Dynamic Bargaining under Ratchet Effects: Evidence from Cardiac Pacemakers in Japan*

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Abstract

This paper examines distortionary incentives arising from government regulation of medical device reimbursement prices. Specifically, it explores how reimbursement prices, determined endogenously based on transaction prices between hospitals and device sellers, create opportunities for these parties to collaboratively influence future reimbursement rates, despite their generally conflicting interests. Using a Nash-in-Nash bilateral bargaining model, this study analyzes the Japanese market for cardiac pacemakers. Structural estimates reveal that hospitals hold greater bargaining power in transactions with device sellers. The findings indicate that wholesale prices are elevated compared to a counterfactual scenario without strategic incentives, with price increase becoming more pronounced in less competitive markets. In categories with three or fewer competing products, these price increases reach up to 2.3%. Simulation results provide robust evidence that ratcheting-based price regulation inflate reimbursement price for the medical device, and, consequently, medical costs.

Keywords: Nash-in-Nash bargaining; Medical device; Reimbursement prices; Competitive externalities
JEL classification: C71; D22; D43; I11

1 Introduction

Governments worldwide have increasingly intensified efforts to curtail health expenditures to manage public budgets effectively. Despite these efforts, they continue to fund approximately three-fourths of all health spending across the OECD countries (OECD, 2018). A significant concern driving these efforts is the rapid escalation of costs associated with pharmaceuticals and medical devices. To mitigate these rising expenses, most countries impose price regulations, either directly or indirectly. However, a complicating issue is

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that prices for pharmaceuticals and medical devices are often determined within a free and profit-driven marketplace. Regulators, faced with asymmetric information regarding the appropriate price or cost of the product, typically rely on historical industry and market outcomes to inform their pricing regulations.

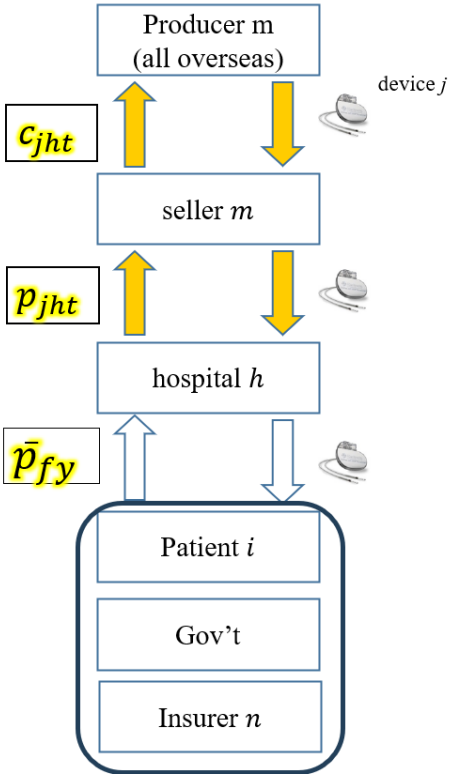
One commonly employed regulatory mechanism is the "ratchet rule," which uses past performance as a benchmark for setting future targets. This rule has been extensively analyzed in theoretical literature (for example, Weitzeman, 1980; Freixas, et al., 1985; Laffont and Tirole, 1993; and Armstrong and Sappington, 2007). The findings consistently indicate that regulated firms, leveraging informational advantage over regulators, strategically manipulate their behavior to secure additional rents. Despite the wealth of theoretical studies, empirical research that directly identifies and quantifies the ratchet effect remains surprisingly scarce. Precise measurement of this regulatory impact necessitates detailed information that elucidates the incentive structures of regulated firms and the interplay between their past performance and the targets set by regulators.

This paper explores the extent to which the regulatory ratchet rule distorts firm behavior and market outcomes. It delves into the Japanese medical device market, focusing on cardiac pacemakers as a unique case study. Figure 1 illustrates the distribution structure and pricing dynamics of cardiac pacemakers within Japan. Unlike other markets, Japan does not have domestic manufacturers for these devices; instead, device sellers import pacemakers from overseas suppliers and sell them to hospitals at a wholesale price, denoted as p. The procurement cost, denoted as c, which represents the price at which device sellers purchase pacemakers from foreign manufacturers, serves as the sellers' marginal cost. A key advantage of focusing on cardiac pacemakers in this study is the availability of detailed data on both p and c for each product across all transactions over a 12-year period. This enables us to directly calculate the markups applied by device sellers – and by hospitals, as discuss later – without the need to estimate marginal costs when analyzing dynamic pricing behavior.

