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The Diffusion of New Medical Technology
The Case of Drug-Eluting Stents

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and Jonathan Skinner

11.1 Introduction

There are large and persistent productivity differences across health care providers and regions—variations in both inputs (utilization) and risk-adjusted outcomes (see Chandra et al. 2013; Baicker, Chandra, and Skinner 2012; Skinner 2012). These studies were largely limited to cross-sectional analysis, and generally tell us little about the dynamic process by which these variations arise. A few studies have examined the role of diffusion for highly effective treatments such as aspirin and beta-blockers for heart attack patients in explaining such productivity differences (e.g., Skinner and Staiger 2009), but these have been limited to a narrow set of technologies with little impact on expenditures. Outside of health economics, however, the idea that the diffusion process of new technologies can explain productivity differences at a point in time is well accepted; for example, in studies of steam engine adoption across countries (Comin and Hobijn 2004). Parente and Prescott (1994) have pointed to modest differences in rates of adoption

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and diffusion across countries as a key factor in why income and growth differ so much across countries. In developing economics, the process and ease of technology diffusion has long been recognized as central to successful income growth (World Bank 2008).

In this chapter, we consider a medical innovation: drug-eluting stents, a commonly used approach to treating the narrowing of coronary arteries, but one with a larger impact on health care cost growth. Until 2003, only bare-metal stents were available to cardiologists seeking to perform revascularization for blockages in the heart. These cylindrical wire meshes were designed to keep arteries from narrowing, and thereby ensure patency (i.e., keeping the blood flowing). Yet bare-metal stents were also subject to restenosis, or a renarrowing of the artery, leading to restricted blood flow. In April of 2003, the Food and Drug Administration (FDA) approved the use of coated antiproliferative drug-eluting stents, designed to further reduce restenosis. In the same month, Medicare allowed for a higher reimbursement for drug-eluting stents, largely to cover their higher cost. Adoption was rapid; by December 2003 more than 65 percent of all stent placements in the Medicare population were drug eluting rather than bare-metal stents. Yet different hospitals exhibited very different diffusion rates; in the bottom quintile of diffusion, drug-eluting stents comprised just 33 percent of total stents for the year following FDA approval, while in the top quintile the equivalent was 83 percent.

We ask why did some hospitals adopt drug-eluting stents earlier than others? In the literature, there are a variety of suggested factors that can lead to more rapid adoption. The classic Griliches (1957) study of hybrid corn hypothesized that profitability was the major incentive to adopting. We define profitability broadly to include both any pure benefit of billing for drug-eluting stents in excess of their costs, as well as placing the specific hospital at an advantage with regard to competition in its market with other hospitals. In other words, drug-eluting stents may not by themselves be profitable, but they could confer a competitive advantage to hospitals seeking to charge insurance companies and employers higher prices for high-quality care.

An alternative explanation relies on physician expertise at the hospital. Higher quality hospitals are the first to adopt drug-eluting stents because they have better knowledge about the benefits or lower costs of adopting them; for example, if they had already been involved with the ongoing randomized trials prior to FDA approval. This explanation is more in line with rural sociologists who, in a debate with Griliches, stressed differences across individuals in their willingness to adopt and/or diffuse the new technology, with those having adopted in the past more likely to adopt the newest technologies (Babcock 1962; Brandner and Strauss 1959).[1]

1. Rates of diffusion at the hospital level may include both the adoption of drug-eluting stents by individual physicians, and the diffusion of drug-eluting stents to a wider range of patients by physicians already using the drug-eluting stent.

A third hypothesis, which is complementary to those mentioned previously, stresses knowledge spillovers; diffusion depends on area norms, but correlated behaviors across providers may reflect mimicry (copycat behavior) or true knowledge spillovers. We distinguish between these two hypotheses by testing whether these spillover effects have real incremental effects on patient outcomes; if they do, then the diffusion is productive and reflects learning. If there is no productive effect from diffusion, the evidence is more consistent with mimicry of the new technology, and models of competition in the form of a "medical arms race."

Our final hypothesis is that diffusion occurs by allocating drug-eluting stents to those hospitals most expert in ensuring that they would be used for patients with the greatest *incremental* benefit. The benefit of a drug-eluting stent is directly related to the risk of target lesion restenosis, which in turn is related to patient characteristics and lesion characteristics. If stent manufacturers were rationing their initial supply and acted as "social planners," we would expect to see the greatest incremental health benefit from the early adopters. While such a model seems hypothetical at best, it still provides a reasonable gold standard to judge the real health effects of the uneven diffusion of drug-eluting stents.

