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ABSTRACT

Since 2006, Taiwan's National Health Insurance (NHI) covers the full cost of baseline treatment in cardiac stents (bare-metal stents, BMS), but requires patients to pay the incremental cost of more expensive treatments (drug-eluting stents, DES). Within this "top-up" design, we study how hospitals respond to a 26% cut of the NHI reimbursement rate in 2009. We find hospitals do not raise the DES prices from patients, but increase BMS usage per admission by 18%, recouping up to 30% of the revenue loss in 2009-2010. Overall, the rate cut is effective in reducing NHI expenditure despite hospitals' moral hazard adjustment.

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I. Introduction

One major challenge faced by many countries is how to constrain the rising health care cost while providing enough medical coverage and treatment choices. In practice, one option is to cover all types of treatment ("full coverage"), which fits patients' various medical needs but induces high medical expenditure. Some "full coverage" programs (e.g. Medicare in the US) attempt to limit expenditure by co-pay and co-insurance, but the realized medical claims still grow fast.[1] A second option, more common in Europe, only covers the baseline treatment ("no top-up coverage"), which alleviates the moral hazard problem, but excludes more advanced treatment choices.[2]

To overcome these shortcomings, a third "top-up design" is proposed to cover the cost of baseline treatment, but it requires patients to pay for the incremental costs of more expensive treatment. Ideally, the top-up design could help patients with basic coverage regardless of the treatment they choose, and attenuates the moral hazard problem since patients pay the price difference if they opt for a more expensive treatment. Academics have discussed its welfare implications (Einav, Finkelstein and Williams, 2016; Shepard, Baicker, and Skinner, 2019; Marone and Sabety, 2019), but more evidence is needed for provider practices under this design. For instance, health providers could raise the price difference to exploit patients willing to opt for a more expensive treatment. If this happens, it could limit patient access to more expensive treatments and reduce consumer welfare. It is also unclear whether the top-up design indeed attenuates moral hazard.[3] Without knowing the provider's response to the top-up design, it is difficult to fully evaluate the welfare consequences of this reimbursement scheme.

[1] In particular, the total Medicare spending has nearly doubled in the last decade, with 22% devoted to fee-for-service (FFS) inpatient care (MEDPAC 2017). Medicare spending is projected to reach $1 trillion in 2021, and the Medicare Hospital Insurance Trust Fund is projected to be insolvent by 2028.

[2] For instance, England limits access to new treatments and technologies which require the National Institute for Health and Care Excellence (NICE) to provide empirical evidence on the cost-effectiveness (Thorlby and Arora, 2019).

[3] Einav, Liran and Amy Finkelstein (2018) point out that "the impact of provider incentives in health insurance has, to date, received comparatively less attention than consumer incentives." To our best knowledge, no studies have discussed provider's mortal hazard under the top-up design.

In this paper, we evaluate hospitals' treatment practices from 2007 to 2010 under a top-up design based on information collected from the Taiwan stent market. We choose this market for three reasons. First, it has implemented the top-up design since October 2006. There are two major vascular stent types in our observation period:[4] bare metal stent (BMS) is the baseline, while drug-eluting stent (DES) adds a drug layer over the metal to further slow down the reclogging of blood vessels. Both stent types are applicable for most patients, but DES is more expensive than BMS, leading to the debate of DES cost-effectiveness (Bagust, 2006).[5] Under the top-up design, patients are fully covered for BMS, but they need to pay the incremental cost for any DES use, and such costs are administered independently by each hospital.[6]

Second, vascular stent is the fastest growing and highest paid medical device with a top-up pricing in Taiwan. The number of stents implanted has increased by 56.6% in 6 years, from 20,243 in 2007 to 36,834 in 2010 and 49,501 in 2014. In addition, total PTCA payment, including National Health Insurance (NHI hereafter) reimbursement for stents, NHI reimbursement for PTCA surgeries (which is necessary for stent implant), and patients' out-of-pocket payment for stents, was up to 3.5 billion NTD in 2010 and exceeded 5 billion NTD in 2014.[7] This total is close to 1% of the total NHI spending in 2014 (520 billions NTD). The rapid adoption and massive scale of reimbursement increase make the stent market well suited to evaluate hospital practices in a top-up reimbursement system.

Third, our data period (from January 2007 to December 2010) covers one major decline of reimbursement rate per stent, which dropped from 27,000 to 19,940

[4]The bio-absorbable stent was introduced and applied after our observation period, and it is not considered in this paper.

[5]Bagust (2006) assesses the cost effectiveness of DES compared with BMS for treatment of symptomatic coronary artery disease in the UK. They conclude that DES are not cost effective except for a small minority of patients, unless the price of DES falls substantially.

[6]On average, a DES costs the patients about 60,000 NTD. (1 USD = 31 NTD) approximately

[7]For the number of BMS and DES used between 2007 and 2014, see the report of top-up design medical devices by National Insurance Agency (https://www.mohw.gov.tw/dl-15125-501102ca-d9d2-45d2-a1d6-01d802c0ded3.html). In addition to the expenditure for vascular stents, the NHI reimbursement for percutaneous coronary dilatation (the surgery that help installing vascular stents) is NTD 44k, 60k, and 76k for one, two, and three vessels respectively.

NTD (-26%) in January 2009.[8] Hospitals anticipate the timing but not the exact scale before the adjustment, so we treat the rate cut as exogenous. This rate cut reduces hospital's revenue from each stent unit implanted, which could trigger hospitals to adjust DES pricing and stent usage for revenue recovery, or induce hospitals to further lower the costs of delivering related medical services (Yip, 1998; Gruber and Owings,1996). By estimating hospitals' responses to this rate cut, we can have a better sense of how hospitals manage various margins simultaneously.

Our data is constructed by combining three components from Taiwan NHI. We first collect patient-admission-level claim records that consist of every patient who has undergone the percutaneous transluminal coronary angioplasty (PTCA) between 2007 and 2010 in Taiwan. For each patient in the record, we observe his demographics and treatment procedures, including any medical device used: for each stent implanted, we observe its brand, manufacturer, quantity used in each surgery admission. We further supplement this medical record data with patient-paid price data for DES models from hospitals' periodic public reports, which is required by NHI regulations. We construct the hospital-model level price spectrum by assuming invariant prices between consecutive reports from the same hospital and stent model combination. In our sample, we observe 129,251 patients receiving PTCA surgery, of which around two thirds (79,054) used at least one stent, and among those stent patients, 39.6% of the surgeries used at least one DES, and 64.0% used BMS.[9]

We utilize the 2009 reimbursement reduction shock to identify hospitals' adjustment incentives. To accommodate hospitals' heterogeneous and non-instant responses, we follow Finkelstein (2007) and use the ratio of stent patients over PTCA patients in each hospital in 2008 ($Ratio08$) as a proxy to hospitals' sen-

[8]Another price adjustment further lowered the payment from 19940 to 16293 NTD in Jan 2012. This adjustment looks large in percentage (-18%), but much smaller in the absolute size as compared with the 2009 adjustment (about half). This is beyond our data period, and likely results in a much smaller impact on the stent revenue for hospitals.

[9]These two percentages are not exclusive because around 3% of patients use both DES and BMS in their surgeries.

sitivity to the rate cut. Our intuition is that hospitals with more stent patients are subject to larger revenue losses from the rate cut, and therefore have stronger incentives to recoup the revenue loss. We correlate each hospital's *Ratio*08 with two potential margins of adjustment: the average number of stents used per stent patient, and the patient-paid price for each DES model.

Our analysis yields several key findings. First, hospitals increased their patient-level stent usage significantly, mostly on BMS, after the 2009 rate cut. On average, a hospital with the average stent ratio (65%) in 2008 increased its BMS use by 0.14 (18%) per stent patient admission. By contrast, DES usage did not see any significant increase. One explanation is that only BMS are fully reimbursed by the NHI and do not require patients' out-of-pocket payment. This suggests that, despite the overuse after the rate cut, the top-up design attenuates the rising medical spending by encouraging patients to choose the baseline treatment.

Second, the increased use of BMS is concentrated in minor teaching hospitals, rather than major teaching hospitals. One potential explanation is that more and more patients choose major teaching hospitals over time. This trend occurred before the rate cut, but because of the trend, minor teaching hospitals have less flexibility to counter the revenue loss after the rate cut.

Third, one mechanism to increase BMS use is to conduct PTCA surgery on a larger number of blood vessels, which generates extra NHI reimbursement for the PTCA procedure in addition to NHI payment for stents. This effect is concentrated in minor teaching hospitals, in the form of an increased likelihood of 2-vessel PTCA treatment (as compared to 1-vessel) on patients with acute and urgent heart conditions.

Fourth, hospitals do not significantly adjust the price of DES to compensate for the rate cut, once we control for stent model fixed effect. It is hard to tell whether the rate cut has caused hospitals to adjust new model adoption, but hospitals are reluctant to hike the DES price within the same stent model, probably because the NHI requires public reporting of DES price and all the price hike must be absorbed by patient payment.

Finally, although hospitals do not increase the price of DES and restrict the increased stent usage to BMS, our estimates still suggest a sizable response to the rate cut – the increased BMS use helps hospitals to recoup up to 30% of revenue loss in 2009-2010. Given that hospital revenue per stent is four times higher in DES than in BMS, our results suggest that hospitals would recoup an even larger share of revenue loss if a "full coverage" insurer implements a rate cut and both DES and BMS are covered in the insurance.