In Japan, hospitals purchase these imported pacemakers from device sellers and implant them into patients, receiving compensation at a reimbursement price, $\bar{p}$, which is set by the government. As depicted in Figure 1, this reimbursement price is the sum of payments from both insurers, tax payers, and the patients receiving the pacemaker. Importantly, this reimbursement price is uniformly applied across all hospitals nationwide, regardless of whether they are private or public institutions. Consequently, the revenue hospitals receive from pacemaker implantation is standardized across the country. Should a hospital purchase a pacemaker from a device seller at a price exceeding $\bar{p}$, the hospital must absorb the difference between $\bar{p}$ and p as a loss. Under Japan's universal health insurance system, hospitals are prohibited from passing these additional costs on to patients.

Given this distribution structure, hospitals are incentivized to minimize p to maximize the profit margin between $\bar{p}$ and p, while device sellers aim to raise p to maximize their profit margin between p and c. This creates a zero-sum game between hospitals and device sellers, centered on the determination of the unregulated wholesale price, p.

Figure 1: Distribution Structure of Cardiac Pacemakers in Japan



An intriguing aspect of the Japanese medical system explored in this paper is the periodic alignment of interests between hospitals and device sellers, which occurs every two years during the revision of the reimbursement price, $\bar{p}$. The reimbursement price is updated biennially through a ratcheting mechanism. During a predefined three-month period in odd-numbered years, data on wholesale prices, p, as negotiated between hospitals and device sellers, are collected by the government. The average value of these prices serves as the basis for adjusting the reimbursement price, $\bar{p}$, for the subsequent period. This mechanism allows the regulated reimbursement price, $\bar{p}$, to reflect changes in the unregulated market price, p, albeit with a lag of up to a year. Since the data collection period is announced in advance, hospitals and device sellers have a strategic incentive to cooperate during this time. By artificially raising p during the data collection period, device sellers not only boost their immediate revenue, but hospitals also stand to benefit from a potential increase in the reimbursement price for the coming years.

It is important to note that the reimbursement price is not determined on a model-by-model basis for pacemakers. Instead, the government categorizes devices into functional groups, with all products within the same category – regardless of manufacturer or specific product features – being assigned the same reimbursement price. As the number of manufacturers within a functional category increases, competitive externalities become more pronounced. This dynamic implies that even if a manufacturer sets a higher wholesale price, p, the marginal impact on the overall reimbursement price, $\bar{p}$, is reduced. This paper

explores the extent of these competitive externalities and their implications for the market.

To quantify the impact of the regulatory ratcheting rule on reimbursement prices discussed above, we use proprietary data obtained from device sellers. The data are at transaction level for each product-hospital pair of cardiac pacemakers, ranging from May 2003 to April 2014. The data identify multi-product sellers. The data covers about 60 percent of the domestic market of Japan, and more than 80 percent of the Tokyo metropolitan area.

We introduce two distinct regimes: one for periods when price updates align the incentives of hospitals and device sellers, and another for periods without updates, where the incentives of the two parties conflict. A difference-in-differences analysis, along with placebo test shows that the wholesale prices are indeed higher by roughly 1.4% during the regime of price updates, compared with the no-update regime. Also the data indicates that the wholesale prices during the price-update regime are in decrease with the number of pacemaker models within a functional category.