11.2 Drug-Eluting Stents: Clinical and Data Issues

Since the 1980s percutaneous coronary interventions (PCIs) have become the preferred strategy for treating patients with blockage(s) of one or more coronary arteries because of atherosclerotic plaque in patients who fail medical management. The original technology used a balloon-tipped catheter to fracture the plaque and stretch the blood vessel. The Achilles' heel of this approach was that as much as half the time the blockage would recur within six to twelve months. This problem stimulated the development of coronary stents: slotted tubes that could be placed across an area of blockage to buttress open the vessel and prevent restenosis. These devices reduced the risk of restenosis but did not eliminate it as the inflammatory and proliferative mechanisms of the vessels response to injury could lead to the ingrowth of smooth muscle through the cells of the stent and restenosis.

In response, the device industry developed drug-eluting stents (DES) which, in contrast to the existing bare-metal stents (BMS), were coated with a drug(s) designed to prevent the overexuberant healing response associated with restenosis. The drug-eluting stent worked, reducing the rate of restenosis from 10–20 percent with bare-metal stents to fewer than 5 percent with a drug-eluting stent. While several studies showed quite different results, the consensus view has converged to one in which the drug-eluting stent confers no advantage in terms of survival or rates of myocardial infarction, but a pronounced decline in the rate of restenosis (and subsequent revascularization).

Based on a premarket experience with 673 patients, the FDA approved the first drug-eluting stent in the United States, the Cordis/Johnson and Johnson CYPHER sirolimus-coated stent, for general use on April 23, 2003. In March of 2004, eleven months later, a second DES stent, the Boston Scientific TAXUS paclitaxel-coated stent, was approved by the FDA.

During the first five months of general distribution of the CYPHER, more than 260,000 stents were shipped. However, during this time the FDA, via Johnson and Johnson, began receiving reports of subacute thrombosis (blood clots forming in the stents causing heart attacks) following placement of the stents. By October 2003 the FDA recognized a significant increase in the number of reported cases of subacute thrombosis compared with what it had been receiving before the DES was introduced. On October 29, 2003, the agency posted a public health notification to physicians describing the receipt, through the voluntary medical device reporting system, of more than 290 reports of subacute thrombosis and sixty deaths associated with use of the CYPHER stent.[2] The notification became a major news item and prompted a flurry of calls from apprehensive patients to physicians asking what they should do. The physician community was left trying to put the FDA's concern in context, and patients were left to deal with their anxiety about having a coronary event. It was unclear at the time whether this flurry of reported cases represented a true increase in the rate of subacute thrombosis over that seen with BMS or a lower threshold for reporting this complication, driven by the high profile of the new device. Over the next several years it was determined that there is a small increased risk of this adverse event but one that can be mitigated by the use of dual antiplatelet agents. Since 2006, there has been a general decline in the use of drug-eluting stents relative to bare-metal stents.

11.2.1 Data

We used a 100 percent national sample of all Medicare Part A hospital claims during 2002–2005 for enrollees age sixty-five and older enrolled in traditional, fee-for-service Medicare programs.[3] The claims data includes unique identifiers for the hospital and patient, the dates of admission and discharge, an admitting diagnosis, procedures performed, and additional diagnoses representing comorbid conditions. The patient's zip code is also reported, which allows us to link him or her to a hospital referral region (HRR), of which there are 306 in the Dartmouth Atlas database. These regions were created to reflect where Medicare enrollees seek tertiary care, such as stents or bypass surgery.

Patients undergoing a percutaneous coronary intervention (PCI) with

2. http://www.fda.gov/MedicalDevices/Safety/AlertsandNotices/PublicHealthNotifications/ucm064527.htm.

3. This section draws heavily from Malenka et al. 2008.

stent placement were identified by the presence of a hospital claim for a bare-metal stent (BMS, ICD-9-CM code 36.06) and/or a drug-eluting stent (DES, ICD-9-CM code 36.07). Patients coded as having placement of both types of stents during their first PCI hospitalization were classified as DES patients.

