Diffusing Innovations Under Market Competition: Evidence from Drug-Eluting Stents

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Abstract

This paper examines how market structure and government policy shape the diffusion of medical innovations through hospitals. Using detailed patient-level data from Taiwan's National Health Insurance system, we estimate a structural model of hospital competition in drug-eluting stent (DES) markets. Our model incorporates patient demand for DES treatments and hospitals' strategic decisions regarding DES portfolio composition and pricing. Counterfactual analyses reveal three key findings: First, increased competition reduces DES prices but decreases hospitals' incentives to adopt new DES models, resulting in partial innovation passthrough. Second, selective contracting can achieve quadruple wins by simultaneously increasing consumer surplus, maintaining hospitals' adoption incentives, controlling government expenditures, and motivating covered manufacturers to offer wholesale discount for sales gains. Third, patient coupons targeting the poorest 10% can redistribute consumer surplus towards low-income patients, but has limited impact on overall market outcomes. These results highlight the importance of considering both market structure and reimbursement design in promoting medical innovation diffusion.

JEL: D4, I18, L13, O33.
Keywords: stent, innovation, hospital competition, health insurance, reimbursement.

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1 Introduction

Medical innovations in diagnostics, treatment procedures, medical devices, prescription drugs, and vaccines have significantly increased life expectancy and quality of life worldwide. However, patient access to these innovations is restricted not only by the pace of technological advancement or health insurance coverage but also by whether and when healthcare providers adopt these innovations in their products and services. In this paper, we highlight the role of hospitals in the diffusion of new drug-eluting stents to individual patients in Taiwan.

Drug-eluting stents (DES) have revolutionized the treatment of coronary artery disease. The first bare-metal stent (BMS) was implanted in 1986 (Sigwart, 2017); however, BMS do not effectively prevent restenosis due to excessive tissue growth within the stent. DES mitigate this issue by incorporating a drug-eluting coating that inhibits cell proliferation, thereby enhancing long-term outcomes in percutaneous coronary interventions (PCI). While DES may not be universally superior to BMS, they are significantly more expensive—typically three to four times the cost of BMS. [1]

Since the first FDA approval of DES in 2002, manufacturers have continuously improved stent design, polymer coatings, and drug formulations. Our dataset includes frequent model updates from five major DES manufacturers: Abbott, BioSensor, Boston Scientific, Cordis, and Medtronic. As all these manufacturers are headquartered outside Taiwan (four in the U.S. and one in Singapore), we treat DES product innovations as exogenous and examine hospital adoption patterns following their introduction into the Taiwanese market.

We argue that hospital adoption of new DES models is driven by strategic incentives, particularly in competitive healthcare markets. In Taipei, Taiwan's largest metropolitan area, patients can choose among 20 hospitals, all offering bare-metal stents (BMS) and a variety of DES models. As stent implantation is an elective procedure, hospitals may adopt or upgrade DES models to attract patients who prefer newer technologies and maintain a competitive edge. However, such decisions involve fixed costs, and new DES models may cannibalize demand for existing BMS and DES options within a hospital's portfolio.

[1] Patients receiving DES generally require prolonged dual antiplatelet therapy (DAPT) to prevent thrombosis, increasing the risk of bleeding and adherence challenges. The choice between DES and BMS depends on individual patient factors, including bleeding risk, ability to maintain DAPT, and specific clinical conditions. This explains why, in our data, older patients with a higher Charlson Comorbidity Index (CCI) are more likely to receive BMS rather than DES. The CCI is a widely used metric for predicting one-year mortality based on comorbid conditions.

Taiwan's National Health Insurance (NHI) program reimburses hospitals a fixed amount per stent implanted, regardless of whether it is BMS or DES. This "top-up" reimbursement model means that while BMS is fully covered and free for patients, DES requires substantial out-of-pocket payments. Although hospitals may capitalize on patient preference for newer technology to charge higher prices for advanced DES models, patients remain price-sensitive given the availability of a zero-cost alternative within the same hospital. Moreover, while adopting new DES models may attract patients from competing hospitals, the potential gains are constrained by market competition and price sensitivity. These factors may weaken hospitals' incentives to adopt or upgrade DES models, thereby slowing the diffusion of DES innovations in a competitive environment.

To capture the complex interplay among hospitals, patients, and the government insurer (Taiwan's NHI) , we develop a structural model that integrates patient demand and hospital decisions regarding DES portfolio adjustments.

On the demand side, we assume that each quarter, patients have full information about the DES portfolios available at all hospitals, including detailed specifications and pricing for each brand. Patients first choose a hospital for stent implantation and then select a stent brand (BMS or DES) from that hospital's portfolio. While the final stent choice may be influenced by both patients and doctors, several factors suggest that patients play a significant role in decision-making. Stent implantation is an elective procedure, the cost of the procedure itself (except for DES out-of-pocket expenses) is fully covered by NHI regardless of hospital choice, and patients can compare out-of-pocket costs for different hospitals and DES models via the NHI's website. These conditions create an environment conducive to price-sensitive hospital and DES brand selection. [2]

To estimate patient preferences for DES, we employ a random coefficient demand model, allowing us to compute market shares for each DES model under various hypothetical portfolio configurations at individual hospitals.

On the supply side, we implement a two-stage model to capture hospital decision-making. In the first stage, each hospital determines whether to adopt a new DES brand, upgrade an existing brand to its latest generation, or maintain its current portfolio at the beginning of each quarter.

[2]Unlike in the U.S. healthcare system, doctors in Taiwan—including cardiologists performing stent implantation—are hospital employees. Due to the lack of detailed information on hospital compensation structures and doctor-patient interactions, modeling individual doctor selection or the agency relationship between doctors and patients is not feasible.

For simplicity, we assume that each hospital maintains only one generation of each DES brand per quarter, a pattern supported by our data. The specific generation retained depends on the hospital's adoption and upgrade decisions. Once hospitals publicly reveal their portfolio adjustments, they then set pricing strategies for the DES models in their portfolios. Using maximum likelihood estimation, we identify the costs associated with hospital- and brand-specific adoption and upgrade decisions.

We estimate the demand model using individual-level inpatient claims data from the NHI, and the DES prices charged by hospitals to patients. Our findings suggest that more expensive DES models are generally less favored, although this aversion is mitigated among patients with higher incomes. A DES model is more preferred over BMS if it represents the latest generation within its brand, particularly among patients with less severe conditions. The supply-side estimates reveal that the costs of upgrading an existing brand to the newest generation are lower than the costs of adopting a new brand into a hospital's DES portfolio.

Based on our demand and supply estimates, we conduct a series of counterfactual analyses to examine the key factors influencing hospitals' pricing strategies and innovation diffusion incentives.

First, we investigate the impact of market competition and patient demand on hospitals' incentives to diffuse innovation. To increase market concentration, we remove a random subset of hospitals from the market and recompute the equilibrium strategies for the remaining hospitals. Our findings indicate that, in a more concentrated market, hospitals adopt more aggressive strategies in both technology adoption and portfolio upgrades due to the higher returns on enhanced portfolios. However, these strategies lead to higher prices for patients and a reduction in the overall number of treatment choices, underscoring the importance of maintaining market competition to preserve patient choice.

Next, we examine the role of patient preferences for new DES models in shaping hospitals' pricing and adoption decisions. When demand for the latest technology increases, we observe that hospitals raise both prices and adoption rates, resulting in higher profit margins. This suggests that strong patient preferences for innovative technology predominantly encourage hospitals to upgrade their existing DES portfolios rather than to introduce entirely new models.

We further explore alternative reimbursement designs aimed at promoting innovation diffusion in the DES market. Our analysis acknowledges that neither increased market competition nor

robust patient demand alone is sufficient to simultaneously incentivize hospitals to adopt new technologies while keeping prices affordable. Although an increase in the NHI reimbursement rate per stent under the current "top-up" structure could benefit both hospitals and patients, it would entail higher NHI expenditure.

To better address the trade-off between affordability and access, we evaluate two alternative reimbursement designs for DES: "selective contracting" targets the supply side, and "patient coupon" targets the demand side.

In the selective contracting scheme, the NHI negotiates directly with selected DES manufacturers to reduce wholesale costs for hospitals and offer reimbursements exclusively for bare-metal stents (BMS) and the selected DES brands. By adjusting the reimbursement and cost discount factors, we identify a balance that can motivate selected manufacturers to offer wholesale discounts for sales gains, improve consumer surplus, maintain hospitals' incentives to adopt new DES models, and keep the government's reimbursement for stents within the same budget constraint. This approach yields benefits for patients, hospitals, selected manufacturers, and the NHI compared to the status quo, although DES manufacturers excluded from the selective contract may experience significant losses in sales.

In the patient coupon scheme, the NHI provides the poorest 10% patients with nontransferable coupons for DES treatments. We allow the NHI to adjust both the magnitude of the coupon and the overall rate of reimbursement for DES for all patients so that the NHI can remain within its budget constraint. Our simulations indicate that, while coupons targeted at low-income patients increase DES usage within this group, hospitals respond by raising DES prices, which in turn reduces usage among higher-income patients. Consequently, patient coupons can redistribute consumer surplus and innovation diffusion towards low-income patients but have limited impact on overall market outcomes.

The rest of the paper is organized as follows. Section 2 reviews related literature. Section 3 describes the background and summarizes the data in our analysis sample. Section 4 lays out our structural model of patient choice of hospital and stent type on the demand side and hospitals' pricing and portfolio management decisions on the supply side. Section 5 presents our estimates, and Section 6 conducts three counterfactual simulations to highlight the interplay of market competition, patient willingness to pay for newness, and government reimbursements for DES. A brief

conclusion is offered in Section 7.

2 Related Literature

Our research contributes to several strands of literature within economics and innovation. Following Schumpeter (1942) and Arrow (1962), a substantial body of work examines the relationship between market competition and firms' incentives to innovate. As summarized by Bryan and Williams (2021), lower profits can undermine firms' incentives and abilities to innovate but monopolistic firms might be reluctant to introduce new products that could cannibalize their existing offerings, leading to underinvestment in innovation within a concentrated market structure. Conversely, excessive entry can occur when firms introduce marginally improved products to attract consumers from competitors, even if these products offer minimal societal value (Berry and Waldfogel, 1999; Mankiw and Whinston, 1986). Aghion et al. (2005) further suggest that moderate competition can stimulate innovation while excessive competition may hinder it.

Our study extends this literature by focusing on the innovation adoption decisions made by intermediaries between product inventors and end consumers (in this case, hospitals). We demonstrate that similar cannibalization and competition concerns arise in hospitals' decisions to adopt DES models. This perspective is novel as it highlights how market competition affects not only manufacturers' innovation incentives but also the adoption behaviors of intermediaries. Because the government insurer can set the reimbursement rate for healthcare providers based on what product is used in the treatment, the adoption incentive for these healthcare providers has direct implications for patient welfare and public policy.

The adoption and diffusion of medical innovation have been explored by several researchers. Kyle (2007) shows that the diffusion of new pharmaceuticals proceeds more rapidly in countries with strong intellectual property (IP) protections and minimal price regulation. While our study focuses on a single geographic area (Taiwan) with consistent IP protection, we examine how changes in government reimbursement rates affect the diffusion of new DES models.

Social learning is another mechanism influencing the diffusion of innovation. Conley and Udry (2010) highlight how social networks and peer effects can accelerate technology adoption. To incorporate potential social learning in our market, our structural model allows a hospital's portfolio

adjustment costs to depend on the penetration of the same brand or generation in other hospitals. We find that larger hospitals tend to maintain more extensive DES portfolios and adopt the latest generations more rapidly than smaller hospitals. As shown by (Skinner and Staiger, 2015), disparities in technology adoption can have significant impact on patient health outcomes. By drawing a distinction between adopting a new brand into the portfolio and upgrading an existing brand to the latest generation, we reveal how these two decisions introduce different strategic incentives in innovation diffusion. This nuance is critical for understanding how hospitals manage their product portfolios and pricing in face of medical innovations.

Our work also relates to studies on consumer adoption of new products. Ching, Erdem and Keane (2013) summarize how consumer learning affects market dynamics. In comparison, we argue that hospitals' portfolio management and pricing strategy play an important role in consumer choice, even if consumer choice is static and the likelihood of repeated consumption is low. Additionally, Collard-Wexler, Grennan and Steck (2024) analyze optimal mechanisms for new drug testing under uncertain product quality. In our case, patients and hospitals take government approval of DES models as given, but patient preference for the newness of DES models (measured by whether a product is of the latest generation of a DES brand) affects hospital's incentives to update its DES portfolio, which in turns affects the diffusion of new DES products among patients.

One alternative design we consider in the counterfactual analysis (selective contracting) is a form of selective contracting. Selective contracting is widely used in healthcare as a strategy for cost containment and quality control. For example, insurers may contract selectively with a limited set of pharmaceutical manufacturers in drug formulary (Duggan and Morton, 2010), insurers may form a narrow network of healthcare providers (Sorensen, 2003; Pakes et al., 2015; Liebman and Panhans, 2021; Ho and Lee, 2019; Ghili, 2022), insurers may contract with selected pharmacies (Starc and Swanson, 2021), and chain pharmacies may only buy from selected generic drug manufacturers (Cuddy, 2020). Most studies on selective contracting focus on the trade-off between access and cost, with little attention to its impact on the suppliers' incentive to innovate or adopt innovations. We fill this gap by examining how a government insurer can engage in selective contracting with product manufacturers while taking into account hospital competition and incentives. Because the insurer's reimbursement policy can significantly reshape hospitals' strategic incentives in product adoption, upgrading, and pricing, the trade-off between access and cost must be achieved through

hospital behavior driven by these incentives.