We then estimate the bargaining model, in which producers and hospitals negotiate over prices of cardiac pacemakers. During the period of price update, both parties have incentive to influence on the future reimbursement prices by solving a multi-period bilateral Nash-in-Nash bargaining model. In other periods, they solve for a static one-period bargaining model. The precise marginal-cost data are available for device-sellers, as all pacemakers were foreign-made, and there were no domestic manufacturers during the period. This feature of the market helps us identify the bargaining parameters in our application. Three observations emerged from the bargaining estimates; (1) The bargaining model estimated in this paper fits the data better than a differentiated-product oligopoly model, the latter which assumes no bargaining power on the side of hospitals; (2) hospitals have higher bargaining power on average than producers, and this difference remains largely unchanged between the sampling period and the non-sampling period.; (3) The wholesale prices under the reference pricing scheme are on average 0.5 percent higher than those under the scenario where no strategic incentives are present. In categories with three or fewer competing products, these price increases reach up to 2.3 percent.

The magnitude of distortionary effects are not at all small; the reimbursement prices are significantly higher than those in the absence of strategic incentives. If we extrapolate to the pharmaceutical drugs and other medical devices, which are under the same regulatory pricing scheme as pacemakers in this study, we find that the magnitude of the effects found in the paper are equivalent to quite a significant amount of Japanese medical expense.

Literature Review

One of the primary contributions of this paper lies in its identification and quantification of the mechanisms through which the regulatory pricing scheme distorts the incentives of economic agents. This is achieved using an analytical framework based on a multi-period bilateral Nash-in-Nash bargaining model. While an increasing number of empirical studies have employed Nash-in-Nash bargaining models, as surveyed

by Lee, Whinston, and Yurukoglu (2021), this paper makes several distinct contributions to the literature.

First, this paper introduces a multi-period approach to the Nash-in-Nash bargaining model, a significant advancement over the static models typically estimated in empirical research. Previous studies, such as those by Crawford and Yurukoglu (2012), Gowrisankaran, Nevo, and Town (2015), Grennan (2013; 2014), and Crawford, Lee, Whinston, and Yurukoglu (2018), have primarily focused on static one-period bargaining models. In contrast, this paper estimates a multi-period bargaining model, specifically applied to the context of reimbursement price determination for Japanese cardiac pacemakers. While Dorn (2024) utilized a proportional bargaining model to analyze the U.S. insurance market, this paper's application of the Nash-in-Nash framework offers a more flexible set of assumptions, making it a novel contribution to the field.

The second major contribution is the estimation of bargaining power using cost data. While many bargaining models, such as Grennan's (2013) analysis of the U.S. stent market, simultaneously estimate cost data and bargaining power, the difficulty of distinguishing between the two has been well-documented, as noted by Lee, Whinston, and Yurukoglu (2021). This paper addresses this challenge by focusing on the fact that all cardiac pacemaker models in Japan are imported. By capturing the prices associated with each transaction during the import process, the paper is able to accurately identify the marginal costs faced by device sellers in Japan, thus enabling a more precise estimation of bargaining power.

Finally, this paper is one of the first to analyze the dynamic effects of regulatory ratcheting using structural estimation. While previous studies, such as Duggan and Morten (1999) on the U.S. insurance market, Ito and Sallee (2018) on energy efficiency, Amano (2016), and Anderson (1992) and Ohashi (2002, Journal of International Economics) on anticipatory effects in trade, have explored the economic impacts of ratcheting, structural estimation has been rarely employed in this context. Among these, only Ohashi (2002) used structural estimation, but this paper is the first to apply such methods to analyze the dynamic ratcheting effects within a regulated market.

The paper is organized as follows. Section 2 describes the cardiac pacemakers market. In this section, we provide an overview of the industry, and also describe the details of Japanese medical system, some features of which differ from the U.S. and European countries. Section 3 introduces the data used in this paper and presents preliminary analyses. Section 4 presents a demand and supply estimation models and Section 5 shows our identification strategy. Section 6 reports estimation results, followed by simulation exercises in Section 7. Section 8 concludes.

2 Cardiac Pacemaker Market in Japan

This section provides an overview of the cardiac pacemakers market in Japan. Section 2.1 describes the market structure, which is divided into wholesale and retail segments. It is noteworthy that all pacemakers are imported from abroad, making the procurement cost effectively the marginal cost for the device seller,

provided that no rebates are involved. This characteristic plays a crucial role in identifying the bargaining parameters within the Nash-in-Nash bargaining framework used in the subsequent section of this paper. Sections 2.2 discusses Japan's healthcare system, which is distinct from systems in countries such as the United States. Japan operates under a universal healthcare model, where the role of insurance providers is largely limited. This structure simplifies the characterization of market dynamics of cardiac pacemakers. Section 2.3 explores the dynamic mechanism governing the reimbursement prices for cardiac pacemakers. In Japan, the price setting rule follows a regulatory ratcheting system, which, while designed to control costs, creates distorted incentives for both hospitals and device sellers, unintentionally to the regulator. The insights provided in this section lay the foundation for empirical analyses in the subsequent sections.