In this analysis, we used exclusion criteria based on the Stent Anticoagulation Restenosis Trial Study (STARS) (Cutlip et al. 1999). Thus, we excluded patients (a) with an emergency admission, (b) with a diagnosis code for myocardial infarction (MI, ICD-9-CM codes 410–410.6, 410.8–410.9, 5th digit 0 or 1), (c) admitted within seven days of discharge from a prior hospitalization, (d) within one year of coronary artery bypass surgery (CABG, ICD-9-CM 36.1–36.19) or a prior PCI (ICD-9-CM 36.0–36.09), and (e) exhibiting evidence of bypass graft disease on their index claim (ICD-9-CM codes 414.02–414.05, 996.72; to eliminate patients who might have had an intervention on a bypass graft rather than on a native coronary artery). In subsequent work, we hope to also consider patients receiving a stent (either bare-metal or drug-eluting) but who would not have been admitted to the STARS trial.

11.2.2 Comorbid Conditions

The claims data includes up to ten medical diagnoses. Using information from the index admission, we identified the following comorbid conditions as defined by Romano, Roos, and Jollis (1993): history of MI, congestive heart failure, peripheral vascular disease, pulmonary disease, diabetes without complications, diabetes with complications, mild liver disease, moderate or severe liver disease, dementia, renal disease, nonmetastatic cancer, and metastatic solid tumor.

11.2.3 Outcomes

We report two sets of regressions. The first is simply whether the hospital in question experienced a rapid or slow diffusion rate. To do this, we dropped April 2003 (when the drug-eluting stent was first allowed), and considered the ratio of drug-eluting to total stents during the subsequent year: May 2003–April 2004, by hospital.

We also considered health outcome measures to judge the impact of diffusion on actual health outcomes. We used three measures. The first is a serious adverse event: during the year following the stent placement, either death or an ST-elevated myocardial infarction (STEMI) that plausibly arises from restenosis.[4] The second measure is death alone, again during a one-year horizon. The final measure is the rate of repeat coronary revascularization, defined as any PCI, whether it comprises a stent (ICD-9-CM codes 36.0–

4. Death was from the denominator file; ST-elevation MI was based on the presence of specific codes on a Part A claim (ICD-9-CM codes 410–410.6, 410.8–410.9, 5th digit 0 or 1).

36.09), or alternatively, a crossover to bypass surgery (CABG ICD-9-CM codes 36.1–36.19).[5]

11.3 Model

In this section we formalize four hypotheses for the diffusion of drug-eluting stents and present candidate variables to test each hypothesis. The first is the classic Griliches (1957) hypothesis that hospitals with the greatest potential financial gains from the new innovation will be the one to adopt it. This may include either hospitals that yield a greater return from using drug-eluting stents either because the markup exceeds the actual cost the hospital pays the stent manufacturer, or because using drug-eluting stents confers a competitive advantage for a hospital in a more crowded market.

To fully test this hypothesis, we would ideally want to know not just Medicare reimbursement rates that may differ across hospitals, but also rates that private insurance pays for the under-sixty-five population. In the absence of such detailed information, we consider instead different types of hospitals, with different levels of financial alignment for adoption decisions. For example, for-profit hospitals should be more likely to adopt new and more profitable technology quickly relative to not-for-profit hospitals, and not-for-profit hospitals would have stronger financial incentives to adopt than government hospitals. And it could well be that the profit-maximizing decision is to not adopt (leading to a negative coefficient for the for-profit dummy variable), since drug-eluting stents were known to reduce the need for revascularization, and thus could cut into volume and hence profits in a dynamic setting.

We can also test for the effect of competition in local markets. We define two variables, one for whether there is another hospital also performing PCI with stenting in the hospital service area (HSA), and if so, how many other hospitals are in the HSA.[6] A positive coefficient for either variable in explaining rates of diffusion would be consistent with a model in which competition leads to more rapid adoption of the newest technology, in this case drug-eluting stents.

Our second hypothesis suggests that the diffusion of stents is driven by expertise of physicians at the hospitals that adopt first. Better places adopt stents first, because they know about the benefit or have a lower cost of adopting them. We test this by considering to what extent rapid diffusion of drug-eluting stents is explained by teaching status of the hospital, the

5. To avoid including patients who experienced an adverse outcome secondary to subacute thrombosis, only patients who survived for at least one day following their procedure were included in the analysis. We also excluded patients with a STEMI coded on their index admission, since we could not determine whether the STEMI was a procedural outcome or the indication for the procedure.

