have different outcomes is that slow responders may make systematically different choices in *when* to give a patient a stent. We refer to the inappropriate use of stents as "off-label" use, defined using the 2007 guidelines and following Marroquin et al. (2008) (see also Section 2.3). We compare the average number of off-label indications between slow and other responders and link off-label use to patient outcomes.

Finally, we compare the personal characteristics of slow responders relative to all other cardiologists to explore whether there are differences which might explain why the outcomes of their patients may differ from the outcomes of patients of other cardiologists.

4. Data

Our data are from the Swedish Coronary Angiography and Angioplasty Registry (SCAAR), a clinical quality register that covers all interventional coronary procedures performed in Sweden from 2002 onward.[15] SCAAR holds data on patients from all 29 centers that perform coronary interventions in Sweden. All patients undergoing coronary interventions are included in the registry together with detailed information on the specific procedures performed.

Our study population contains 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 ensure the sample is homogeneous. For the same reason, we also exclude all treatment episodes where multiple-type stents were used.

The data contain a large set of patient outcomes. We focus on four of the most common types of adverse cardiac events associated with a PCI, ranked in terms of clinical severity (see also discussion in Section 2 above). These are death, myocardial infarction (MI, heart attack), stent thrombosis (ST), and restenosis, all coded as events occurring within one year from the first observed treatment. The two first outcomes are frequently-used endpoints in the clinical literature (see e.g., Hicks et al., 2018), while the next two allow us to study stent-specific adverse events. Finally, we also create a binary variable that equals one if at least one of these adverse event occurred, and zero otherwise.

Table 1 presents summary statistics of the variables in our sample. The upper panel of the table shows that of the 29 hospitals that perform catheterization around one-fifth are teaching hospitals. The large hospital measure is defined as a hospital that has a PCI case volume above the 75th percentile of the volume distribution in 2002. The middle panel displays characteristics of the 121 unique cardiologists we observe in the data. About ten percent are female and 25 percent are experienced, defined as being above the 75th percentile of the distribution of cumulatively treated cases at the start of the analysis period. Finally, the bottom panel of the table displays the different patient-level outcomes that we include in the analysis. This shows that 13 percent of patients experience some adverse clinical event after the procedure.[16]

5. Results

5.1. Cardiologist responsiveness

Before we discuss the cardiologist-specific responsiveness parameters, we report the estimates of the aggregate responsiveness from Eq. (1) (i.e. α^p and β^p) in Table B.1 in Appendix B. The table presents the estimated monthly change in DES take-up in the initial positive news period (P1 slope), in the medical reversal period (P2 slope), and in the guideline period (P3 slope), along with the period-specific intercepts. Column (1) shows unconditional estimates and the subsequent columns add additional covariates to explore robustness of the estimates to the inclusion of a large set of patient, cardiologist and hospital characteristics (listed in Table D.1), as well as hospital and cardiologist fixed effects. The results show our estimates closely match the descriptive patterns shown

[14] In other words, "decision error" is defined as the deviation from best practice where the latter is based on patient observable characteristics. For simplicity, we normalize this difference to lie between zero and one as the original variable has a range between −1 and 1 by the following transformation: $z_i = \frac{s_i - s_{\min}}{s_{\max} - s_{\min}}$.

[15] The registry dates back to 1991 but does not include the full population of PCIs performed in Sweden until 2002; the data before this is more selective. The registry is independent of commercial funding.

[16] Table D.1 in Appendix D presents the means and standard deviations of additional patient level characteristics that we use to adjust for patient–physician sorting in further analysis.

Table 1
Sample summary statistics.

	Mean	Standard deviation
Hospital-level characteristics		
Large hospital	0.241	(0.435)
Teaching hospital	0.172	(0.384)
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 experienced	0.256	(0.438)
Cardiologist female	0.116	(0.321)
Cardiologist old	0.207	(0.407)
Cardiologist specialized	0.446	(0.499)
No. of cardiologists	121	
Patient-level characteristics		
Death	0.067	(0.250)
Any myocardial infarction	0.056	(0.231)
Any stent thrombosis	0.009	(0.095)
Any restenosis	0.046	(0.209)
Any adverse event	0.129	(0.335)
No. of patients	51,939	

Note.— Data from the Swedish Angiography and Angioplasty Register (SCAAR). Large hospitals and cardiologist experience are defined by the upper quartile of the respective distribution (hospital and cardiologist annual number of performed PCIs, respectively) in 2002. Cardiologist old refers to the share of cardiologists in the upper quartile of the age distribution in 2002. Cardiologist specialized refers to the share of cardiologists who have a sub-specialization in interventional cardiology. Any adverse event refers to the share of patients with at least one adverse outcome listed in the table. See Table D.1 in Appendix D for the full set of variables used in the analysis.