A separate literature has examined the relationship between reimbursement policy and medical innovation, often without any explicit focus on selective contracting. For example, Bruen et al. (2016) note a lack of empirical evidence that directly connects reimbursement practices with innovation outcomes. Dunn, Fernando and Liebman (2023) find that conditions targeted by more cost-effectiveness studies have experienced significantly more spending growth, possibly because more cost-effective innovations are more likely to be adopted. This suggests that lower reimbursement may encourage cost-reducing innovations. However, after matching treatment quality data and medical claims for 13 important medical conditions, Dunn, Fernando and Liebman (2024) also find that higher quality innovations generally diffuse but in many instances innovations are priced so high that they are not cost effective and can lower consumer welfare, but still diffuse due to insurance. These counter examples suggest that insurer reimbursement could encourage inefficient diffusion of medical innovations. Another example of the tricky relationship between insurer reimbursement and innovation incentives appears in generic drugs. As shown by Yurukoglu, Liebman and Ridley (2017), lower Medicare reimbursement for generic drugs has been associated with increased drug shortages, as manufacturers have less incentive and capacity to invest in production and new product launches. We contribute to this literature by examining the effects of reimbursement policies on DES diffusion, patient welfare, hospital profits, and insurer expenditure simultaneously. We find that reimbursements directed toward selected brands in exchange for discounted wholesale cost can improve patients' welfare and hospitals' profits within the government budget, potentially leading to broader adoption of new DES models. This aligns with the goals highlighted in the National Academy of Medicine's report on payment reform for better value and medical innovation (McClellan et al., 2017), which emphasizes the need for nuanced policy approaches that balance multiple objectives.

Another closely related literature is how healthcare providers respond to reimbursement rate changes, not necessarily specific to new products or services. For instance, Dafny (2005) shows that, after a 1988 policy reform that generated large diagnosis-specific reimbursement rate changes for 43 percent of Medicare admissions, hospitals responded by upcoding patients to diagnosis codes with the largest price increases, rather than increasing the volume of admissions or the intensity or quality of care differentially in these diagnoses. In our context, it would be difficult to upcode or

downcode stent implantation given its distinctive feature, hence we ignore this potential response when we simulate different reimbursement policies. Using claims data in Taiwan, Jin, Lien and Tao (2024) find that minor teaching hospitals increased the use of BMS (but not DES) per stent patient when the NHI cut the reimbursement rate by 26% in 2009. In this paper, we focus on Taipei only but explicitly incorporate the 2009 rate cut in the demand and supply model. Our model also accounts for how hospitals change DES portfolio and price in response to reimbursement policies and how patient choice of stent brand may vary accordingly. In this sense, our work is similar to Garthwaite, Ody and Starc (2022), who show that hospitals facing more privately-insured patients in the US have more incentives to make costly investment in quality improvement because private insurers are more willing to pay a higher reimbursement rate for higher-quality services than public insurers.

Lastly, our work is related to a growing economic literature on cardiac stents. Grennan (2013, 2014); Grennan and Swanson (2020) study how hospitals and stent manufacturers negotiate the wholesale price and how information transparency affects this price negotiation. Grennan and Town (2020) examine how the different approval stringencies of new stent products in the US and European Union affect the trade-off between consumer welfare and entry costs. Bergman, Grennan and Swanson (2021, 2022) document marketing payments from medical technology firms to physicians and hospital device procurement, with a potential to influence physician and procurement preferences in favor of paying firms. In comparison, we focus on the retail interaction between hospitals and end consumers, while being agnostic on hospital-manufacturer interactions. Regardless how hospitals and manufacturers interact, we use our demand estimates and supply model to infer each hospital's marginal cost and one-time fixed costs of adopting a new brand or upgrading an existing brand to the newest generation. These inferred costs could be a result of hospitals negotiating with DES manufacturers, with and without marketwide transparency or marketing engagement.

3 Background and Data Description

In this section, we first provide an overview of stent implantation procedures and the innovation of drug-eluting stents (DES). We then present the data sources used in our empirical analysis, including detailed descriptions of how we compile the dataset. Finally, we summarize key patterns

and descriptive statistics that motivate our structural modeling approach.

3.1 Background on Stent Surgery and DES Innovation

Patients with cardiac conditions typically face a spectrum of treatment options, including pharmacological therapy, stent implantation, and open-chest surgery. Pharmacological therapy, while non-invasive, may not sufficiently address issues of arterial blockage. In the meantime, open-heart surgery, although potentially effective, carries significant risks and requires a lengthy recovery period. Consequently, stent implantation has emerged as a less invasive yet effective alternative over the past few decades.

A standard stent implantation procedure involves guiding a balloon catheter with a mounted stent through the vasculature to the site of the blockage. Once properly positioned, the balloon is inflated, expanding the stent and providing structural support to the blood vessel to mitigate the likelihood of re-occlusion (complete blockage or closure of an artery). The earliest stents, known as Bare Metal Stents (BMS), are composed solely of metal alloys. While BMS reduce the risk of immediate vessel closure, the metal material can sometimes trigger allergic responses and encourage excessive tissue growth, thereby limiting their effectiveness in preventing restenosis (re-narrowing of the artery).

To address these limitations, manufacturers introduced Drug-Eluting Stents (DES), which are coated with drugs designed to inhibit tissue growth. Compared to BMS, DES substantially reduce restenosis but often require a longer duration of dual antiplatelet therapy (DAPT) by post-implantation blood-thinning medications, making them more appropriate for patients without serious comorbidities that could complicate such pharmacological regimens. Over time, DES designs and drug formulations have been refined to minimize allergic reactions, resulting in multiple generations of DES. Although they are more expensive than BMS, DES have gained widespread acceptance because of their improved safety and effectiveness in preventing restenosis and re-occlusion.

Nonetheless, DES may not be superior for all patient groups, as drug coating could imply longer healing time and pose additional risks for older individuals or those with severe health conditions. DES of different generations are also associated with different risks. For example, older-generation DES tend to carry a higher risk of stent thrombosis (a blood clot that forms within or on the surface of a stent) than BMS, especially if DAPT is stopped too soon. This is because thicker or

less biocompatible coating of DES can prolong inflammation around the stent struts, which increases the risk of clot formation. However, newer-generation DES have reduced that risk through better stent design or shorter DAPT requirement for selected patients. When patients adhere to the recommended antiplatelet regimen, current DES generally have stent thrombosis rates comparable to or even lower than BMS.

3.2 Data Sample Description

We construct our dataset from three primary sources, enabling a comprehensive examination of both DES and BMS usage in Taiwan.

First, we use individual claims data from the Taipei agency of Taiwan's National Health Insurance (NHI) system from January 2007 to December 2013. These records include each patient's pre-surgery diagnoses, the quantity and model specifications of any stents used, and various hospital-level characteristics (e.g., location, number of beds, teaching hospital status, and a unique hospital identifier). In rare instances in which a patient undergoes multiple stent surgeries during the observation period, each surgery is recorded separately and can be linked via a unique patient identifier. We restrict our analysis to the Taipei agency area, which is the largest region in Taiwan, to capture in-depth local hospital competition.

Under NHI's reimbursement policy, hospitals receive the full cost of a BMS for each stent implanted, regardless of whether it is a BMS or a DES; patients bear the incremental cost of any DES out of pocket. For instance, in 2007, the NHI reimbursed hospitals at a fixed rate of 27,000 NTD per stent. If a patient received one BMS and one DES, the hospital would receive $2 \times 27,000 = 54,000$ NTD from NHI and charge the patient the additional DES cost. In the middle of our sample (January 2009), NHI reduced the reimbursement rate from 27,000 to 19,940 NTD for all stents. In the above example, this universal 26% cut reduces hospital revenue by 7,060 NTD per stent used, but the patient's out of pocket payment does not change unless the hospital also changes its DES price in response to the rate cut. Since NHI compensates hospitals uniformly per stent without differentiating by type, the NHI claims data contain only stent quantities, rather than detailed patient-paid prices.

To account for patient-paid prices, we exploit NHI regulations that require hospitals to periodically report the DES prices charged to patients. These reports are publicly available on the NHI

website. We collect these price reports and construct a panel of DES prices by hospital and DES model, assuming that a reported price remains in effect until the hospital submits a subsequent report for the same model. We successfully match price data for approximately 90% of the DES claims in our dataset.

Finally, we enrich the dataset with income information based on patients' areas of residence, drawing from the location-based health premium records of retired individuals. Each patient is matched to the average income level of the township in which they reside. Additional demographic characteristics, such as age and gender, are directly observed in the NHI records.

We categorize DES models by both manufacturer and generation. For example, the code *CBP06ELUT1SB* indicates the first generation ("1") produced by Boston Scientific (abbreviation "SB"). For each brand-generation, we document detailed specifications, including stent alloy composition and drug coating formulation, as shown in Table 1.

Table 1: List of Major Drug-Eluting Stent Models

Brand Name (Abbr.)	Gen	Initial Use	Stent Material	Coating Material	Length Choices	Diameter Choices	Note
Abbott (AB)	1	Oct 2008	L-605 CoCr Alloy	Everolimus and polymers	6	6	
	2	Nov 2008	L-605 CoCr Alloy	Everolimus and polymers	6	4	Consolidated with Gen 1
	3	Feb 2011	L-605 CoCr Alloy	Everolimus and polymers	8	5	
Medtronic (M4)	1	Mar 2007	Co alloy and PC coating	ABT-578	8	6	
	2	Jun 2008	Co alloy and PC coating	Zotarolimus	8	6	
	3	Jul 2009	Co alloy w/ BioLinx coating	Zotarolimus	8	6	
	4	Apr 2011	Co alloy w/ BioLinx coating	Zotarolimus	9	6	Rarely used, dropped
	5	Jan 2013	Co alloy w/ BioLinx coating	Zotarolimus	11	6	
Cordis (CD)	1	Nov 2006	316L stainless steel w/ Titanium Oxynitride	Sirolimus and polymers	6	8	
	2	Jul 2007	316L stainless steel	Sirolimus and polymers	6	5	
Boston Scientific (SB)	1	Nov 2006	316L stainless steel w/ polymers	Paclitaxel	7	8	Consolidated with Gen 2
	2	Oct 2006	316L stainless steel w/ Translute Polymer Carrier	Paclitaxel	7	5	
	3		316L stainless steel w/ Translute Polymer Carrier	Paclitaxel	8	8	Not observed in data
	4	Jan 2011	PtCr alloy w/ Translute Polymer Carrier	Paclitaxel	8	8	
	5	Nov 2010	PtCr alloy w/ PBMA-poly coating	PVDF-HFPpoly and Everolimus	8	6	Consolidated with Gen 4
Bio Sensor (BS)	1	Oct 2010	316L stainless steel	Biolimus w/ PLA	7	7	
	2	Feb 2012	316L stainless steel	Biolimus w/ PLA	8	6	

We focus on five prominent DES manufacturers: Abbott, Medtronic, Cordis, Boston Scientific, and Bio Sensor. Each introduced at least two DES generations during the sample period, and each new generation typically features modifications to both alloy composition and drug coating. To meet diverse patient needs, some brands also offer multiple lengths and diameters for each generation.

In some cases, models cannot be cleanly distinguished from earlier generations due to near-simultaneous release and overlapping technical specifications. For example, Abbott Generation 2 closely resembles its Generation 1 and is thus consolidated as part of the same product release.

Additionally, although our data contain other DES brands (e.g., B. Braun, Hexacath, Orbus, Terumo, and CID), we aggregate these less commonly used products into an "Other" category without generational differentiation. Further, some models (e.g., Boston Scientific Generation 3) may be available globally but do not appear in our dataset, possibly due to low usage or a lack of import into Taiwan.

We define a "hospital-specific upgrade" as the first time a hospital switches from an older generation within a brand to a newer generation in that same brand, and an "adoption" as the first time a hospital begins using a brand that was not previously included in its stent portfolio. Because different hospitals may choose to adopt or upgrade at different times, these decisions reflect individual hospital-level considerations after a DES brand or generation enters the Taiwanese market.

Throughout the paper, BMS is included as a baseline option in hospitals' stent portfolios, ensuring that patients who do not receive DES treatment instead receive BMS. This broad framing allows us to capture the interplay between patient choices, hospital adoption decisions, and the welfare implications of DES innovations in Taiwan's healthcare system.

3.3 Summary Statistics

We begin by illustrating aggregate patterns of stent usage and pricing across the five major DES brands. Figure 1 shows the evolution of stent usage by brand and generation across all 20 hospitals in the Taipei sample.

Within each brand, the introduction of a newer generation is typically followed by a marked decline in usage of the preceding generation, indicating that new generations tend to replace older ones rather than coexist with them. We rarely observe hospitals using multiple generations of the same brand beyond a short transitional period. Moreover, the timing of these generational upgrades varies considerably by brand, suggesting that brand-specific factors, such as technology introduction dates, may drive the observed substitution patterns more strongly than common market-wide shocks.