2.1 Cardiac Pacemakers Market

Cardiac pacemakers are battery-operated medical device, and help patients control irregular heartbeat. During arrhythmia, the heart is unable to pump enough blood to other parts of the body, causing faint and fatigue, and in the worst, leading to sudden death. The pacemakers are segmented into implantable (internal) and external ones. The former device, the focus of this paper, is placed inside the chest or abdomen, with leads guided through blood vessel and sent electrical signals to the heart, while the external device is used at a fully equipped clinical facility for temporary treatment. The pacemaker market has been dominated by implantable pacemakers, accounting for a share of more than 90 percent of the market in Japan during the study period.

The market structure of pacemakers is primarily composed of two layers; the wholesale market, where hospitals purchase pacemakers from device sellers; and the retail market, where hospitals "sell" pacemakers to patients through surgery operation. The wholesale market is unregulated, with cardiac pacemakers priced through transactions between device sellers and hospitals. This paper utilizes transaction records of these sales to model pricing using a bilateral Nash-in-Nash bargaining framework. We present the data and outline the model in the subsequent sections. In contrast, the retail market is regulated under Japan's universal healthcare system, as we discuss shortly below.

All pacemakers available in Japan are manufactured abroad and imported into Japan. No domestically produced pacemakers were available during the study period. Our data reveals that each foreign device producer appoints a single domestic wholesaler as its exclusive sales agent; there are no instances of multiple sales agents or resale markets.

Our transaction data allows us to observe the price at which the device seller procures each pacemaker from the foreign producer and the price at which it is subsequently sold to a hospital.

The procurement price can be viewed as the marginal cost to the device seller. In the absence of sales rebates, the margin between the sale price and the procurement price can be directly captured in our data for each transaction. To the best of our knowledge, this paper is unique in that, unlike previous studies, it allows us to observe marginal costs directly in the context of bargaining. This enables us to identify the

bargaining parameter independently of its influence on marginal costs, which is a significant contribution to the literature. In Section xxx, we discuss how the estimation of bargaining parameters would differ if marginal costs were unobserved in our analysis, and how this potential bias can be mitigated through the use of cost-side proxy variables.

2.2 Japan's Healthcare System

Japan operates under a universal healthcare system, in which all citizens are required to enroll in health insurance. Based on attributes such as age, residence, and employment status, individuals are automatically assigned to a specific healthcare insurance provider, which may be either public or private. Although premiums may vary across providers, consumers do not have the freedom to choose or switch providers based on personal preference.

In the event of illness, patients have the right to select any hospital or physician, regardless of their insurance provider. Reimbursement rates for medical treatments are set nationally by the Ministry of Health, Labor and Welfare (MHLW). This means that hospitals receive the same reimbursement for identical treatments, irrespective of the patient's insurer. In this system, insurance providers serve primarily as payment intermediaries, collecting premiums and paying hospitals for treatment. They have no influence over physicians' practices, nor do they have the authority to set hospital fees or restrict patient access to hospitals or treatments.

Patients typically bear approximately 30% of the total reimbursement cost out-of-pocket, while the remaining 70% is covered by insurance providers and partially subsidized by tax revenues, as shown in Figure 1. For treatments costing over one million yen, any amount exceeding this threshold is fully covered by tax subsidies. We will explore this aspect further when modeling demand for cardiac pacemakers. It is important to note that physicians in Japan are salaried employees of hospitals, and there are no direct payments from insurers or the government to individual physicians.

