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ABSTRACT

Since 2006, Taiwan's National Health Insurance (NHI) has covered the full cost of baseline treatment in cardiac stents (bare-metal stents, BMS). Still, it requires patients to pay the incremental cost of more expensive treatments (drug-eluting stents, DES). Within this “top- up” design, we study how hospitals responded to a 26% cut of the NHI reimbursement rate in 2009. We find that hospitals that were more revenue reliant on cardiac patients increased BMS usage per stent patient by 0.05 or 6% but not DES usage. In addition, while the average of DES prices remains almost unchanged, minor teaching hospitals that were more revenue reliant on cardiac patients raised the DES price by 12.6%, and therefore could recoup at most 32.7% of the revenue loss from the NHI rate cut in 2009-2010. Overall, the rate cut was effective in reducing NHI expenditure without any substantial changes in patient outcomes, although some minor teaching hospitals made moral hazard adjustments in response.

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1 Introduction

Many countries face a major challenge: constraining rising healthcare costs while providing sufficient medical coverage and treatment choices. In practice, one option is to cover all types of treatment ("full coverage"), which fits patients' 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"), alleviating the moral hazard problem but excluding 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.[3] Ideally, a top-up design could help patients with basic coverage regardless of the treatment they choose and attenuate the moral hazard problem because 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, 2020; Marone and Sabety, 2022), but more evidence is needed for provider practices in this design. For instance, healthcare providers could raise the price difference to exploit patients' willingness to opt for more expensive treatments. If this occurs, it could limit patient access to more expensive treatments and reduce consumer welfare. It is also unclear whether the top-up design attenuates moral hazard.[4] Without knowing

[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 2023, 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] A comparable proposition is presented in the book "We've Got You Covered: Rebooting American Health Care", where the authors propose a dual-layered health insurance system to overhaul the American healthcare system. The first layer would ensure that every American receives a fundamental level of medical care that is both automatic and cost-free. The second component involves individuals having the choice to purchase supplementary coverage in addition to the basic coverage (Einav and Finkelstein, 2023).

[4] Einav and 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.

the provider's response to the top-up design, it is difficult to fully evaluate the welfare consequences of this reimbursement scheme.

In this study, we evaluate hospitals' treatment practices from 2007 to 2010, using a top-up design based on information collected from the Taiwan vascular stent market. We choose this market for three reasons. First, it has implemented the top-up design since October 2006 based on two major vascular stent types in our observation period: bare metal stent (BMS) is the baseline, and drug-eluting stent (DES) serves as the better option, which adds a drug layer over the metal to slow down the blood vessel reclogging.[5] Both stent types are applicable for most patients, but DES is more expensive than BMS, leading to a debate on DES's cost-effectiveness (Bagust, 2006).[6] Under the top-up design, patients must pay the incremental cost for any DES use, and each hospital administers such costs independently.[7] Abundant inpatient records on BMS and DES make it feasible to compare the usage of these two types of treatment.

Second, vascular stents are the fastest-growing and highest-paid segment among all medical services under top-up pricing in Taiwan. The number of implanted stents increased by 82% in four years, from 20,243 in 2007 to 36,834 in 2010. In addition, the total PTCA payments, including National Health Insurance (NHI) reimbursement for stents, PTCA surgeries, and patients' out-of-pocket payments for DES, exceeded 5 billion NTD in 2014 (1 USD is approximately 30 NTD),[8] accounting for 1% of the total NHI spending (520 billion NTD). The rapid adoption and massive scale of reimbursement increases make the stent market well-suited for evaluating hospital practices in a top-up reimbursement system.

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

[6] 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.

[7] On average, a DES costs the patients about 60,000 NTD or approximately $2000 (1 USD = 31 NTD)

[8] 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

Third, our data period (January 2007–December 2010) covers one major reimbursement rate cut from 27,000 to 19,940 NTD (-26%) per stent in January 2009.[9] Hospitals anticipated the timing but not the exact scale before the adjustment, so we treat the rate cut as exogenous. This rate cut reduced hospitals' revenue per stent unit implanted, which could motivate hospitals' adjustments to recoup revenue loss regarding PTCA patient enrollment, DES pricing, and stent usage (Yip, 1998; Gruber and Owings, 1996; Dafny, 2005). This shock provides an opportunity to evaluate the hospitals' management of various treatment margins under top-up pricing.

Our data were constructed from two components of the Taiwan NHI records. We first collected the patient-admission-level claim records of every patient who underwent percutaneous transluminal coronary angioplasty (PTCA) between 2007 and 2010 in Taiwan. For each patient in the record, we recorded their demographics (sex, age, and general health condition) and treatment details, including the brand, manufacturer, and quantity of each stent used during surgery. We further supplemented these medical record data with patient-paid price data for the DES models from hospitals' periodic public reports in compliance with NHI regulations. We constructed the hospital-model-level price spectrum by assuming invariant prices between consecutive reports for the same hospital-stent model combinations, which yielded a 90% matching rate with the patients' claim records of DES usage. In our analytical sample, we observe 157,401 patients undergoing PTCA. Approximately two-thirds of these patients (75,738) received at least one stent implantation, and approximately 38% and 65% of these surgeries adopted at least one DES and BMS, respectively.[10]

We utilize the 2009 reimbursement rate cut shock to identify hospitals' multi-margin management incentives. To examine hospitals' responses to the rate cut, we construct a ratio dummy of stent patients to PTCA patients in each hospital in 2008 ($Ratio08$) before the rate cut as a proxy

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

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

for hospitals' sensitivity to a rate cut. Our intuition is that hospitals with a higher ratio of stent patients were subject to larger revenue losses from the rate cut and therefore had a stronger incentive to recover from revenue loss. To facilitate the analysis, we further categorize each hospital into the "higher ratio" or "lower ratio" group based on whether its $Ratio08$ was located in the upper half of all samples in 2008. We correlate each hospital's $Ratio08^H$ dummy with three potential margins of adjustment: the likelihood of a PTCA patient receiving any stent treatment, the average number of stents used per stent patient, and the patient-paid price for each DES model.

Our analysis yields several key results. First, higher-ratio hospitals significantly increased their patient-level stent usage relative to lower-ratio hospitals, mostly for BMS, after the 2009 rate cut, without generating any substantial changes in patient outcomes. On average, for each patient that uses any stents, the number of BMS increased by 0.052 or 6%. In contrast, the usage of DES did not show a significant differential increase in the higher-ratio hospitals.

Second, hospitals generally refrained from increasing the price of DES to offset the rate reduction in 2009. We surmise that hospitals were reluctant to increase DES prices, particularly for existing stent models, possibly due to the National Health Insurance's (NHI) requirement for public disclosure of DES prices as well as concerns over their social reputations. Nonetheless, despite the average price of DES remaining stable, we observe a variation in DES pricing between major and minor teaching hospitals: within minor teaching hospitals, those with $Ratio08^H$ have on average increased the DES price by 12.6% after the rate cut than those without $Ratio08^H$. This suggests that minor teaching hospitals may use DES price increase to mitigate revenue loss from the rate cut. In comparison, the corresponding estimate on major teaching hospitals is negative but fails to pass the pre-treatment trend test, and thus it difficult to infer the effect of the rate cut on the DES pricing strategy of major teaching hospitals.

Third, our estimates suggest a sizable response to the rate cut. For example, the increased

BMS use and the increase in DES price helped minor teaching hospitals to recoup at most 32.7% of their 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 implemented a rate cut and both DES and BMS are covered in the insurance.

Our study contributes to two strands of literature. The first strand empirically examines providers' responses to financial incentives. (See McGuire (2000) for a review). Numerous studies have exploited reimbursement variations to identify the impact of a rate change on healthcare utilization (Gruber and Owings, 1996; Yip, 1998; 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, 2020). One direct study on stent price is by Deo et al. (2020), who showed that private hospitals increased PTCA procedures after India put price caps on cardiac stents in 2017 (both BMS and DES). In addition to providing another example, we explore how hospitals might adjust the price and quantity of medical devices to recover revenue loss due to the insurer's rate cut.[11]

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) explored the optimal insurance coverage of a top-up design for different treatments of a given disease and quantitatively calibrated the social welfare under different insurance designs. Based on a simple model of health demand, Shepard, Baicker and Skinner (2020) investigated the impact of various insurance designs on income inequality, medical technology growth, and distorting taxes. These studies highlight the advantage of the top-up design but ignore the possibility that health providers might have different incentives to adjust under exogenous and negative revenue

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

shocks. We provide empirical evidence of hospital moral hazards using a specific top-up design to fill this gap.

The remainder of this paper is organized as follows: Section 2 describes the industry background of vascular stents and the health system in Taiwan, and provides the summary statistics. Section 3 presents the estimation model and results. Section 4 discusses the revenue decomposition and mechanism. Finally, Section 5 concludes the paper.

2 Industry Background and Summary Statistics

In this section, we first describe the institutional details of cardiac surgery and the top-up payment employed by Taiwan's NHI, and then provide summary statistics for the sample we use.