Another noteworthy observation is that newer generations do not always achieve higher sales volumes than their predecessors. For example, Abbott's first-generation models exhibit higher overall usage than Abbott's third-generation models. This could stem from several factors, including

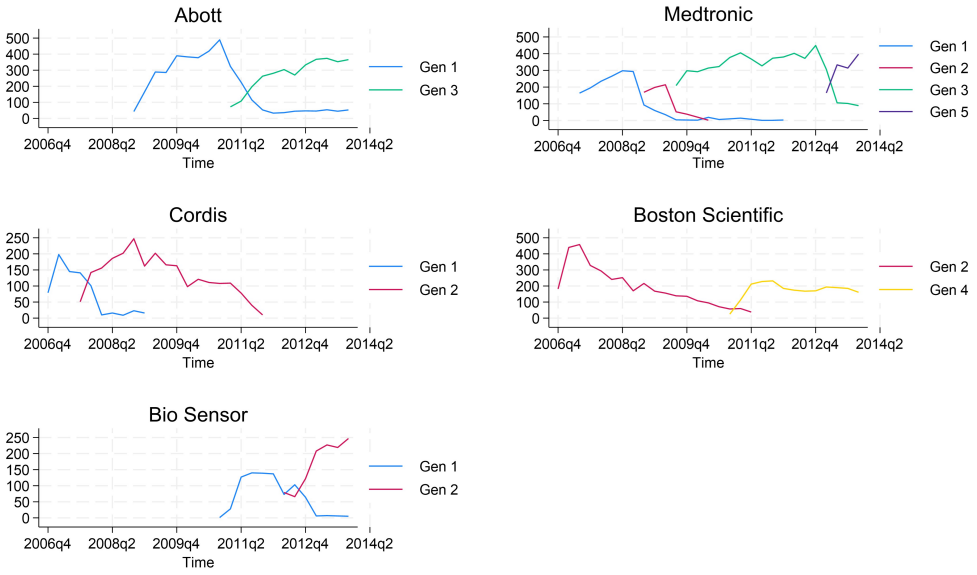


Figure 1: DES Quantity of Different Generations by Brand

limited perceived quality improvements or competition from other manufacturers offering superior alternatives. These demand- and supply-side considerations will be explicitly incorporated in our structural analysis.

Figure 2 presents the evolution of average prices for each brand-generation over time, alongside a weighted average price (dashed lines) at the brand level. The former is defined as the simple mean of the reported prices for each generation, while the latter is computed by weighting each generation's price by its share of that brand's total stent placements.

We find that price trends vary by brand following the introduction of a new generation. For instance, Abbott's average price declines over time, whereas Cordis exhibits an upward trajectory. In some cases, older models initially appear more expensive than newly introduced models, though these higher prices generally affect only a small set of hospitals that do not rapidly adopt the newer generation. Consequently, the weighted average price at the brand level closely tracks the average price of the newest generation, suggesting that certain hospitals face either higher costs or additional frictions when upgrading to newer stent models.

Figure 3 examines the distribution of adoption and upgrade delays, measured in quarters from the time a DES brand or generation first appears in the market to the time a hospital first uses it.

The distribution of these delays is skewed toward zero, indicating that many hospitals either

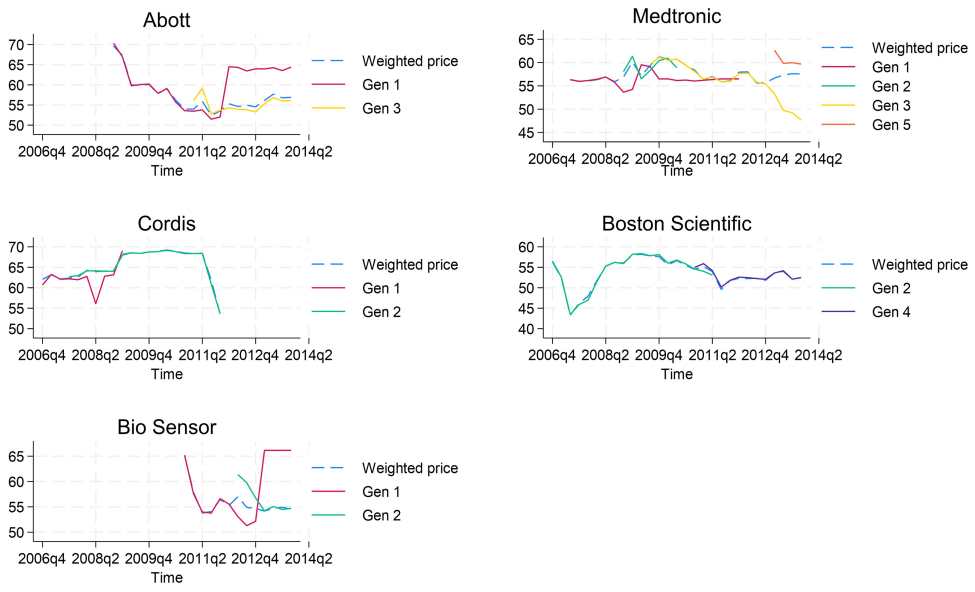
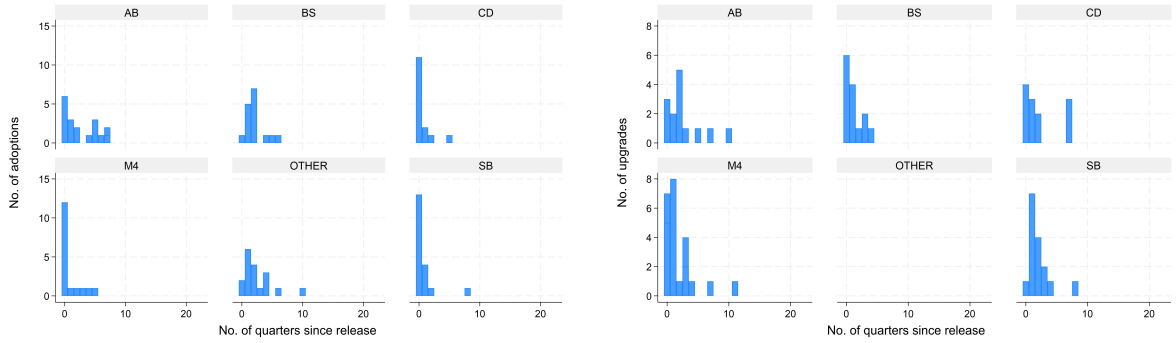


Figure 2: Average Price Across Generations



(a) Adoption Delay

(b) Upgrade Delay

Figure 3: Distribution of Adoption and Upgrade Delays (in quarters)

adopt or upgrade to new stent models relatively quickly (within two to three quarters) or never do so at all. This observation, combined with the fact that the set of hospitals remains fixed throughout our sample, motivates a modeling framework in which hospitals make (largely) static decisions about which stent models to offer in each period.

Table 2 reports summary statistics on stent choices at the hospital-brand-quarter level. On average, we observe around 108 patients per hospital-quarter, with about half receiving DES and half using BMS. Each patient faces roughly 90 distinct hospital-brand options each quarter, corresponding to an average of about 4.55 brands per hospital (counting BMS as its own brand).

Table 2: Summary Statistics on Patients' Stent Usage and Choices

	Mean	Std. Dev.	Min	Max
Number of patients per hospital-quarter	108.15	92.29	1	377
Patients using DES	52.56	62.94	1	279
Patients using BMS	56.74	39.90	1	251
Number of hospital-brand choices	90.18	19.19	41	114
Number of brand choices within hospital	4.55	1.39	1	7
Patient-paid prices of DES (1,000 NTD)				
Abbott	56.90	7.66	30.66	78.75
Bio Sensor	55.40	7.44	44.36	68.22
Cordis	65.69	3.90	43.31	74.56
Medtronic	57.40	5.95	29.71	67.96
Boston Scientific	52.45	9.52	26.09	72.00
Other	52.22	6.08	32.92	70.05
Percentage of patients using DES per quarter	40.17%	20.20%	0%	100%

Prices for DES vary considerably both across brands and across hospitals. On average, patient-paid prices range between roughly 52,000 and 65,000 NTD per stent, with substantial variation within and across brands. This price is comparable to the average monthly wage of Taiwanese in the study period (roughly 50,000 NTD), and thus stent affordability remains a hotly debated topic in public policy. In total, about 40% of patients per quarter receive DES, indicating that BMS remain a significant alternative in this market.

These descriptive patterns underscore the heterogeneity in hospital adoption and pricing strategies. Such variability highlights the potential role of hospital-specific factors, learning effects, and competition in shaping the diffusion of medical innovation. In the subsequent sections, we develop a structural model to analyze how these factors jointly influence hospital stent portfolios, patient choices, and resulting welfare outcomes.

4 Model

To analyze the diffusion of DES innovations, we consider the interactions among three agent types: (i) upstream medical device manufacturers who periodically introduce new generations of stents; (ii) downstream hospitals that decide whether to incorporate new stent brands and upgrade existing brands to their latest generations; and (iii) patients who choose both the hospital and the DES

brand for their stent treatment. We do not model doctors as a separate player, because in Taiwan cardiac doctors that can perform stent implantation are typically hospital employees and do not earn money directly from their treatment choices but we do not observe how hospitals define employee compensation or how doctors interact with individual patients. Similarly, we do not explicitly model the activity or influence of sales representatives from DES manufacturers because the data contains no such information. In general, if a hospital includes a particular DES brand in its portfolio, a sales representative from that brand will stay inside the hospital to provide stents on spot (which reduces the hospital's need to carry inventory) and sometimes even educate patients on features of DES products.

Because DES manufacturers base their innovation decisions on global market considerations—and the Taiwanese DES market represents a relatively small portion of global demand—we treat the introduction and quality advancement of new DES models in Taiwan as exogenous. Therefore, our model focuses on two main components: (i) hospitals' portfolio management decisions, which involve expanding their portfolios by adopting new brands (*adoption*), upgrading existing brands to their latest generations (*upgrade*) and updating prices for each brand in the portfolio, and (ii) patients' choices of hospitals and stent models in Taipei for treatment. We model these two stages recursively, as described below.

4.1 Patients' Demand

Let i index patients, h index hospitals, m index stent brands (each corresponding to a unique manufacturer), and t index time periods (in quarters). When patient i requires stent treatment, she observes all hospitals in Taipei ($h \in H$, with H constant over our sample period) and their respective stent portfolios M_{ht} for the current period. For each brand m offered in hospital h's portfolio M_{ht}, the patient observes the patient-paid price p_{hmt}, the generation number g_{hmt}, and whether it is drug-eluting (denoted by $isDES_m$, as opposed to a BMS). Additionally, the patient observes whether a DES option is currently the latest generation of the brand in the market, defined by a dummy variable $New_{hmt} = 1(g_{hmt} = \bar{g}_{mt})$, where $\bar{g}_{mt} = \max_{h \in H} g_{hmt}$ represents the newest generation used in the market. Finally, to measure patients' disutility of traveling distance, we define dis_{ih} as the distance between the center locations of patient's and hospital's township area.

We assume that patients have full information of all the hospitals and their currently active

treatment options based on two market facts. First, Taiwan NHI maintains a website to publicly collect and reveal the prices of all hospitals' DES models, which is intended to help patients discover DES offerings and prices.[3] Second, the price discrepancy within the same DES model across hospitals have been largely reported and analyzed in Taiwan media due to widespread affordability concerns, which in turn helps patients get better knowledge of different hospitals' treatment choices. Nonetheless, we recognize that the treatment decision process may involve significant patient-doctor interactions and the observed treatment choice likely reflects a patient decision upon doctoral advice.

Given the widespread availability of BMS, we assume that every hospital offers a BMS option in every period, denoted by $m = 0$. According to the NHI reimbursement schedule, all BMS options are free of charge to patients. The newest generation dummy New_{hmt} is also set to zero for BMS.

We specify patient i's utility from choosing stent brand m at hospital h in period t as

$$u_{ihmt} = \beta_{1ih} isDES_m + \beta_{2ih} New_{hmt} + \beta_{3ih} dis_{ih} + \alpha_{ih} p_{hmt} + \xi_h + \xi_m + \varepsilon_{ihmt} \equiv \delta_{ihmt} + \varepsilon_{ihmt}, \quad (1)$$

where $\beta_{1ih}, \beta_{2ih}, \beta_{3ih}$ captures patient i's preference for DES over BMS, the newest DES generation and the travel distance, respectively. α_{ih} represents price sensitivity, ξ_h and ξ_m are hospital and brand fixed effects accounting for unobserved attributes, and ε_{ihmt} is an idiosyncratic error term.

To capture heterogeneity in patient preferences, we specify random coefficients that vary with patient characteristics, specifically their health condition (measured by the Charlson Comorbidity Index), income level[4] and distance to hospital:

$$\begin{aligned}
\beta_{1ih} &= \beta_{10} + \beta_{11} charlson_i + \beta_{12} income_i + \beta_{13} dis_{ih} + v_{1i}, \\
\beta_{2ih} &= \beta_{20} + \beta_{21} charlson_i + \beta_{22} income_i + \beta_{23} dis_{ih} + v_{2i}, \\
\beta_{3ih} &= \beta_{30} + \beta_{31} charlson_i + \beta_{32} income_i + \beta_{33} dis_{ih} + v_{3i}, \\
\alpha_{ih} &= \alpha_0 + \alpha_{11} charlson_i + \alpha_{12} income_i + \alpha_{13} dis_{ih} + v_{4i}
\end{aligned}$$

$\mathbf{v}_i \triangleq (v_{1i}, v_{2i}, v_{3i}, v_{4i})$ are unobserved individual-specific preference shocks, assumed to be indepen-

[3] The website is available at (in traditional Chinese) https://info.nhi.gov.tw/INAE2000/INAE2011S02.

[4] We have tried to include age and gender in the demand model but do not find much impact from them, once we include Charlson Comorbidity Index and income. Thus, the demand model reported in the paper does not include age and gender.

dently distributed according to $G(\cdot)$. The hospital-specific fixed effect ξ_h captures attributes such as overall hospital reputation, while the brand-specific fixed effect ξ_m captures brand reputation and other time-invariant brand characteristics. The error term ε_{ihmt} is assumed to be independently and identically distributed (i.i.d.) Type I extreme value.[5] We assume that each hospital offers a BMS option ($m = 0$) and that the mean utility from choosing BMS at hospital h equals the hospital fixed effect, i.e., $\delta_{ih0t} = \xi_h$.