As mentioned earlier, the reimbursement price is applied uniformly across all hospitals, whether they are private or public. This standardization means that the revenue hospitals receive for pacemaker from a device seller at a price higher than the reimbursement rate, it must absorb the loss, as hospitals in Japan are prohibited from passing these additional costs on to patients under the universal healthcare system. Therefore, hospitals are incentivized to keep the wholesale price of pacemakers low to maximize the difference between the procurement cost from a device seller and the reimbursement price. This dynamic is likely a key factor driving competition in the wholesale market and reflects the logic behind Japan's reimbursement price system. However, as we will explain below, this system creates unintended incentives that may work against cost containment in healthcare[1].

[1]Hospitals and physicians would have financial incentives to perform treatments that may differ from what is medically necessary in order to maximize profits. In Japan, hospitals submit invoices for services at the end of each month to payment agencies, and reimbursement is received approximately two months later. During this period, review agencies thoroughly

2.3 Pricing rule of Reimbursement

Thus far, we have treated the reimbursement price as exogenously set by the regulator. In this subsection, we explain how the reimbursement price is, in fact, endogenously determined within Japan's healthcare system.

Medical devices usually generate two potential reimbursement schemes (see Japan External Trade Organization, 2011). The first, specialty treatment material (STM) reimbursement, is direct reimbursement for the device itself based on its therapeutic category. The second, technical fee reimbursement, is offered for the procedure associated with the device and is paid in addition to the STM reimbursement.[2] Cardiac pacemakers are applied to the former. A key broad difference between Japanese and US systems is that Japan provides product and procedure-specific reimbursement, as opposed to lump sum payments of diagnosis related group (DRG) and prospective payment system (PPS) in the US.

For STM products, initial reimbursement levels are set based on consideration of a variety of factors. Upon regulatory approval on safety and effectiveness, the price of a new device is determined by comparison to existing therapeutic substitutes, i.e., products of a similar therapeutic function already available in the market. Thus, if different brands, j and j' are considered as therapeutic substitutes by the regulator, they receive the receive the same reimbursement price. On the other hand, if a newly introduced device is considered to have significantly higher quality than the existing devices, the regulator creates a new therapeutic category, and decides an initial reimbursement price for the device.[3]

The reimbursement price is revised by the rgulator every other year in April. The regulator collects data on the wholesale prices, $p_{j,h,t}$, of pacemaker j sold to hospital h at month t during the period from May through September of the sampling year y, in which $t \in T_y$. The study period ranges from May 2003 to April 2014. The following ratcheting formulae is used for the biennial revision on the reimbursement prices for every odd-numbered year, y:

$$\overline{p}_{f,y+1} = \frac{\sum_{t\in T_y}\sum_{h\in H_t}\sum_{j\in J_{f,h,t}} p_{j,h,t}q_{j,h,t}}{\sum_{t\in y}\sum_{h\in H_t}\sum_{j\in J_{f,h,t}} q_{j,h,t}} + 0.04 \cdot \overline{p}_{f,y}, \tag{1}$$

and

$$\overline{p}_{f,y+2} = \overline{p}_{f,y+1}. \tag{2}$$

Note that $q_{j,h,t}$ is the number of units of pacemaker j sold to hospital h at time t. Also note that H_t is a set of hospitals that purchase pacemakers at time t, and $J_{f,h,t}$ is the set of pacemakers in therapeutic

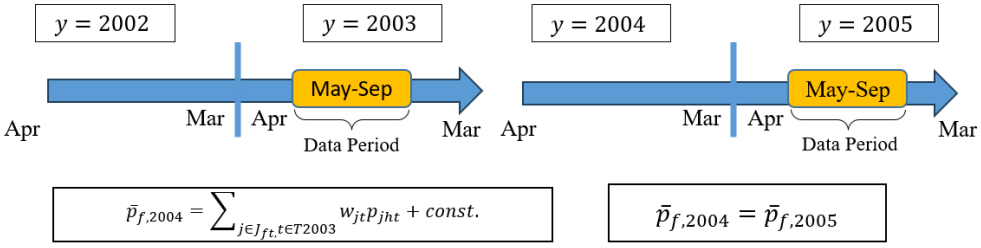
examine all claims. If fraudulent practices are detected, not only is reimbursement withheld, but in cases of serious misconduct, the hospital's certification as a medical institution may be revoked. For instance, in March 2020, out of 120 million invoices submitted, 1.1–1.2% were flagged for issues. This review process likely serves as a deterrent to moral hazard in hospitals and physicians.