Our study contributes to two literatures. The first is the empirical literature that examines providers' responses to financial incentives (See McGuire (2000) for a review). Numerous studies have exploited reimbursement variations to identify the impact of rate change on health care utilization (Yip, 1998; Gruber and Owings,1996; Dafny, 2005; Ho and Pakes, 2014; Clemens and Gottlieb, 2014; Xiang, 2019) and the coding of diagnosis related groups (Silverman and Skinner 2004; Geruso and Layton 2019). One direct study on stent price is Deo et al. (2020), which shows that private hospitals increase the use of PTCA procedures after India put price caps on cardiac stent in 2017 (both BMS and DES). Not only do we provide another example in this regard, we also explore how hospitals might adjust the price and quantity of medical device to recover revenue loss due to the insurer's rate cut.[10]

More importantly, we contribute to a second strand of literature that discusses the welfare implications of a top-up design. Chernew, Encinosa and Hirth (2000) and Einav, Finkelstein and Williams (2016) explore the optimal insurance coverage of a top-up design for different treatments of a given disease, and quantitatively calibrate the social welfare under different insurance designs. Based on a simple model of health demand, Shepard, Baicker, and Skinner (2019) investigate the impact of various insurance designs on income inequality, medical technology

[10]Einav, Finkelstein and Williams (2016) evaluates the top-up design in breast cancer treatment in California. Nonetheless, they use the distance between patients' residence and the nearest treatment facility as a proxy for treatment price, since they are unable to obtain the actual price paid by the patient.

growth, and distortionary taxes. These studies highlight the advantage of the top-up design, but ignore the possibility that health providers may have different incentives to adjust under a top-up design. To fill this gap, we provide the empirical evidence of hospital moral hazard under a specific top-up design.

The rest of this paper is arranged as follows. Section 2 describes the industry background of vascular stents and the health system in Taiwan. Section 3 describes our data and sample. Section 4 presents the estimation model and the estimated results. We conclude in Section 5.

II. Industry Background

A. Cardiac Stent

When patients suffer from coronary atherosclerosis, the artery loses its original elasticity and starts to clot, causing hypoxia in the heart. Left untreated, the stenosis will be completely blocked, resulting in life-threatening myocardial infarction or cardiac arrest. The treatment of coronary heart disease ranges from a simple drug therapy, percutaneous transluminal coronary angioplasty (PTCA), to coronary artery bypass grafting (CABG) in the worst case. Bypass surgery improves the obstruction site by re-implanting the patient's own blood vessels, but the risk is relatively high. In contrast, cardiac catheterization is less invasive, more responsive, and involves a shorter hospital stay. Thus, since the first successful coronary artery angioplasty in 1977, PTCA has gradually replaced CABG in treatment priority (Cutler and Huckman, 2003).

Cardiac catheter therapy was originally a simple balloon dilation, with a success rate of around 80%. Nonetheless, the chance of restenosis due to retraction and tissue hyperplasia is as high as 30-50%. A coronary stent can be implanted to support the stenotic coronary artery, reducing the rate of restenosis to 10-20% (Dihu, 2011). The earliest model of stents is BMS that is typically made of stainless steel or cobalt-chromium alloy. Stent implantation can damage endothelial cells of blood vessels, DES is invented to slowly release a drug that can inhibit cell proliferation. Though long-term results are not yet available, it is reported that DES, compared with BMS, lowers the rate of restenosis by up to 5 to 10% in five years (Morice et al, 2007; Dangas, et al, 2010; Dihu, 2011). As a result, there has been a steady increase of DES use over time.[11] In Taiwan, the use of DES reached almost 50% since 2012.[12] At present, the global stent market has a production value up to 6 billion US dollars.

B. Taiwan Top-Up Design

Taiwan implemented NHI in 1995 with two primary goals: to provide equal access to healthcare for all citizens and to control total health spending at a reasonable level (Council of Economic Planning and Development, 1990). To achieve the goal of equal access, the NHI provides a comprehensive benefit package, ranging from conventional outpatient and inpatient services, preventive medicine, prescription drugs, dental services, as well as Chinese medicine. In addition, the NHI charges a very modest cost sharing: $5 for clinic visit, $8-$15 for hospital visit, and 10% coinsurance rate for inpatient care (capped at 10% of the average national income per person).[13]

The NHI takes two measures to control the expenditures of medical devices. Since 2006, a top-up design is employed to cover 11 categories of expensive medical devices (stent implantation is fully covered and not included in these 11 categories). For cardiac stents, the NHI reimburses hospitals the payments of BMS, and patients pay for the incremental costs to employ DES. To prevent hospitals from charging excessive prices from patients, each hospital is required to

[11] The major applicator brackets of stents include Cordis, founded in 2002, a subsidiary of Johnson & Johnson. The Cypher TM's Sirolimus was developed followed by Boston Scientific's Taxus applicator, and Medtronic's Endeavor. Subsequently, ABOTT acquired the vascular interventional therapy business of Guidant in the United States in 2006 and quickly entered the global market for vascular stents.

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[13] The cap of out-of-pocket expense per admission and per year is approximately $1000 and $1670 in 2012 respectively.

Table 1—Adjustment in NHI reimbursement of vascular stents

Effective date	Reimbursement	Reduced amount	% of change
Jul-06	27000	9750	27%
Jan-09	19940	7060	26%
Jan-12	16293	3647	18%

Note: All numeraire is in the unit of NTD. Each rate change is effective the first day of the corresponding month. We obtain the reimbursement rate from NHI payment reports between 2005 and 2013.

publicly report their charged prices for DES. On average, the additional charge for a DES is approximately 60,000 NTD ($1=31NTD). Despite the notable price difference, there is still a growing popularity of DES over time: the fraction of stent patients using DES has increased from 37% in 2007 to 58% in 2016.

In addition, the NHI sets up a payment scheme in which reimbursement for medical devices is based on average input cost plus a fixed markup (usually 20%). In Taiwan, each hospital can negotiate the input price of medical devices with medical suppliers. To incentivize hospitals, the NHI allows hospitals to reserve the markup between reimbursed payment and the input cost. In return, each hospital has to submit their input costs and the NHI uses the submitted costs to calculate the reimbursed payment of medical devices in the next two or three years. Notice that the payment is based on the average input costs of "all" hospitals, not a specific one. Therefore, the average is unlikely to be influenced by the pricing decision of an individual hospital. In the case of cardiac stents, the NHI sets up the reimbursement rate based on the average costs of BMS.

Table 1 lists the reimbursed rate for cardiac stents between 2007 and 2012. Notice that NHI payment is much lower than the price of DES because NHI's stent payment is based on the input prices of BMS only in the top-up pricing. The NHI lowers the payment almost every three years. While those price adjustments are regular and can be expected, no hospital knows the exact size of payment reduction because it is calculated according to the input costs of bare-metal stents at all hospitals in Taiwan. Thus, we assume price adjustments are exogenous to individual hospitals. We later test this assumption in the analysis.

From 2006 to 2013, we observe two rate cuts by the NHI: a 26% reduction from 27,000 to 19,940 NTD in Jan 2009, and an 18% reduction from 19,940 to 16,293 NTD in Jan 2012. In absolute amount, the second rate cut is only half the size of the first one (3,647 v.s. 7,060). Our data extends from 2007 to 2010, which covers the first rate cut.

III. Data and Sample

A. Data Description

Our data are constructed from two components. First, we collect hospital claim records of all PTCA patients from the NHI between 2007 and 2010. These medical claims contain detailed information of inpatient admissions, including patient demographics (gender, date of birth), hospital characteristics (bed size, teaching status, and profit status), diagnoses, performed surgeries, installed medical devices (e.g. stents), as well as the reimbursements NHI paid to hospitals. We also observe unique identifiers for the doctor and the hospital in each inpatient admission record. Based on these medical records, we first construct our main data sample with all patients receiving at least one PTCA surgery from 2007 to 2010. For each patient using at least one stent, we obtain the information about all stents used, including their manufacturers, stent model ID, stent model type (bare metal model or drug eluting stent model). If a patient uses more than three stent models, we observe her three most used models.[14]

The medical claim data provides abundant details on patient-level treatment records. Nonetheless, one key missing information is the "actual" price patient paid for DES. Given that NHI record only includes the reimbursed amount, we use a second data source to supplement the price difference patients paid for DES. As indicated earlier, the NHI requires all hospitals to disclose patients' out-of-pocket expenses charged for DES and publishes this information periodically.

[14]Of all stent surgeries, only 1.23% use 3 or more stent models so this truncation has limited effect.

Based on NHI publications, we infer the patient-paid price for each DES model at each hospital in each month. For example, if we observe that hospital A announced model X's price as 60,000 in Jan 2010 and 70,000 in Sep 2010, we assume A's price for model X is 60,000 any time between Jan 2010 and Sep 2010. We then match the inferred price with the models of stents installed at each hospital admission, which achieves a 90% matching rate. With the two data sources combined, we construct a comprehensive patient-level stent usage data linking patients, hospitals, as well as the prices paid for both BMS and DES.

B. Summary Statistics

We refer to two samples in data analysis: the "PTCA patients" sample includes all PTCA patients admitted to hospitals that have conducted at least one stent surgery in the sample period, excluding those admitted in hospitals that never perform any stent surgery. This sample includes every PTCA patient that could receive a stent surgery, no matter whether he eventually underwent a stent surgery. In contrast, the "stent patients" sample focuses on the subset of the PTCA patients that have received any stent treatment during the sample period. We use the PTCA patient sample to construct the stent ratio for every hospital, and the stent patient sample to examine the impact of the rate cut.