6. There are more than 3,000 hospital service areas, as defined by the Dartmouth Atlas; these were drawn to reflect migration patterns of Medicare patients in 1992–1993. Alternative market measures are also those such as circles with specified radii around each hospital.

log total number of hospital beds, and the log of the volume of bare-metal stents performed during April 2002–March 2003, prior to the introduction of drug-eluting stents. An additional measure is the hospital level of risk-adjusted adverse events during the year prior to the introduction of drug-eluting stents (April 2002–March 2003), where the risk adjusters include age, sex, race, and comorbidities (described in more detail later.)

Both mimicry and knowledge spillovers can explain our third hypothesis: that the probability of adoption in hospital *i* is an increasing function of adoption in other hospitals in the hospital referral region (HRR).[7] But knowledge spillovers also predict that outcomes at hospital *i* are an increasing function of adoption in other hospitals in HRR. Thus we consider whether spillovers can explain the adoption of drug-eluting stents; this is a hypothesis consistent with either mimicry or knowledge spillovers. We further test whether spillovers can explain differences in health outcomes—if it does, then the knowledge spillover hypothesis is supported; if not, the mimicry hypothesis gains support.

To explore the fourth hypothesis, the extent to which the distribution of drug-eluting stents is consistent with a first-best allocation as determined by the social planner, we focus on whether the early adopters experienced greater or less incremental gains whether with respect to adverse outcomes (where, on average, there were no benefits), or with regard to a reduction in rates of PCI following the initial placement of the stent(s).

We first estimate hospital-level regressions, where the dependent variable is the hospital-level diffusion rate (drug-eluting stents relative to total stents in the year following FDA approval), and key covariates were noted earlier. To further test the implications of our model for health *outcomes*, we consider patient-level tests of our three outcome measures: an adverse outcome, death, or a subsequent PCI. In this regression analysis, we use a full set of risk-adjustment measures: a secular trend variable, by month; age-sex (five-year categories, by sex); and comorbidities such as past myocardial infarction, vascular disease, pulmonary disease, dementia, diabetes, liver disease, renal disease, and any cancer.

11.4 Results

Table 11.1 presents summary statistics for both the entire sample, and broken out by quintile of diffusion. First, while the average use of drug-eluting stents was 62 percent, there were dramatic differences in the ratio of drug-eluting stents between the highest quintile regions (83 percent) and the lowest quintile regions (33 percent). A graph of the diffusion rates is shown in figure 11.1; as can be seen, most of the gap in diffusion is apparent in the

7. There are 306 hospital referral regions (HRRs) in the Dartmouth Atlas; these in turn are built up from the hospital service areas.

Table 11.1 Summary statistics by quintile of diffusion for drug-eluting stents

	Total	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5
Fraction drug-eluting stents	0.620	0.327	0.543	0.658	0.743	0.830
Age	74.71	74.78	74.70	74.63	74.44	74.68
Female	0.411	0.432	0.418	0.409	0.406	0.390
African American	0.043	0.046	0.043	0.043	0.048	0.036
Death or STEMI (1 yr)	0.057	0.064	0.058	0.057	0.054	0.050
PCI (1 yr)	0.140	0.138	0.135	0.138	0.145	0.144
For-profit hospital	0.138	0.189	0.196	0.088	0.132	0.082
Government hospital	0.070	0.100	0.044	0.109	0.059	0.036
Teaching hospital	0.247	0.091	0.178	0.218	0.338	0.417
Adult hospital beds	243	176	222	239	284	298