Given the set of hospitals and their stent portfolios, the probability that patient i chooses stent brand m at hospital h in period t is:

$$s_{ihmt}(\mathcal{P}_t, \mathcal{M}_t) = \frac{\exp(\delta_{ihmt})}{1 + \sum_{h' \in H} \sum_{m' \in M_{h't}} \exp(\delta_{ih'm't})}, \tag{2}$$

where the denominator sums over all available hospital-brand combinations, including BMS. $\mathcal{P}_t$ and $\mathcal{M}_t$ denotes the set of all hospitals' portfolio offering and corresponding patient-paid prices.

To obtain the aggregate demand for each hospital-brand combination, we integrate the individual choice probabilities over the distributions of patient demographics and unobserved preference shocks:

$$s_{hmt}(\mathcal{P}_t, \mathcal{M}_t) = \iint s_{ihmt} \, dF(Income_i, Charlson_i) \, dG(\mathbf{v}_i). \tag{3}$$

Price Endogeneity and Instrumental Variables

A potential concern is that DES prices p_{hmt} may be endogenous due to correlation with unobserved quality attributes that affect utility δ_{ihmt}. To address this, we employ a control function approach using instrumental variables (IVs) that are correlated with prices through cost shifters but uncorrelated with unobserved demand shocks.

Our IVs include:

1. **Exchange Rate Fluctuations**: The quarterly average relative exchange rate the New Taiwan Dollar (NTD) with respect to the U.S. Dolla (USD) and the Singapore dollar (SGD). Since all major DES stents are imported from the US, except Bio Sensor which is imported

[5] We also considered a two-level nested logit model, with hospital choices as the upper nest and brand choices as the lower nest. However, the estimated nesting parameter σ was close to zero, suggesting minimal correlation within nests, so we proceed with the random coefficients logit model.

from Singapore, exchange rate fluctuations affect import costs and, consequently, wholesale and retail prices.

2. **Hospital Adoption of the Same Brand**: The number of other hospitals that have adopted the same DES brand up to the beginning of the study period. Wider adoption may lead to economies of scale or learning spillovers, influencing costs and prices.

3. **Hospitals Offering the Latest Generation**: The percentage of other hospitals that have adopted the latest generation stents within the same brand up to the beginning of the study period. Competitive pressures may compel hospitals to adjust prices based on peers' adoption of the latest technology.

We first regress DES prices on the exogenous variables and the IVs to obtain residuals capturing unobserved quality-related factors. These residuals are then included in the utility specification as control functions, mitigating the endogeneity bias in price coefficients. We provide further details of the estimation procedure in Section 5.

4.2 Supply Model

Hospitals compete by adjusting their DES portfolios—adopting new brands, upgrading existing brands to the latest generations—and by setting patient-paid prices for each DES model. We model this competition as a sequential game with the following timeline:

- **Initial Stage**: At the beginning of each period t, hospitals observe their own and competitors' portfolios from the previous period, as well as the set of available portfolio modifications.

- **Stage 1**: All hospitals simultaneously decide whether to (i) upgrade an existing DES brand to its latest generation (if available), (ii) adopt the latest generation of a new brand not yet in their portfolio (if available), or (iii) make no changes to their portfolios.

- **Stage 2**: After portfolio adjustments become observable, hospitals simultaneously set patient-paid prices p_{hmt} for each DES model in their updated portfolios.

- **Stage 3**: Given the updated portfolios and prices, patients make their hospital and stent brand choices as described in the demand model.

Next we explain Stage 1 and 2 in recursive order to model hospitals' strategies.

Stage 2: Hospitals' Pricing Decisions

In Stage 2, given their updated portfolios from Stage 1 ($\mathcal{M}_t = \{M_{ht}\}$), hospitals choose prices to maximize current-period profits. Note that in Taiwan, doctors are affiliated with hospitals and do not engage directly in DES portfolio update and pricing, so we assume that prices are uniform across patients and do not vary with their demographics and health conditions. Hospitals receive revenue from patient-paid prices and the NHI reimbursement, and incur costs based on negotiated wholesale prices.

Hospital h's profit maximization problem is

$$\pi_h(M_{ht}, \mathcal{M}_t) = \max_{\{p_{hmt}\}_{m \in M_{ht}}} \left\{ \sum_{m \in M_{ht}, m \neq 0} (p_{hmt} + r_t - c_{hmt})\, s_{hmt}(\mathcal{P}_t, \mathcal{M}_t) + 0.2 r_t s_{h0t}(\mathcal{P}_t, \mathcal{M}_t) \right\}, \tag{4}$$

where s_{hmt} is the market share of stent patients choosing hospital h and model m at time t, which depends on all hospitals' prices $\mathcal{P}_t$ and portfolios $\mathcal{M}_t$; r_t is the NHI reimbursement amount; c_{hmt} is the wholesale cost for DES model m at hospital h; and $0.2r_t$ represents the profit margin from BMS ($m = 0$), based on an estimated 20% markup over BMS cost.

Assuming Bertrand-Nash pricing, the first-order condition for hospital h's pricing problem can be written as

$$0.2\mathbf{r}_t \Delta_{0t} + \mathbf{s}_t + \Delta_{-0t} (\mathbf{r}_t + \mathbf{p}_t - \mathbf{c}_t) = 0, \tag{5}$$

where $\mathbf{s}_t$ is the vector of DES market shares, $\mathbf{r}_t$, $\mathbf{p}_t$, and $\mathbf{c}_t$ are vectors of NHI reimbursements, patient-paid prices, and marginal costs, respectively; Δ_{0t} is the vector of derivatives of the BMS market share with respect to DES prices; and Δ_{-0t} is the matrix of derivatives of DES market shares with respect to DES prices.

From the first-order condition, we can invert it to recover hospitals' marginal costs:

$$\mathbf{c}_t = \mathbf{r}_t + \mathbf{p}_t + (\Delta_{-0t})^{-1} (0.2\mathbf{r}_t \Delta_{0t} + \mathbf{s}_t). \tag{6}$$

These marginal cost estimates are used to compute the period profits for different portfolio choices

in Stage 1.

Stage 1: Hospitals' Portfolio Adjustment Decisions

Empirically, we observe that hospitals rarely make multiple portfolio adjustments simultaneously or drop brands from their portfolios (except in rare cases due to health risks scandal for Cordis). Based on these patterns, we assume that in Stage 1, each hospital chooses one of three actions: (i) upgrade an existing DES brand to its latest generation (if available), (ii) adopt the latest generation of a new brand not yet in their portfolio (if available), or (iii) make no portfolio changes. Given that hospitals maintain a relatively small amount of inventory and make frequent purchases of DES, we assume that this portfolio modification takes effect immediately in the current period, i.e. a hospital only maintains one generation within each brand in the portfolio at any time.

The number of feasible portfolio adjustments depends on the hospital's current portfolio and the available DES models in the market. For example, if all six DES brands are available and a hospital currently uses three brands (with two not being the latest generation), it chooses one of the six options: upgrading one of the two outdated models, adopting one of the three brands not yet in their portfolio, or continuing with their previous portfolio.

Hospital h's expected profit from adjusting its portfolio from M_{ht} to M'_{ht} is

$$V_{ht}(M'_{ht}, M_{ht}, \mathcal{M}'_t) = \pi_h(M'_{ht}, \mathcal{M}'_t) - c^M_{ht}(M_{ht}, M'_{ht}), \tag{7}$$

where $c^M_{ht}(M_{ht}, M'_{ht})$ is the cost of portfolio modification (adoption or upgrade), which indicates the one-time fixed cost associated with coordinating with new manufacturers in the treatment procedure, updating the inventory information in the system, and bargaining with the manufacturers over potential lumpsum discount. We assume that the portfolio adjustment cost includes a stochastic component v_{ht}, which is i.i.d. Type I extreme value.

Although portfolio management decisions may embody long-term strategic considerations, we adopt a static supply model where hospitals adjust portfolios and prices based solely on current-period payoffs. This simplification is motivated by (a) most new adoption and upgrading decisions are concentrated within the first 1-3 quarters after such options become available (Figure 3); (b) the number of hospitals in Taipei never changed in our sample period, which minimizes the strategic

incentives of using stent portfolios to preempt hospital entry or force exit; and (c) a fully dynamic model is computational intractable given the size of the state space.[6] Similar static approaches have been used in the literature, such as Wollmann (2018) in modeling truck manufacturers' product portfolios and Olssen and Demirer (2024) in studying health insurers' periodic drug formulary choices.

The probability that hospital h chooses portfolio M'_{ht} is then given by

$$Pr_t(M'_{ht}|M_{ht}, \mathcal{M}_t) = \frac{\exp\left(V_{ht}(M'_{ht}, M_{ht}, \mathcal{M}_t)\right)}{1 + \sum_{M' \in \mathcal{M}_{ht}} \exp\left(V_{ht}(M', M_{ht}, \mathcal{M}_t)\right)}, \tag{8}$$

where the denominator sums over all feasible portfolio adjustments for hospital h in period t. We use the observed portfolio choices and the model-predicted probabilities to estimate the adoption and upgrade costs via maximum likelihood estimation, as detailed in the next section.

5 Estimation Results

This section first presents the demand estimation results, and then turns to the recovery of hospitals' marginal costs and fixed costs in adoption and upgrade.

5.1 Demand Estimation

We use individual-level data on patient treatment choices to estimate the preference parameters governing hospital and stent brand selection. Each patient faces a choice set comprising all hospitals in the Taipei region and the stent brands offered by those hospitals in the relevant quarter. Because hospitals offer a fully reimbursed BMS option (denoted as $m = 0$) in every period, we treat BMS as an additional outside option within each hospital's portfolio.

To allow for patient heterogeneity, we specify random coefficients for key variables in the utility function, including out-of-pocket price, DES status, newest-generation status, and travel distance. Observed characteristics, such as income, travel distance, and Charlson Comorbidity Index, also interact with these variables. The model is estimated by simulated maximum likelihood, integrating over the distribution of random coefficients across patients.

[6] For example, for each hospital-brand combination, it could be one of the three states, {not adopted, adopted but not newnest, newest}, so with 20 hospitals and 5 major DES brands, there are $3^{20\times5}$ possible states.

A potential concern is that out-of-pocket DES prices may be correlated with unobserved treatment quality. To address this endogeneity, we employ a control-function approach. In the first step, we regress DES prices on a set of cost-shifters (such as exchange rates and measures of other hospitals' adoption of the same brand) and exogenous regressors. We then include the residual from that regression in the demand estimation to control for unobserved factors correlated with prices.

Table 3 reports the estimates from several specifications. Columns (1) and (2) present conditional logit estimations without and with the control-function residual. The inclusion of the residual (Column 2) substantially increases the estimated magnitude of price sensitivity relative to Column (1). In both columns, hospital and brand fixed effects capture time-invariant hospital- and brand-specific attributes.

Columns (3) and (4) introduce random coefficients for out-of-pocket price, DES status, newest-generation status, and travel distance, while continuing to include the control-function residual. Column (4) adds additional interactions between distance and patient demographics. Relative to the simpler specifications, Column (4) reveals richer patterns of patient heterogeneity. Patients with higher income are less price-sensitive, more likely to choose DES, and more sensitive to distance, whereas patients with more serious health conditions display higher price sensitivity and lower valuation of DES. The results also indicate that, on average, patients place a significant premium on receiving the newest-generation stent.

Column (4) is our preferred specification in subsequent analysis. It indicates that patients are highly responsive to changes in DES prices, with own-price elasticities typically ranging from about -6 to -4 over time. This finding is consistent with the fact that BMS are fully reimbursed and provide an effectively cost-free alternative. Figure 4 shows how these elasticities evolve over time, demonstrating that small changes in DES out-of-pocket prices induce substantial shifts in patient demand.

Average DES prices of around 60,000 NTD (approximately \$2,000) represent more than a month's worth of per capita GDP for many Taiwanese households, which further explains the high sensitivity to price. Because of this strong competition from BMS, the resulting DES markups are modest, ranging between 16.7% and 25%, consistent with industry estimates of around 20%.

Table 3: Demand Estimation Results

	(1)	(2)	(3)	(4)
	Conditional Logit		Random Coefficients	
Main Coefficients				
Patient-paid price	-0.00601**	-0.0943***	-0.0954***	-0.0934***
	(0.00219)	(0.00313)	(0.00316)	(0.00318)
Patient-paid price × income	0.00389*	0.00699***	0.00718***	0.00502*
	(0.00195)	(0.00211)	(0.00213)	(0.00213)
Patient-paid price × Charlson	-0.00346***	-0.00384***	-0.00378***	-0.00385***
	(0.00076)	(0.00083)	(0.00083)	(0.00083)
Distance	-0.0909***	-0.0911***	-0.0912***	-0.0895***
	(0.00071)	(0.00071)	(0.00071)	(0.00300)
DES dummy	-1.425***	3.612***	3.634***	3.538***
	(0.139)	(0.188)	(0.191)	(0.190)
DES dummy × Charlson	-0.116*	-0.0941	-0.143**	-0.109*
	(0.0478)	(0.0510)	(0.0532)	(0.0527)
DES dummy × income	0.471***	0.255	0.331*	0.402**
	(0.122)	(0.131)	(0.134)	(0.133)
Distance × Charlson				-0.00759***
				(0.00085)
Distance × income				-0.00857**
				(0.00286)
Newest gen. dummy	0.643***	0.723***	0.724***	0.702***
	(0.0718)	(0.0722)	(0.0724)	(0.0728)
Newest gen. × Charlson	-0.0311	-0.0462	-0.0465	-0.0497
	(0.0254)	(0.0254)	(0.0255)	(0.0260)
Newest gen. × income	-0.201**	-0.167**	-0.169**	-0.142*
	(0.0620)	(0.0624)	(0.0626)	(0.0632)
Control function residual		0.0977***	0.0990***	0.0989***
		(0.00226)	(0.00229)	(0.00230)
Random Coefficients (Std. Dev.)				
Price			-0.000135	-0.000647
			(0.00276)	(0.00254)
DES dummy			-0.820***	0.509**
			(0.124)	(0.162)
Newest gen. dummy			0.0789	-0.220
			(0.203)	(0.177)
Distance				0.0726***
				(0.00149)
Hospital FE	Yes	Yes	Yes	Yes
Brand FE	Yes	Yes	Yes	Yes
N	5,579,861	5,579,861	5,579,861	5,579,861
Log-likelihood	-228665.2	-227705.5	-227696.5	-227118.2

Notes: Standard errors in parentheses. ***, **, * indicate significance at the 1%, 5%, and 10% levels, respectively. All specifications include hospital and brand fixed effects.