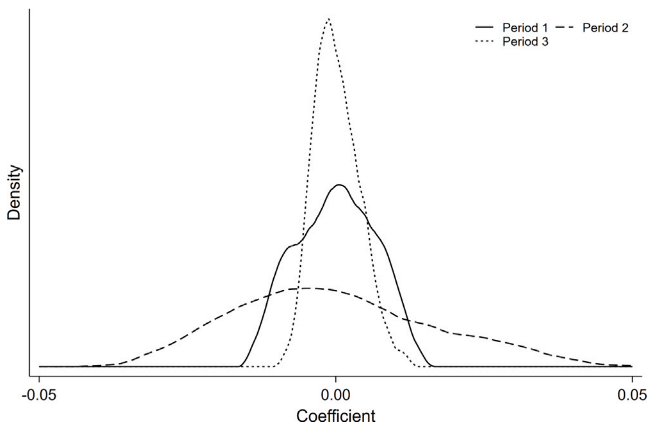

Fig. 2. Cardiologist responsiveness to news in the three periods.
Note.— Data from the Swedish Angiography and Angioplasty Register (SCAAR). Empirical distributions of cardiologist adjusted slope parameters based on period-specific estimation of Eq. (1).

in Fig. 1 and the trend estimates are very stable across the different specifications, showing that the average responsiveness to news is not driven by patient selection and holds within-hospital as well as within-cardiologist.

Our focus however, is not the *aggregate* but the *cardiologist-specific* estimates from Eq. (1). The variation in responsiveness across individual cardiologists by period is plotted in Fig. 2. This shows plausible responses to the news shocks, with the largest distribution observed in period two. The introduction of national guidelines in period three substantially reduced practice variation, indicating that the guidelines restricted individual discretion, as they were intended to. The greater heterogeneity of response in period two indicates that the negative news resulted in different responses to the news and mirrors findings from other medical reversals: there is a significant minority who do not respond, or respond only slowly, to the negative news. The heterogeneity in estimates in the period of initial positive news (period one) lies in between the medical reversal and the guidelines periods.

In the rest of our analysis we focus on responsiveness to the initial positive news. We use estimates of period one responsiveness to define cardiologists who are slow to respond to the initial positive news, designating the slow as those cardiologists in the bottom quartile of the period one distribution shown in Fig. 2.

Cardiologist responsiveness: robustness

We subject our cardiologist-specific estimates of responsiveness, b_c^1 from Eq. (1), to a series of tests which examine (a) alternative empirical specifications to define the cardiologist-specific period one trend, (b) changes in the composition of our sample and (c) changes in stenting behaviors.

To explore alternative definitions, we first re-run Eq. (1), but restrict the period one intercept to be zero (i.e., $\alpha_c^1 = 0,\ \forall\ c \in C$). This addresses the potential concern of underestimating responsiveness for cardiologists who immediately respond to news, increasing their intercept and, with that, reducing their slope. We denote this corresponding set of coefficients by $b_{c,nocons}^1$.

Second, we define responsiveness as the difference in the average predicted value from a *global* linear regression of Eq. (1) in the first and last three months of period one. In other words, we estimate cardiologist-specific slope coefficients for period one by regressing our DES indicator on an intercept and a continuous variable for the number of months passed since the beginning of the period (i.e., m_{t_1}) separately for each cardiologist. Denote the set of slope coefficients from this regression model by $\hat{\gamma}_{c,global}^1$. We then estimate the same model pooled across all cardiologists and subtract the population-level slope, $\hat{\gamma}_{global}^1$, from each cardiologist-specific slope coefficient (i.e., $b_{c,global}^1 = \hat{\gamma}_{c,global}^1 - \hat{\gamma}_{global}^1$). Finally, for each physician we take the difference of the population-subtracted predicted value between the average slope in the three last and three first months of the period, respectively. Mathematically, we estimate

$$\Delta(b_{c,global}^1) = \sum_{k=M_{t_1}-2}^{M_{t_1}} \frac{b_{c,global}^1(m_{t_1} = k)}{3} - \sum_{k=0}^{2} \frac{b_{c,global}^1(m_{t_1} = k)}{3}. \tag{4}$$

Third, we define responsiveness as the difference in the average predicted value from a *local* linear regression of Eq. (1) in the first and last three months of period one. As in the second definition described above, we estimate both pooled and physician-specific slopes predicted for each month, but instead of using a globally linear slope, we apply a mean-smoothing local linear regression estimator with a triangular kernel and rule-of-thumb bandwidth to obtain the corresponding, *non-linear*, population-subtracted slopes, denoted $b_{c,local}^1$. As above, the pooled estimate is then subtracted from each physician's monthly estimate and the overall difference is computed as the difference between the averages of the three last and first months of the period. Mathematically, we estimate

$$\Delta(b_{c,local}^1) = \sum_{k=M_{t_1}-2}^{M_{t_1}} \frac{b_{c,local}^1(m_{t_1} = k)}{3} - \sum_{k=0}^{2} \frac{b_{c,local}^1(m_{t_1} = k)}{3}. \tag{5}$$

Table D.2 presents the correlations across each of our measures of responsiveness (i.e., b_c^1, $b_{c,nocons}^1$, $\Delta(b_{c,global}^1)$, and $\Delta(b_{c,local}^1)$, respectively). They are highly correlated (coefficients ranging 0.91 to 0.97).