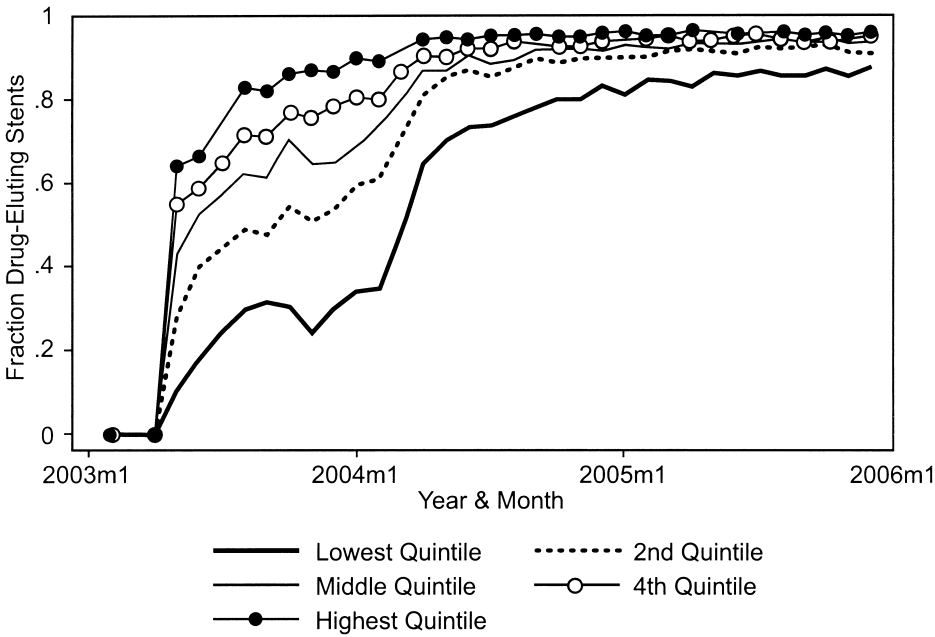

Fig. 11.1 Diffusion pattern of drug-eluting stents, by quintile of hospital, 2003–2004

first year, but by mid-2005 rates of use for drug-eluting stents were well over 80 percent across all quintiles.

The regional variability in the diffusion of drug-eluting stents can also be seen in figure 11.2, which shows the fraction of drug-eluting stents relative to total stents by HRR across the United States. While a few of the regions experienced fewer than 100 observations (and thus might exhibit statistical noise), there is still a remarkable degree of variation in adoption rates that

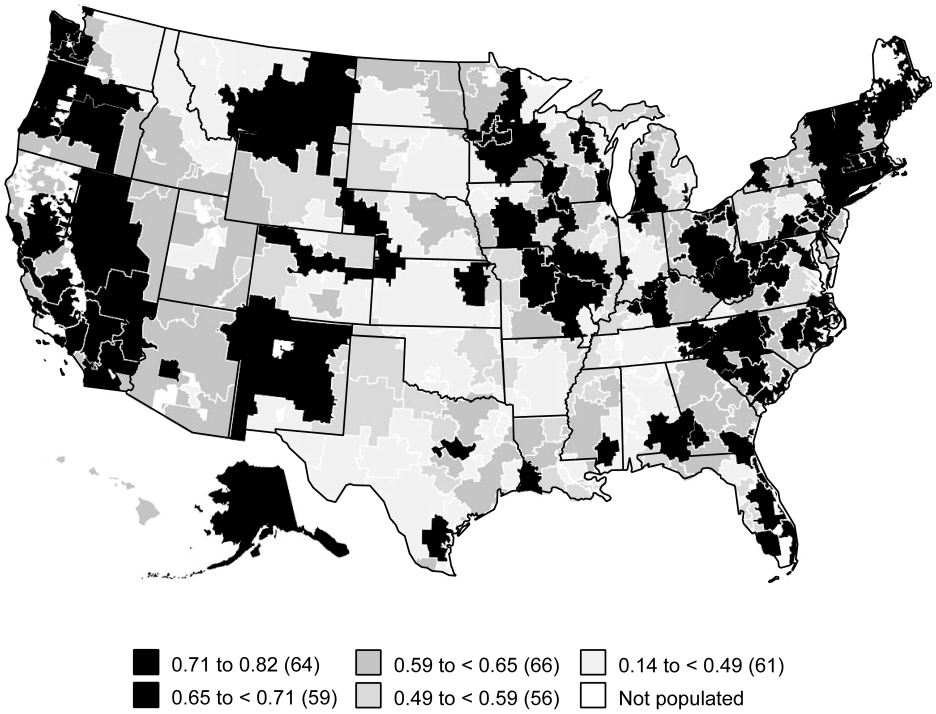

Fig. 11.2 Drug-eluting stents as a fraction of total stents in the Medicare population by HRR, May 2003–April 2004

are not uniform across regions, and suggest the importance of spatial autocorrelation or spillover effects for individual hospitals.

Returning to table 11.1, there were no differences in age of patients being stented across the groups, nor were there large differences in racial composition, except for the smaller fraction of African Americans in the highest-diffusion quintile. Women were less likely to be stented in the highest-diffusion group, perhaps owing to a lack of appropriate stents in this group.