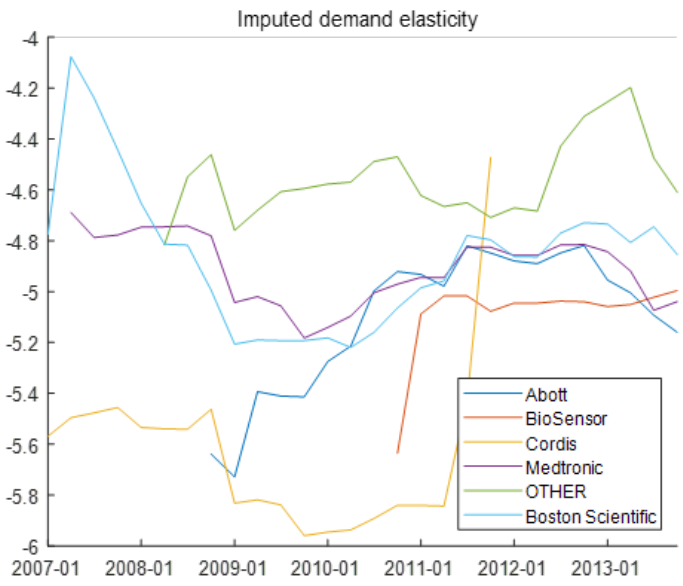


Figure 4: Estimated Own-Price Elasticities for DES Over Time

5.2 Supply Estimation

Recovering Marginal Costs

We use the demand estimates from Table 3 Column (4) to recover hospitals' marginal costs. The first-order conditions for the Bertrand–Nash pricing game imply that a hospital's marginal cost for a given DES model can be backed out by inverting the system of equations linking prices, shares, and the NHI reimbursement rate:

$$\mathbf{c}_t = \mathbf{r}_t + \mathbf{p}_t + (\Delta_{-0t})^{-1}\Big(0.2\,\mathbf{r}_t\,\Delta_{0t} + \mathbf{s}_t\Big),$$

where Δ_{-0t} and Δ_{0t} are the derivatives of the DES and BMS shares with respect to DES prices. This approach recovers marginal costs for all observed hospital–brand–quarter combinations. For cases in which a hospital might counterfactually adopt or upgrade a brand it did not previously use, we impute marginal costs by regressing the recovered costs on hospital, brand, and time fixed effects. We then use the resulting estimates to predict unobserved costs in hypothetical adoption or upgrade scenarios.

Adoption and Upgrade Cost Estimation

Hospitals incur fixed costs when adopting a new DES brand or upgrading an existing brand to its newest generation. These costs may depend on current portfolio size, the extent to which other hospitals have adopted or upgraded the same brand, and the time during which the newest generation has been available. Formally, if a hospital changes its portfolio from M_{ht} to M'_{ht}, its current-period payoff depends on the resulting profit $\pi_h\big(M'_{ht}, \mathcal{M}'_t\big)$ net of a stochastic adjustment cost $c^M_{ht}\big(M_{ht}, M'_{ht}\big)$. Assuming that the unobserved portion of the adjustment cost is drawn from a Type I extreme-value distribution, we estimate adoption and upgrade cost parameters via maximum likelihood by matching observed hospital choices.

Table 4 presents the resulting estimates for adoption and upgrade costs. The negative coefficient on portfolio size indicates that hospitals managing larger stent portfolios tend to incur lower additional costs when adding or upgrading a brand, possibly reflecting economies of scale in inventory and procurement processes. The number of other hospitals using the same or newest generation of a brand also affects adoption and upgrade costs, in some cases reducing a hospital's desire to adopt a widely used brand (due to lower differentiation potential) but in other cases making it easier to transition to a newer generation. Longer market availability of the latest generation reduces the cost of upgrading, which may reflect model familiarity and social learning gained over time. Overall, the estimated costs of adopting a new brand are widely distributed, with 0.88 million NTD in the 25th percentile, 5.64 million in the median, and 8.56 million in the 75th percentile. They are significantly higher than the estimated costs of upgrading an existing brand to the latest generation (0.36 million NTD in the 25th percentile, 1.36 million in the median, and 2.74 million in the 75th percentile.

We examine how well the estimated model reproduces observed adoption and upgrade events. Table 5 compares the actual and model-imputed numbers of adoptions, upgrades, and no-change decisions by DES brand. The close correspondence in each category, despite minor differences for some brands, indicates that the model captures important aspects of hospital decision-making. Figure 5 shows how these model-imputed choices evolve over time and aligns well with the actual data.

Finally, since we can infer the marginal costs of DES for each hospital-brand-quarter, Figure 6(a)

Table 4: Adoption and Upgrade Cost Estimates

	Adoption cost		Upgrade cost	
	Est.	Std. Err.	Est.	Std. Err.
Portfolio size	-9.3839	0.4520	-2.6069	0.2927
No. of hospitals using same brand/20	7.2305	2.4505	4.4424	0.8599
No. of hospitals using the latest same brand/20	-7.5626	2.6493	3.1648	1.3940
No. of latest generation within own portfolio	4.4993	0.6159	2.5624	0.3041
Duration of current generation			-0.0083	0.0315
Duration of newest gen since introduction			-0.8153	0.2868
Duration of newest gen since introduction, sq			0.0497	0.0211
Adopt Dummy			Yes	
Brand FE	Yes		Yes	
Year FE	Yes		Yes	
Hosp FE	Yes		Yes	

Table 5: Comparison Between Imputed and Actual Adoption and Upgrade Occurrences

	Abbott	Bio Sensor	Cordis	Medtronic	Other	Boston Sci.
Actual adoptions	19	15	3	17	15	0
Imputed adoptions	19	15	5	17	15	0
Actual upgrades	14	13	11	45	0	13
Imputed upgrades	14	13	10	36	0	9
Actual no-change	153	77	65	145	51	82
Imputed no-change	153	79	64	157	54	88

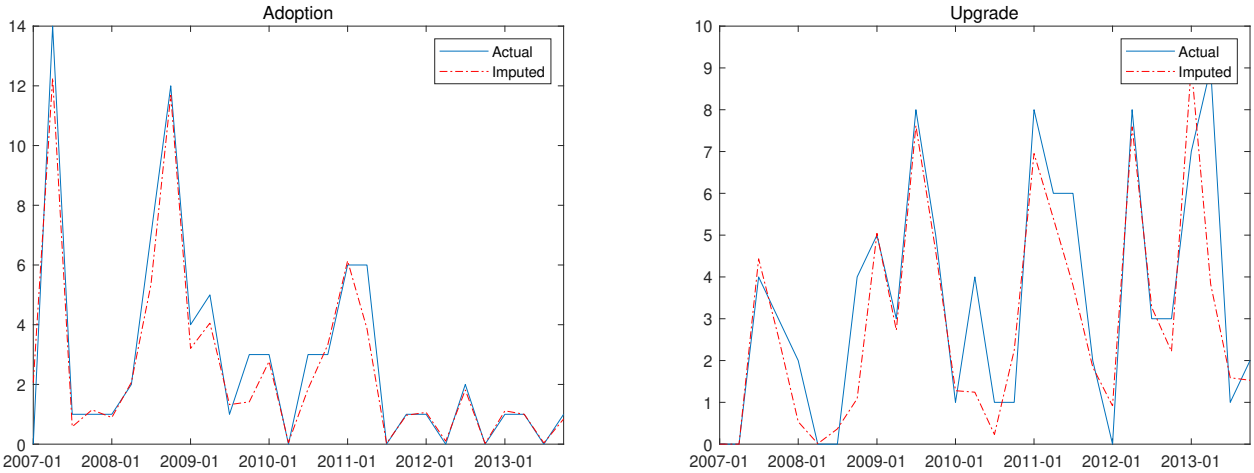
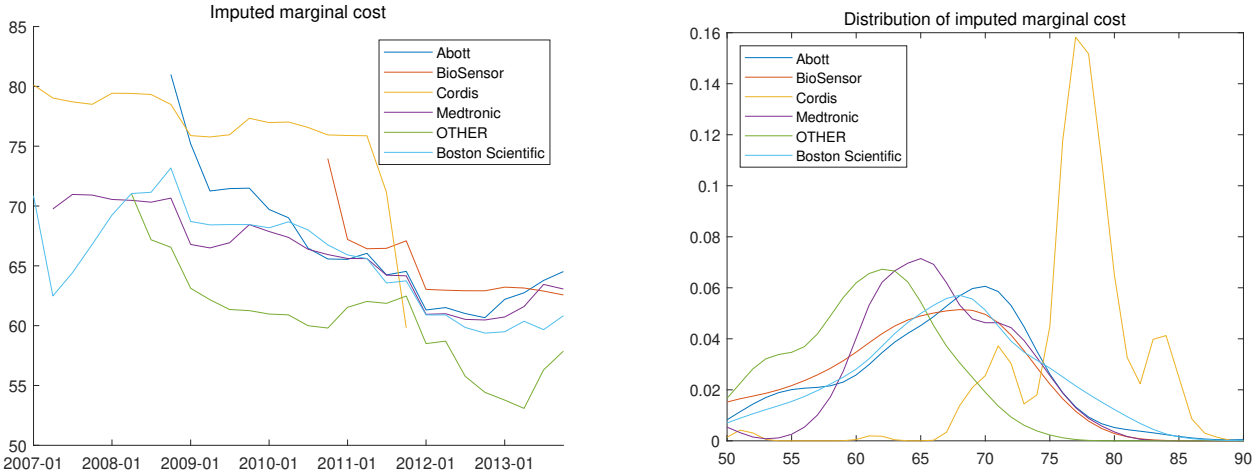


Figure 5: Imputed vs. Actual Frequency of Adoption and Upgrade Over Time

plots the average of estimated marginal costs by brand-quarter. The average marginal costs range from 55,000 to 80,000 NTD, which is below the average revenue a hospital can obtain from NHI reimbursement and patient's out-of-pocket payment per DES, implying a markup between 16.7% and 25%. As shown in Figure 6, there is a generally declining trend in estimated marginal costs over time. This decline partly coincides with the January 2009 reduction in the NHI reimbursement rate and the entry of additional DES brands, which may have shifted bargaining power in favor of hospitals. Figure 6(b) displays the distribution of marginal costs by DES brand, highlighting Cordis as a costlier and less frequently used outlier.



(a) Estimated Marginal Costs Over Time

(b) Distribution of Marginal Costs by Brand

Figure 6: Estimated Marginal Costs

Overall, the estimation results on both demand and supply sides suggest that the model fits well. The demand specification captures meaningful patient heterogeneity and strong sensitivity to out-of-pocket prices, and the supply estimates reflect how hospitals' adoption, upgrade, and pricing decisions respond to competitive pressures, cost fluctuations, and NHI reimbursement policies.

6 Counterfactual Simulations

When upstream manufacturers introduce new DES models, it is not immediately clear whether downstream hospitals have sufficient incentives to adopt these innovations, nor is it clear how patients' financial burdens are affected by potential incremental charges for newer-generation DES. In this section, we investigate these issues by empirically analyzing innovation diffusion through

hospitals' product-portfolio decisions and pricing strategies, as well as the potential impact of government reimbursement policies. Building on our demand and supply estimates, we explore the mechanisms of innovation diffusion and examine how alternative reimbursement designs might enhance diffusion and improve social welfare.

Our analysis proceeds in three main parts. First, we examine how market competition and patients' demand for new-generation DES shape innovation adoption, thereby highlighting certain market limitations in sustaining efficient levels of new-technology diffusion. Second, we evaluate the effectiveness of alternative NHI reimbursement designs. We show that selective contracting with wholesale discount from covered DES brands can improve welfare for both hospitals and patients while containing government expenditures. Finally, we discuss how the diffusion of new DES technologies can be guided to promote equity among lower-income populations via patient coupons.

6.1 Market Competition and Patient Demand

A substantial body of work in empirical industrial organization has studied how market structure affects incentives to innovate (Aghion et al., 2005). In our setting, upstream manufacturers conduct the primary research and development, whereas downstream hospitals decide whether to adopt the newest DES models and how to price them. This differs from the canonical framework where firms themselves invest in innovation. Once an upstream DES innovation becomes available, hospitals have the option to adopt it at a (relatively) predictable cost rather than bearing the uncertainty typically associated with research and development.

Downstream hospitals thus face adoption or upgrade expenses for incorporating new DES models into their treatment portfolios. They do not extend the technology frontier through risky, uncertain innovation; rather, they choose whether to add the newest-generation devices already commercialized by manufacturers. Although their decisions do not involve inventing or patenting the technology, these choices are nonetheless critical in determining how quickly new DES models diffuse into actual medical practice.

Simulating Different Degrees of Market Concentration

We begin by asking how market structure in hospital competition may affect equilibrium prices and hospitals' decisions to adopt or upgrade to the newest DES models. To address this question, we consider a series of simulated markets in which the number of hospitals N takes a value of 2, 10, or 20. The case of $N = 20$ corresponds to our original empirical sample. When simulating $N < 20$, we randomly select N hospitals from the dataset, and then track how their equilibrium portfolio and pricing decisions evolve over time. In each simulated period, hospitals sequentially update their adoption and upgrade choices, set DES prices, and then move to the next period with the new market state. After repeating these simulations five times for each N with different random draws, we average the results to arrive at the outcomes in Table 6. More details of equilibrium computation in our counterfactual simulations are provided in the Appendix.