To explore compositional changes over time in our sample, Table D.3 in Appendix D presents estimates from Eq. (1) with additional interactions between the period trends and a number of hospital, cardiologist and patient characteristics. The results suggest a significant negative interaction effect for the teaching status of the hospital, as well as for older patients (defined as being above the 75th percentile of the age distribution), indicating that each of these characteristics is associated with a more conservative treatment method.[17] 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.

The number of patients with CAD could change during our observation period and this may affect our results. To examine this, we plot the use of stents changes within the "stent-eligible" population.[18] Figure D.2 illustrates the total monthly stenting volume between 2002 and 2011 (dashed line; right axis) and the share of patients with CAD who were given a stent (solid line; left axis). This shows that the total stenting volume increases throughout period one but stays relatively constant afterwards.[19] Thus our results are unlikely to be driven by changes in the stent-eligible population.

Our estimated responsiveness measure may give a misleading picture if the observed variation in DES were derived from a few cardiologists who deterministically switch back and forth between the old and new stents across periods. To explore this, we estimate the distribution of the cardiologist-specific use of DES for each month over the sample period. Figure D.3 presents these distributions as monthly box plots for each of the three periods. The figure indicates a general increase in the share of DES used over time in periods one and three and a general decrease in period two. This suggests that the changes in DES use over time reflect a general trend among all cardiologists rather than being driven by just a small group.

[17] As a graphical example, Figure D.1 in Appendix D illustrates the average trend in DES take-up across the three periods separately for relatively 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 D.3.

[18] The denominator here includes CAD patients who have an angiography.

[19] The share of stent use among CAD patients only shows a slight dip at the start of period one, after which it reverts back to just under 60 percent of patients and remains at this level until the end of our observation period.

A final issue is that the responsiveness distributions may be driven by cardiologists who stop using any type of stent in period two.[20] Figure D.4 presents the distributions of the total number of stents used each month 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 sample period, suggesting that the changes in use of DES was entirely due to switching between DES and BMS. It also shows that the median number of stents placed by cardiologists is relatively constant at around five stents per month throughout our observation period.

From these analyses we conclude that our responsiveness definition is robust to alternative definitions and does not appear to be driven by compositional change in the sample of patients nor in changes in whether stents were used for this population.

Cardiologist responsiveness: potential determinants

We now turn to an examination of whether cardiologist responsiveness is associated with either their, or their patients', characteristics. Figure D.5 in Appendix D shows the standardized estimates from a regression of the (continuous) cardiologist responsiveness definition on a large set of characteristics (the estimates include hospital fixed effects). This shows no systematic variation in responsiveness by cardiologist or their patients' characteristics. For example, we find no evidence that patient volume, cardiologists' experience or their patients' SES (captured by the median income of patients' postcode of residence) explain any variation in responsiveness. Similarly, cardiologists with predominantly female, older patients, or those with pre-existing conditions (e.g. hypertension, diabetes) are not systematically treated by faster or slower responders to the initial positive news. None of the predictors are significant at the 10 percent level either individually or jointly.

5.2. Patient outcomes

Fig. 3 presents regression estimates of patient outcomes on whether a cardiologist is a slow responder to the initial positive news about the innovation, as defined by their behavior in period one, controlling for cardiologist, hospital and patient characteristics, as in Eq. (2).[21] We examine five adverse clinical outcomes (in order of clinical severity): death, myocardial infarction (MI, heart attack), stent thrombosis, restenosis and any adverse event.

The bottom right figure presents the results for all periods and the other figures present results for each period separately. There are no significant differences across the two sets of cardiologists in terms of the worst outcome, death, though slow responders do have lower death rates in the medical reversal period (period 2). The bottom right figure shows that slow responders have significantly improved MI rates compared to other cardiologists, averaged over all three periods. This difference is present in each period, particularly in period 2, but also in period 3, which is after the issuance of guidance on the appropriate use of DES stents. Slow responders also have lower incidence of stent thrombosis in period 1, though not in period 2 or 3. Restenosis is higher for slow responders in period 1, which follows from the fact that use of DES stents (which are being used more by the rest of the cardiologists in our sample) result in lower rates of restenosis.

In sum, in terms of outcomes ranked by clinical severity, the slow responders to period 1 news have better outcomes. The differences between the two sets of cardiologists are largest in period two, but even in the guidelines period there is evidence of better outcomes of the slow responders.

Patient outcomes: robustness

As a robustness check, we examine the sensitivity of these results to the use of the *continuous* measure of responsiveness in Table D.5 and Figure D.6 in Appendix D. This shows that a 0.01 unit increase in responsiveness (i.e., an increase of the monthly take-up of DES by one additional percentage point relative to the national average) is associated with an increased probability of experiencing any adverse event, death, stent thrombosis, and MI, where the increase in mortality and stent thrombosis is mainly observed in period one and MI in period two.