There are large differences in rates of adverse events across the quintiles of adoption, ranging from 6.4 percent of patients in the lowest-diffusion quintile to only 5.0 percent in the highest-diffusion quintile. One might be tempted to attribute this pattern to the greater effectiveness of the drug-eluting stents over bare-metal stents—as one might do in studies that use distance from the hospital as the "instrument"—but in fact these patterns are present for stent patients both before and after April 2003 when drug-eluting stents were introduced. As we show later, hospitals with greater (risk-adjusted) quality of stenting (as measured by lower adverse event rates) were more likely to adopt, but exhibited no incremental improvement (or any improvement, for that matter) in adverse events.

Finally, while table 11.1 shows a very strong association between teaching hospital status and rates of diffusion (as well as the size of the hospital as measured by beds), there was no consistent pattern of association between for-profit or government hospitals and diffusion of drug-eluting stents. We next turn to a more formal regression analysis that considers these factors in light of our model.

Table 11.2 reports coefficients from a regression of the hospital-level diffusion rate of drug-eluting stents on a variety of different variables as noted previously in section 3. In equation (1), the more parsimonious specification, hospitals with larger shares of African Americans and females are substantially less likely to adopt drug-eluting stents. For example, a hospital with a 10 percent higher fraction of women would exhibit a 3.4 percentage point lower fraction of drug-eluting stents. Teaching hospitals are strongly associated with higher diffusion of drug-eluting stents (10 percent) while for-profit hospitals are almost 5.0 percentage points less likely to adopt. The hypothesis that hospitals adopt in competitive markets is not supported by this regression because we do not see the number of hospitals in an area predict the diffusion of DES.

The fuller specification in table 11.2 includes additional measures hypothesized earlier. (Hospitals in HRRs without other hospitals performing stents are dropped, as there is no plausible spillover effect.) The apparent importance of for-profit hospitals (from equation [1]) disappears when other factors are included. Both the size of the hospital and the cumulative stent volume are significant and positively associated with diffusion rates, although the magnitudes are not large relative to observed differences in the data.

The spillover level—the rate of diffusion of other hospitals in the HRR during the same period—is highly significant with a coefficient of 0.077, consistent with the HRR-level map in figure 11.2. The coefficient on teaching hospital status is still large and significant, as is the pre-drug-eluting stent quality measures. Recall that we used only the pre–April 2003 stenting outcomes data to estimate risk-adjusted rates of adverse events by hospital as a measure of "expertise." These were then used to create quintiles of hospital expertise, with quintile 1 the lowest quality and quintile 5 (the excluded quintile) the best quality. As can be seen from table 11.2, the lowest-quality hospitals (quintile 1) were almost 8 percentage points less likely to adopt drug-eluting stents.[8]

The regressions in table 11.2 therefore are supportive of an expertise model of adoption—given the strong importance of quality-adjusted outcomes and the teaching hospital coefficient—as well as the presence of some

8. This pattern is also consistent with an otherwise puzzling finding presented in an earlier JAMA letter, and reproduced in appendix figure 11A.1. This shows the rate of two-year adverse complications for patients treated with drug-eluting stents (post–April 2003) and those treated with bare-metal stents. While the drop in adverse outcomes for the drug-eluting stent patients may appear to be consistent with greater benefit for these treatments, the sudden jump in complication rates for those with bare-metal stents makes much less sense—except in a world where there is selection bias, not so much because of patient unmeasured confounding, but because of hospital unmeasured confounding—higher quality hospitals adopted drug-eluting stents first.

Table 11.2 Explaining diffusion at the hospital level

Variable	Equation 1 (N = 950)	Equation 2 (N = 776)
Share African American patients	–0.171	–0.179
	(1.69)	(1.74)
Share other racial/ethnic patients	0.055	0.102
	(0.60)	(1.04)
Average age	–0.002	–0.011
	(0.44)	(1.53)
Fraction female	–0.339	–0.242
	(3.91)	(2.51)
For-profit hospital	–0.047	0.0068
	(2.72)	(0.34)
Government hospital	–0.028	0.021
	(1.20)	(0.82)
Teaching hospital	0.101	0.076
	(7.21)	(4.76)
Two or more hospitals in the HSA (1 = yes)	0.019	0.019
	(1.19)	(1.07)
Number of hospitals in the HSA	–0.000	–0.000
	(0.849)	(0.21)
Spillover (rate of diffusion in other hospitals in HRR)		0.073
		(2.75)
Log(beds)		0.013
		(1.00)
Log(stent volume) during April 2002– March 2003		0.040
		(6.01)
Q1 (risk-adj. outcomes)		–0.076
		(3.83)
Q2 (risk-adj. outcomes)		–0.033
		(1.66)
Q3 (risk-adj. outcomes)		–0.021
		(1.07)
Q4 (risk-adj. outcomes)		–0.012
		(1.01)
Q5 (reference quintile)		–
R^2	0.11	0.19