To better understand the number of PTCA and stent patients over time, Figure 1 plots the monthly count of PTCA and stent patients from 2007 to 2010. Both populations grow steadily over time, reflecting the growing popularity of PTCA and stent treatments. Both counts fall at the beginning of each year due to lunar Chinese New Year (which is usually in February or late January). Figure 2 plots the monthly ratio of stent patients among PTCA patients. This figure does not suggest any significant change around January 2009 when the NHI started to reduce its reimbursement for cardiac stents. It is rather difficult to convert a PTCA patient into a stent patient simply because of the NHI rate cut, as all cardiac doctors we talked to confirm that they need to justify stent use based on

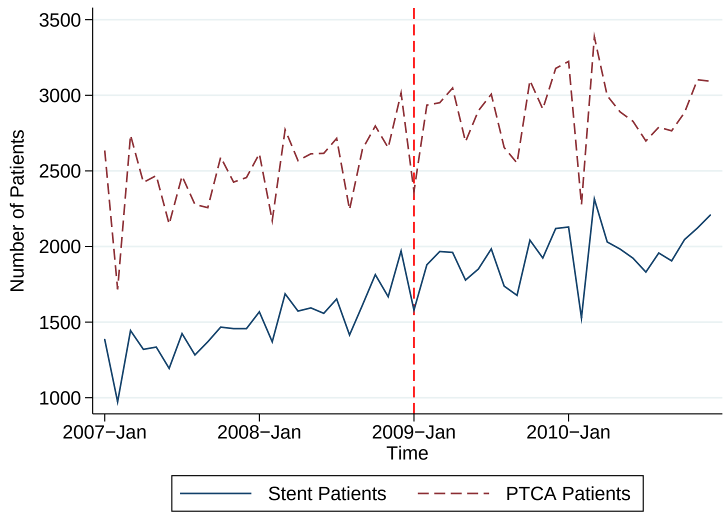

FIGURE 1. NUMBER OF PTCA AND STENT PATIENTS BETWEEN 2007-2010

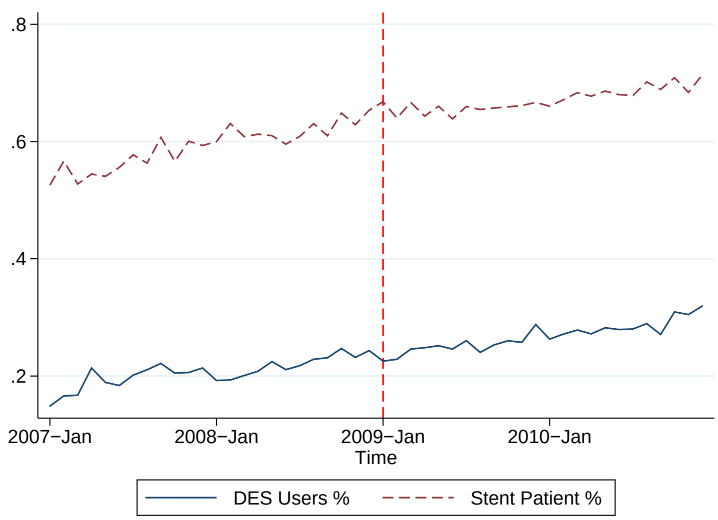

FIGURE 2. PERCENT OF STENT AND DES PATIENTS AMONG PTCA PATIENTS

the patient's medical conditions, a point that we will return to later.

To detect any changes in usage among different stent types, Figure 2 also plots the ratio of DES patients over all PTCA patients. Despite a higher price charged

Table 2—Summary statistics of PTCA patients by years (2007-2010)

	2007	2008	2009	2010
% Stent patients				
Overall	56.3%	62.0%	65.6%	68.6%
Major teaching hospitals	59.9%	63.7%	67.8%	71.4%
Minor teaching hospitals	55.1%	61.0%	65.3%	68.9%
% DES stent patients				
Overall	19.4%	22.0%	25.1%	28.5%
Major teaching hospitals	24.2%	26.4%	29.8%	33.7%
Minor teaching hospitals	14.8%	17.3%	20.9%	24.4%
N	28,605	31,423	34,288	34,935

Note: The PTCA sample is constructed from NHI inpatient files, including all patients admitted for PTCA between 2007 and 2010. Major and minor teaching hospitals are defined by hospital accreditations conducted every three years.

for patients, the percentage of DES patients fluctuates between 20% and 25% in 2007 and 2008, then gradually approaches 30% in 2010.

Table 2 lists the number of PTCA patients in our analytic sample. In total, there are 129,251 PTCA patients between 2007 and 2010, of which approximately 60% received at least one cardiac stent during the admission. As shown in Table 2, the ratio of stent patients – defined as the count of stent patients divided by the count of PTCA patients in each year– has increased over time from 56.3% in 2007 to 68.6% in 2010. Likewise, percentage of DES patients among all PTCA patients increases from 19.4% in 2007 to 28.5% in 2010; and percentage of DES patients within stent patients increases from 34.4% in 2007 to 41.6% in 2010.

Table 2 also displays the percentage of stent patients and DES patients by the teaching status of the admitting hospitals. In Taiwan, only major and minor teaching hospitals are capable of PTCA surgeries and cardiac stent implantation.[15] On average, a major teaching hospital, as compared to a minor teaching hospital, recruits approximately twice more PTCA patients and three times more stent patients. Patients who receive PTCA surgeries in a major teaching hospital

[15]In Taiwan, major teaching hospitals are mostly medical centers with more than 600 beds. By contrast, a typical minor teaching hospital has a smaller bed size, roughly between 300 and 600.

have more complicated health conditions (e.g. involving more cardiac vessels), and therefore are more likely to install stents; the probability of DES use is also higher for patients admitted by major teaching hospitals. Among stent patients, a little more than 40% have DES implants, of which 59.5% are conducted at major teaching hospitals in 2010.

Table 3 summarizes the characteristics of stent patients by the type of admitting hospitals. A little less than 60% of stent patients were admitted to major teaching hospitals at the beginning, and then steadily declines to 54.6% in 2010. More than 60% of hospitals are non-profit hospitals and less than 8% of patients are admitted to for-profits hospitals. About 75% of stent patients are males. In terms of diseases, more than 60% were admitted for minor cardiac problems (ischemic heart disease, IHD), 30% for acute myocardial infarction (AMI), and less than 2% suffer from congestive heart failures (CHF). Although patient age slightly increases over years, the Charlson Comorbidity Index remains unchanged. Moreover, there is no increase in the percentage of patients admitted for more than three cardiac vessels.

Table 3 also shows the average use of BMS and DES for stent patients. The average number of cardiac stents per stent patient was close to 1.33 in 2007 and 2008, jumped to 1.42 in 2009, and remained 1.41 in 2010. By comparison, the average number of DES per stent patient rises steadily from 0.45 in 2007 to 0.56 in 2010.

Figure 3 plots the average number of stents used per stent patient admission. It is striking that the average stent quantity jumped from 1.32 to 1.4 right after the NHI rate cut in January 2009.

Figure 4 further displays the jump of stent number before and after the rate cut, separated by different stent types. As shown in the Figure 4, the jump in stent usage is mainly due to the increase in BMS, which jumped from 1.3 per patient before 2009 to 1.38 after 2009. By comparison, the number of DES used per DES-patient increases more modestly from 1.3 to 1.35. One possible explanation

Table 3—Summary statistics of stent patients by years (2007-2010)

	2007	2008	2009	2010
Installed stents (per patient)				
# of stents	1.33	1.33	1.42	1.41
	(0.59)	(0.59)	(0.71)	(0.70)
# of bare metal stents	0.88	0.87	0.90	0.85
	(0.75)	(0.75)	(0.85)	(0.85)
# of drug eluting stents	0.45	0.46	0.52	0.56
	(0.70)	(0.70)	(0.77)	(0.78)
Price of stents (NTD)				
Prices of drug eluting stents (paid by patients)	52,568	57,448	61,567	59,118
	(13,017)	(8,922)	(6,198)	(6,433)
Prices of bare metal stents (paid by the NHI)	27,000	27,000	19,940	19,940
Hospital characteristics				
Teaching status				
Major teaching hospitals	58.19%	55.85%	54.43%	54.62%
Minor teaching hospitals	41.81%	44.15%	45.57%	45.38%
Ownership Status				
For profit	6.85%	7.61%	7.26%	7.51%
Non-profit	62.61%	62.41%	63.83%	63.81%
Public	30.54%	29.99%	28.91%	28.68%
Demographic and pre-health status				
Male	74.72%	74.93%	73.85%	74.38%
Age (60-)	34.75%	35.76%	34.56%	34.83%
Age (60-70)	25.73%	25.54%	25.53%	25.61%
Age (70-80)	28.26%	26.73%	26.86%	25.82%
Age (80+)	11.27%	11.97%	13.05%	13.74%
Acute myocardial infarction (AMI)	30.11%	30.44%	29.00%	29.91%
Congestive Heart Failure (CHF)	1.66%	1.68%	1.59%	1.75%
Ischemic heart disease (IHD)	63.02%	62.01%	62.46%	60.90%
Charlson index	0.68	0.69	0.68	0.68
PTCA (Vessels)				
1	67.2%	69.0%	69.0%	69.2%
2	29.0%	27.3%	27.3%	27.4%
3	3.8%	3.7%	3.7%	3.4%
N	15,409	18,836	21,801	23,008

Note: The stent sample includes patients who were admitted for PTCA and received vascular stent implants between 2007 and 2010. We obtained the number and types of stents for all patients in NHI inpatient files and merged them with the price reports of every hospital collected by the NHI on a quarterly basis. Major and minor teaching hospitals are defined by hospital accreditations conducted every three years.