2.1 PTCA and Stent Implantation Surgery

Patients with coronary atherosclerosis may experience artery clogging and hypoxia, and if not treated properly, the stenosis will be completely blocked, leading to life-threatening myocardial infarction or cardiac arrest. The typical treatment methods for coronary clotting include simple drug therapy, percutaneous transluminal coronary angioplasty (PTCA), and coronary artery bypass grafting (CABG). Simple drug therapy only applies to patients with minor conditions. CABG surgery involves reimplanting the patient's blood vessels through open-chest surgery, with a relatively high risk of surgery and recovery. In contrast, PTCA is less invasive and more responsive, requires a shorter hospital stay, and has gradually replaced CABG in treatment recommendation (Cutler and Huckman, 2003).

PTCA was originally a one-time balloon dilation of the clotting blood vessel; nonetheless, the chance of restenosis due to retraction and tissue hyperplasia remains as high as 30-50%. A coronary stent implantation is then introduced to support the stenotic coronary artery after PTCA balloon dilation, which reduces the restenosis rate to 10-20% (Dihu et al., 2011). The bare metal stent (BMS), typically made of stainless steel or cobalt-chromium alloy, was first introduced among all stent models. BMS is inexpensive and effective in lowering the restenosis rate; however, the stent implantation process can damage the endothelial cells of blood vessels and cause additional cell proliferation. To alleviate this problem, manufacturers have coated the stent model with various drug components and introduced a drug-eluting stent (DES) that slowly releases drugs that inhibit cell proliferation. Although long-term results are not yet available, it has been reported that DES, compared with BMS, lowers the rate of restenosis by 5% to 10% in five years (Morice et al., 2007; Dangas et al., 2010; Dihu et al., 2011). Therefore despite its higher price and additional requirements for doctors' treatment experience (to select the appropriate DES model), there has been a steady increase in DES usage over time during our sample period.

Given these medical options, the typical treatment procedure for patients diagnosed with coronary atherosclerosis is as follows. First, the physician chooses simple drug therapy, open-chest surgery (CABG), or simple balloon dilation (PTCA). Next, if PTCA is selected, the doctor decides whether to implant a stent during the PTCA process, or only implement a one-time balloon dilation with no sustaining devices. Finally, if a stent is adopted, the doctor will choose the type of stent, either a BMS or DES, as well as its brand and quantity. Doctor treatment suggestions are not mandatory and may be reversed based on patient preferences, especially regarding the implantation of expensive DES models. Given the limited adoption of CABG and simple drug therapy, we only collected records of patients who chose PTCA in the first stage, with treatment details in the following two stages of balloon dilation and stent usage.

2.2 Top-Up Design and Reimbursement Rate Cut in 2009

Taiwan established the National Health Insurance (NHI) in 1995 with two primary goals: to provide all citizens equal healthcare access and control total health spending reasonably (Taiwan Council of Economic Planning and Development, 1990). The NHI provides a comprehensive benefits package to patients, from conventional outpatient and inpatient services to preventive medicine, prescription drugs, dental services, and Chinese medicine to achieve equal access. In addition, the NHI charges a very modest cost for common treatment options: $5 for clinic visits, $8-$15 for hospital visits, and a 10% coinsurance rate for inpatient care (capped at 10% of the average national income per person).[12]

This healthcare system covers the patients' treatment costs, but at the expense of increasing the healthcare budget. To address it, the NHI takes two measures: a top-up design and a fixed-markup reimbursement scheme. In 2006, a top-up design started to cover 11 categories of expensive medical devices, including cardiac stents. Hospitals are reimbursed by the NHI for each implanted cardiac stent based on the average cost of bare metal stents (BMS) with a fixed markup (explained below).[13] The average additional cost for DES implantation was approximately 60,000 NTD (approximately 2,000 USD). All other costs associated with stent treatment, including PTCA balloon dilation and implantation surgery, were fully reimbursed and did not require patient payment. Despite the cost differences, there was an increasing preference for DES use over time, owing to its higher potential effectiveness in recovery. The percentage of stent patients using DES increased from 37% in 2007 to 58% in 2016 in Taiwan.

Apart from the top-up arrangement, the NHI has established a fixed-markup payment plan for hospital reimbursement, which calculates the reimbursement for medical devices based on their

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

[13] The difference in BMS cost across models and hospitals are negligible.

average cost throughout Taiwan in the last two to three years, in addition to a fixed markup (typically 20%). Hospitals can negotiate the input prices of medical devices with medical suppliers individually. This fixed markup scheme helps prevent hospitals from being overcompensated for any additional input costs they may incur.[14] The reimbursement calculation is based on the average input costs of all hospitals in Taiwan. Therefore, we ignore the strategic motivation to influence future reimbursement rates when hospitals negotiate their wholesale charges with medical device manufacturers.

Our study examines the impact of a policy shock that occurred when the NHI reduced the reimbursement rate for BMS. This reduction took effect on January 1, 2009, and decreased the reimbursement for each cardiac stent from 27,000 NTD to 19,940 NTD. This reduction continued until the next adjustment was made in January 2012. The policy change resulted in an immediate reduction in revenue for hospitals, as they received lower reimbursements for each stent implanted after 2009. As hospitals typically maintain their revenue at a certain level, this rate reduction creates an opportunity to identify how they manage their revenue across different margins, including enrollment of stent patients from PTCA patients, stent category choices between BMS and DES, and the DES price charged for stent patients.

2.3 Hospitals in Taiwan

Only major and minor teaching hospitals in Taiwan can perform PTCA surgeries and cardiac stent implantation. Major and minor teaching hospitals differ in size and other dimensions: on average, a major hospital has 1611 hospital beds, almost double the size of that of minor teaching hospital (841). Almost all major teaching hospitals locate in large, urban areas with high population den-

[14] Hospitals are permitted by the NHI to retain the difference between the reimbursed payment and the input cost, but in exchange, they must provide their input costs to be utilized in calculating the reimbursed payment of medical devices in the subsequent stage.

sity[15]. Conversely, while over half of minor teaching hospitals are also located in densely populated areas, a significant number of them, predominantly owned by the government, serve in remote or suburban locations with fewer residents.

Probably because of these differences, minor hospitals often operate on a thinner profit margin than major hospitals, which makes them more vulnerable to revenue losses as a result of the NHI rate cut. More specifically, the NHI compensates major teaching hospitals at a rate approximately 5% higher than that provided to minor teaching hospitals for the same category of hospital admissions. For instance, in 2015, the fee for a diagnostic evaluation per inpatient day was NT353 at major teaching hospitals and NT333 at minor teaching hospitals (NT30 for 1 USD). Importantly, the disparities in size and location allow major teaching hospitals to achieve greater revenue and profit margins, thus better equipping them to withstand economic fluctuations.

In addition, public or non-profit hospitals are more likely to cross subsidize between different departments or different types of patients. To the extent that other parts of a public or non-profit hospital may count on stent revenue from the cardiac department to cover their operation costs, the NHI rate cut may motivate different responses from different types of hospitals.

In 2010, we observe in total 19 major hospitals and 49 minor teaching hospitals conducting any stent surgeries. By definition, the distribution of patients (and stent surgeries) is uneven across hospitals. For example, in 2010, more than 57.70% of stents were implanted in major hospitals. Among stent surgeries performed in the 49 minor hospitals, 94.86% are concentrated in the 36 largest minor hospitals, and 13 smallest minor hospitals account for only 5.14% of these stent surgeries. As detailed below, our final analysis sample excludes a few minor hospitals with very low volumes in stent surgery, because they are subject to idiosyncratic fluctuations and are not always comparable to other minor hospitals.

[15] As of 2012, there were 19 major teaching hospitals, all situated in large urban areas with the exception of one located in the eastern part of Taiwan.

2.4 Data Description and Summary Statistics

We collected our data from two sources. First, we collected hospital claims records of all patients receiving PTCA surgery from the Taiwan NHI database between January 2007 and December 2010. These medical claims contain detailed information on inpatient admissions, including patient demographics (sex, date of birth, and general health conditions), hospital characteristics (number of beds, teaching hospital status, and profit status), diagnoses, performed surgeries, installed medical devices (e.g., stents), and the reimbursement amount paid by NHI per stent. We also observed unique identifiers for the doctor and hospital in each inpatient admission record, allowing us to control for provider fixed effects. For each PTCA patient who used at least one stent, we obtained information about all the stents used, including their manufacturers, stent model ID, and stent model type (BMS or DES) during the surgery. Based on inpatient records, we constructed dummies indicating whether a patient was readmitted to hospital within one and three months post the PTCA surgery, or died within one, three, and six months.

A key missing piece of information from these medical claim records is the price patients pay for the DES models, which was not included in the hospitals' reimbursement reports to the NHI. Relying on hospitals' mandatory public reporting of all medical expenses charged to patients, which the NHI required to promote transparency in pricing, we constructed the DES price spectrum as follows: We collected price reports on cardiac stents from all hospitals in Taiwan during the sample period (2007 to 2010). Then, for the same hospital-DES model combination, we assumed its price was invariant up to four quarters between consecutive reports. If the gap was longer than four quarters, we treated the price after four quarters within the gap as missing. To account for any delay in hospitals' initial price reporting, we assumed that the first reported price of each hospital-DES model was effective within four quarters of the first reporting date, which completed the construction of price spectrum. We then matched this price spectrum with hospital claims data.

Over 90% of DES implantations were matched with their corresponding prices.