Notes: Dependent variable is the rate at which a hospital uses DES. The OLS regression is at the hospital level, with hospitals weighted according to their patient populations. Absolute value of z-statistic in parentheses.

kind of spillover effect (or a geographically correlated unobservable). We next turn to health outcome regressions (at the patient level) to further distinguish between a "mimic" versus a "knowledge spillover" effect, and the hypothesis that hospitals that diffused most rapidly also got the greatest incremental benefits from drug-eluting stents.

Table 11.3 shows these outcome variables using logistics models, so the null hypothesis of no effect corresponds to a coefficient of 1.00. First note

Table 11.3 Logistic analysis predicting health outcomes

Dependent variable	Death or STEMI (N = 127,072)	1-year mortality	Subsequent PCI
For-profit hospital	1.05	1.04	0.96
	(1.48)	(1.05)	(1.13)
Government hospital	1.126	1.11	0.997
	(2.56)	(2.07)	(0.34)
Teaching hospital	1.017	1.03	1.07
	(0.34)	(0.79)	(4.67)
HRR spillover	1.04	1.03	1.16
	(0.77)	(0.65)	(0.93)
Log (stent volume) pre–April 2003	0.97	0.98	1.14
	(2.90)	(2.42)	(12.79)
Log (beds)	1.02	1.011	0.88
	(1.20)	(0.66)	(6.32)
Diffusion Q1	1.194	1.14	0.97
	(3.15)	(1.96)	(0.77)
Diffusion Q2	1.035	1.04	0.97
	(0.59)	(0.65)	(0.84)
Diffusion Q3	1.129	1.10	0.96
	(2.05)	(1.18)	(0.28)
Diffusion Q4	1.011	0.996	1.04
	(0.33)	(0.11)	(0.74)
Q1 * post-DES	0.983	1.03	1.04
	(0.47)	(0.39)	(0.91)
Q2 * post-DES	1.035	1.04	0.82
	(0.66)	(0.69)	(3.75)
Q3 * post-DES	0.965	1.02	0.89
	(0.59)	(0.37)	(2.27)
Q4 * post-DES	0.988	1.02	0.88
	(0.14)	(0.27)	(2.67)
Q5 * post-DES	0.908	0.93	0.842
	(1.19)	(0.66)	(3.14)
Pseudo R^2	0.044	0.057	0.006

Notes: Dependent variable is the presence of an adverse event, death, or subsequent PCI. Logistic regression (reporting odds ratios) regression is at the patient level Additional variables include month trend, age-sex (five-year categories, by sex), race, comorbidities (past myocardial infarction, vascular disease, pulmonary disease, dementia, diabetes, liver disease, renal disease, any cancer). Absolute value of z-statistic in parentheses.

that the HRR spillover variable is never large in magnitude nor is it significant. This may not be so surprising for health outcomes, where we would not expect large effects of increased drug-eluting stents on adverse events (death or STEMI), but it is more surprising that we do not find such effects on subsequent PCIs, where we would expect a decline if there was "learning by doing." Thus we are led towards a mimic model of adoption rather than one involving knowledge spillovers.

It may appear also from these results that subsequent PCI is not entirely a

hard variable, but that higher rates (conditional on other factors and health status) may be observed in teaching hospitals and in hospitals that perform a high rate of stents (conditional on hospital bed size). That is, the likelihood of a second PCI may depend not solely on clinical factors, but also reflect physician opinions about appropriateness for revascularization.

Finally, we can use these logistic regressions to consider the hypothesis that hospitals with the most rapid diffusion also experienced the best health outcomes. While one cannot reject the null that the interaction effects (the quintiles of diffusion times the post-DES dummy variable) are jointly different from zero, one can detect a general pattern; the most rapidly diffusing hospitals appeared to exhibit the greatest relative decline in rates of revascularization (no improvement for the lowest diffusion quintile, versus a significant drop of more than 10 percent for the highest diffusion quintile). In sum, while the results for adverse events are not significant, it does appear that the rapidly adopting hospitals were most effective in reducing rates of restenosis.