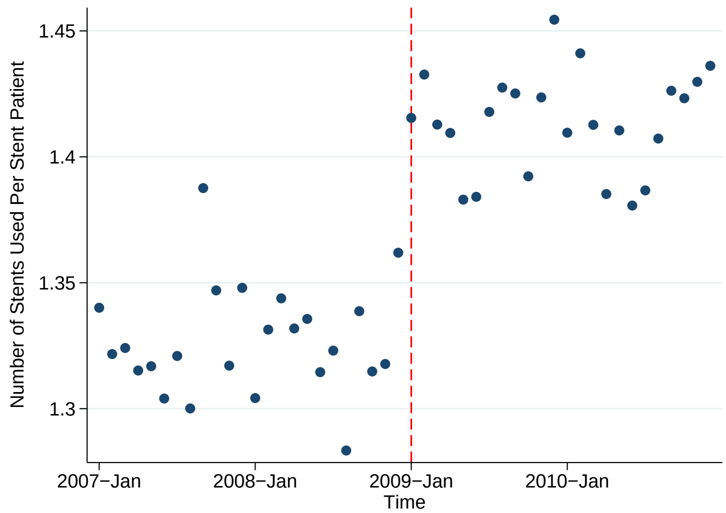

Figure 3. Average Number of Stents Used Per Stent Patient

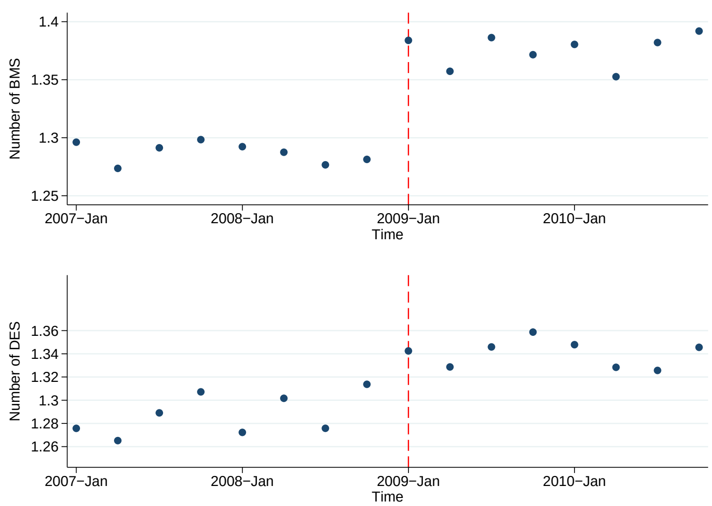

Figure 4. Average Number of BMS (DES) used per BMS (DES) Patient

is that BMS incurs no additional cost for patients and therefore is easier to adjust. Given that government reimbursement is based on total stent quantity only, it is

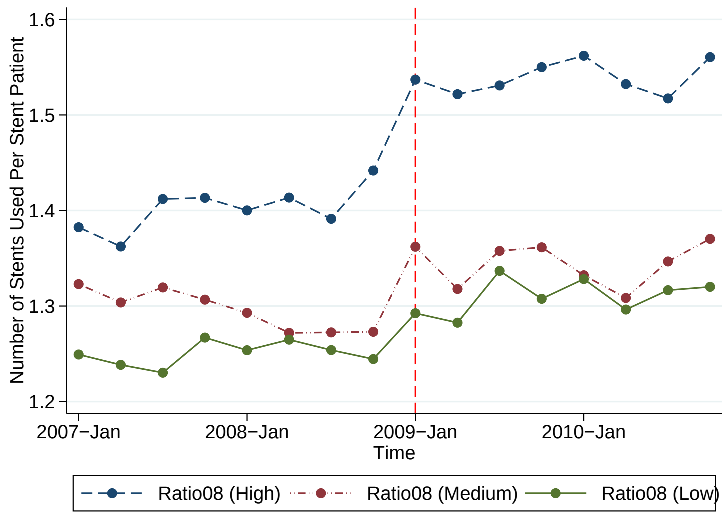

Figure 5. Average Number of Stents Used Per Stent Patient

easier to increase BMS use than DES use.

So far we have shown that the number of stents jumps after the rate cut. It is unclear, however, whether the jump is associated with the hospital's response. To illustrate if hospitals do respond to the 2009 rate cut, Figure 5 displays the average number of stents by three hospital groups: the top group has $Ratio08$ above the 66th percentile of all hospitals,where $Ratio08$ is defined as percent of stent patients in the hospital as of 2008. The medium group has Ratio08 between the 33rd and 66th percentiles, and the low group has Ratio08 below the 33rd percentile. From the figure, it is clear that the size of the jump in average stents is the largest for patients admitted to the top group, from 1.4 in the third quarter of 2008 to 1.54 in the first quarter of 2009 and continues to stay above that level for almost two years. By comparisons, the difference is much smaller for hospitals in the medium and low groups. It appears that the response is larger for hospitals that expect a larger amount of revenue loss from the rate cut.

It is also possible that hospitals may adjust DES price as well after the rate cut in 2009 to increase its revenue, but the higher price born by patients may

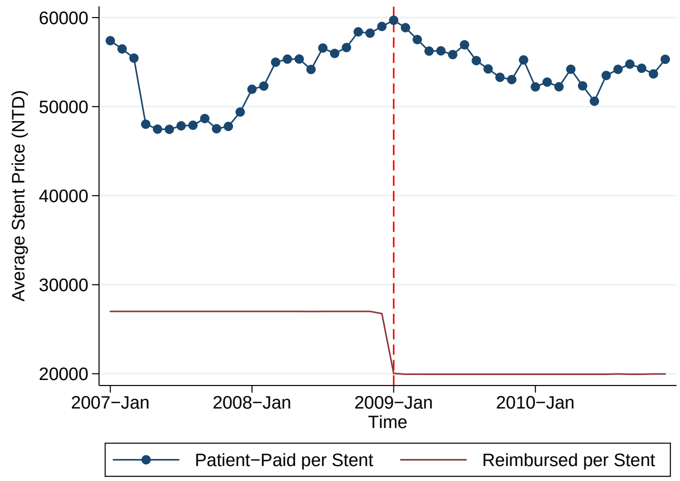

Figure 6. Patient-Level DES Price (2007-2010)

discourage patient adoption of DES. Therefore, it is unclear in theory how this margin will be adjusted by hospitals. From the data, we see that the average price of DES rises from 52,568 NTD in 2007, to 57,448 NTD in 2008, and peaked at 61,567 in 2009. While this price increase is significant in scale, we find no evidence in the correlation between actual price adjustment and hospitals' potential revenue loss, with more details discussed in the next section.

IV. Empirical Specification and Results

We assume that hospitals' revenue from PTCA surgeries are separately administered from other departments. Therefore, when faced with the rate cut in 2009, each hospital can only adjust the margin related to PTCA patients to recoup the revenue loss. Our analysis focuses on how the rate cut affects two margins: (i) the number of BMS and DES used per stent patient, and (ii) the price of DES charged for patients.

A. Empirical Specification

The NHI's rate cut in 2009 applies to stent reimbursement in all hospitals. We cannot adopt the difference-in-difference (DID) analysis because it is difficult to find a control group that is completely immune from the policy. Regression discontinuity (RD) is a second possibility, but it assumes that all hospitals react instantly to the rate cut, which seems unrealistic given that PTCA surgeries are selective and could be scheduled weeks ahead of time.

Following Finkelstein (2007), we assume that a hospital with a higher ratio of stent patients before 2009 was more adversely affected by the 2009 rate cut. This assumption is reasonable, because the 2009 rate cut only applies to cardiac stents, not to the PTCA procedure itself. Hospitals that earn most revenue from the PTCA procedure are less affected than hospitals that count on stents for revenue. To capture this feature, we construct the ratio of stent patients at hospital j in year 2008 ($Ratio08_j$), as a proxy for the extent of the policy shock. The empirical specification is:

$$y_{ijt} = \beta_0 + \lambda Ratio08_j \times Aft09_t + X_i\beta + \xi_j + \alpha_t + \varepsilon_{ijt}. \quad (1)$$

where y_{ijt} denotes the outcome measure of patient i admitted to hospital j at time t. The variable $Aft09_t$ is the dummy which equals one for observations in 2009 and 2010, and 0 otherwise. X_i denotes patient characteristics including patient age, sex, Charlson Comorbidity Index, as well as the type of diseases at admission (AMI, IHD, CHF). ξ_j captures unobserved hospital-specific characteristics, which can be accounted for by area fixed effects or hospital fixed effects. α_t captures the year fixed effects.[16] Finally, ε_{ijt} is the idiosyncratic error.

The key parameter of interest λ indicates how hospitals with a higher $Ratio08$ respond to the NHI rate cut. In the stent market, a hospital's stent revenue can

[16]We tested the year-month fixed effect and continuous time effect in the robustness check, and our estimates are robust to these alternative time effect choices.

be decomposed as follows:

$$R_j = R_j^b + R_j^d, \quad R_j^b = P_j^b q_j^b N_j^b, \quad R_j^d = P_j^d q_j^d N_j^d$$

where R^b, R^d are hospital revenue from BMS and DES usage respectively; P^b, P^d are the average price that hospitals earn for each BMS or DES (including NHI reimbursement and patient's out-of-pocket payment); q^b, q^d are the quantities of stents used, and N^b, N^d are the numbers of patients that receive implant of the corresponding stent type. While in theory a health provider can adjust all three margins, in practice it is less plausible for hospitals to influence the number of stent patients, given that installing stents requires proper indications.[17] We thus focus on the other two components as the outcome variables (y_{ijt}):

- Margin 1: patient-level stent usage, namely, q^b, q^d. The hospital may increase the number of stents used in each patient to increase the total revenue.
- Margin 2: price of DES (P_j^d). Note that price includes both government reimbursement (for BMS and DES models), and patients' payment (for DES model only). When the reimbursement rate decreases, hospitals' revenue from a BMS decreases, but it is possible for health providers to increase the DES price to counter the impact from the rate cut.