[2]The only devices that do not receive STM reimbursement are capital equipment and commodities used during a procedure.

[3]To ensure transparency and accountability of the decision making, MHLW delegates to a neutral outside panel (Central Social Insurance Medical Council) on whether new device be classified as therapeutic substitutes, and if not, what the initial reimbursement price be.

category f sold to hospital h in time t. The first term of eq.(1) is the sales-weighted average of the wholesale prices of all pacemakers under category f sampled in T_y. If this sales-weighted average is set more than 4 percent below the reimbursement price at year y, the reimbursement price in the following year falls. If y takes an even number, the reimbursement price remains the same as the previous year's, as shown in eq. (2). Figure 2 summarizes how the reimbursement price is determined when y takes 2003.

Figure 2: Updating



The price setting rule presented in eqs. (1) and (2) is considered as a variant of regulatory ratcheting principle. Every other year, the regulator revises the reimbursement price using the past wholesale prices, according to eq.(1). Notice that this rule may leave an opportunity for both device sellers and hospitals to "game" the market; the wholesale prices during the sampling period T_y would affect the future reimbursement price through eq.(1). An increase in $p_{j,h,t}$, where t belongs to T_y, would raise $\overline{p}_{f,y+1}$, thus benefiting both the hospital and the device seller, at the cost of insurers and patients. The reimbursement rule would thus create incentive common for both hospital and device seller to edge up the wholesale prices in the sampling period, while their interests conflict each other during other times.

In addition, reimbursement prices are set at the therapeutic category level rather than on an individual device basis. This implies that as the number of products in a therapeutic category increases, competitive externalities become more pronounced. Even if a hospital and a device seller manage to raise the wholesale price for a particular product, the marginal effect on the overall reimbursement price is diluted across the category. In the next section, we examine the extent to which these two features – the ratcheting effects and competitive externalities – influence the Japanese pacemaker market, using the data we have collected.

3 Data and Preliminary Analysis

A primary panel data used in this paper are at transaction level for each product-hospital pair of cardiac pacemakers, ranging from from May 2003 to April 2014. The data identify multi-product sellers. The data contain 22,862 transactions with the coverage of about 60 percent of the overall domestic market of Japan, and more than 80 percent of the Tokyo metropolitan area. We aggregate the data into monthly for the purpose of our subsequent analyses. The resulting data contain 11,096 transactions with 265 products and 141 hospitals. We supplement the data with hospital and product characteristics. Data sources are available

at the appendix. The summary statistics are shown in Table 1.

Table 1: Summary statistics

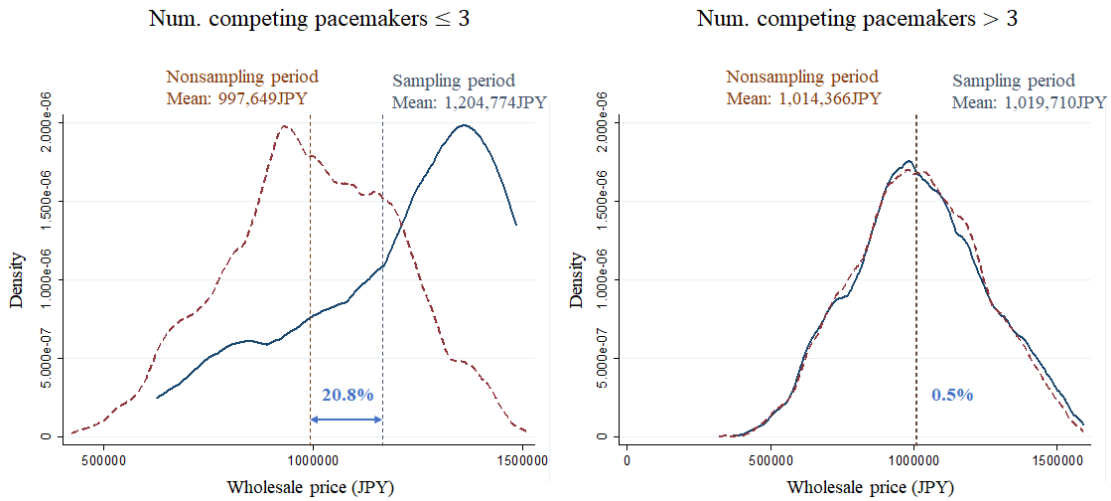
	Sampling period		Nonsampling period		Difference (%)	
	Mean	Std. Dev.	Mean	Std. Dev.		
Wholesale price (JPY)	1,023,658.00	231,380.40	1,004,406.00	212,150.70	1.92%	***
Reimbursement price (JPY)	1,203,282.00	225,810.00	1,182,138.00	207,176.00	1.79%	***
Purchase price (JPY)	831,138.50	185,357.50	817,592.80	175,005.60	1.66%	***
Seller markup (JPY)	192,519.70	97,905.36	186,813.00	93,133.38	3.05%	***
Hospital markup (JPY)	179,623.50	114,423.60	177,732.60	122,578.00	1.06%	
Product characteristics:						
Battery lifetime (year)	8.33	2.01	8.37	2.02	-0.49%	
Size (mm^3)	14,423.50	2,429.40	14,462.37	2,492.93	-0.27%	
Hospital characteristics:						
# of beds	649.95	363.11	646.91	359.34	0.47%	
# of inpatients per year	528.51	305.99	529.68	309.04	-0.22%	