Figure D.7–Figure D.9 present the coefficient estimates from robustness checks where we use our alternative measures of cardiologist responsiveness as defined in the robustness analysis to Section 5.1. Our results are robust to each of these modifications.

We also explore non-linear effects of cardiologist responsiveness. Appendix C examines how patient outcomes are correlated to the different quartiles of the period one responsiveness distribution, conditional on hospital, patient, and cardiologist characteristics. Consistent with our findings above, we show that the risk of any type of adverse event is substantially higher among cardiologists who responded relatively faster to the initial positive news.

5.3. Patient sorting, stent selection and off-label stent use

The previous section showed that slow responders to the initial positive news about the DES innovation have better patient outcomes than other cardiologists. In this subsection we explore three potential mechanisms for this finding: (i) differential patient selection, (ii) differential stent selection, and (iii) inappropriate use of stents. The first explanation is more of a sorting story (slow responders may take on less severe cases) but the latter two are more related to the performance of physicians.

[20] Although there are no obvious alternative treatments to PCI, it may be that some cardiologists chose instead to administer thrombolytic drug treatment, anti-clotting agents, or surgical treatment, such as CABG, if they lost faith in the efficacy of stents altogether. If this were the case, we would see a reduction in the overall use of stents in the treatment of patients with CAD, particularly in the bad news period.

[21] Table D.4 in Appendix D shows the estimates from this regression in table-format.

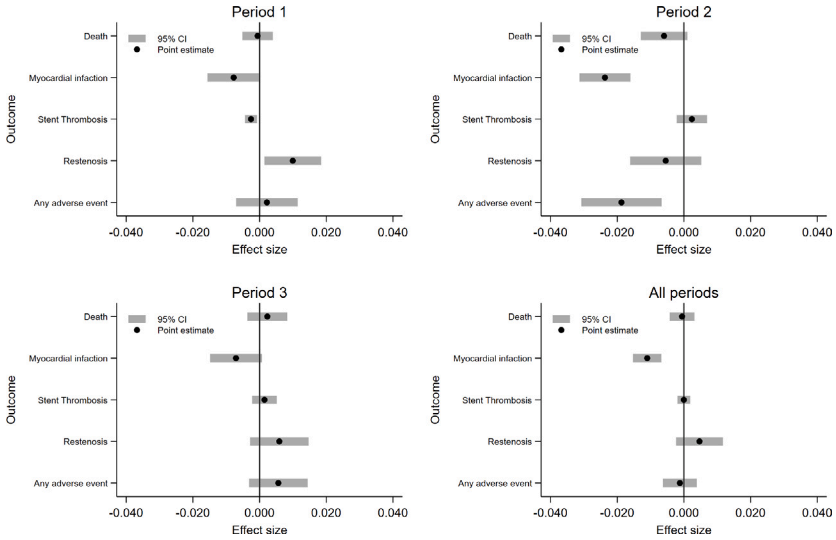

Fig. 3. Association between slow-responding cardiologists and patient outcomes.
NOTE.— Data from the Swedish Angiography and Angioplasty Register (SCAAR). Point estimates and 95% confidence intervals of δ from OLS estimation of Eq. (2) using a discrete binary indicator to define slow-responding cardiologists. Cardiologist responsiveness is defined by cardiologist-specific adjusted slope estimates from estimation of Eq. (1). A slow-responding cardiologist is defined as a cardiologist in the bottom quartile of the distribution of slopes in the first period.

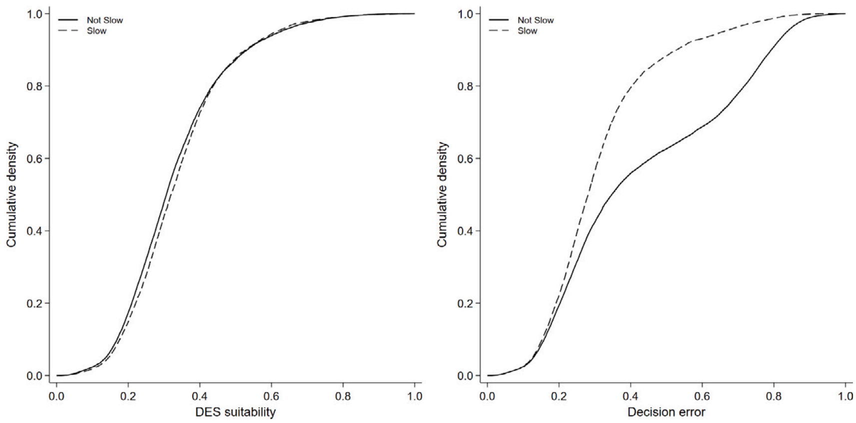

Fig. 4. Predicted patient DES suitability by cardiologist type.
NOTE.— Data from the Swedish Angiography and Angioplasty Register (SCAAR). Empirical cumulative densities of patient DES suitability in period one and two by cardiologist type. DES suitability is defined by predicted values from a bivariate logistic regression of a binary indicate for the use of DES a set of patient risk factors from Table D.1 in Appendix D in period three. DES decision error is defined as the absolute difference between the DES suitability score and the actual treatment received. A lower value of the decision error corresponds to a lower decision error. Cardiologist responsiveness is defined by cardiologist-specific adjusted slope estimates from estimation of Eq. (1). A slow-responding cardiologist is defined as a cardiologist in the bottom quartile of the distribution of slopes in the first period.