Given that the number of BMS and DES are non-negative integers, we estimate the first margin using the Poisson regression and the second margin using the OLS regression. Standard errors are clustered at the hospital level to account for the serial correlation among admissions at the same hospital.

B. Estimation results

The first margin examines whether hospitals adjust the number of stents used by each stent patient. Table 4 reports the estimation result based on various

[17]This observation is confirmed by our conversation with numerous cardiac doctors.

Table 4—Effects of the Rate Cut on Number of Stents Used per Stent Patient (Margin 1)

	# of DES	# of BMS	# of DES	# of BMS	I(BMS>0)	# of BMS BMS patients only
All samples						
$Ratio08_j \times Aft09_t$	0.159	0.473	-0.045	0.210	0.069	0.157
	(0.127)	(0.101)	(0.120)	(0.070)	(0.052)	(0.082)
N	79054	79054	79054	79054	79054	51693
Major teaching hospitals						
$Ratio08_j \times Aft09_t$	0.302	0.587	0.041	0.099	0.012	0.141
	(0.320)	(0.263)	(0.267)	(0.111)	(0.097)	(0.172)
N	43920	43920	43920	43920	43920	26490
Minor teaching hospitals						
$Ratio08_j \times Aft09_t$	0.006	0.393	-0.084	0.289	0.105	0.167
	(0.112)	(0.138)	(0.096)	(0.079)	(0.056)	(0.082)
N	35134	35134	35134	35134	35134	25203
Patient characteristics	x	x	x	x	x	x
Year FE	x	x	x	x	x	x
Area FE	x	x				
Hospital FE			x	x	x	x

Note: Standard errors are in parentheses. Intercepts not shown. Results control for age group dummies (60-, 60-70, 70-80, 80+), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospitals. All outcomes (except for I(BMS>0) are estimated by Poisson regression while I(BMS>0) is estimated by linear probability model. Coefficients of Poisson regressions are expressed as marginal effects at means.

measures of stent use per stent patient. For the ease of expressions, all the coefficients of Poisson regressions (e.g. number of stents) are displayed with marginal effects. The first two columns report estimated λ for the number of total DES and BMS, respectively, controlling for area fixed effects, patient demographics, diagnosis of admission (AMI, IHD, and CHF), as well as the Charlson index to capture patient's severity. The third and fourth columns replace area fixed effects with hospital fixed effects. These columns highlight the importance of hospital fixed effects: when we control for hospital fixed effects, the coefficient λ for the number of DES per stent patient drops from 0.16 in the first column to -0.05 in the third column (both insignificant); while λ for the number of BMS per stent patient drops from 0.47 to 0.21 (both significant).

Our results indicate that, in light of the rate cut, BMS use is more responsive to the rate cut than DES use. This is consistent with the belief that the top-up design could contain moral hazard by persuading patients towards more "free" BMS rather than paying for expensive DES. According to our estimates, the average marginal effect from Poisson estimation (0.21) of a hospital with the average stent ratio (0.65 percentage points in $Ratio08_j$) will increase BMS use by approximately 0.14 (=0.21*0.65).

In the second and third panels of Table 4, we separate the sample into major and minor teaching hospitals. Results suggest that the positive effect of the rate cut on the number of BMS per stent patient, is concentrated in minor teaching hospitals. On average, a minor teaching hospital with the average stent ratio (65 percentage points in 2008) will increase its BMS use per stent patient by 0.19 (0.29*0.65). By contrast, major hospitals do not demonstrate a significant increase in its stent use or BMS use once we control for hospital fixed effects. Within minor teaching hospitals, the increased use of BMS is driven by both the extensive margin (percent of BMS patients) and the intensive margin (average number of BMS conditional on BMS patients), though only the latter is significant at 5%.[18]

So far, our specification assumes that the stent ratio posits a linear impact on the stent use. To accommodate the possibility that the impact of stent ratio is non-linear, we categorize the stent ratio of 2008 into tercile groups (high, medium and low), and re-estimate equation (1) by replacing $Ratio08_j$ with dummies of tercile groups. The three panels of Table A1 (in the appendix) presents the estimated marginal effects of the interactions between high and medium group dummy ($Ratio08^H$ and $Ratio08^M$) and the post-2009 dummy based on the full sample, the major teaching hospital sample, and the minor teaching hospital sample respectively. The bottom group (with the lowest third of Ratio08) is served as the baseline. Comparing results of Table A1 and Table 4, it is clear that results from tercile group dummies yield similar findings – the rate cut results

[18]Because the effect of the rate cut on stent use is concentrated on minor teaching hospitals, the full sample is too noisy to identify a significant effect on either the percent of BMS patients or the average number of BMS conditional on BMS patients (Columns 5 and 6 of Table 4 Panel A).

Table 5—Effect of the Rate Cut on DES Price (Margin 2, Stent Patients)

	All sample		Major teaching hospital		Minor teaching hospital	
Price of DES (log)						
$Ratio08_j \times Aft09_t$	0.013	0.02	-0.464	-0.119	0.432	0.155
	(0.193)	(0.115)	(0.173)	(0.154)	(0.197)	(0.118)
N	37,185	37,185	24,428	24,428	12,757	12,757
Patient characteristics	x	x	x	x	x	x
Year FE	x	x	x	x	x	x
Hospital FE	x	x	x	x	x	x
Model FE		x		x		x

Note: , **, *: significance at 1%, 5% and 10% level. Standard errors are in parentheses. Intercepts are not shown. All regressions control for age group dummies (60-, 60-70, 70-80, 80+), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospital.

in a larger impact on BMS than DES use. In addition, its impact concentrates on minor teaching hospitals rather than major teaching hospitals. Nonetheless, results of tercile groups suggest that the impact of rate cut on stent use is non-linear—the impact is much larger for patients admitted to top ratio group than those in medium ratio group.[19]

Another way to recover from the revenue loss due to the rate cut is to increase the price charged for DES (Margin 2). However, this strategy entails a tradeoff: raising DES price (for patient payment) will discourage patients from adopting DES. To understand how hospitals deal with this tradeoff, we regress the average price of DES charged for each stent patient on $Ratio08_j$ and its interactions with the post-2009 dummy and present results of Margin 2 in Table 5. Since one patient may use different brands and different models of DES in a hospital admission, we use the stent as the unit in the estimation of Margin 2.

The first three columns of Table 5 present the estimated λ for the full sample, the sample of major teaching hospitals, and the sample of minor teaching hospitals, all controlling for hospital fixed effects. Roughly 10% of DES models cannot be matched with the price constructed from hospital reports to the NHI,

[19]Another explanation is that the bottom group served as the baseline group which cancels out some impact of rate cut. As a result, the impact of the NHI rate cut appears only in patients admitted to minor teaching hospitals with high stent ratio.

and thus the observation number is lower than the total number of DES stents in the sample (see Appendix for details). While there seems to be no change on the average price of DES in the full sample, λ is estimated to be negative (-0.46) in the sample of major teaching hospitals and positive (0.43) in the sample of minor teaching hospitals, suggesting rather different pricing strategies between the two types of hospitals. However, all three estimates become insignificant once we control for stent-model fixed effects. Therefore, the different price reaction to the rate cut between major and minor teaching hospitals is probably confounded by their adoption of different stent models. In other words, hospitals do not raise the price of DES within the existing DES models. Rather, major and minor teaching hospitals may follow different strategies in new model adoption.

Again, we present the estimated coefficients of top and medium group and its interactions with the post-2009 dummy on the DES price for three different samples in the second panel of Table 5. Similar to the above, major and minor teaching hospitals have different pricing strategies, but when we control for model fixed effects, the coefficients either lose statistical significance or become negative.

To further understand new DES model adoption, we look at each hospital's aggregate DES stent usage in 2009-2010, and calculate what fraction of this aggregate is on new DES models that the hospital adopted on or after 2009.[20] We then regress this fraction on the hospital's $Ratio08$. As shown in Table 8, a hospital of higher $Ratio08$ is less likely to apply new DES models on stent patients, and this result is solely driven by minor teaching hospitals. Because this is a hospital-level regression with minimal controls, it is hard to tell whether this effect reflects a causal effect of the rate cut or other reasons that drive major and minor teaching hospitals to differ in DES model adoption. It is more plausible that hospitals are reluctant to raise price within a DES model because the NHI requires public posting of DES price and all price hike on DES must be absorbed

[20]Note that a hospital may adopt a DES model in 2009, even if that model has been available for adoption in 2008. We still count this case as the hospital's new DES adoption in 2009.

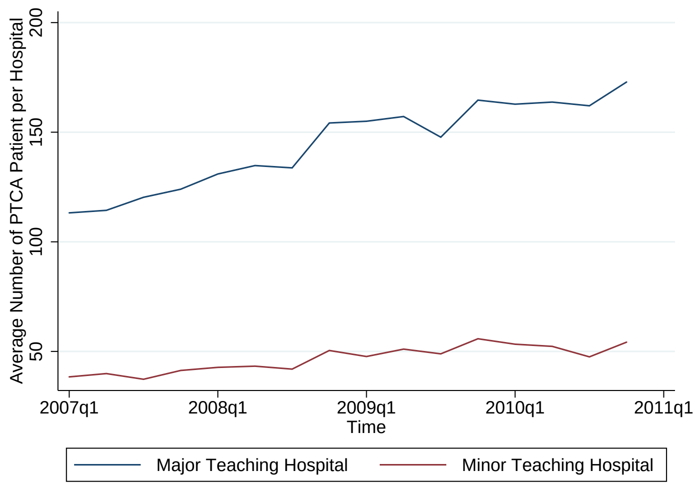

Figure 7. Average Number of PTCA Patient Per Hospital

by patient payment. The salience of DES price change could make price hike a publicity crisis for any hospital.