Finally, we applied several refinements to the data. First, because each patient record reports up to three most used stent model brands, we cannot tell the model and brand name of the stents beyond this limit. Thus, we had to limit our analysis to the three most used stent model brands in a patient's hospital admission. Note that this did not restrict the stent quantity to three. For example, a patient may use three stents of brand A, two stents of brand B, two stents of brand C, and one stent of an unknown brand. All seven stents under brands A, B and C are included in our analysis. Of all stent procedures in our sample, only 0.62% of patients use 3 or more stent brands so we believe this data limitation has minimal impact.

Second, we limited our analysis to hospitals that conducted at least 75 PTCA cases and 50 stent cases annually for four consecutive years between 2007 and 2010. This ensures that our analysis was not driven by hospitals that had few stent surgeries and thus did not count on these surgeries for hospital revenue. While our restrictions reduced the number of hospitals in our sample by 15%, they only dropped less than 5% of the total observations because the majority of excluded hospitals were smaller ones.[16]

To investigate hospitals' response to the reduction in NHI reimbursement, we analyze patient samples: those who underwent PTCA at hospital admission (PTCA sample), and those who underwent stent implantation during PTCA surgeries (Stent sample). Table 1 presents patient characteristics and stent surgery summary for these two samples separately. PTCA admissions increased from 54,483 in 2007-8 to 61,257 in 2009-10. Within the PTCA patient population, the percentage of patients receiving stents also increased from 61.1% to 69.3%, resulting in 33,278 stent cases in 2007-08 and 42,460 stent cases in 2009-10 respectively.

The left section of Table 1 displays the hospital and patient characteristics of the PTCA sample

[16] In 2010, there are in total 19 major teaching hospitals, and 49 minor teaching hospitals conducting stent surgeries. After the sample selection, our analysis consists of 19 major teaching hospitals and 38 minor teaching hospitals. These hospitals account for 95.04% of PTCA patients and 95.81% of stent patients in the NHI records.

Table 1: Summary statistics of PTCA and stent patients

	PTCA patients		Stent patients	
	2007-2008	2009-2010	2007-2008	2009-2010
Hospital teaching status				
Major teaching hospital	57.8%	57.3%	58.6%	57.5%
Minor teaching hospital	42.2%	42.7%	41.4%	42.5%
Hospital ownership status				
For-profit	7.7%	7.2%	7.0%	6.9%
Non-profit	63.5%	63.9%	63.2%	64.7%
Public	28.8%	28.9%	29.8%	28.4%
Patient demographics				
Male	74.9%	74.3%	74.9%	74.3%
Age (<60)	35.8%	35.8%	35.3%	35.0%
Age (60-70)	26.1%	25.9%	25.7%	25.7%
Age (70-80)	27.6%	26.3%	27.4%	26.2%
Age (>80)	10.5%	12.0%	11.5%	13.1%
Patient health Status				
Acute myocardial infarction (AMI)	25.3%	25.3%	30.3%	29.5%
Congestive heart failure (CHF)	1.9%	1.7%	1.7%	1.7%
Ischemic heart disease (IHD)	65.8%	63.6%	62.4%	61.6%
Charlson index	0.88	0.90	0.97	0.97
PTCA implanted vessels (#)				
1	72.9%	71.9%	68.0%	68.1%
2	24.2%	25.1%	28.1%	28.2%
3+	3.0%	3.0%	3.9%	3.7%
% Stent patients	61.1%	69.3%	100.0%	100.0%
N	54,483	61,257	33,278	42,460

Notes: The stent sample included patients admitted for PTCA and underwent vascular stent implantation between 2007 and 2010. Teaching status of hospitals are defined by hospital accreditation conducted every three years. Charlson Comorbidity Index is the most widely used comorbidity index for estimating the risk of death from comorbid diseases.

before and after rate reduction. While our sample consists of 19 major teaching hospitals and 38 minor teaching hospitals, more than 60% of inpatient observations came from major teaching hospitals. As a result, a major teaching hospital recruited more than twice the number of PTCA patients and three times more stent patients than a minor teaching hospital on average.

Slightly under 30% of patients were admitted to public hospitals, whereas over 60% opted for non-profit hospitals. The teaching and ownership status proportions remained virtually constant before and after the rate reduction. Likewise, no significant changes are observed in patient characteristics before and after the rate reduction, including age, gender, admission diagnosis (AMI, IHD, or CHF), or the Charlson index (ranging from 0 for healthy to 6 for death).[17] Additionally, no apparent changes are found for PTCA patients when we examine the number of treated vessels during the surgical procedure. PTCA and stent patients demonstrated a similar distribution of teaching and ownership status. However, they differed in AMI and Charlson index, indicating that stent patients may have worse health conditions.

Table 2: Summary statistics of stent usage before and after the rate cut

	All		High		Low	
	2007-08	2009-10	2007-08	2009-10	2007-08	2009-10
Installed stents (per patient)						
# of stents	1.33	1.42	1.36	1.46	1.29	1.36
	(0.59)	(0.71)	(0.61)	(0.74)	(0.55)	(0.65)
# of bare metal stents	0.87	0.87	0.90	0.93	0.83	0.77
	(0.76)	(0.86)	(0.78)	(0.89)	(0.72)	(0.79)
# of drug eluting stents	0.46	0.55	0.46	0.53	0.45	0.59
	(0.70)	(0.78)	(0.71)	(0.78)	(0.69)	(0.78)
% of DES only patients	32.4%	37.3%	32.0%	34.8%	33.0%	41.0%
% of BMS only patients	64.4%	58.8%	64.5%	60.9%	64.5%	55.6%
% of BMS+DES patients	3.2%	3.9%	3.5%	4.3%	2.6%	3.4%
Price of stents						
Prices of drug eluting stents	55115	60261	55749	59981	53388	60589
(paid by patient)	(10,772)	(6,316)	(10,766)	(6,536)	(11,098)	(5,892)
Prices of bare metal stents	27000	19940	27000	19940	27000	19940
(paid by the NHI)						
N	33,278	42,460	20,807	25,719	12,471	16,741

Notes: Each observation indicates an inpatient record. “High” and “Low” are defined at the hospital level, and indicate whether the ratio of stent patients in 2008 in each hospital is above the median. Standard deviations are reported in parentheses. Patients can use the BMS and DES models jointly in a single surgery.

Table 2 presents summary statistics of stent usage and prices before and after the rate cut. From Table 2, there was an increasing trend in the average stent usage among PTCA patients,

[17] The Charlson Comorbidity Index is an established technique for assessing the likelihood of mortality resulting from comorbid conditions. It is commonly utilized as a forecaster of extended-term outlook and survival, with a scale of 0 to 6, where 0 is the most favorable outcome, and 6 is the least favorable.

rising from 1.33 stents per patient in 2007 and 2008 to 1.42 stents in 2009 and 2010. This increase was largely driven by DES implantation, which increased from 0.46 to 0.55 stents per patient. The percentage of patients receiving any DES increased from 32.4% to 37.3%. In contrast, the average BMS usage was almost unchanged, although the percentage of BMS-only patients dropped by 6%. The incremental payment of DES increased from 55k to 60k while that of BMS reduced from 27k to 20k due to the NHI rate cut.

Given these strong trends in stent treatments, to assess the impact of the rate cut on hospital revenues, we categorize hospitals into two groups based on the proportion of patients who underwent stent implantation in 2008: hospitals whose stent ratio exceeded the median in 2008 are classified into the "High" group; all other hospitals are in the "Low" group. By examining patient-level treatment decisions in both groups after 2009, we aim to verify whether hospitals in the High group adjusted more in response to the rate cut, relative to those in the Low group, after controlling for the common trends in stent treatments.[18]

The right side of Table 2 shows the number of stents used before and after the rate reduction, separated by the High and Low group. Both groups showed an increase in average stent usage; however, there were notable differences in the types used. BMS usage increased only in the High group (from 0.90 to 0.93) after the rate cut, while DES usage increased in both groups. In addition, the percentage of DES-only patients increased from 33% in 2007-08 to 41% in 2009-10 for hospitals in the Low group, but the increase of this percentage was much slower for hospitals in the High group (32% to 34.8%).

Why did hospitals in the High group respond more aggressively to the rate cut on BMS? A likely explanation is that BMS is entirely reimbursed to patients, making it easier to encourage them to use more BMS models without incurring additional costs. Conversely, boosting the usage of DES

[18] We have also tested different ways of hospital level group definition by stent ratio, and found similar results.

among patients entailed higher costs, which might lead to budget-conscious patients switching to other hospitals or opting out of stent treatment.

The bottom of Table 2 shows the average DES prices for the High and Low group. The Low group exhibited a stronger price response, with DES prices increasing from 53.4k to 60.6k after the rate reduction, compared to a relatively smaller increase in the High group. Although hospitals could charge higher DES prices to recoup revenue loss, hospitals in the High group respond moderately to the DES price probably owing to potential reputation concerns.

3 Empirical Specification and Results

We assume that, when faced with the rate cut in 2009, each hospital could adjust several margins to recoup the revenue loss. Our analysis focuses on three margins: (i) the likelihood of PTCA patients using any stents, (ii) the number of BMS and DES used per stent patient, and (iii) the price of DES charged for patients. Below we present a formal decomposition of hospital revenue into these margins, followed by an empirical framework to quantitatively estimate the impact within each margin.