Patient selection

Figure D.5 showed that a large set of patient characteristics were largely unable to explain variation in the speed of response of cardiologists, suggesting that patient selection is not a reason for the difference in patient outcomes. We examine this further by investigating whether patient suitability for a DES, as defined in Eq. (3) above, differs between slow responders to the innovation and other cardiologists. The left panel of Fig. 4 shows the cumulative density of patients' predicted suitability (combined for periods one and two for brevity) separately for slow responders and other cardiologists. The figure suggests that there is no difference between the two groups across the entire distribution of patient suitability, again indicating the lack of patient selection. Furthermore, although formally statistically significant, mean suitability for DES is practically indistinguishable between slow (0.338, $s.e.$ = 0.002) and non-slow cardiologists (0.331, $s.e.$ = 0.001). Thus it does not appear that patient selection is the reason why slow responders have better outcomes.

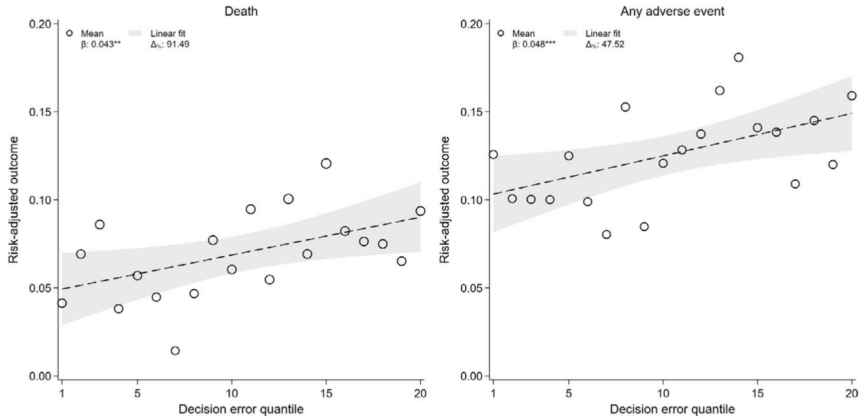

Fig. 5. Relationship between physician decision errors and patient outcomes.
Note.— Data from the Swedish Angiography and Angioplasty Register (SCAAR). Risk-adjusted outcome measures are residuals taken from a regression of the unadjusted outcome on the set of patient risk factors from Table D.1 in Appendix D. DES decision error is defined as the absolute difference between the DES suitability score and the actual treatment received. A lower value of the decision error corresponds to a lower decision error. DES suitability is defined by predicted values based on a bivariate logistic regression of the use of DES on a patient as a function of the same patient risk factors in period three.

Stent selection

Slow responders may be better at deciding when to use DES for their patients compared to other cardiologists, which in turn affects their outcomes. We explore this empirically in the right panel of Fig. 4. This shows the decision error on the horizontal axis (defined as above as the absolute difference between the stent used and the suitability for a DES standardized to lie between zero and one), and its cumulative density on the vertical axis. The mean decision error is lower for slow responders (0.313, $s.e. = 0.002$) than for the non-slow (0.431, $s.e. = 0.002$). In addition, Fig. 4 clearly shows that slow responders to the initial positive news are less likely to make decision errors across the whole distribution of decision errors. This suggests that stent selection is a potential driver of our results.

Given this, we examine the relationship between decision errors and patient outcomes. To control for patient frailty we first regress our outcomes on our rich set of observed patient characteristics at the patient-level, pooling periods one and two. We then examine whether the residuals from this regression are correlated with decision error. Fig. 5 shows this association. While there is considerable variation, higher levels of decision errors are associated with a higher likelihood of any adverse event as well as of patient death. The estimated slope coefficients across the range of the plots are 0.043 ($p = 0.087$) and 0.048 ($p = 0.073$), respectively. This suggests differential stent selection by slow and other responders is one potential driver of our results; slow responders making fewer decision errors.

Off-label stent use

The guidelines specifically state when stents should *not* be used. We refer to such use of stents as "off-label" use and interpret it as a measure of bad practice. Each patient can have up to five off-label indicators, though having more than three is rare.[22]

We start by comparing the average number of off-label indications over time between the slow and other responders. The left panel of Fig. 6 shows that although both groups have a relatively high rate of off-label use in the first year (i.e., at the introduction of DES, before the publication of any guidelines), the slow responders have substantially fewer off-label indicators throughout the rest of the period.