One might be concerned with the interpretation of these outcome data if the introduction of drug-eluting stents was also associated with an increase in the overall number of stenting, thus potentially confounding the introduction of stents with an expansion of patients with potentially less (or more) unmeasured confounding factors. However, as shown in Malenka et al. (2008), the total number of stents in this population, on a monthly basis, did not vary appreciably over the time period.

11.5 Conclusion

In April of 2003, the FDA approved the use of drug-eluting stents, designed to reduce renarrowing of the artery at the location of the original stent. Using Medicare claims data, we found remarkable variations in the rates of diffusion of these drugs across hospitals and regions of the United States. We further tested several models of diffusion, and found the most empirical support for models of expertise (better-quality hospitals adopt quicker) and spillover models with correlated diffusion behavior within regions. There is suggestive evidence that hospitals that gained the greatest incremental benefit from drug-eluting stents diffused more rapidly, but there is no support for models of competition, knowledge spillovers, or profit maximization.

Our finding that the quality of the provider is highly predictive of the diffusion of the new technology has implications for studies that use (for example) distance from a catheterization laboratory as an instrument for the specific technology. As McClellan, McNeil, and Newhouse (1994) noted at the time, the risk is that the estimated benefits of the new technology become conflated with the quality of the provider. For this reason, the use of panel studies, rather than cross-sectional analysis, that seek to measure the impact of new technology on health outcomes may be particularly valuable.

There are several limitations to the study. Drug-eluting stents are quite similar to bare-metal stents from the view of the interventional cardiolo-

gist. Thus the potential implementation barriers present for, for example, hybrid corn, or the capacity issues associated with the presence of backup catheterization laboratories, are not present for this study as they were for many previous technological advances. Nonetheless, we believe that there are a sufficient number of new drugs and devices with similar characteristics to make these results generalizable.

Drug-eluting stents were also different because they were subsequently found to have more risks than previously understood in the early months of their introduction. A fuller analysis would include not simply the rapid expansion, but also the more gradual "exnovation" of such treatments among those least appropriate for drug-eluting stents. Still, a better understanding of the welfare implications for the uneven diffusion of new technology appears to be a worthwhile goal.

In sum, the diffusion of drug-eluting stents appeared to have been driven by expertise and perhaps even productivity considerations, and so there does not appear to be large welfare costs associated with the uneven diffusion rates.

Appendix

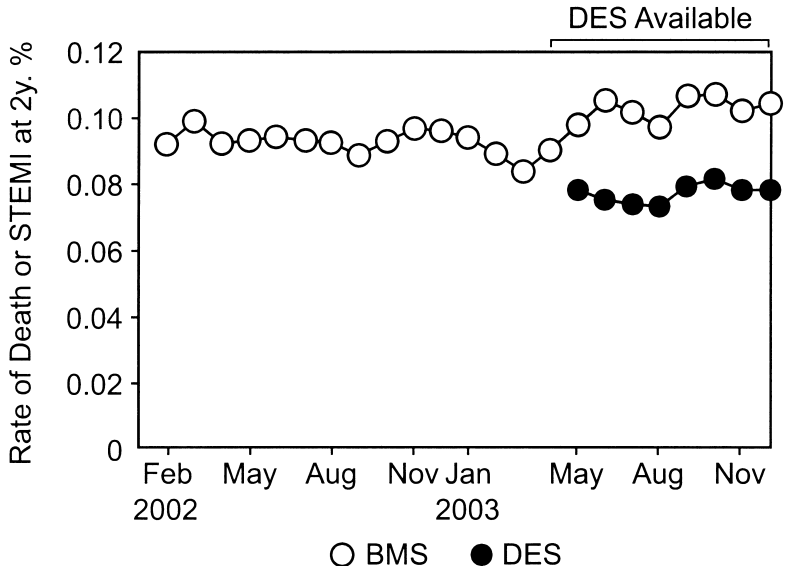

Fig. 11A.1 Mortality and ST-elevation myocardial infarction rates for patients receiving bare-metal stents versus drug-eluting stents

Source: Malenka et al (2008).

Note: BMS indicates bare-metal stents; DES, drug-eluting stents; and STEMI, ST-elevation myocardial infarction.

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