Table 6: Market Outcomes Under Alternative Market Structures

	No. of hospitals		
	2	10	20
A. Market outcome per quarter			
Consumer surplus (million NTD)	1.56	4.57	5.68
Avg. price (thousand NTD)	64.34	60.16	59.82
Profit (million NTD)	24.66	15.65	16.22
CS+Profit (million NTD)	26.22	20.22	21.89
DES Demand elasticity	-5.56	-5.43	-5.44
Subsidy (million NTD)	43.97	43.97	43.97
Subsidy towards DES	12.57	13.47	14.49
% of DES usage	28.96%	30.63%	32.52%
B. Consumers' Product Choices			
Portfolio Modification Probability per Hospital			
Overall	15.67%	5.41%	3.70%
Adoption	6.72%	1.56%	0.56%
Upgrade	17.37%	12.02%	9.55%
Total hospital-model DES choices	4.81	17.14	30.78
w/ newest generation	4.01	12.34	20.67
Ratio of newest choices	83.36%	72.00%	67.15%
% of patients using newest generation	26.64%	26.77%	28.36%

Notes: "Portfolio Modification Probability" is the proportion of adoption or upgrade occurrences among those samples where such modification is feasible. "Overall" is the fraction of samples where any adoption or upgrade occurs.

Panel A shows that increasing N lowers the average DES price, raises consumer surplus, and reduces hospitals' profits. These patterns reflect standard competition effects, although DES demand remains elastic even for $N = 2$ because hospitals typically offer multiple DES options plus a zero-cost BMS alternative for patients. The total government reimbursement does not change because every patient ultimately gets one stent, and the per-stent reimbursement remains constant. Nevertheless, since lower DES prices lead more patients to choose DES over BMS in highly competitive markets, a greater share of the government subsidy is devoted to DES when N increases.

Panel B indicates that hospitals in more concentrated markets have stronger incentives to adopt or upgrade to the newest-generation DES, which yields a relatively high ratio of newest models among fewer hospitals. In contrast, when N is large, hospitals reduce their incremental prices on DES, which encourages usage but also reduces their payoff from adding or upgrading new models. The net effect on the share of patients receiving the newest DES is thus driven by two opposing forces: (i) greater incentives for adoption and upgrading in a more concentrated market, versus (2) improved affordability for patients in more competitive settings.

Patients' Preference for Newness

Hospitals' incentives to adopt and upgrade to new DES models partly reflect patient demand. If consumers place a stronger value on the "newness" of a DES model, hospitals stand to gain more from offering the latest products. In our data, patients do exhibit a notable preference for the newest generation within each DES brand. This pattern is consistent with the broader phenomenon in the medical device industry, where patients—often lacking detailed comparative quality information—use easily observable indicators such as brand or stated generation.

To gauge how stronger or weaker "newness" preferences alter market outcomes, we rescale patients' valuation for new DES by a factor ζ. Values $\zeta > 1$ signify higher willingness to pay for the newest models than what is observed, while $\zeta < 1$ imply lower willingness. We simulate equilibrium outcomes for two market sizes ($N = 2$ and $N = 10$) and present the results in Table 7.

A higher ζ leads more patients to choose DES, thereby increasing both consumer surplus and hospital profits. Although patients benefit from an enhanced product offering, part of the surplus gain goes to hospitals, as they exploit patients' stronger willingness to pay by charging higher prices. This incomplete pass-through is especially pronounced when $N = 2$, where hospitals possess greater

Table 7: Market Outcomes Under Alternative Patient Newness Preferences

	N=2		N=10	
Pref Factor	1	2	1	2
Patients-related				
Consumer Surplus	1.56	1.76	4.57	5.09
% of DES usage	28.96%	34.51%	30.63%	44.07%
% of patients using newest generation	26.64%	32.59%	26.77%	41.42%
Hospital-related				
Profit (million NTD)	24.66	29.48	15.65	18.85
Avg. Patient-Paid Price	64.61	65.90	60.28	60.30
Portfolio Modification Probability per Hospital	15.67%	14.55%	5.41%	7.41%
NHI-related				
Subsidy (million NTD)	43.97	43.97	43.97	43.97
Subsidy towards DES	12.57	14.95	13.47	19.36

market power.[7]

Stronger preferences for the newest models also raise hospitals' incentives to adopt or upgrade, which translates into a larger set of new-generation options. The effect on total usage of the newest DES is tempered by price competition. For instance, under $N = 10$, lower equilibrium prices mean that an even higher fraction of patients ends up receiving the newest DES, despite somewhat weaker per-hospital incentives compared to $N = 2$.

In summary, these simulations underscore a trade-off. More intense market competition drives down prices but reduces hospitals' returns from adopting the newest DES. By contrast, stronger demand for newness encourages adoption but also allows hospitals to extract higher markups. Either way, there is no guarantee of affordable prices alongside widespread diffusion of advanced DES models. This motivates our investigation of reimbursement schemes that might better align incentives of adoption with price containment.

6.2 Alternative Reimbursement Designs for Enhanced Innovation Diffusion

So far, our counterfactual analysis suggests that hospital competition results in lower DES prices, but competition also undermines hospitals' incentives to adopt and upgrade new models due to

[7]For example, when ζ rises from 0.5 to 2, the pass-through ratio—defined as the change in consumer surplus relative to the change in aggregate hospital profit—is 0.03 for $N = 2$, compared to 0.17 for $N = 10$.

their limited payoffs. Similarly, patients' high demand for the newest generation of DES models encourages hospitals to speed up the innovation adoption, which is, however, accompanied by higher prices. Therefore, solely relying on competition or high consumer willingness to pay for the newest generation may not achieve widespread diffusion and affordability simultaneously.

In the following three subsections, we explore the possibility that government reimbursement policies could be modified in ways that encourage adoption of the newest DES without imposing steep financial burdens on patients. More specifically, we consider three alternative designs: modified DES reimbursement rate, selective contracting, and patient coupons for the poorest 10% patients.

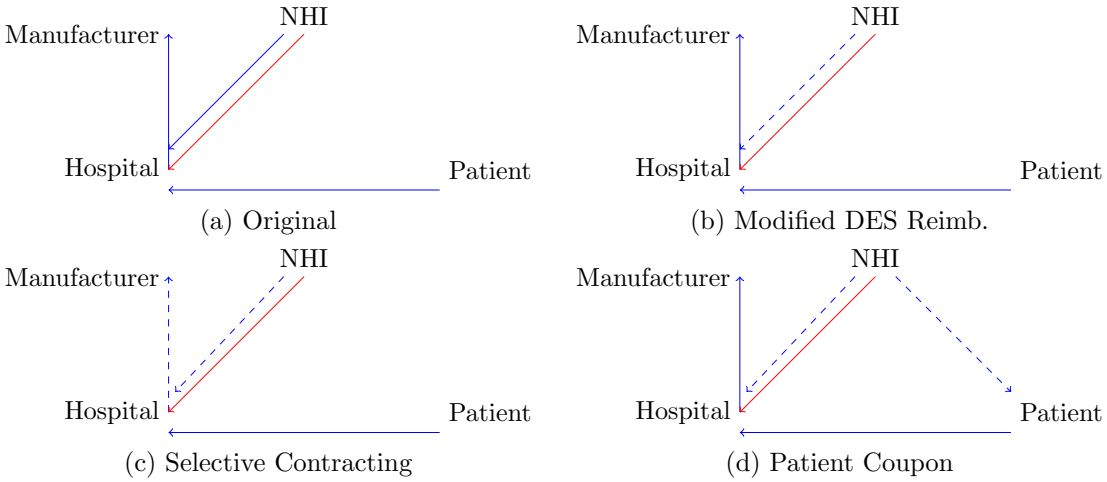


Figure 7: Comparison of Alternative NHI Reimbursement Designs

Figure 7 provides a schematic overview, where arrowed lines indicate flow of payment, line colors indicate DES (blue) and BMS (red) separately, and dashed lines denote modifications to the original scheme observed in the current data. As shown in Figure 7(a), the original scheme reimburses each stent (BMS or DES) at a single rate r_t and allows hospitals to charge patients any incremental amount for DES. A straightforward modification shown in Figure 7(b) may allow the NHI to reduce or increase the reimbursement rate for each DES used by hospitals. When the DES reimbursement rate is close to zero, the modified scheme is close to only covering the baseline BMS treatment but no top-up coverage for DES. When the DES reimbursement rate is high enough to cover the hospital's marginal cost in DES, the modified scheme is close to the traditional full-coverage in health insurance. Figure 7(c) turns to the possibility of selective contracting, where the NHI

negotiates wholesale cost discounts with selected DES manufacturers and only reimburse hospitals for DES usage if they use DES products from the selected manufacturers. Finally, Figure 7(d) allows the NHI to provide coupons for low-income patients if they use any DES. To ensure the NHI can balance the budget, we allow the NHI to adjust DES reimbursement rate as it engages in selective contracting or patient coupons.

Alternative Design #1: Modified DES Reimbursement

The current top-up design reimburses hospitals at a fixed amount r_t per stent, regardless of whether it is a BMS or a DES, and leaves patients to pay the difference for DES. We adjust this by allowing the NHI to reimburse each DES unit at $r^d \cdot r_t$ for the hospital while keeping the BMS reimbursement at r_t. By varying r^d from 0 to 2, we approximate a continuum between baseline only (with $r^d = 0$) and closer to full coverage of DES (with $r^d = 2$).

Table 8 reports simulated outcomes under this scheme for $N = 2$ and $N = 10$. As r^d increases, hospitals receive more reimbursement from NHI, and therefore lower their prices charged for patients, which results in higher consumer surplus. Hospital profits increase as well because the NHI provides more payment per DES. Consequently, hospitals exhibit stronger incentives to adopt more new-generation DES models. On the down side, due to the excessive reimbursement, the financial burden of NHI grows significantly: when $r^d = 2$, total DES subsidy rises by around 50% relative to the original top-up design in both markets ($N = 2$ and $N = 10$).

As shown in Table 8, increasing the DES reimbursement factor r^d from 0 to 2 leads to notable changes in market outcomes in both concentrated ($N = 2$) and competitive ($N = 10$) markets. Specifically, higher DES reimbursement results in lower patient-paid prices for DES and increased consumer surplus. Consequently, a larger proportion of patients opt for DES over BMS, and the percentage of patients using the newest generation of DES increases significantly.

Despite the reduced prices charged to patients, hospitals' profits rise due to the higher NHI reimbursement. This profit increment is more pronounced in the concentrated market ($N = 2$), where hospitals have greater market power. Regarding hospitals' portfolio modification strategies, higher DES reimbursement enhances hospitals' incentives to adopt new brands and upgrade existing ones to their newest generations. This expansion of offerings allows consumers to access a broader variety of DES options, including the latest generations. This effect is amplified in the concentrated

Table 8: Market Outcomes Under Alternative DES Reimbursement Ratios

	N=2		N=10	
DES Reimbursement Factor r^d	1	2	1	2
Consumer-related:				
Consumer Surplus (million NTD)	1.56	2.16	4.57	7.00
% of patients using DES	28.96%	42.47%	30.63%	74.30%
% of patients using newest DES	26.64%	38.36%	26.77%	68.67%
Total choices	4.81	5.93	17.14	20.44
Newest choices	4.01	5.08	12.34	15.81
Hospital-related:				
Profit (million NTD)	24.66	75.67	15.65	26.87
Avg. Patient-Paid Price (thousand NTD)	64.34	61.03	60.16	39.84
Avg. Prob. of Portfolio Modification	15.67%	22.39%	5.41%	9.33%
NHI-related:				
Subsidy amount (million NTD)	43.97	62.67	43.97	77.06
DES Subsidy amount (million NTD)	12.57	37.39	13.47	66.17

market, where hospitals can capture higher returns from portfolio enhancement. Thanks to lower DES price and increased access to newer models, consumer surplus increases substantially, especially in the competitive market ($N = 10$).

While the market outcomes under higher DES reimbursement favor both hospitals (through increased profits) and consumers (through lower prices and improved access to advanced DES options), the financial implications for the NHI are significant. Specifically, when the DES reimbursement is doubled ($r^d = 2$), the additional government subsidy required increases by approximately 18.7 million NTD (42.5%) compared to the original top-up design in the concentrated market, and by over 33 million NTD (75.3%) in the competitive market.

In summary, these findings highlight a fundamental trade-off: the NHI can either increase spending to encourage the adoption of new DES models and reduce patients' out-of-pocket expenses, or it can limit the NHI expenditures at the cost of reduced patient surplus and slower hospital adoption of new technologies. This trade-off motivates us to consider more sophisticated reimbursement schemes.

Alternative Design #2: selective contracting

In the current design, the NHI provides equal reimbursement to hospitals regardless of stent type or DES brands. However, many countries and regions have adopted centralized procurement,

where the government aggregates demand from all hospitals and negotiates with a selected group of manufacturers. The bulk purchase enhances the government's bargaining power, potentially lowering wholesale costs. For the selected manufacturers, higher procurement volume may reduce manufacturing costs due to economy of scale, possibly leading to increased profits.

In this subsection, we examine whether such a policy can simultaneously achieve three objectives: (1) controlling patient out-of-pocket expenses for DES, (2) maintaining hospitals' incentives to adopt new DES models, and (3) controlling government expenditure.