The right hand panel of Fig. 6 shows the risk-adjusted outcome (i.e., death or any other adverse event) as a function of the number of off-label indications. This figure highlights three important results. First, the risk of an adverse event substantially increases with the number of off-label indications. Second, this relationship is less pronounced among slow responders (indicated by "S"), who experience fewer such adverse events compared to other cardiologists (denoted "NS"). Third, the difference in (risk-adjusted) deaths between slow and other responders increases with the number of off-label indications, though the pattern is much less clear for other adverse events.

In summary, our findings show that slow responders have better patient outcomes. We find no evidence that these effects are driven by differential sorting of patients to cardiologists. Instead, our analysis suggests that at least some of this relationship is driven by (a) differential stent selection and (b) differential off-label stent use between slow responders and other cardiologists. Specifically, slow responders are less likely to make decision errors when selecting stents for their patients and they are less likely to use stents when they should not be used according to the guidelines.

[22] The five off-label indicators we use are based on Marroquin et al. (2008) and defined in Footnote 2.3 above. Table D.1 shows that a minority of patients have off-label indications, with 34 percent having one, 13 percent having two, 4.5 percent having three or more.

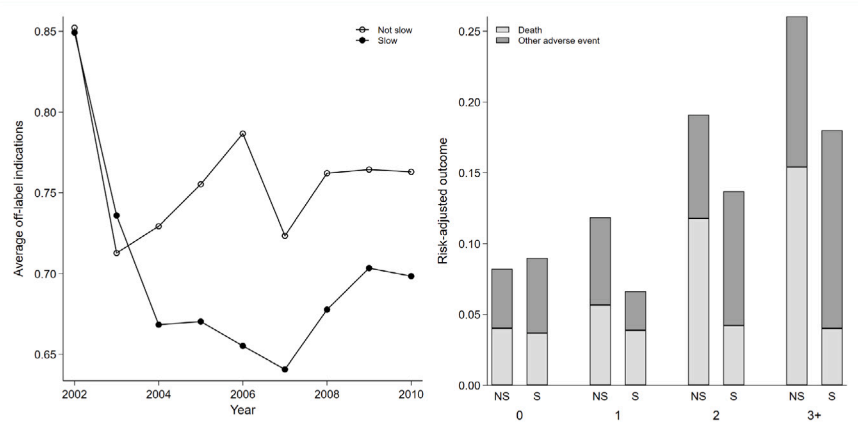

Fig. 6. Relationship between off-label use and patient outcomes.
Note.— Data from the Swedish Angiography and Angioplasty Register (SCAAR). The left panel shows the average number of off-label indications (defined as in Marroquin et al. (2008)) over time for slow-responding and other cardiologists. The right panel presents the risk-adjusted outcome (death, any adverse event) as by the number of off-label indications for slow responding and other cardiologists.

We now examine the importance of these two behaviors in explaining the better outcomes of patients of slow responders. We reestimate Eq. (2), additionally controlling for either a binary indicator for the patient having received a DES or a count of the number of off-label indications.[23] The estimates are presented in Fig. 7, with the circle denoting the estimate without additional controls (also shown in Fig. 2), the diamond showing the estimate that controls for whether the patient was given a DES and the triangle denoting the estimate where we control for the number of off-label indications.[24,25]

This analysis shows first, that controlling for DES reduces the estimate for restenosis in all periods other than period two. This follows from the fact that the non-slow cardiologists are more frequent uses of DES (by definition) and that DES reduces restenosis (see Section 2.2). Second, in all periods other than the guideline period when inappropriate use was defined explicitly, controlling for off-label use reduces the estimated difference between slow and non-slow responders (i.e. the estimated parameter is closer to zero). This suggests that lower rates of off-label use among slow responders partially explain their patients' improved outcomes. Third, controlling for DES or off-label indications does not have large impacts on the estimates for myocardial infarction in any period. All in all, this suggests that while differences in both DES and off-label use explain some of the gap in patient outcomes, these behaviors do not explain all of the gap between slow and other responders. Patients of slow responders still have better outcomes than those of other cardiologists even after accounting for DES and off-label indications. Thus we are not able to fully explain the mechanisms behind the better outcomes of patients treated by slow responders.

Characterizing slow responders to good news

Finally, we can compare the personal characteristics of cardiologists that we observe in our data. Table 2, column (1) shows the average characteristics of slow responders to the initial positive news, column (2) presents the averages for the other cardiologists and column (3) shows whether the differences are significantly different from zero. Slow responders have slightly lower pre-DES (i.e., pre-2002) patient mortality rates, though the sample sizes are such that the difference between the two groups are not statistically significant.[26] The main difference between the groups, however, is that the slow responders are more likely to be in teaching hospitals.

These locational differences may also indicate that hospital level factors play a large part in determining behavior. Analysis of the variation in responsiveness between and within hospitals shows that 77 percent of the variation is between-hospitals and 23 percent is within-hospitals, though the within-component is slightly smaller in teaching hospitals (25 percent) than in non-teaching hospitals (31 percent). However, our analyses of both responsiveness and patient outcomes control for differences across hospitals, and cardiologists have always had free choice to use either BMS or DES, with both options being available throughout this period. So while this does not rule out that hospital-level policies or peer effects play a role in shaping the cardiologists practice styles (see e.g., Molitor, 2018), it does suggest that differential availability of stent type across hospitals is unlikely to drive our finding that the slow responders to positive news have better outcomes.