While the rate cut may or may not drive the difference in new DES model adoption, our earlier estimates do suggest that minor teaching hospitals respond to the rate cut by installing more BMS per patient but major teaching hospitals do not do so. One possible explanation is that major teaching hospitals are more capable of attracting new patients, and therefore less financially pressured by the rate cut. To explore this, Figure 7 presents the average number of PTCA patients per hospital over time, separated by major and minor teaching hospitals. The slope of major teaching hospitals is steeper than that of minor teaching hospitals, indicating that the patient share of major teaching hospitals continues to expand. A large base of stent patients might enhance the bargaining power for major teaching hospitals when negotiating input prices and newer models with stent manufacturers. By contrast, minor teaching hospitals have difficulty growing new patients, and hence have a greater incentive to exploit patients by inducing more stents per patient.

Table 6—Test the Endogeneity of Rate Cut on Stent Use (2007-8, Stent Patients)

	Margin 1				Margin 2
	# of DES	# of BMS	I(BMS>0)	# of BMS BMS patients only	ln(DES price)
All samples					
$Ratio07_j \times Aft08_t$	-0.002	-0.054	0.001	-0.081	0.129
	(0.103)	(0.103)	(0.065)	(0.082)	(0.148)
N	34,245	34,245	34,245	23,220	15,155
Major teaching hospitals					
$Ratio07_j \times Aft08_t$	-0.018	-0.083	0.020	-0.151	0.133
	(0.166)	(0.173)	(0.102)	(0.143)	(0.245)
N	19,486	19,486	19,486	12,184	10,376
Minor teaching hospitals					
$Ratio07_j \times Aft08_t$	-0.010	-0.002	0.002	-0.024	0.049
	(0.104)	(0.119)	(0.083)	(0.090)	(0.063)
N	14,759	14,759	14,759	11,036	4,779
Patient characteristics	x	x	x	x	x
Year FE	x	x	x	x	x
Hospital FE	x	x	x	x	x
Model FE					x

Note: Standard errors are in parentheses. Intercepts are not shown. Results control for age group dummies (60-, 60-70, 70-80, 80+), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospital. All count outcomes (e.g. # of bare or elut stents) are estimated by Poisson regression while others are estimated by linear ordinary least squares. Coefficients of Poisson regressions are expressed as marginal effects at means.

C. Robustness checks

One potential concern of using $Ratio08_j$ as a proxy for treatment intensity is that it might be correlated with other unobserved hospital-specific factors. To rule out this possibility, we conduct a placebo test using the pre-2009 sample. Focusing on 2007 and 2008, we include the interaction between a hospital's stent patient ratio in 2007 ($Ratio07_j$) and a post-2008 dummy in all regressions. Table 6 presents the placebo test results for the sample of all hospitals, major teaching hospitals, and minor teaching hospitals, respectively. The interaction of $Ratio07_j$ and the post-2008 dummy is statistically zero for the first and second margins, suggesting that the previously identified effects on the number of stents used per stent patient and the price of DES are likely driven by the 2009 rate cut.

Another way to justify the use of $Ratio08_j$ is checking whether the tercile groups of hospitals (in low, medium, and high $Ratio08$) follow similar time trends in key outcome variables before the treatment time (January 2009). We perform the pre-treatment trend test by quarter, using the bottom group as the baseline. For both the medium and high groups, we are able to pass the pre-treatment tests for the number of BMS per stent patient and whether a stent patient uses any BMS.[21] This suggests that our main results on the moral hazard response (in BMS use per stent patient) are likely attributable to the 2009 rate cut. In comparison, our pretreatment trend test fails for the price of DES, which reinforces the conclusion that we cannot relate the 2009 rate cut to discernible changes in DES price.

In another robustness check, we examine if our results vary by different sampling frames. In the first alternative sample, we exclude the third and fourth quarters of 2008; this could reduce the possible endogeneity in case hospitals anticipated the NHI rate cut before its formal implementation in January 2009. Next, the NHI also relaxed some restrictions of stent implant in 2009, and the most notable change is that NHI increased the maximum allowable number of stents per patient from 2 to 3 within a year.[22] To gauge if our results are affected by this policy change, we top-code the number of stents per patient as two after 2009, and rerun the regressions, which is our second alternative sample. In the third alternative sample, we drop hospitals with fewer than 50 stent admissions in a year, in case small hospitals with infrequent stent use are different from other hospitals.

Recall that for Margin 1 (number of stents used per stent patient) we only observe a significant effect of the rate cut for minor teaching hospitals. To save space, we show only the robustness results for minor teaching hospitals in Table 7. In all three alternative samples, we continue to find a positive effect of the rate cut on the number of BMS used per stent patient. The effect has a similar

[21] The p-value for the joint test of the medium group being similar to the bottom group is 0.11 for the number of BMS per stent patient and 0.65 for whether a stent patient uses any BMS. The corresponding p-values between the high group and low group are 0.33 and 0.88.

[22] There are some exceptions (urgent cases) for the maximum number of stents to be implanted, such as the inner membrane peeling length is greater than 50 mm.

Table 7—Robustness Checks on the Effect of the Rate Cut (Minor Teaching Hospitals Sample, Stent Patients)

	Margin 1				Margin 2
	# of DES	# of BMS	I(BMS>0)	# of BMS, only BMS patients	ln(DES price)
Excluding the third and four quarters of 2008					
$Ratio08_j \times Aft09_t$	-0.065	0.294	0.096	0.183	0.197
	(0.110)	(0.088)	(0.065)	(0.096)	(0.139)
N	30,799	30,799	30,799	22,022	11,201
Replacing patients installing more than two as two stents					
$Ratio08_j \times Aft09_t$	-0.072	0.192	0.102	0.052	0.155
	(0.094)	(0.066)	(0.056)	(0.061)	(0.118)
N	35,134	35,134	35,134	25,203	12,757
Excluding hospitals with less than 50 cases in a year					
$Ratio08_j \times Aft09_t$	-0.082	0.284	0.102	0.165	0.156
	(0.095)	(0.079)	(0.056)	(0.082)	(0.120)
N	35,134	35,134	35,134	25,203	12,733
Patient characteristics	x	x	x	x	x
Year FE	x	x	x	x	x
Hospital FE	x	x	x	x	x
Model FE					x

Note: Standard errors are in parentheses. Intercepts are not shown. Results control for age group dummies (60-, 60-70, 70-80, 80+), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospital. All count outcomes (e.g. # of BMS or DES) are estimated by Poisson regression while others are estimated by linear ordinary least squares. Coefficients of Poisson regressions are expressed as marginal effects at means.

magnitude as in our full sample except for the case that limits the maximum number of stents installed in a hospital admission after 2009 to two. Nonetheless, the marginal effect of BMS of the second row still has 66% of the size of the full sample of minor teaching hospitals, indicating the presence of inducement even accounting for the relaxed maximum number of stents installed by NHI in 2009. In all specifications, Margin 2 – the price of DES – is not responsive to the rate cut once we control for hospital and model fixed effects when we exclude hospitals with fewer than 50 stent admissions a year.

Table 8—Effect of the Rate Cut on New DES Models

	All sample	Major teaching hospitals	Minor teaching hospitals
% of 2009-2010 DES usage from new DES models post 2009			
$Ratio08_j$	-0.232	0.034	-0.273
	(0.094)	(0.191)	(0.110)
N	68	19	49

Note: Standard errors are in parentheses. Unit of observation is one hospital, using 2009-2010 data only.

V. Mechanism and Implication of Hospital Response

A. *Mechanism of hospital response*

Though we observe a surge of BMS use after the rate cut, it remains unclear how the surge is achieved. In our context, stents are implanted during a PTCA surgery, thus one can increase a patient's stent use by performing PTCA on more blood vessels, or applying more stents to each vessel treated in the PTCA. A distinction between the two may help us understand the underlying mechanism of stent use and shed light on the potential over-use of PTCA surgery. On the one hand, the marginal benefit of implanting more stents on the same blood vessel is probably lower than that of implanting a stent in a different vessel. On the other hand, PTCA surgery is reimbursed by the number of treated vessels (separately from stent reimbursement). It is possible that some of the PTCA treatment could be unnecessary if it is only added to justify unnecessary stent use.

To illustrate the distinction between the number of stents and the number of vessels, Figure 8 presents the average number of stents used per stent patients, separately by their number of treated vessels. Notice that the average number of stents is lower than the number of treated vessels, as some vessels receive PTCA treatment without implanting stents. From the figure, it is clear that the increase is small for patients with one vessel, moderate for 2 vessels patients, and the largest for patients with three vessels or above. This suggests that some of the increase in stent use following the NHI rate cut may be driven by an increase in stents per vessel, especially for those that received PTCA treatment for more

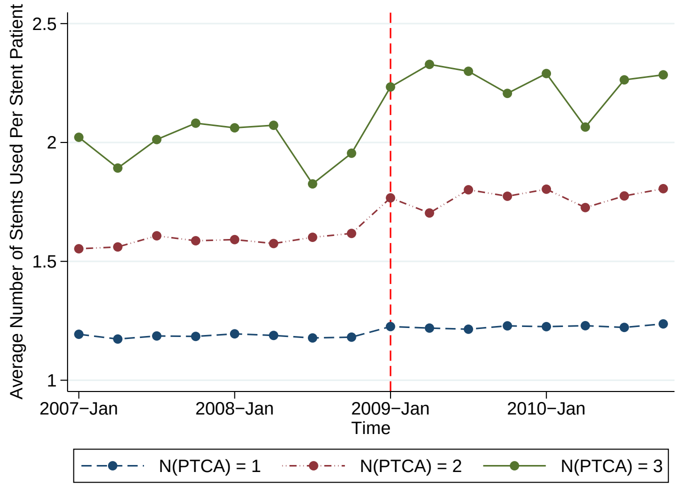

Figure 8. Average Number of Stents Used Per Stent Patient by the Number of Treated Vessels

than one vessel.