To this end, we consider a new subsidy design in which the NHI has two levers to pull: one is the hospitals' wholesale cost for DES models from the two largest manufacturers (Abbott and Medtronic). In the simulation, we assume the NHI can reduce such wholesale cost by a factor of r^c thus the adjusted wholesale costs per unit for Abbott and Medtronic DES becomes $r^c \cdot c_{hmt}$, where c_{hmt} denotes the previously estimated marginal cost. When r^c drops from 1 to 0.5, it cuts hospitals' wholesale costs by half when they purchase DES from Abbott and Medtronic. We assume the wholesale cost of BMS is unchanged.

The second lever available to the NHI is selective reimbursement. We maintain the current reimbursement structure but limit NHI reimbursement to BMS, DES from Abbott, and DES from Medtronic; other DES brands are not covered. To further explore the effects of reduced reimbursement, we assume that the NHI reimbursement per unit of DES from Abbott and Medtronic is adjusted by a factor of $r^d = 0.5$ or 1, i.e., the adjusted reimbursement is $r^d \cdot r_t$, where r_t is the original reimbursement per period. We assume the reimbursement for BMS remains unchanged at r_t.

To see the direct impact of wholesale discount factor, Table 9 presents the simulated market equilibrium when the wholesale costs of targeted brands are discounted by 50%. For comparison, we also include the market outcome under the original market setup (i.e. all DES brands are reimbursed equally with BMS, and no wholesale discount exists). When the targeted brands carry 50% wholesale cost discount, we observe a significant price discrepancy between the targeted brands (Abbott and Medtronic) and other DES brands. Consequently, more patients opt for the targeted brands, and hospitals' profits increase due to the larger share of more profitable DES usage of the targeted brands. The government's reimbursement amount is approximately the same as before for each stent used, although now the reimbursement is concentrated in BMS and the targeted DES

Table 9: Market Outcomes Under Selective Contracting

	N=2			N=10		
Reimbursement factor	Original	1	1	Original	1	1
Cost Factor	Setup	1	0.5	Setup	1	0.5
Consumer-related:						
Consumer Surplus	1.56	1.37	3.42	4.57	4.14	7.52
% of DES usage	28.96%	22.77%	63.11%	30.63%	16.59%	79.40%
% of patients using newest generation	26.64%	21.85%	61.49%	26.77%	15.20%	78.98%
Hospital-related:						
Profit (million NTD)	24.66	20.10	82.83	15.65	13.26	30.32
Avg. Patient-Paid Price	64.34	76.96	71.62	60.16	77.91	67.66
Targeted DES		59.49	45.69		58.67	27.70
Non-targeted DES		82.61	97.73		80.37	81.98
Portfolio Modification Probability per Hospital	15.67%	15.19%	25.00%	5.41%	5.27%	11.78%
Targeted DES		10.61%	43.94%		3.27%	8.80%
Non-targeted DES		6.59%	4.55%		2.93%	3.92%
NHI-related:						
Subsidy (million NTD)	43.97	42.48	43.87	43.97	41.97	43.64
Targeted DES		8.31	27.52		5.07	34.55
BMS	31.41	34.17	16.35	30.51	36.90	9.09

brands. Given that only the targeted brands are reimbursed for DES usage, this suggests that almost all DES sales are concentrated among the two targeted brands.

Regarding hospitals' portfolio modification, lower wholesale costs significantly enhance hospitals' propensity to adopt and upgrade to newer DES models while almost eliminating the usage of any new models from non-targeted brands. As a result, patients are offered more options of the newest generation DES, primarily among the targeted brands. The overall product variety slightly increases as the presence of targeted brands grows while other DES brands diminish in market share.

Comparing the outcomes between competitive ($N = 10$) and non-competitive ($N = 2$) markets, we observe that reduced wholesale costs benefit consumers mainly through lower prices in competitive markets and through hospitals' offering of newer generations in concentrated markets.

Table 10: Preferred Direction of Policy Parameters

	NHI	Consumers	Hospitals	Manufacturers
Cost Factor, r^c	Lower	Lower	Lower	Mid-range
Reimbursement Factor, r^d	Lower	Higher	Higher	Higher

As summarized in Table 10, the NHI prefers a lower reimbursement factor to reduce its expendi-

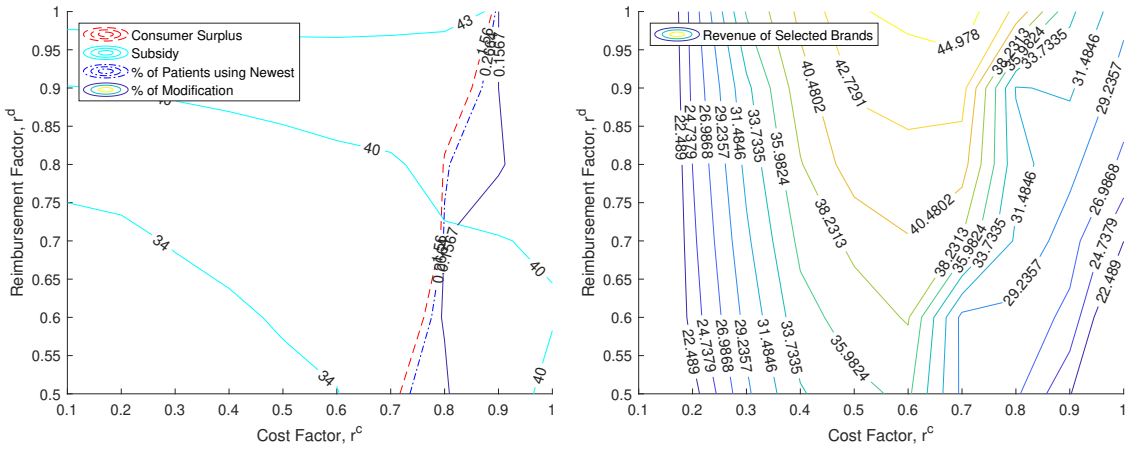
ture per unit of the targeted DES brands, as well as a lower cost factor to enhance bargaining power. Consumers prefer lower cost factors and higher reimbursement factors to reduce their out-of-pocket expenses. Hospitals favor a lower cost factor and a higher reimbursement factor to increase their profit margins. Given these conflicting interests, particularly between the NHI and the other two parties regarding the reimbursement ratio, it is important to identify the scenarios where all three parties are better off compared to the original setup.

For selective contracting to work, it is also important that the targeted manufacturers have sufficient financial incentives to join the regime (as compared to the status quo). We do not know manufacturers' production costs, but if they are sufficiently low, we can test the manufacturers' incentive compatibility constraint by investigating whether their sales revenue under selective contracting would exceed that at the status quo.[8] Because offering discount r^c is accompanied by the NHI's exclusion of non-targeted brands from reimbursement, the targeted manufacturers may prefer to give some discount in exchange for sales increases, as compared to status quo. Depending on how hospitals may pass through lower wholesale costs into lower patient-facing price and how price sensitive patients are, the sales revenue for targeted manufacturers may be a non-linear function of r^c. This is why targeted manufacturers in Table 10 may prefer r^c to be in a mid-range rather than extremely high or extremely low.

To examine the trade-offs between the two levers that the NHI has in the selective contracting scheme (namely the reimbursement factor r^d and the wholesale cost factor r^c), we conduct additional simulations for discrete $r^d \in [0.5, 1]$ and $r^c \in [0.1, 1]$ with an increment of 0.1. We then plot in Figure 9 the iso-curves representing different levels of consumer surplus, hospitals' probability of portfolio modification, government expenditure, and the percent of patients using the newest generation DES. As before, we present the market outcomes for $N = 2$ and $N = 10$.

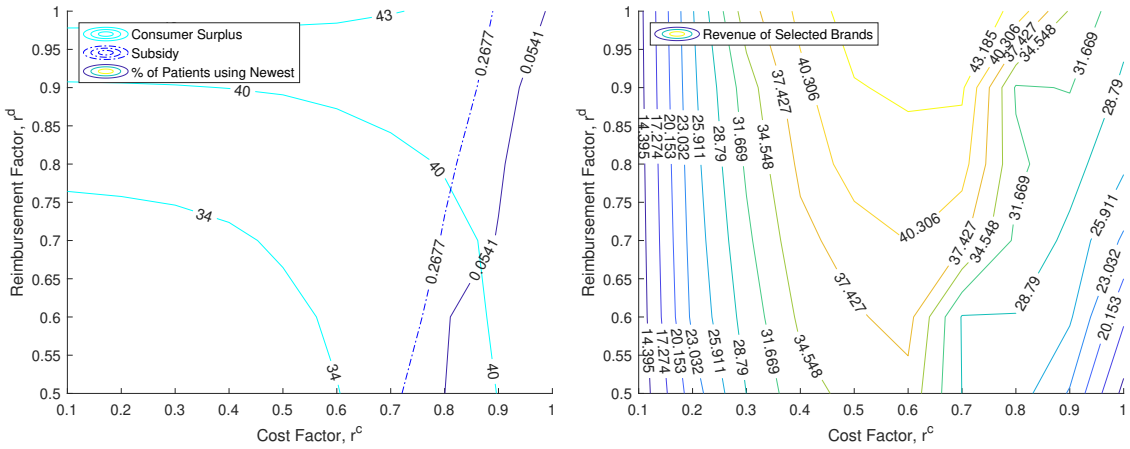
Consistent with our findings in Table 10, consumer surplus increases with a higher reimbursement factor and a lower cost factor (towards the north-west corner), while government reimbursement decreases when both factors are smaller (towards the south-west corner). To read Figure 9, let us focus on the upper-left graph first ($N = 2$). In the status quo, the total consumer surplus

[8] In reality, the NHI could announce that it only covers N DES brands and run an auction inviting all five DES manufacturers to bid in r^c to compete for the limited N positions. In this sense, the incentive compatibility constraint we check for selected manufacturers is a necessary condition to support selective contracting but the particular selected contracting regime is not necessarily the best that the NHI could achieve via a competitive auction.



(a) NHI, Patient, Hospital for $N = 2$

(b) Manufacturer for $N = 2$



(c) NHI, Patient, Hospital for $N = 10$

(d) Manufacturer for $N = 10$

Figure 8: Policy Outcomes Under selective contracting: Varying (r^c, r^d)

is 1.56 million NTD, thus any points on the red dashed line marked 1.56 can achieve the same consumer surplus. In comparison, 26.64% of patients use any DES of the newest generation in the status quo, hence any points on the blue dashed line marked 0.2664 can achieve the same outcome. By the same logic, in the original top-up design, hospitals' probability of modifying their portfolio is 15.67% for $N = 2$, and one can keep this outcome by tracing the purple real line marked 0.1567. All these three lines would gain a higher value as the NHI works harder in selective contracting (by raising reimbursement r^d DES stent or negotiating harder with the targeted brands for a lower r^c). In the meantime, the NHI would prefer to keep the total NHI expenditure below the status quo of 43 million NTD (the toppest real line of light blue), By balancing these forces, we find that a combination of reimbursement and cost discount factors —namely, all points to the northwest of the red dashed, blue dashed, and purple real lines of the status quo and to the south-west of

the NHI budget line marked 43 — can improve consumer surplus, encourage hospitals to update portfolios beyond what can be achieved in the status quo while keeping the government expenditure within the current budget.

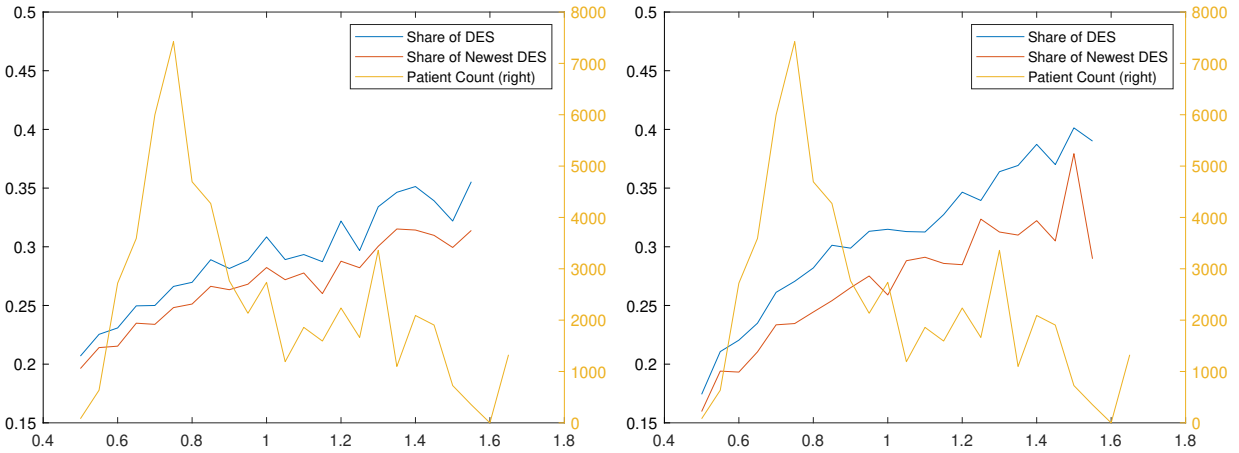
The upper right graph of Figure 9 plots the iso-revenue curves for the two targeted DES manufacturers under selective contracting. Because some wholesale discounts may be passed through into lower DES price and more quantity sold, targeted manufacturers can achieve revenue as high as 44.98 million NTD in the upper-mid part of the graph, more than their revenue at the status quo (22.489 million). Together, Figures 9(a) and 9(b) suggest that selective contracting could achieve a quadruple-win outcome for patients, hospitals, NHI, and targeted DES manufacturers, while nontargeted DES manufacturers would lose almost all of their market shares.