Notes: "Sampling period" refers to the months from May through September in every odd-numbered year, as described in Section 2.3, while "Nonsampling period" refers to all other months. The last column reports the results of t-tests. ***, **, and * indicate $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

Figure 3 compares the difference in the wholesale prices between the sampling and non-sampling periods. We make two observations. One is that the average wholesale price is higher in the sampling period than in the non-sampling period. The second observation is that the difference in the wholesale prices is larger for the therapeutic category with fewer device types. The difference in the average wholesale prices between the sampling and non-sampling periods for categories with three pacemaker products or less, is 20.8 percent, whereas the difference in the other is only 0.5 percent. This second finding may also be consistent with a theoretical implication of regulatory ratcheting. A company in a more competitive environment may have less incentive to increase its prices during the sampling period because the effect of such a price increase on the reimbursement price in the next year is smaller. If the market is monopolistic with no fear of entry, the monopolist internalizes the competitive externality and therefore, has greater incentive to inflate prices in the sampling period. In the following two subsections, we will conduct preliminary analyses of the data, which leads us to a more structural analysis in the subsequent sections.

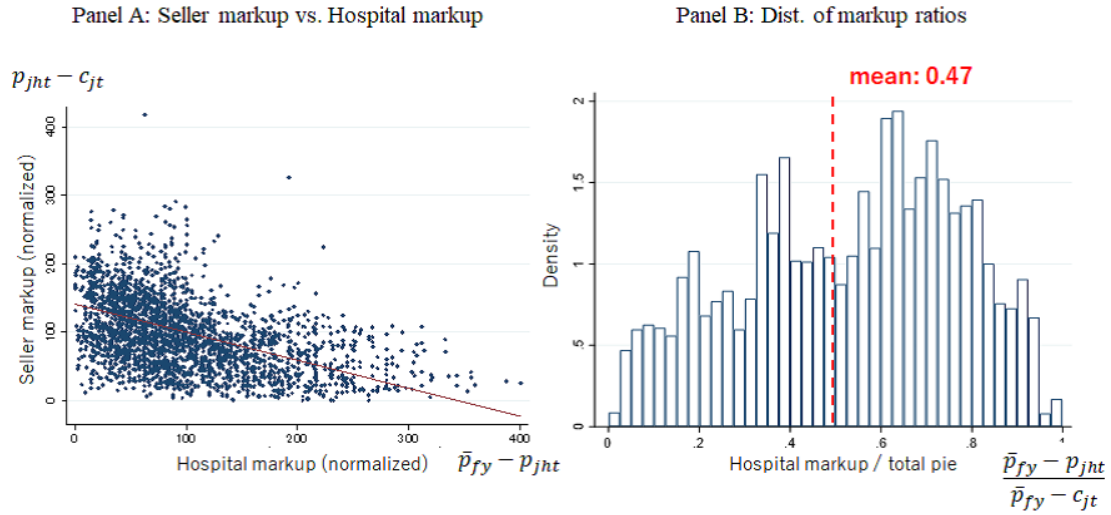
Before the preliminary analyses, we also examine the markups of device sellers and hospitals during the study period. For each j, the hospital markup is defined by $\overline{p}_{f,y} - p_{j,h,t}$, and the markup for device seller