23 This is not a causal analysis but allows us to explore these potential mediators.

24 Since the off-label indications are not a one-to-one function of patient characteristics (see Footnote 2.3), we can include both in the regressions.

25 Additionally, we include a specification where we control for the application of Dual Anti-Platelet Therapy (DAPT) in association with the intervention (see discussion in Appendix B). Estimates including a dummy for DAPT are indicated by squares in Fig. 7.

26 The pre-DES data is more selective; of the 121 cardiologists whom we observe in our main analysis sample, we only observe ∼50 before the introduction of DES.

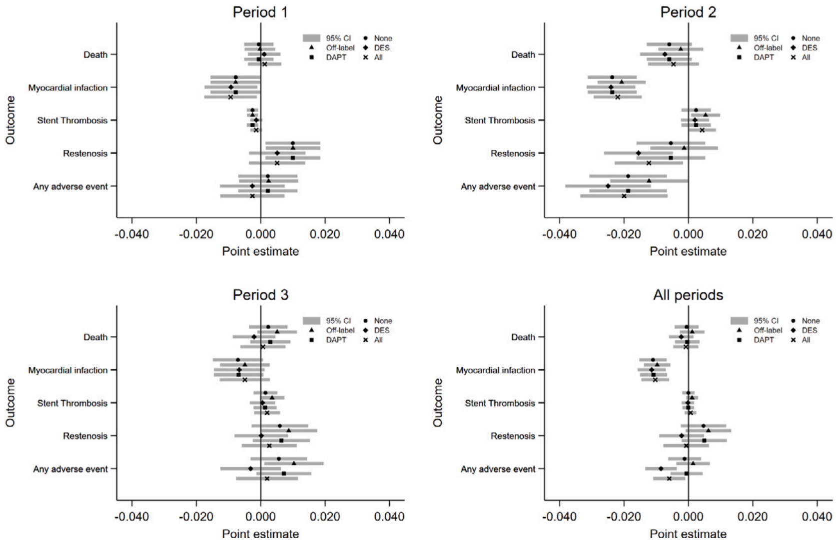

Fig. 7. Explaining physician type differences in patient outcomes: Off-label use, stent type, and DAPT.
Note.— Data from the Swedish Angiography and Angioplasty Register (SCAAR). The estimates shown in the figure represent those from an OLS regression of the relevant outcome on the dummy for being a slow responder to the initial positive news (circle), controlling for the number of off-label indications (defined as in Marroquin et al. (2008); triangle), controlling for the choice of stent (i.e., DES vs. BMS; diamond), and the application of Dual Anti-Platelet Therapy (DAPT; square). Crosses indicate point estimates when jointly controlling for all three factors.

Table 2
Predictors of cardiologist type.

	(1) Slow	(2) Not slow	(3) Difference
Pre-DES mortality rate	0.022	0.032	−0.010
Experienced	0.241	0.261	−0.019
Female	0.138	0.109	0.029
Age	48.250	48.604	−0.354
Specialized	0.483	0.435	0.048
Patient volume	326.552	315.717	10.834
Large hospital	0.448	0.304	0.144
Teaching hospital	0.586	0.109	0.478***
No. of observations	29	92	121

Note.— Data from the Swedish Angiography and Angioplasty Register (SCAAR). Mean values for selected cardiologist characteristics by cardiologist type and their differences. Cardiologist responsiveness is defined by cardiologist-specific adjusted slope estimates from estimation of Eq. (1) by cardiologist and period. A slow-responding cardiologist is defined as a cardiologist in the bottom quartile of the distribution of slopes in the first period. Pre-DES mortality rate is the average one-year mortality share for cardiologists prior to the entry of DES in Sweden. Specialized is a binary variable indicating whether the cardiologist has a sub-specialization in interventional cardiology. Significance levels are based of a differences in means t-test assuming unequal variances. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

6. Conclusions

This paper examines physician responses to new medical information and the association of responses with patient outcomes. Our setting covers all interventional cardiologists in Sweden between 2002 and 2011 when news about the safety of drug-eluting stents (DES) caused global information shocks. This allows us to examine cardiologists responses to the initial positive news about the innovation. We find substantial variation in the speed of cardiologists' responses to positive news and we find that the speed of response is related to patient outcomes. Patients of cardiologists that responded relatively slowly to positive news had a significantly lower risk of post-treatment adverse cardiac events compared to those treated by all other cardiologists. We find no evidence that the better patient outcomes of slow responding cardiologists were the result of patient–physician sorting. Instead, we find that differences in patient outcomes were associated with slower responding cardiologists being better at matching treatments to patients: slow responders were less likely to make decision errors in the choice of appropriate stent for their patients and this was somewhat associated with fewer adverse events. In addition, slow responders were less likely to use stents inappropriately, and inappropriate use was associated with increased adverse cardiac events. This may indicate that they are better doctors, which is given support by several other pieces of evidence our analysis provides, including that we see indications of fewer heart attacks for slow respondents not just in period 1 and period 2, but also in period 3 in which there are smaller differences across cardiologists in stent choices. This suggests that non-stent related reasons may partly explain why slow respondents perform better.