3.1 Empirical setup

In the stent market, Hospital j's stent revenue can be decomposed as follows:

$$R_j = R_j^b + R_j^d = P_j^b q_j^b N_j^b + (P_j^b + P_j^d) q_j^d N_j^d$$

where R^b, R^d are the hospital revenue from BMS and DES usage respectively; P^b is the reimbursement a hospital receives from the NHI for each stent implantation; P^d is the additional price paid for DES implantation; q^b, q^d are the quantities of cardiac stents each patient receives; and N^b, N^d

are the numbers of patients that receive the corresponding stent type. Based on this expression, we decompose the hospital revenue into the following three margins:

- Margin 0: hospitals decide whether to adopt stent treatment among PTCA patients (N^b, N^d)
- Margin 1: hospitals choose the number of stents that each patient receives, namely, (q^b, q^d).
- Margin 2: hospitals choose the DES price (P_j^d) charged for patients.

Each margin can be plausibly adjusted to maintain the revenue affected by the policy. For instance, hospitals might encourage or persuade more PTCA patients to use cardiac stents. Using more stents during surgery would increase number of stents used, and the reimbursement received from the NHI. Moreover, DES prices can be leveraged to increase revenue from patients with DES. We quantitatively estimate whether hospitals make significant adjustments after the policy for each margin, and then discuss the overall effect of different margins in the next section.

The NHI's 2009 rate cut applied to stent reimbursement in all hospitals; therefore, we cannot adopt a conventional difference-in-difference (DID) analysis because finding a control group completely immune from the policy was difficult. Regression discontinuity (RD) is a second possibility. Still, it assumes that all hospitals react instantly to the rate cut, which seems unrealistic given that PTCA surgeries are elective and could be scheduled weeks ahead.

Thus, we explore an alternative DID approach to determine the causal effect of rate reduction. We assume that hospitals with a higher proportion of stent patients among PTCA patients before 2009 were more severely impacted by the 2009 rate reduction. This enables us to compare hospitals with higher ratios to those with lower ratios. However, it should be noted that this identification method may underestimate the effects of the rate reduction if hospitals in the lower ratio group also responded, at least partially, to the rate cut (Finkelstein, 2007).

We divide the hospital-level stent-patient ratio in 2008 into two groups: the upper half and lower half. We then define a binary variable $Ratio08_j^H$ for hospital j, where it takes a value of 1 if the hospital's ratio is in the High group in 2008, and 0 otherwise. The index j indicates that a hospital's group classification remained constant within the sample period. Using this definition of the policy effect proxy, we run the following empirical specification

$$y_{ijt} = \beta_0 + \lambda Ratio08_j^H \times Aft09_t + X_i\beta + \xi_j + \alpha_t + \varepsilon_{ijt}, \tag{1}$$

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

The key parameter of interest λ indicates how hospitals in the High group behave separately from those in the Low group. We use this DID specification for the three samples separately to examine the aforementioned margins. For Margin 0, we use all PTCA inpatient samples; y_{ijt} indicates whether the patient receives any cardiac stent implantation to measure if more PTCA patients are persuaded into stent usage. For Margin 1, we use the stent patient sample; y_{ijt} is the number of stents (BMS, DES, both) to test whether certain stents were preferred and implanted by high group hospitals. For Margin 2, we use patients with at least one DES (DES sample), and chose y_{ijt} as the patients' actual paid amount to test if the High-group hospitals additionally charged these DES patients. Finally, we run a separate regression for inpatient records for major and minor teaching hospitals to investigate the heterogeneous effect across hospitals.

One key assumption in this DID specification is that hospitals in the High and Low groups share

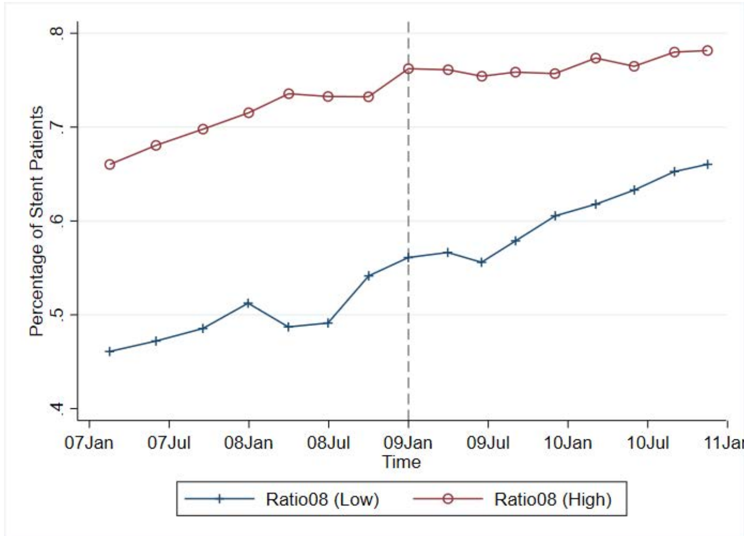
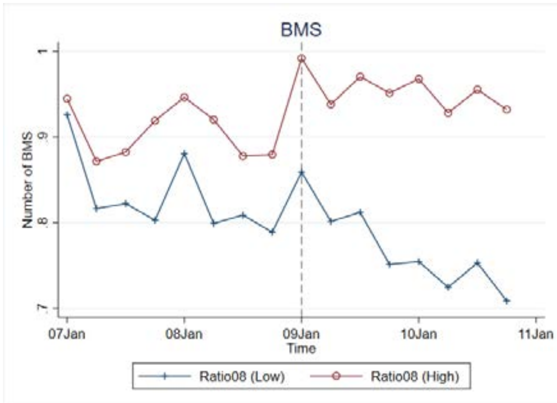


Figure 1: The percentage of stent patients by High/Low group (PTCA sample)

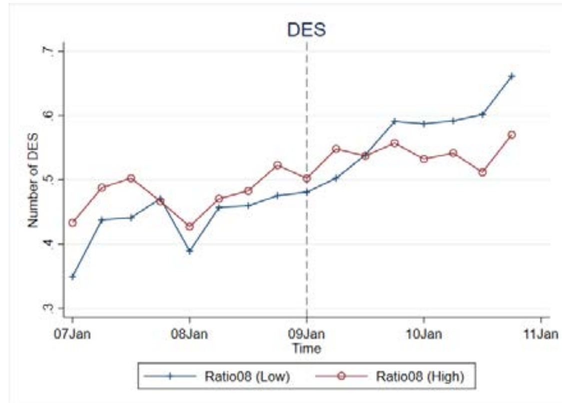
similar trends before the rate cut. In Appendix B, we outline the specifications and formally test the parallel trend assumptions for the outcome variables across the three margins. Based on the results presented in Table B.1, we observe that all but one specifications pass the parallel trend test with 95% confidence level. The only exception is for DES price in the sub-sample of major teaching hospitals before we control for DES model fixed effects; once they are controlled, the parallel trend test passes, which suggests that major teaching hospitals in the High and Low groups might differ significantly in the timing and choices of DES model adoption. Strategic DES model adoption is beyond the scope of this paper and on our future research agenda.

Figures 1 to 3 illustrate the raw trend of the outcome variables of the three margins. Figure 1 presents the stent ratio by quarters from 2007 to 2010. As shown in Figure 1, the stent ratio of the High and Low groups were quite similar before 2009, but the slope of two groups then changed after the rate reduction.

The utilization of BMS and DES per admission from 2007 to 2010 is depicted in Figures 2a and 2b, respectively, with a distinction made between hospitals in the High and Low groups. Before the rate reduction, both groups exhibited similar BMS and DES usage trends. However, there



(a) BMS usage per admission



(b) DES usage per admission

Figure 2: BMS and DES usage by High/Low group (Stent sample)

was a noticeable divergence in stent usage patterns after this rate reduction. Both groups saw an immediate jump in BMS usage per patient when the policy took effect, and the scale of this jump was larger among High group hospitals. Furthermore, there was a clear difference in the utilization of BMS and DES between the High and Low groups. BMS usage in the High group remained stable, whereas that in the Low group decreased significantly since 2009. In contrast, DES usage changed gradually over time, with hospitals in the Low group exhibiting a steeper slope than those in the High group.

Figure 3 further illustrates the average DES price from 2007 to 2010. As before, we segregate the quarterly trends based on High and Low hospital groups. On average, before the rate reduction, quarterly DES prices in both the High and Low group exhibited similar trends, with the High group's prices being slightly higher than those of the Low group. Following the rate reduction, the average price for the High group decreased faster than that for the Low group, indicating that hospitals in different groups might have reacted differently to the rate cut.