Turning to potential change in the number of treated vessels, we now focus on stent patients and examine the relationship between the number of vessels treated in a PTCA surgery and the stent ratio interaction term ($Ratio08_j \times Aft09_t$). By definition, a stent patient must have at least one vessel treated by PTCA. Hence, we construct two dependent variables on vessel volume – a dummy of whether a stent patient has PTCA on two or more (2+) vessels, and a dummy of whether a stent patient has PTCA on three or more (3+). We then regress them on $Ratio08_j \times Aft09_t$ respectively, according to equation (1).

The regression results are presented in the first two columns of Table 9. It is clear that, controlling for patient characteristics, year fixed effects and hospital fixed effects, a stent patient is more likely to report 2+ PTCA vessels after the rate cut. Consistent with our previous findings, such an increase appears mostly in minor teaching hospitals, rather than major teaching hospitals. However, we could not find any significant result when we use the dummy of 3+ vessels as the dependent variable. This suggests that the increase of PTCA vessels is driven by

Table 9—Regression Results on the Number of PTCA Vessels (Stent Patients)

	Dependent variable			
	vessels (2+)	vessels (3+)	# of stents per vessel	# of BMSs per vessel
Full sample				
$Ratio08_j \times Aft09_t$	0.09	0.008	0.067	0.103
	(0.045)	(0.015)	(0.058)	(0.062)
N	79,054	79,054	79,054	79,054
Major teaching hospitals				
$Ratio08_j \times Aft09_t$	0.108	0.003	0.108	0.003
	(0.101)	(0.034)	(0.101)	(0.034)
N	43,920	43,920	43,920	43,920
Minor teaching hospitals				
$Ratio08_j \times Aft09_t$	0.075	0.011	0.046	0.164
	(0.036)	(0.012)	(0.065)	(0.067)
N	35,134	35,134	35,134	35,134
Patient characteristics	x	x	x	x
Year FE	x	x	x	x
Hospital FE	x	x	x	x

Note: Standard errors are in parentheses. Intercepts not shown. Results control for age group dummies (60-, 60-70, 70-80, 80+), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospital. All regressions are estimated by linear probability model.

the change from one to two vessels, not from two to 3+ vessels. In other words, most increase in PTCA vessels come from the marginal patients that would have PTCA (and stent implant) on only one vessel before the rate cut.

In the third and fourth columns of Table 9, we present the relationship between the average number of stents per vessel, and the stent ratio interaction term ($Ratio08_j \times Aft09_t$). Controlling for all other factors, we observe the coefficient of the interaction term is not different from zero among major teaching hospitals but there is a positive effect among minor teaching hospitals. In short, the rate cut results in both an increased likelihood of 2-vessel PTCA treatment and an increase of BMS stents per vessel.

To what extent can we attribute the additional stent use to the increase of vessels treated in PTCA surgery? Based on our estimates, only minor teaching hospitals demonstrate this response and the effect corresponds to a 7.5 percent point increase in a stent patient reporting 2+ vessel treatment. Therefore, on average, a minor teaching hospital with the average stent ratio (65%) would observe a 4.88% (=0.075*0.65) increase for patients reporting 2+ PTCA vessels.[23] Given that 45% of hospitals are minor teaching hospitals, and 2-vessel patients on average use 0.28 more BMS than one-vessel patients,[24] an increase in reporting 2+ vessels adds about 9% of the total induced BMS (1568) in 2009.

TABLE 10—REGRESSION RESULTS ON THE NUMBER OF PTCA VESSELS (WITH DEMOGRAPHIC INTERACTIONS, STENT PATIENTS)

		Dependent variable: vessel (2+)				
		Male	Age (60-70)	Age (70-80)	Age (80+)	AMI
Full sample						
$Ratio08_j \times Aft09_t$	0.054					
	(0.048)					
$Ratio08_j \times Aft09_t \times$		0.006	0.018	0.028	0.030	0.045
		(0.010)	(0.013)	(0.014)	(0.017)	(0.016)
N	79,054	79,054	79,054	79,054	79,054	79,054
Major teaching hospitals						
$Ratio08_j \times Aft09_t$	0.073					
	(0.101)					
$Ratio08_j \times Aft09_t \times$		0.007	0.036	0.035	0.047	0.049
		(0.010)	(0.017)	(0.020)	(0.023)	(0.027)
N	43,920	43,920	43,920	43,920	43,920	43,920
Minor teaching hospitals						
$Ratio08_j \times Aft09_t$	0.047					
	(0.045)					
$Ratio08_j \times Aft09_t \times$		0.005	-0.004	0.018	0.010	0.042
		(0.017)	(0.021)	(0.018)	(0.024)	(0.018)
N	35,134	35,134	35,134	35,134	35,134	35,134
Patient characteristics	x	x	x	x	x	x
Year FE	x	x	x	x	x	x
Hospital FE	x	x	x	x	x	x

Note: Standard errors are in parentheses. Intercepts are not shown. Results control for age group dummies (60-, 60-70, 70-80, 80+), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospital. All regressions are estimated by linear probability model.

Who, among the stent patients, are more likely to experience an increase in the

[23]Notice that the percentage of 2+ vessels patients is approximately 28.3% in 2008, this corresponds to a 2.2 increase in absolute percentage points (from 28.3% to 30.5%) or a 7.7% jump in the relative term.

[24]Our results suggest the effect is significant for patients reporting from 1 vessel to 2 vessels, not from 2 to 3 vessels, since the coefficient of vessel (3+) is insignificant (column (2)). Therefore, we compare the stent number between patients reporting 2 vessels with 1 vessel.

number of PTCA vessels post the rate cut? To answer this question, in addition to having $Ratio08_j \times Aft09_t$ on the right hand, we further interact it with patient characteristics (e.g. age, sex, health condition), and present the results in Table 10. Each panel represents one regression, while each entry in the second row of the panel is the coefficient corresponding to the interaction of $Ratio08_j \times Aft09_t$ and the demographic variable in the column name. Results suggest that the increase in 2+ vessels does not vary by patient age and sex but is closely related to the urgency of patient's health. Relative to IHD and CHF, patients diagnosed with AMI are more likely to have an increase in PTCA vessels, and this effect is only significant for minor teaching hospitals. It looks like that the rate cut has motivated minor teaching hospitals to persuade patients to receive PTCA treatment on more vessels (and therefore install more stents) when they have acute and urgent heart conditions.

B. Revenue implication of hospital response

How much does the moral hazard behavior help hospitals recoup the revenue loss? In 2009, the government reduces the reimbursement rate of cardiac stents by approximately 7,000 NTD or 26%. Our results show that hospitals increase the use of BMS, but not that of DES. In addition, no evidence indicates that hospitals raise the DES price. Therefore, we focus on the induced use of BMS.

The upper panel of Table 11 shows our estimates based on the full sample (Scenario I). The rate cut results in an increase of 0.14 BMS per stent patient (0.21*0.65; marginal effect times the average stent ratio). Given that the total number of stent admissions in 2009 is 21,801 (Table 3), the number of induced BMS is 2,976, which is worth of 59.3 million NTD.

To understand how much stent revenue hospitals actually recoup, we need to first calculate hospitals' stent usage absent their motivation of boosting their BMS usage due to the policy. The actual number of BMS in 2009 (19,579) is inflated because it includes the induced demand, and subtracting the induced demand directly from the actual 2009 BMS number is not correct either. As one can see from Table 3, despite the jump in 2009, there is a steady decline in BMS per stent patient over time, since more and more patients opt for DES.

We take two steps to obtain the counterfactual revenue loss from stent. First, we obtain the coefficients of 2008 and 2009 year dummies in estimating the stent use equation (column 4, Table 4) to calculate the counterfactual BMS use per stent patient. The counterfactual figure equals to the number of BMS per stent patient in 2008, plus 2009 fixed effect minus 2008 fixed effect, while the difference of two year coefficients accounts for the change of other outside factors between 2008 and 2009 unrelated to the rate change. Our estimates show that the counterfactual BMS per patient in 2009 is 0.76 (0.87-0.13+0.02). Multiplying this number by the number of stent admissions in 2009, the total number of BMS without induced demand is 16,569.

In other words, the rate cut induces 18.0% (2,976 out of 16,569) more BMS in 2009. Likewise, the total number of BMS (without inducement) is 16,336 while the induced BMS is 3,141 or 19.2% in 2010. Once we have the counterfactual BMS number, we can calculate the revenue loss by adding up the number of BMS and DES stents times the NHI rate cut. Relative to the revenue loss, providers are able to recoup 30.5% and 30.6% of revenue loss from induced use of BMS in 2009 and 2010 respectively.[25] This estimate is conservative because it does not include the extra vessel treatment of PTCA in response to the rate cut, which seems to happen systematically in minor teaching hospitals.

[25] Our estimates show that the counterfactual BMS per patient in 2010 is 0.71 (0.87+0.02 -0.18). Multiplying this number by the number of stent admissions in 2010 (23008), the total number of BMS without induced demand is 16336.