We also examine whether there are any observed differences between cardiologists who responded differently to the DES innovation. In contrast to Staats et al. (2017), who examine the fall in take-up only during the medical reversal period among US cardiologists, we do not find differences in experience prior to the use of DES stents to be associated with speed of response to the initial period of innovation. Instead, we find that cardiologists who responded less rapidly than their peers to the innovation were significantly more likely to work in teaching hospitals. This perhaps indicates that they were better at weighing up information shocks because they were in an academic environment where this is facilitated, whereas others ignore the information because it is more difficult (and therefore costly) to process outside an academic environment. This would fit with ideas of rational inattention by individuals exposed to frequent information shocks that are difficult to evaluate. Or it could be that those in teaching hospitals have private information which is internal to them and their networks (e.g., knowledge about on-going clinical studies) that they can use alongside the publicly available news to make decisions. We are unable with our data to distinguish between the two explanations. We also cannot separate out speed of response from attitudes towards innovation more generally. However, our results suggest that caution in response to new information may be warranted in medical settings where the initial good news can often be followed by more nuanced news.

Finally, a recent review of the economics literature on physician behavior and patient outcomes noted that physician responses to financial incentives that were designed to overcome market failures have been far more studied than responses to non-financial incentives, despite it being clear that some physicians continue to make choices that are bad for themselves, their patients and others, even when financial incentive are absent (Godager and Scott, 2023). Our study contributes to the evidence base on the effect of information in a context where financial incentives are absent. Our results show that patients who are treated by physicians who are more cautious in responding to the new information have a 13 percent lower probability of a myocardial infarction than those of less cautious physicians.

It is, however, not obvious how to benchmark the magnitude of this effect. There are many different sources of information and information may have different effects in different contexts (e.g., information in the context of an innovation compared to information in the context of continued use of an established procedure). Furthermore, within the literature that explores the impact of information on providers, most studies have examined effects on provider behavior rather than on patient outcomes (Godager and Scott, 2023).

One important source of information for physicians is their peers. In the context of adoption of innovation, the impact of peers on physician behaviors has been studied in cancer drug prescribing. Relatively large (at least initial) effects have been found. For example, Agha and Molitor (2018) found that individuals connected to "star physicians" (defined as those with a large number of academic citations and based on their clinical trial role) increased their prescribing by 36 percent initially. Keating et al. (2020) found the odds ratio of use of the innovation among physicians whose peers were in the highest tercile of early use was 1.64 times higher than those with peers in the lowest tercile of early use.[27] In contrast, in a context in which a new technique has to be learned for the innovation to be adopted (and thus where responses would be expected to be much smaller), a recent study of a surgical innovation (again in the cancer context) in the English NHS found that having a peer who adopted the innovation raised the probability of own use by 3.3 percent relative to the mean (Barrenho et al., 2020).

Another source of information comes from the publication of information on individual provider behavior. In this context responses to information have been linked to patient outcomes. Dranove et al. (2003) concluded that cardiac surgery report cards in New York and Pennsylvania led both to selection behavior by providers and to improved matching of patients with hospitals. The net effects were higher levels of resource use and worse health outcomes, particularly for sicker patients. On the other hand, using data from the same programme, Kolstad (2013) concluded that report cards had an important role in quality improvement for CABG surgery in Pennsylvania. The bulk of that impact, though, was driven by information observed by surgeons and not by incentives generated by consumer responses to reporting. Surgeons' response to profit incentives led to a 3.5 percent decline in mortality, while the intrinsic response to quality reporting alone led 13 percent decline. In our context, there are no financial incentives for Swedish physicians and there is no direct demand channel. Thus the only channel through which incentives can operate is the intrinsic channel. Our findings suggest the differential response to public and positive news about an innovation to be broadly comparable to the response found for the intrinsic responses to public news (quality reporting) about individual performance.

CRediT authorship contribution statement

Daniel Avdic: Data curation, Formal analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Stephanie von Hinke:** Formal analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Bo Lagerqvist:** Resources, Validation, Writing – review & editing. **Carol Propper:** Formal analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Johan Vikström:** Methodology, Resources, Writing – review & editing.

[27] Interestingly these responses to peer behavior are much larger than the responses to financial incentives in the form of direct payments to physicians for all drugs. A recent study (Carey et al., 2021) examined the effect on physician behavior of payments by pharmaceutical firms to US physicians. They found that physicians who received payments increased the number of patients taking the marketed drug in the first six months by 2.2 percent relative to the mean.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.jhealeco.2023.102846.

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