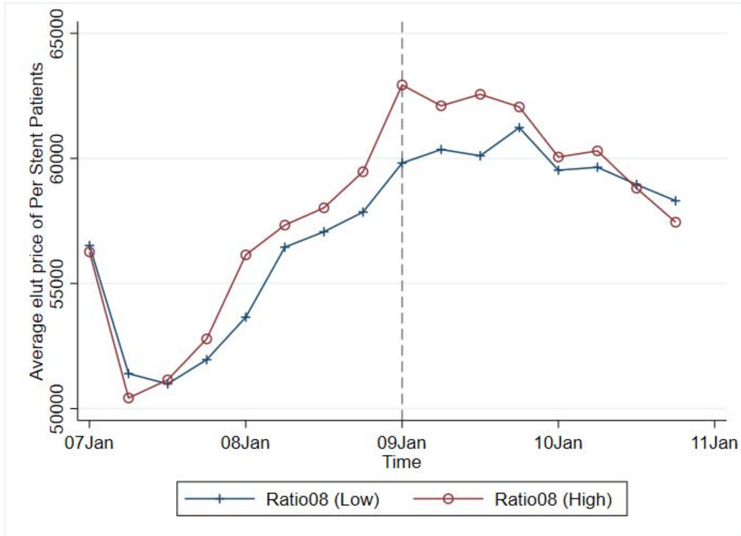


Figure 3: Average DES price by High/Low group (DES sample)

3.2 Estimation Results

Table 3 shows the estimated results for the three margins, with the first, second, and third columns representing the coefficients of Margin 0 (percentage of stent implantation), Margin 1 (stent usage at each admission), and Margin 2 (DES price), respectively. To simplify the presentation, only the coefficients of interest, $Ratio08_j^H \times Aft09_t$, which reflects the relative difference between the high and low groups after the rate cut, are reported in the table. All specifications employed linear regression models, controlling for patient characteristics (age, sex, disease dummies, and Charlson index), year-quarter fixed effect, and hospital fixed effects.[19] Standard errors are clustered at the hospital level.

The first row of Table 3 presents the estimates based on observations from all hospitals, where the group indicator $Ratio08^H$ is defined on the patient level, i.e., the patient observations with the stent patient ratios of their hospital in the top half of our PTCA sample were defined as the High group. Our results show that High group hospitals did not significantly impact patients'

[19] We have also considered the specifications employing zero inflated Poission regressions for the number of BMS and DES to account the fact that the stent number are discrete values. Results from different specifications yield similar findings

Table 3: Effects of the rate cut on PTCA and stent patients

	Margin 0		**Margin 1**			**Margin 2**	
	I(stent)	# of DES	# of BMS	I(BMS>0)	# of BMS, on any BMS patients	ln(DES Price)	
Full sample (stent ratio dummy measured by PTCA sample)							
$Ratio08^H$ × Aft09	-0.053*	-0.031	0.052**	0.022	0.035	-0.06	-0.047
	[0.030]	[0.035]	[0.024]	[0.019]	[0.027]	[0.044]	[0.032]
N	115740	75738	75738	75738	49150	36337	36337
Full sample (stent ratio dummy measured by hospitals)							
$Ratio08^H$ × Aft09	-0.042	-0.034	0.052**	0.027	0.029	-0.037	-0.036
	[0.033]	[0.034]	[0.023]	[0.018]	[0.028]	[0.046]	[0.029]
N	115740	75738	75738	75738	49150	36337	36337
Patient characteristics	x	x	x	x	x	x	x
Continuous quarter FE	x	x	x	x	x	x	x
Hospital FE	x	x	x	x	x	x	x
Model FE							x

Notes: ***, **, *: significance at 1%, 5%, and 10% level. The results control for age group dummies (60-, 60-70, 70-80, 80+ years), disease dummies (AMI, IHD, and CHF), and the Charlson index. Huber or robust standard errors were clustered by hospitals. Outcomes for Margin 0, Margin 1, and Margin 2 used PTCA, Stent, and DES sample respectively.

likelihood of receiving stent implantation, as the Margin 0 coefficient was marginally negative at 10% confidence level.

For Margin 1, we examine whether the rate reduction affected the average quantity of BMS and DES per stent patient. Our findings suggest that BMS use was 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 encouraging patients to opt for "free" BMS rather than expensive DES. After the rate reduction, stent patients in the High group hospitals increased their BMS use by 0.052 (or 6%); however, there was no significant impact on DES usage.

To investigate the source of the increased BMS usage, we consider two related margins: the increase in the percentage of BMS patients (extensive margin), and the other is the increase in the number of BMS conditional on patients with any BMS (intensive margin). Columns 4 and 5 in Table 3 report the estimate of λ for the extensive and intensive margins separately. Neither of the estimated coefficients λ is found to be statistically significant.

The last two columns of Table 3 report the estimates of Margin 2, which examines whether DES prices surged after 2009. We only use samples with matched DES prices, which drops approximately 10% of DES inpatient samples, thus the observation number is lower than the total number of DES stents in the sample (see Appendix A for details). We have considered two specifications: one only controlling for the hospital fixed effect (in addition to other factors in our main specification), and the other with DES model fixed effects additionally controlled, to check if hospitals immediately raised the DES price after the reimbursement rate. Our results show that neither coefficient is significantly different from zero, suggesting no discernible change in full sample in the average DES price after the rate reduction.

In our previous specification, one might argue that our patient-level percentile definition might assign fewer hospitals to the High group if hospitals in the High group tend to be large. For example, if hospital A, B, C and D each has 50, 20, 20 and 10 PTCA patients and 30, 6, 5, 1 stent patients, then the patient-level definition attributes only hospital A to the High group since its patients consist half of patient samples; if we use the hospital-level definition, both hospital A and hospital B would be classified as the High group, since they are the top two hospitals with the highest stent patient ratio. To test if this alternative definition affected our results, we have employed the hospital-level definition of High/Low group by ranking $Ratio08^H$ based on each hospital's stent ratio and rerun the same specifications. As the results in the second row of Table 3 suggest, we still observe the increased usage of BMS, though the coefficient of margin 0 turned insignificant.

3.3 Robustness Checks

To assess whether our empirical results are robust to various institutional factors, we consider three different cases. First, one may argue that the rate cut was announced in December 2008, leading to hospitals' pre-adjustment prior to the policy being in effect. To control for the potential influence of information leaking and pre-adjustment, we exclude inpatient records in the fourth quarter of 2008, so that any information sources hardly affected the pre-policy observations. The final results—reported in the first panel of Table 4—are slightly larger in scale than the results in Table 3. This indicates that hospitals' preparation for the policy might dampen the overall impact, and thus the impact reported in our main specification is conservative.

Second, we examine the impact of a concurrent policy that modified the annual limit on stent installations for non-urgent conditions from three (pre-2009) to four (post-2009). While the restriction is set to implement on an annual basis, data suggests that its enforcement was notably stricter on a per-surgery basis, highlighted by the infrequency of surgeries exceeding the maximum allowed stents. Specifically, surgeries involving the implantation of four or more stents were less than 0.2% before 2009 and those with five or more stents were under 0.1% after 2009. In light of this, we conduct the sensitivity analysis on the per-surgery basis.

To assess if the removal of the stent installation cap contributed to the observed increase in BMS usage, we first exclude cases surpassing the maximum allowed stents—likely urgent scenarios. For patients observed to use four stents after 2009, we replace their stent quantity as three (holding the combinations of BMS and DES) and rerun the same specification. In doing so, our results should only reflect the quantity increase among patients whose stent usage were not affected by this cap-increase policy.[20] As reported in the second panel of Table 4, the estimated results are similar to those of Table 3, though the coefficient of BMS is now slightly reduced but still significant at 10%.[21] In short, we conclude that the cap-increase policy was not the main force driving the BMS usage increase.

Finally, we test a specification in which each hospital's stent patient ratio, rather than the group

[20]It is important to note that this analysis likely adopts a more conservative approach, as imposing a higher number of restrictions could lead to a greater likelihood of physicians opting to divide surgeries into smaller but separate procedures.

[21]We have also conducted another analysis which implemented the stent limitation on the annual basis. The coefficient of BMS is further reduced to 0.38, thought still marginally significantly at 10%

Table 4: Robustness checks on the effect of the rate cut on the utilization of stents

	Margin 0	Margin 1				Margin 2	
	I(stent)	# of DES	# of BMS	I(BMS>0)	# of BMS, any BMS patients	ln(DES price)	
Excluding the fourth quarter of 2008							
$Ratio08^H$ × Aft09	-0.058*	-0.029	0.055**	0.023	0.038	-0.067	-0.050
	[0.033]	[0.037]	[0.026]	[0.020]	[0.029]	[0.049]	[0.036]
N	108104	70674	70674	70674	45851	33801	33801
Drop more than 4 (before 2009) and 5 (after 2009)							
$Ratio08^H$ × Aft09	-0.053*	-0.031	0.052**	0.022	0.035	-0.060	-0.047
	[0.030]	[0.034]	[0.024]	[0.019]	[0.027]	[0.044]	[0.032]
N	115681	75679	75679	75679	49095	36328	36328
Ration08 continuous variable							
$Ratio08$ × Aft09	-0.191*	-0.053	0.251***	0.085	0.203**	0.008	0.03
	[0.103]	[0.113]	[0.082]	[0.057]	[0.091]	[0.207]	[0.125]
N	115740	75738	75738	75738	49150	36337	36337
Patient characteristics	x	x	x	x	x	x	x
Continuous quarter FE	x	x	x	x	x	x	x
Hospital FE	x	x	x	x	x	x	x
Model FE	x						x