Similarly, for $N = 10$, Figure 9(c) identifies the iso-curves for the portfolio modification probability (5.41% purple real line), consumer surplus (4.57, red dashed line), and percent of patients using the newest generation (26.77% blue dashed line) in the status quo. The areas to the left of these three lines and below the iso-curve for the total NHI expenditure in the status quo (43 light blue real line) can achieve improvements for patients, hospitals and the NHI simultaneously. Figure 9(d) plots the iso-revenue curves for the two targeted manufacturers under selective contracting. Similar to the case of $N = 2$, targeted manufacturers can earn higher revenue in the upper-mid part of the graph (43.18 million NTD). Thus it is possible to have a quadruple-win outcome for patients, hospitals, NHI and targeted manufacturers.

Alternative Design #3: Patient Coupon Program

In this section, we examine an alternative policy design in which the NHI provides coupons to low-income patients to enhance their access to DES treatments. Specifically, the NHI grants a coupon of value $r^c \times 60$k NTD to patients in the lowest 10% of the income distribution. This coupon can be used exclusively to offset the out-of-pocket cost of DES. Coupons are not applicable to BMS, because BMS is already free for all patients. Regarding hospitals, we maintain the reimbursement design in the status quo, but allow the NHI to lower the DES reimbursement rate by the factor r^d in case it has budget concerns about how to fund patient coupons. More specifically, the NHI reimburses hospitals r_t for each BMS and $r^d \cdot r_t$ for each DES.

To assess the impact of the patient coupon program, we simulate market outcomes for two



(a) $N = 2$ (b) $N = 10$

Figure 9: Policy Outcomes Under selective contracting: Varying (r^c, r^d)

market structures ($N = 2$ and $N = 10$) using the algorithm described in previous sections.

As a start, Figure 9 presents the distribution of patient income levels alongside the probabilities of receiving any DES treatment and the newest-generation DES treatment under the status quo (no patient coupons). Our demand estimates indicate that higher-income patients have a stronger preference for DES and, in particular, for the latest-generation models. For instance, in a market with $N = 2$ hospitals, the probability of receiving any DES treatment is 28.96% and that of receiving the newest DES is 26.64% for the overall population, compared with approximately 22% and 21%, respectively, for patients in the lowest income decile. This disparity is even more pronounced in more competitive markets. Thus, by providing financial assistance to low-income patients, the patient coupon program has the potential to reduce inequities in access to advanced treatments.

The simulation results with patient coupons are summarized in Table 11. They indicate that an increase in the coupon amount leads to higher utilization of DES—and particularly the newest-generation DES—among low-income patients. Conversely, patients who are not eligible for the coupon exhibit a reduction in DES usage. This occurs because, with low-income patients receiving coupons and hospitals unable to engage in price discrimination, hospitals raise overall prices, which in turn discourages DES usage among non-eligible patients.

Regarding hospital behavior, simulations reveal that in a concentrated market ($N = 2$), hospitals exhibit lower incentives to adopt and upgrade to newer DES models due to the limited marginal payoff of portfolio enhancements. In contrast, in a more competitive market ($N = 10$),

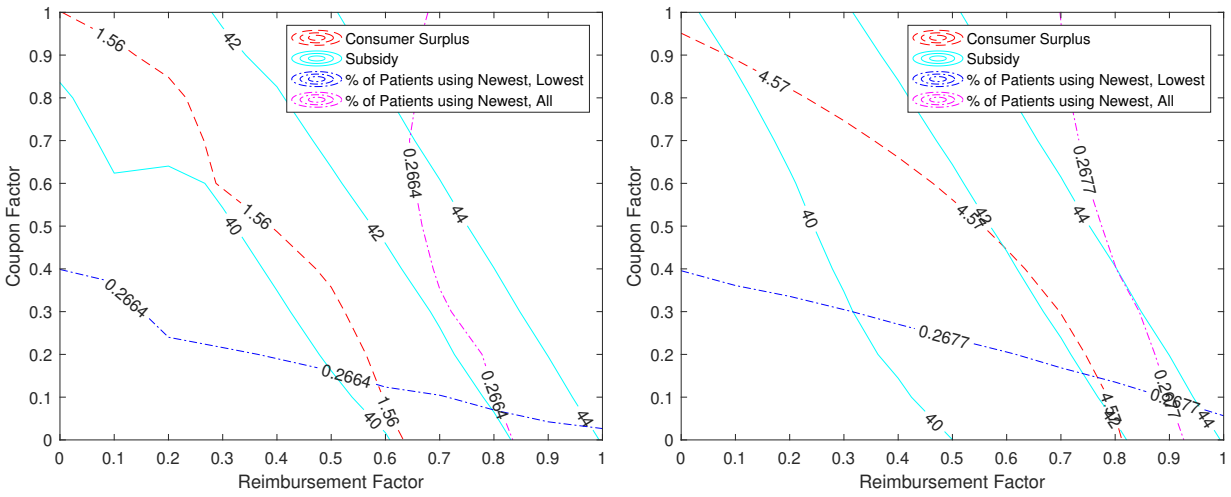
higher coupon values prompt hospitals to pursue more aggressive portfolio adoption and upgrades. Thus, the effect of the patient coupon program on hospitals' adoption incentives is ambiguous and depends on the market structure. With respect to government expenditure, although the introduction of patient coupons increases overall subsidy costs, the impact is limited since only 10% of patients qualify for the coupon.

Table 11: Market Outcomes under the Patient Coupon and Reimbursement Design

Coupon Factor	0	0.5	0	0.5
	N=2		N=10	
Patient-related:				
Consumer Surplus	1.56	1.81	4.57	4.91
Hospital-related:				
Profit	24.66	25.59	15.65	17.20
Price	64.34	65.22	60.16	60.27
% of modification	15.11%	13.67%	5.21%	5.64%
% of DES usage				
Low-income	25.70%	77.26%	24.30%	78.47%
Others	31.54%	30.02%	33.53%	34.56%
NHI-related:				
Reimbursement	44.08	44.08	44.08	44.08
Coupon amount	0	0.81	0.00	0.82
Coupon+Reimb	44.08	44.89	44.08	44.90

To more comprehensively examine the influence of the patient coupon on market equilibrium, we simulate outcomes over a range of the reimbursement factor for DES ($r^d \in [0,1]$), and the patient coupon factor ($r^c \in [0,1]$). The resulting outcome statistics are presented in Figure 10.

In general, the government would favor lower values of both factors to minimize overall expenditure (as indicated by the bottom-left region of Figure 10), whereas patients would prefer higher values to maximize access to advanced treatments (upper-right region). In Figure 10(a) for $N = 2$, the purple dashed line marked 0.2664 represents all policy combinations that would make the coupon-eligible low-income patients use the newest DES at the same rate (26.64%) as average patients in the status quo. The magenta dashed line marked 0.2664 represents all policy combinations under which an average patient uses the newest DES at the same rate as in the status quo. The red dashed line marked 1.56 shows the consumer surplus of all patients under the status quo. The light blue real lines show different levels of NHI expenditure. Points between the two lines



(a) $N = 2$ (b) $N = 10$

Figure 10: Policy Outcomes under Varying Patient Coupon and Reimbursement Factors

marked 0.2664 can improve the newest DES-adoption rate for low-income patients, but reduce that for other patients. Meanwhile, the overall consumer surplus can increase or decrease depending on whether the gains to low-income patients dominate the losses to high-income patients. And these redistribution effects and overall consumer surplus changes can be achieved within the current budget constraint if NHI lowers the DES reimbursement rate when it issues patient coupons. Figure 10(b) shows similar tradeoffs when $N = 10$.

7 Conclusion

Frequent innovation in healthcare markets makes the timing and extent of new-technology adoption a critical determinant of patient access and financial burden. In this paper, we have analyzed how hospitals, in deciding when to adopt or upgrade DES models, respond to market competition and patient demand. We have also examined whether government reimbursement policies can be structured to encourage adoption without imposing excessive costs on patients or on public budgets.

Our findings suggest that, although greater competition among hospitals drives down prices and raises consumer surplus, it can also reduce hospitals' incentives to incorporate newer-generation DES. As competition intensifies, the marginal payoff from adopting or upgrading advanced devices falls, and the pace of innovation diffusion slows. This outcome highlights an important tension between making DES more affordable to patients and ensuring sufficient returns for hospitals to

continue offering the newest technologies.

By contrast, strong patient demand for advanced DES models motivates hospitals to revise their portfolios more frequently. This effect, however, may be accompanied by higher patient-paid prices, particularly in settings with limited competition. When patients place a high value on obtaining the latest devices, hospitals gain pricing power that allows them to internalize a portion of this higher willingness to pay.

Our counterfactual simulations show that selective contracting and patient coupon schemes can alter these dynamics in both promising and problematic ways. A selective contracting policy—where the NHI negotiates lower wholesale costs with certain DES manufacturers and offers brand-specific coverage—can yield quadruple-win outcomes for hospitals, patients, targeted manufacturers, and the government. Yet this comes at the expense of non-targeted brands, which may lose market share to the point of exit. If the targeted coverage is not updated over time, there is a risk of weakening long-run competition and innovation incentives among the excluded manufacturers.

Subsidies directed to patients through coupon programs, particularly when aimed at lower-income populations, can achieve redistribution goals by reducing the financial barrier for DES adoption. However, these coupons also encourage hospitals to raise list prices to capture the subsidy indirectly from patients, limiting the overall increase in adoption incentives and undermining the broader diffusion of new DES models.

Taken together, these results point to the need for carefully calibrated policy approaches in healthcare markets characterized by imperfect competition. Neither enhanced competition nor strong consumer demand alone can simultaneously guarantee affordable prices, robust adoption of new technologies, and prudent government spending. Policymakers may wish to blend patient-facing subsidies with selective contracting to manage trade-offs between equity goals, overall market efficiency, and long-run innovation incentives. Exploring how these short-run reimbursement decisions interact with manufacturers' long-run incentives to invest in new technology remains an important area for future work.

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Appendix A Details on Equilibrium Computation

In this section, we outline the procedure used to compute the counterfactual market outcomes based on our demand and supply model estimates. Our goal is to capture hospitals' dynamic decisions regarding their drug-eluting stent (DES) portfolios and pricing choices under alternative market conditions. Specifically, each hospital decides whether to adopt or upgrade its set of available DES technologies, taking into account the costs of changing portfolios and the anticipated impact on profits.

To reflect realistic dynamic adjustments, we use an iterative simulation approach in which each period's equilibrium portfolios serve as the starting point for the subsequent period. Moreover, within each period, hospitals update their portfolios iteratively (one at a time), holding other hospitals' portfolio choices fixed. This procedure continues until no hospital finds it profitable to deviate from its current portfolio, thereby yielding a convergent solution that approximates a Nash equilibrium in portfolio choices and prices. We formalize this procedure in Algorithm 1 below.

Algorithm 1 (Counterfactual Equilibrium Simulation)**.**

1. ***Initialize for period*** t*:*

   - *At the beginning of period* t*, each hospital observes the simulated portfolios and prices from period* $t-1$*.*
   - *For the initial iteration (*$s=0$*), set each hospital* h*'s portfolio to its portfolio from the previous period:*

   $$M_{ht}^{0} = M_{h,t-1}.$$

2. ***Iterative best responses****:*

   - *For iteration* $s \geq 1$*, sequentially consider each hospital* h *and compute its optimal portfolio update given the portfolios of all other hospitals from iteration* $s-1$*, denoted by* $\mathcal{M}_t^{s-1}$*. Specifically, for each feasible portfolio* M_{ht}^{s}*, compute:*

     (a) All hospitals' equilibrium prices

     $$\mathcal{P}\big(M_{ht}^{s}, \mathcal{M}_t^{s-1}\big),$$

(b) Hospital h's resulting payoff

$$\pi_{ht}\Big(p_{ht}^{s}, M_{ht}^{s}, \mathcal{P}\big(M_{ht}^{s}, \mathcal{M}_{t}^{s-1}\big), \mathcal{M}_{t}^{s-1}\Big),$$

(c) Net payoff, which accounts for the cost of modifying the portfolio relative to period $t-1$,

$$\pi_{ht}\Big(p_{ht}^{s}, M_{ht}^{s}, \mathcal{P}\big(M_{ht}^{s}, \mathcal{M}_{t}^{s-1}\big), \mathcal{M}_{t}^{s-1}\Big) \;-\; C\big(M_{ht}^{s}, M_{h,t-1}\big).$$

- *Update hospital h's portfolio to the choice M_{ht}^{s*} that maximizes this net payoff:*

$$M_{ht}^{s*} \;=\; \arg\max_{M}\Big\{\pi_{ht}\Big(p_{ht}^{s}, M_{ht}^{s}, \mathcal{P}\big(M_{ht}^{s}, \mathcal{M}_{t}^{s-1}\big), \mathcal{M}_{t}^{s-1}\Big) \;-\; C\big(M, M_{h,t-1}\big)\Big\}.$$

- *After all hospitals have updated their portfolios in iteration s, denote the resulting portfolio set by $\mathcal{M}_t^s$. If*

$$\mathcal{M}_{t}^{s} \;=\; \mathcal{M}_{t}^{s-1},$$

then convergence is achieved, and the algorithm proceeds to the next period. Otherwise, continue to iteration $s+1$.

3. ***Finalize period-t equilibrium portfolios**:*

   - *The convergent set of portfolios in period t is denoted by $\mathcal{M}_t$. These portfolios, along with the associated equilibrium prices, form the simulated market outcome for period t.*

4. ***Repeat for** $t+1$ **until the final period**:*

   - *The portfolio set $\mathcal{M}_t$ becomes the starting point for period $t+1$.*
   - *If t is the final period, terminate the algorithm.*

To obtain the final counterfactual market outcome, we simulate this process for a single dynamic sequence and then repeat it for five independent random simulation sequences (e.g., varying initial conditions or random draws in the cost or payoff functions). The reported counterfactual outcome is the average across these five random sequences. This procedure ensures that our counterfactual results are robust to variation in the initial portfolios and other stochastic components of the simulation.