Table 11—Effects of the Rate Cut on Hospital Revenue Due to Induced Demand

	2009			2010		
	Actual	Counterfactual	Induced	Actual	Counterfactual	Induced
			Scenario I			
All samples						
BMS	19579	16569	2976	19596	16336	3141
ELUT	11315	11315	0	12945	12945	0
Revenue loss (Millions)		194.3			205.0	
Recouped surgery revenue (Million)			0.0			0.0
Recouped stent revenue (Million)			59.3			62.6
Recouped Revenue (%)			(30.5%)			(30.6%)
			Scenario II			
Major teaching hospitals						
BMS	10001	10001	0	9942	9942	0
ELUT	7213	7213	0	8147	8147	0
Revenue loss (Millions)		120.5	0		126.6	0
Minor teaching hospitals						
BMS	9578	8345	1568	9654	8456	1589
ELUT	4102	4102	0	4798	4798	0
Revenue loss (Millions)		87.1			92.8	
Recouped surgery revenue (Million)			7.7			8.1
Recouped stent revenue (Million)			31.3			31.7
Recouped revenue (%)			(18.8%)			(18.1%)

Note: The "Actual" column lists the number of BMS and ELUT installed in that year. The "Counterfactual" column lists the simulated number of BMS and ELUT stents used in that year, excluding induced demand. The "Induced" column lists the estimated number of induced BMS stents in 2009 and 2010 respectively. Revenue loss calculates hospitals' expected loss of stent revenue without the induced demand, which equals to the number of total stents (counterfactual) times the 2009 NHI rate cut (7k NTD). The recouped revenue equals to the number of induced BMS stent times NHI reimbursment rate (around 20K NTD).

The lower panel of Table 11 shows the estimates that separate the impact by major and minor teaching hospitals. Recall from Table 4 that the impact of rate cuts concentrates in minor teaching hospitals: the rate cut results in an induced use of BMS by 0.19 per patient (0.29*0.65; marginal effect times the average stent ratio). Multiplying by the number of admission in minor teaching hospitals, the induced BMS is 1,568, worth of 31.3 million NTD. Additionally, the rate cut induces 2.2% more patients reporting 2+ vessels in PCTA surgery. Since the reimbursement gap between two vessels and one vessel is 16k NTD, our results indicate that minor teaching hospitals can recoup about 12 million from the PTCA Surgery.[26]

Following the same method, we calculate the counterfactual BMS use as 8,345 and the total revenue loss as 207.6 million in 2009. Relative to the revenue loss due to the NHI rate cut, providers are able to recoup 18.8% of the revenue loss through induced use of BMS and more vessels treated by PTCA in 2009. Likewise, in 2010, minor teaching hospitals induced BMS use by 18.1% (1589 out of 8456) and recouped 20.2% of revenue loss from the induced BMS and PTCA surgery.

VI. Conclusion

We examine how hospitals respond to a 2009 rate cut in Taiwan's government reimbursement for cardiac stent. Because the rate cut is within a top-up design of government-provided health insurance, it provides a rare opportunity to demonstrate the key tradeoff between curbing health care spending and hospital moral hazard. We look at two margins: the number of stents used per stent patient, and the patient-out-of-pocket price of DES. We only find evidence for hospital moral hazard in the first margin: hospitals, especially minor teaching hospitals, increase the number of BMS stents used per stent patient right after the rate cut.

According to our full sample estimates, on average, we find the rate cut results

[26]The NHI reimbursed rate of PTCA surgery are 44k, 60k and 76k for one, two and three vessels, respectively, between 2007 and 2010.

in an induced use of BMS by 0.14 per stent patient (0.21*0.65; marginal effect times the average stent ratio). In comparisons with no induced demand estimates, the induced use results in 18-19% of additional BMS, amounting 59.3 and 62.6 millions NTD more NHI reimbursement in 2009 and 2010 respectively. Given that NHI rate cut for cardiac stents reduces by 26% in 2009, hospitals' moral hazard accounts for about 30% of the total stent revenue loss should the hospitals not engage in such moral hazard. Results on subsamples generate more conservative estimates, with hospitals recouping approximately 20% of total revenue loss, from both the increase in BMS use and the increased vessel treatment under PTCA. Regardless, all these estimates suggest that the 2009 rate cut is still effective in reducing NHI claims for cardiac stents, although this effect is partly offset by hospital moral hazard.

Our study has a number of limitations. First, because the NHI rate cut applies to all hospitals at once, we do not have a clean control group. Our results hinge on the assumption that a hospital's ratio of stent patients before the rate cut is a good proxy for the intensity of the policy treatment for that hospital. Second, our study focuses on patient level decisions such as whether to use any stent, how many and which type of stents to use. Our data also contains hospital level decisions, for example, which stent model to adopt for the whole hospital. But without information on the negotiation between stent suppliers and hospitals, it is difficult to examine the timing of model drop, model adoption, and model upgrades explicitly. This question is worth exploring in future research. Finally, our empirical setting is universal health insurance of Taiwan, thus our results may not be generalizable to other countries or to other non-government insurance programs.

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Appendix

Price Matching Procedures

Because the NHI covers partial payment of DES, hospitals are required to disclose the additional payments of DES charged to patients (e.g. on the hospital's website). In addition, the NHI routinely collects price information of DES stents at every hospital. In the first two years, the frequency of price collections is every two months. Later it reduces to every six months given the prices of drug-eluting stents do not change frequently. To facilitate price comparison across hospitals, the NHI launched a website in 2012, where every hospitals is asked to report the prices of DES stents once there are price changes.

We obtain DES price by stent type and brand directly from the NHI. The data contains 12,827 price report observations, including 44 DES models from 102 hospitals spanning from Dec, 2006 to Nov, 2013. On average, each hospital has around 126 price reports, and each hospital-stent model combination has 8 price reports. To overcome the missing data between adjascent report, we take three steps to construct the hospital-model-quarter price data. First, we calculate the average price reported in each quarter (if there is any) for each hospital-model combination. In total we observe 7,771 such combination, with approximately 40% of duplicated price reports eliminated. Next, we fill in the gaps by assuming that hospitals do not change their price between their consecutive price reports for the same stent model. Finally, we observe that some stent usage occurred even before the first price reporting date. We suspect that hospitals might be late to submit their price reports. To match these observations, we assume that, for each stent model, hospitals charge the same price as their first report up to four quarters before their first reporting date. The price spectrum constructed this way matches 89.99% of DES usage records in the NHI claim data.

The matching rate is lower (77%) if we do not impute any price for DES usage before the hospital's first price report, and higher (94.74%) if we impute all missing

DES prices before the first report (it is not 100% because some DES models show up in the claim data but never occur in the price report of the corresponding hospital). Our results on DES price are not sensitive to how we impute the missing prices.

Supplemental Tables

Table A1—Effects of the Rate Cut on Number of Stents Used per Stent Patient (Margin 1, by Tercile Group of *Ratio*08, Stent Patients)

	# of DES	# of BMS	# of DES	# of BMS	I(BMS>0)	# of BMS BMS patients only
All samples						
$Ratio08^H \times Aft09_t$	-0.022	0.207	-0.007	0.070	0.023	0.046
	(0.042)	(0.024)	(0.046)	(0.022)	(0.022)	(0.030)
$Ratio08^M \times Aft09_t$	-0.034	0.022	-0.049	0.013	0.023	-0.031
	(0.038)	(0.039)	(0.033)	(0.032)	(0.022)	(0.025)
N	79054	79054	79054	79054	79054	51693
Major teaching hospitals						
$Ratio08^H \times Aft09_t$	-0.025	0.190	0.029	0.043	0.003	0.055
	(0.068)	(0.051)	(0.082)	(0.030)	(0.035)	(0.054)
$Ratio08^M \times Aft09_t$	-0.037	-0.083*	-0.075*	0.015	0.037	-0.048
	(0.082)	(0.046)	(0.043)	(0.043)	(0.030)	(0.033)
N	43920	43920	43920	43920	43920	26490
Minor teaching hospitals						
$Ratio08^H \times Aft09_t$	-0.048	0.211	-0.044	0.100	0.045	0.038
	(0.028)	(0.036)	(0.036)	(0.030)	(0.022)	(0.029)
$Ratio08^M \times Aft09_t$	-0.115	0.183	0.019	0.012	0.002	-0.01
	(0.036)	(0.041)	(0.060)	(0.047)	(0.036)	(0.038)
N	35134	35134	35134	35134	35134	25203
Patient characteristics	x	x	x	x	x	x
Year FE	x	x	x	x	x	x
Area FE	x	x				
Hospital FE			x	x	x	x

Note: Standard errors are in parentheses. Intercepts are not shown. Regressions control for age group dummies (60-, 60-70, 70-80, 80+), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospital. All outcomes (except for I(BMS>0) are estimated by Poisson regression while I(BMS>0) is estimated by linear probability model. Coefficients of Poisson regressions are expressed as marginal effects at means.

Table A2—Effect of the Rate Cut on DES Price (Margin 2, Stent Patients)

	All sample		Major teaching hospital		Minor teaching hospital	
Price of DES (log)						
$Ratio08^H \times Aft09_t$	-0.003	0.007	-0.102	-0.015	0.127	0.037
	(0.053)	(0.030)	(0.051)	(0.045)	(0.060)	(0.032)
$Ratio08^M \times Aft09_t$	-0.069	-0.084	-0.133	-0.091	0.027	-0.097
	(0.054)	(0.043)	(0.055)	(0.056)	(0.034)	(0.045)
N	37,185	37,185	24,428	24,428	12,757	12,757
Patient characteristics	x	x	x	x	x	x
Year FE	x	x	x	x	x	x
Hospital FE	x	x	x	x	x	x
Model FE		x		x		x

Note: Standard errors are in parentheses. Intercepts not shown.Regression results control for age group dummies (60-, 60-70, 70-80, 80+), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors on which they are based allow for hospital clustering. All regressions are estimated by linear probability model.