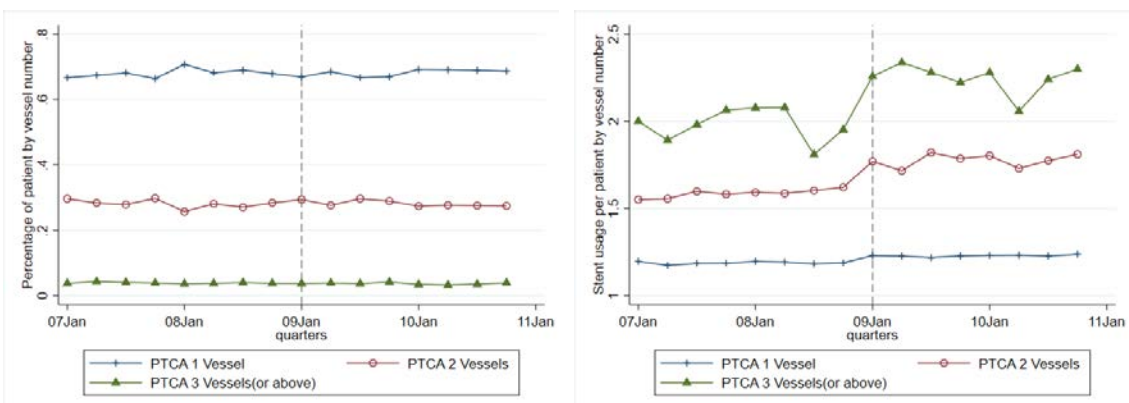
Notes: ***, **, *: significance at 1%, 5%, and 10% level. The results control for age group dummies (60-, 60-70, 70-80, 80+ years), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospitals. Outcomes for Margin 0, Margin 1, and Margin 2 use PTCA, Stent, and DES sample respectively.

indicator (High/Low group), was directly plugged into the regression. As shown in the third panel of Table 4, the main estimates in Margins 1 and 2 still preserve the same (in)significance as in Table 3, with a different coefficient scale owing to the alternative stent ratio definitions. The effect on the intensive margin of Margin 1 (number of BMS used conditional on the sample of BMS patients) now becomes statistically significant with 99% confidence, probably because the continuous measure of $Ratio08$ has more variations in the data.

4 Mechanisms and Implications of Hospital Responses

4.1 Mechanisms of Hospital Response

Regression results suggest that the use of BMS increased relatively more in High than in Low teaching hospitals after the rate cut, even accounting for various alternative specifications. However, it is unclear how this surge was achieved and whether it affected patient health outcomes. In our context, stents are implanted during PTCA surgery. Therefore, the increase of stents could be achieved by performing PTCA on more blood vessels or by applying more stents to each treated vessel during PTCA. The first method may be associated with sicker patients, because patients with more blockages in their arteries may be more likely to need PTCA surgery. The second method is associated with additional treatment, but not necessarily sicker patients, given implanting more stents in the same vessel may have lower marginal benefits. Distinguishing between these two methods could help us understand stent use and identify potential overuse of PTCA surgery.



(a) Percentage of patient by vessel number (b) Stent usage per patient by vessel number

Figure 4: Percentage of patients and stent usage by vessel number (stent sample)

Figure 4a shows the composition of stent patients by the number of vessels that received PTCA treatment. More than 65% received PTCA treatment on a single vessel, and approximately 25% on two vessels, and less than 10% on 3+ vessels. These percentages were stable before and after the rate reduction. In the meantime, Figure 4b exhibits the average number of stents used per stent patient, categorized by the number of vessels they have received PTCA treatment. Notably the average number of stents was lower than the number of treated vessels, as some vessels underwent PTCA treatment without stent implantation. The graph indicates that the increment was minimal for patients treated with a single vessel, moderate for those treated with two vessels, and highest for those treated with three or more vessels. This suggests that the increase in stent utilization following the rate cut might be attributable to more stents per vessel, especially in patients receiving PTCA treatment for multiple vessels.

To estimate the potential changes in the number of treated vessels, we focus on stent patients and examine the relationship between the number of treated vessels and the stent ratio interaction term ($Ratio08_j \times Aft09_t$). By definition, a stent patient must have at least one vessel treated with PTCA and implemented with at least one stent. Hence, we have constructed two dependent variables on vessel volume: a dummy for whether a stent patient has PTCA on two or more (2+) vessels, and a dummy for whether a stent patient has PTCA of three or more (3+) vessels. We then regress them on $Ratio08_j \times Aft09_t$ according to equation (1). Furthermore, to check whether the average number of stents increased after the rate cut, we also regressed the number of total stents and BMS stents on $Ratio08_j \times Aft09_t$.

Table 5: Impact of rate cut on the vessel number and stent usage per vessel

	PTCA (# of vessel)			
	Vessels (2+)	Vessels (3+)	# of stents per vessel	# of BMSs per vessel
Full Sample				
$Ratio08^H$ × Aft09	0.030**	0.001	0.035	0.039**
	[0.012]	[0.004]	[0.023]	[0.018]
N	75,738	75,738	75,738	75,738
Patient characteristics	x	x	x	x
Continuous quarter FE	x	x	x	x
Hospital FE	x	x	x	x

Notes: ***, **, *: significance at 1%, 5%, and 10% level. The results control for age group dummies (60-, 60-70, 70-80, 80+ years), disease dummies (AMI, IHD, and CHF), and the Charlson index. Huber or robust standard errors were clustered by hospitals.

Table 5 presents the estimated result. It is clear that, after controlling for patient characteristics, as well as dummies of continuous quarters and hospitals, a stent patient was slightly likely to report 2+ PTCA vessels after the rate cut. However, we do not find significant results when we use the dummy for 3+ vessels as the dependent variable. This suggests that the effect in PTCA vessels was driven by the change from one to two vessels, not from two to three+ vessels. In other words, most of the increase in PTCA vessels came from marginal patients with PTCA (and stent implant) on only one vessel before the rate cut.

The third and fourth columns of Table 5 present the relationship between the average number of stents per vessel, and its interaction with the stent ratio group indicator ($Ratio08_j^H \times Aft09_t$). Controlling for all other factors, the coefficient of BMS per vessel was different from zero. In summary, the sources of BMS use increase came from more BMS usage per vessel, indicating a larger chance to use unnecessary care.

Next, we examine whether hospitals selectively targeted BMS usage in certain stent patients. To answer this question, we run the following regression

$$y_{ijt} = \beta_0 + \sum_k \lambda_k Ratio08_j^H \times Aft09_t \times W_i + X_i\beta + \xi_j + \alpha_t + \varepsilon_{ijt}, \tag{2}$$

where y_{ijt} is the number of BMS, W_i is patient i's characteristic, and λ_k reflects the difference in hospital treatment if the hospital recruited more stent patients among the PTCA patients. We choose the number of BMS as the sole dependent variable since our findings indicate the rate cut increased the use of BMS. W_i includes the male indicator, age group dummy, and AMI indicator. The regression results are presented in Table 6.

Each panel represents one regression, and each entry in the second row is the coefficient corresponding to the interaction of $Ratio08_j^H \times Aft09_t$ and the demographic variables in the column

Table 6: Results of the rate cut on BMS usage with demographic interactions (stent sample)

		Male	Age (70-80)	Age (80-90)	Age (90+)	AMI
Full sample						
$Ratio08^H$ × Aft09	0.068*					
	[0.035]					
$Ratio08^H$ × Aft09		-0.044**	-0.008	0.016	0.034	0.032
		[0.018]	[0.017]	[0.017]	[0.028]	[0.037]
N	75,738	75,738	75,738	75,738	75,738	75,738
Patient characteristics	x	x	x	x	x	x
Continuous quarter FE	x	x	x	x	x	x
Hospital FE	x	x	x	x	x	x

Notes: ***, **, *: significance at 1%, 5%, and 10% level. The results control for age group dummies (60-, 60-70, 70-80, 80+ year), disease dummies (AMI, IHD, CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospitals.

name. According to Table 6, the increase in BMS usage after the rate cut is more pronounced for female patients than for male patients, but the change is similar across age groups and AMI conditions.

4.2 Impact on health outcomes

To evaluate the impact of rate reductions on patient health outcomes, this study replicated the specifications outlined in Table 3, modifying only the dependent variable to health outcomes. This analysis focused on five key health outcome indicators: re-admission rates within one and three months, and mortality rates within one, three, and six months post-stent implantation. Re-admissions unrelated to cardiac illnesses or subsequent stent implantation were excluded to isolate the effects of cardiac-related re-admissions.

The findings, presented in Table 7, indicate that the rate reduction had no significant impact on patient health outcomes. The interaction term $Ratio08H$ × Aft09 yielded statistically insignificant results across nearly all health outcome metrics, with a 10% significance observed only in the one-month readmission rate. However, this marginal effect did not persist for re-admissions extending to three months, suggesting a transient impact with no sustained effects on mortality rates over any observed duration.

Table 7: Impact of the rate cut on health outcomes (stent sample)

	readmission (1 month)	readmission (3 months)	death (1 month)	death (6 months)	death (12 months)
Full sample					
$Ratio08^H \times$ Aft09	-0.006*	-0.006	0.001	0.001	0.002
	[0.004]	[0.007]	[0.003]	[0.005]	[0.006]
N	75,738	75,738	75,738	75,738	75,738
Patient characteristics	x	x	x	x	x
Continuous quarter FE	x	x	x	x	x
Hospital FE	x	x	x	x	x

Notes: ***, **, *: significance at 1%, 5%, and 10% level. The results control for age group dummies (60-, 60-70, 70-80, 80+ age), disease dummies (AMI, IHD, and CHF), as well as Charlson index. Huber or robust standard errors are clustered by hospitals.

4.3 Heterogeneous effects by hospital type

Our analysis to this point has highlighted the average effect of the 2009 rate cut, yet it hasn't addressed the variability in responses across different hospital types. Distinctions in behavior between non-profit and for-profit hospitals in response to financial pressures have been well-documented, with non-profit hospitals often exhibiting different strategic responses due to their operational and financial objectives (Sloan, 2000). Moreover, studies have indicated that a hospital's financial condition significantly influence their reactions to the reimbursement policy changes. For instance, Dafny (2005) looks at hospital response to a change in the PPS reimbursement rate, and examined heterogeneous effects by hospital types (e.g. ownership status, financially distressed or not). Likewise, Dranove, Garthwaite and Ody (2017) demonstrated that hospitals with significant market power engaged in cost-shifting strategies during the financial turmoil of 2008.

To understand these dynamics across hospitals, we categorized our sample based on specific hospital characteristics related to financial health. The upper panel of Table 8 displays the estimated results categorized by ownership status, distinguishing among public, non-profit, and for-profit

Table 8: Heterogeneous effects of the rate cut on the utilization of cardiac stents

	Margin 0	**Margin 1**				**Margin 2**	
	I(stent)	# of DES	# of BMS	I(BMS>0)	# of BMS, any BMS patients	ln(DES price)	
Public hospitals							
Ratio08H × Aft09	-0.032	-0.072	0.107**	0.064*	0.054	0.057	-0.078
	[0.057]	[0.055]	[0.038]	[0.032]	[0.047]	[0.045]	[0.064]
N	33398	21975	21975	21975	12663	13439	11941
NFP hospitals							
Ratio08H × Aft09	-0.061*	-0.013	0.029	0.003	0.03	0.028	-0.051
	[0.036]	[0.046]	[0.031]	[0.023]	[0.036]	[0.035]	[0.060]
N	73713	48509	48509	48509	29754	31587	22864
FP hospitals							
Ratio08H × Aft09	-0.027	-0.018	0.014	0.03	-0.017	-0.022	-0.136
	[0.062]	[0.057]	[0.055]	[0.035]	[0.076]	[0.075]	[0.076]
N	8629	5254	5254	5254	4016	4124	1532
Hospitals with competitors within 10km radius							
$Ratio08^H$ × Aft09	-0.052	-0.026	0.017	0.01	0.007	0.008	-0.096*
	[0.038]	[0.039]	[0.028]	[0.023]	[0.038]	[0.038]	[0.049]
N	86161	54435	54435	54435	31777	33717	28071
Hospitals without competitors within 10km radius							
$Ratio08^H$ × Aft09	-0.028	-0.047	0.110**	0.052	0.067	0.067	0.092
	[0.060]	[0.074]	[0.045]	[0.042]	[0.042]	[0.039]	[0.077]
N	29579	21303	21303	21303	14656	15433	8266
Major teaching hospitals							
$Ratio08^H$ × Aft09	-0.052	0	0.01	0	0.019	-0.153***	-0.084*
	[0.048]	[0.055]	[0.033]	[0.029]	[0.044]	[0.038]	[0.048]
N	66604	43920	43920	43920	26490	24428	24428
Minor teaching hospitals							
$Ratio08^H$ × Aft09	-0.052*	-0.072**	0.109***	0.052**	0.053*	0.126**	0.03
	[0.030]	[0.031]	[0.032]	[0.024]	[0.031]	[0.050]	[0.035]
N	49136	31818	31818	31818	22660	11909	11909
Patient characteristics	x	x	x	x	x	x	x
Continuous quarter FE	x	x	x	x	x	x	x
Hospital FE	x	x	x	x	x	x	x
Model FE							x

Notes: ***, **, *: significance at 1%, 5%, and 10% level. The results control for age group dummies (60-, 60-70, 70-80, 80+ years), disease dummies (AMI, IHD, and CHF), and the Charlson index. Huber or robust standard errors were clustered by hospital. Outcomes for Margin 0, Margin 1, and Margin 2 used PTCA, Stent, and DES sample, respectively.

hospitals. The findings suggest that public hospitals are more likely to increase the use of BMS by 0.11 or 12% in response to the rate cut, whereas non-profit and for-profit hospitals do not show any significant response. No response is observed for DES's usage or prices.

The middle panel assesses hospitals operating in various competitive environments. We specifically differentiate hospitals situated in towns with or without nearby competitors within a 10k radius. The analysis reveals that hospitals without competition are more inclined to enhance their usage of BMS, but no responses for other outcome variables.

The lower panel investigates the differential effect on major and minor teaching hospitals, as they differ in the level of financial distress. For instance, the 2015 Hospital Financial Reports released by the NHI reveal that major teaching hospitals in our study generated approximately NT9.5 billion from NHI revenues, nearly four times the NHI revenue (NT2.6 billion) of minor teaching hospitals. Regarding medical service profit margins, major teaching hospitals recorded an average margin of 2.0%, compared to a 1.2% average margin observed in minor teaching hospitals.[22]

The lower panel of Table 8 shows the estimates of major and minor teaching hospitals. Results show quite divergent patterns with respect to stent usage: among minor teaching hospitals, patients in High-group hospitals, on average, used 0.072 fewer DES and 0.109 more BMS, and were 5.2% more likely to use any BMS compared to patients enrolled into Low-group minor teaching hospitals. In contrast, major teaching hospitals did not respond to stent usage after the shock.

Interestingly, major and minor teaching hospitals also adopted different pricing strategies for their DES implantation. After we control for DES model fixed effects, the average DES price was not significantly different from zero (the last column) for both major and minor teaching hospitals. When the model fixed effects are not included, however, the DES price decreased by 15.3% among major teaching hospitals and increased by 12.6% among minor teaching hospitals; this implies that the price hike of DES at minor hospitals is done by introducing new but more expensive DES

[22] The profit margin for a hospital's medical services is calculated by dividing its annual earnings from these services by its total medical revenue. It is important to note that this calculation excludes profits and revenues from non-medical services. Furthermore, the actual profit margins for major teaching hospitals could be higher when non-medical services are considered.

models.[23]

Why are public hospitals, minor teaching hospitals, or hospitals without nearby competitors more likely to respond to rate reductions? One possible explanation lies in the disparities in financial resilience. Large teaching hospitals — many of whom are major — often locate in urban areas and can adapt by attracting a larger patient base, thus mitigating financial distress. This increased patient volume may also enhance their negotiating leverage with stent manufacturers, particularly concerning the input prices of newer models. Conversely, medium-sized public hospitals in remote areas — which are more likely to be minor than major — operate within tighter financial margins and often carry policy-driven missions. Consequently, these institutions find it more challenging to navigate financial difficulties (Dranove, Garthwaite and Ody, 2017).[24] They may be incentivized to increase the number of stents deployed per patient and potentially raise the pricing of newer DES models.[25]

4.4 Revenue Implication of Hospital Response

We now address the policy implications of our central inquiry: to what extent does moral hazard behavior enable hospitals to mitigate revenue losses? Although Table 8 includes responses of hospitals of different characteristics to the rate cut, the results from minor teaching hospitals (the lower panel) are particularly illustrative in demonstrating how these institutions recouped revenue losses. Our estimates suggest that, following a 26% cut in reimbursement rates in 2009, minor teaching hospitals increased the price of DES by 12.6%, which corresponded to a reduction of 0.072

[23] As described before, the price effect observed in major teaching hospitals (without DES model fixed effects) does not pass the test of parallel trend, so we would not interpret it as causal.

[24] Our findings are to some extent similar to Dranove, Garthwaite and Ody (2017), which examines the impact of market competition faced by each hospital and found that only hospitals with substantial market power engage in cost shifting by raising prices.

[25] In order to assess the rate of adoption of new DES models, we conducted an analysis of DES stent utilization within individual hospitals during the period spanning 2009 to 2010. Specifically, we quantified the proportion of DES stents employed by each hospital during this time frame that were of newer DES models introduced by the hospital after the year 2009. Our findings showed a notably diminished percentage within high-ratio minor teaching hospitals, indicating that minor teaching hospitals might be slow to adopt new DES models.

in DES usage and an increase of BMS by 0.109 per stent patient. Conversely, major teaching hospitals exhibited no significant changes in DES or BMS usage, but a relative decrease in the DES price was observed.

We thus calculate and report the estimates of policy impact on these hospitals in 2009 and 2010, respectively, in Table 9. A simple measure might be that, we multiply the total number of admitted patients in 2009 for high stent ratio hospitals, 5,022, by the effect of rate cut on BMS, 0.109, which equals 547 BMS (worth 10.8 million NTD). But this result is biased since the patient count (5,022) was also inflated by the policy where hospitals implants more stents per patient. Alternatively, subtracting the induced demand directly from the actual 2009 BMS number is also incorrect. As one can see from Table 2, despite the jump in 2009, there was a steady decline in BMS per stent patient over time, since more patients opted for DES.

We take two steps to obtain the counterfactual revenue loss from the rate cut. First, we obtain the coefficients of 2008 and 2009 year dummies in column 3 of Table 3 to calculate the counterfactual BMS use per stent patient.[26] Then the counterfactual stent demand without demand inducement is calculated by adding the number of BMS per stent patient in 2008 with the difference between 2009 and 2008 fixed effect estimates, which equals 1.025 (1.066+0.001-0.042). We include this difference of year-specific dummies to account for the general time trend while excluding the policy impact. Then we multiply 1.025 by the number of stent admissions in 2009, which yields the total number of BMS without induced demand as 5,148. The difference between the actual (5,614) and counterfactual number (5,148) was the induced demand of BMS after the policy, which accounted for 9.1% (466 out of 5,148) more BMS in 2009. Likewise, for DES implantation, number of DES without inducement was 2,566, and the induced DES was -485 or -18.1% in 2009.

Once we have the counterfactual BMS and DES numbers, we then calculate the revenue loss by

[26]In Table 3, year-quarter dummies are included as the control for time fixed effect in the estimation. To obtain the coefficient of year 2008, 2009, and 2010, we use year- and quarter-specific dummies alternatively.

Table 9: Decomposition of induced demand for minor teaching hospitals

	2009			2010		
	Actual	Counterfactual	Induced	Actual	Counterfactual	Induced
BMS(high)	5614	5148	466	5603	5072	531
DES(high)	2081	2566	-485	2110	2744	-634
BMS(low)	2805	2805	0	2816	2816	0
DES(low)	1746	1746	0	2258	2258	0
Revenue unit (Millions, NTD)						
Hospital revenue loss		85.9			90.2	
Recoup revenue from DES			18.7			19.0
Recoup revenue from BMS			9.3			10.6
Hospital recouped revenue (%)			(32.6%)			(32.7%)
NHI reduced reimbursement		86.2			92.3	

Notes: The "Actual" column lists the number of BMS and DES actually installed. The "Counterfactual" column lists imputed number of BMS and DES stents installed when induced demand is excluded. Revenue loss calculates hospital's expected loss of stent revenue without the induced demand, which equals the number of total stents (counterfactual) times the 2009 NHI rate cut (7k NTD). The recoup revenue equals to the revenue from induced use of BMS or DES and from the change of DES price.

multiplying the total stent count by the NHI rate cut amount, which reflects the amount of potential revenue loss if hospitals' current stent sales remained constant after the policy. In addition, we also evaluate the revenue impact from the DES price increase in the calculation by multiplying the price variation with the DES stent count. As reported from Table 9, High-group minor teaching hospitals were able to recoup 9.3 million NTD from BMS and 18.7 million NTD from DES. In the end, High-group hospitals recouped 32.6% of revenue from the induced use of BMS and higher DES price in 2009. For the NHI, our estimates suggest that the rate cut has generated even larger savings on the reduced NHI reimbursement than the total loss of hospital revenue in the counterfactual, once we account for hospital response to raise the use of BMS and adjust the price of DES.[27]

Using the same approach, the right portion of Table 9 presents our evaluation of moral hazard in 2010. The counterfactual BMS and DES stents were 5,072 and 2,744, respectively, and hospitals recovered 32.7% of the revenue loss from the NHI rate cut. It is worth noting that our estimates are conservative as they assume that Low group minor teaching hospitals did not react to the rate cut at all. In other words, these estimates merely reflect the relative difference in revenue

[27]While the rate cut induces an additional use of BMS, a higher DES price also reduces the use of DES. On the net, the reduction in the NHI's reimbursement is in total NTD 86.2 millions.

recoup between High and Low group minor teaching hospitals. If hospitals of Low group also made adjustment in the same direction, then our results provide the lower bound of the policy impact.

5 Conclusion

We examine how hospitals responded to the 2009 rate cut in Taiwan's government reimbursement for cardiac stents. Because the rate cut is within the top-up design of government-provided health insurance, it provides a rare opportunity to demonstrate the key trade-off between curbing health care spending and hospital moral hazard.

We have examined three margins: the percentage of PTCA patients that underwent stent implantation, the number of stents used per stent patient, and the patient-out-of-pocket price of DES. The strongest evidence lies in Margin 1: hospitals that were more revenue reliant on PTCA patients before the rate cut increased the number of BMS stents used per stent patient immediately after the rate cut. There is also some evidence on Margin 2: while the average DES price is not changed, major and minor teaching hospitals adopted different pricing strategies—these revenue-sensitive minor teaching hospitals raised the price of DES stents by 12.6%, potentially through upgrades of DES stent models. Overall, relative to the revenue loss caused by the NHI rate cut, these minor teaching hospitals recovered up to 32.7% of their revenue loss in 2009 and 2010. Nevertheless, the estimates suggest that the 2009 rate cut still effectively reduced NHI spending on cardiac stents, without substantial changes in patient outcomes.

Our study has several limitations. First, we lack a proper control group because the NHI rate cut applied to all hospitals simultaneously. Our conclusions are based on the assumption that hospitals with a higher stent patient ratio before the rate cut are more likely to be affected by the stent reimbursement reduction. Second, our research focuses on patient-level decisions within the treating hospital, such as the choice to use a stent, the number and type of stents employed, rather than the decision on which hospital to visit. Patients tend to visit major teaching hospitals over time, which may or may not have been related to the 2009 rate cut. While our data includes hospital-level decisions, such as the stent model pricing and usage, it is challenging to explicitly examine the timing of model drops, adoptions, and upgrades without information about the negotiations between stent suppliers and hospitals. This is an area for future research. Finally, this study is conducted within Taiwan's universal health insurance system. Hence, we caution readers who aim to generalize our findings to other countries or non-governmental insurance programs.

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A Price Matching Procedures

Because the NHI covers partial payments for DES, hospitals must disclose additional payments for DES charged to patients (e.g., on the hospital's website). In addition, the NHI routinely collects price information on DES at every hospital. In the first two years, price collection occurs every two months. Later, it is reduced to every six months, given that the prices of drug-eluting stents do not change frequently. To facilitate price comparisons across hospitals, the NHI launched a website in 2012 in which every hospital was asked to report the prices of DES once there were price changes.

We have obtained DES prices 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 Dec 2006 to Nov 2013. On average, each hospital had approximately 126 price reports, and each hospital-stent model combination had eight price reports. To overcome the missing data between adjacent reports, we took three steps to construct the hospital-model-quarter price data. First, we calculated the average price reported in each quarter (if any) for each hospital-model combination. There were 7,771 combinations, with approximately 40% of the duplicate price reports eliminated. Next, we filled these gaps by assuming that hospitals did not change their prices between consecutive price reports for the same stent model. Finally, we observe some stent usage before the first price reporting date, where hospitals might be delayed in submitting price reports. To match these observations, we assume that hospitals charge the same price as their first report for each stent model up to four quarters before their first reporting date. The price spectrum constructed in this manner matched 89.99% of the DES usage records in the NHI claims 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 showed up in the claim data but their prices were never reported in the corresponding hospitals). Our DES price results are not sensitive to how we imputed the missing prices.

B Parallel trend test

Our main analysis defines the relative difference between High- and Low-group hospitals as hospitals' additional response to the policy shock. This analysis requires that such a difference be stable before the policy and only changed in response to the shock. To test whether this pattern exists, we use PTCA (Margin 0), Stent (Margin 1) and DES price sample (Margin 2) in 2007 and 2008 to run the following regression:

$$y_{ijt} = \sum_t \gamma_t Ratio08_j^H I(t) + X_i\beta + \xi_j + \varepsilon_{ijt} \tag{3}$$

where 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 hospital fixed effects, and $I(t)$ is a dummy for quarter t. Based on the regression estimates, we then test if all coefficients of γ_t (seven quarter dummies in total) are jointly and significantly different from zero, and report the F values in Table B.1. None of the outcome variable yields $p < 5\%$ in the full sample, indicating that the parallel assumption holds in the DID analysis for all hospitals sample. For parallel trend tests on the sub-samples of major or minor teaching hospitals, all but one have p values higher than 5%. The only exception is the log of DES price for major teaching hospitals in the last column, when the model fixed effect are not controlled.

Table B.1: Test Parallel Trends of Varous Outcome Variables (2007-8)

	Margin 0		**Margin 1**			**Margin 2**	
	I(stent)	# of DES	# of BMS	I(BMS>0)	# of BMS, only BMS patients	ln(DES price)	
All hospitals							
F	1.79	0.76	1.52	1.18	0.85	1.57	1.67
Prob > F	0.1076	0.6197	0.1805	0.3279	0.5526	0.1641	0.1371
Major hospitals							
F	2.18	1.19	2.19	2.33	0.86	5.15	0.9
Prob > F	0.087	0.3551	0.0852	0.0707	0.5554	0.0024	0.5289
Minor hospitals							
F	1.91	1.47	0.5	0.52	1.21	2.07	2.13
Prob > F	0.0973	0.209	0.8266	0.8162	0.3213	0.0746	0.067
Patient characteristics	x	x	x	x	x	x	x
Continuous quarter FE	x	x	x	x	x	x	x
Hospital FE	x	x	x	x	x	x	x
Model FE							x

Notes: ***, **, *: significance at 1%, 5%, and 10% level. The results control for age group dummies (60-, 60-70, 70-80, 80+ age), disease dummies (AMI, IHD, CHF), and the Charlson index. Huber or robust standard errors were clustered by hospitals. Outcomes for Margin 0, Margin 1, and Margin 2 use PTCA, stent, and DES samples respectively.