Figure 3: Difference in wholesale prices



Notes: The left figure focuses on therapeutic categories with up to three pacemaker products, while the right figure focuses on categories with more than three. "Sampling period" refers to May through September in every odd-numbered year, while "Nonsampling period" covers all other months. The blue solid line shows the wholesale price distribution during the sampling period, and the red dashed line shows it during the nonsampling period. Vertical lines indicate the mean prices for each period.

Figure 4: Seller markup and hospital markup



Notes: The left panel shows the scatter plot of the hospital markup, $\overline{p}_{f,y} - p_{j,h,t}$, against the markup for the device seller, $p_{j,h,t} - c_{j,h,t}$. Each markup is scaled to have a mean of 100. The right panel shows the distribution of the ratio of the hospital markup to the total pie, $\overline{p}_{f,y} - c_{j,h,t}$.

by $p_{j,h,t} - c_{j,h,t}$ for t is the month of year y. Figure 4 contains two panels. Panel A illustrates two markups, indicating that the correlation between the two is negative. We also calculate the ratio of the hospital markup to the total pie, $\overline{p}_{f,y} - c_{j,h,t}$. The value of this ratio ranges between 0 and 1. Panel B plots the distribution of the markup ratios, and shows that the mean of the markup ratios is 0.47.

3.1 Preliminary Analysis on Reimbursement Prices

Table 2: Estimation results: preliminary analysis

The dependent variable: Wholesale prices (JY)	(1-1)		(1-2)		(1-3)		(1-4)	
(A) Treatment dummy	11177.82	***	14543.46	***	8082.52		21806.16	***
	(2304.60)		(1411.32)		(5413.45)		(3139.10)	
(B) Num. competing pacemakers					2648.44	***	3301.70	***
					(142.83)		(82.91)	
(A) × (B)					-1290.43	***	-2370.28	***
					(348.91)		(202.37)	
Time trend	No		Yes		No		Yes	
Product dummy	Yes		Yes		Yes		Yes	
Hospital dummy	Yes		Yes		Yes		Yes	
R-squared	0.805		0.927		0.811		0.937	
F value	107.00	***	327.90	***	110.83	***	380.07	***
Observation	10,792		10,792		10,792		10,792	

Notes: The dependent variable is the wholesale prices (in Japanese Yen). The explanatory variables are the treatment variable, which takes the value of 1 when the month belongs to the sampling period, and 0 otherwise; the number of competing pacemakers to product j; the interaction of the first two explanatory variables; the monthly time trend, and the dummy variables specific to products and hospitals. Standard error is inside parenthesis. ***, **, and * indicate $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

To check the validity of the theoretical implication, we perform a simple reduced-form analysis, and regress $p_{j,h,t}$ onto product- and hospital-specific dummy variables, along with the treatment dummy variable that takes the value of one when t belongs to T_y, and otherwise zero. The estimation results are shown in Table 2. The estimates of the first two specifications (1-1) and (1-2) show that the wholesale prices in the sampling period are higher than those in the non-sampling period (namely, the months other than T_y). The average difference is approximately 145 USD, equivalent to 1.4 percent of wholesale prices in the non-sampling period.

In the rest of the specifications, (1-3) and (1-4), we include in the regression the new explanatory variable representing the number of pacemakers competing to product j in the same therapeutic category. The estimated coefficients of the interaction term between the new variable and the treatment dummy indicate that the average difference in the wholesale prices becomes smaller as the number of competing therapeutic substitutes increases. This finding may be consistent with the hypothesis that the benefit for device seller m to raise its wholesale prices would dissipate away to a greater degree, with an increase in the number of competing therapeutic substitutes.

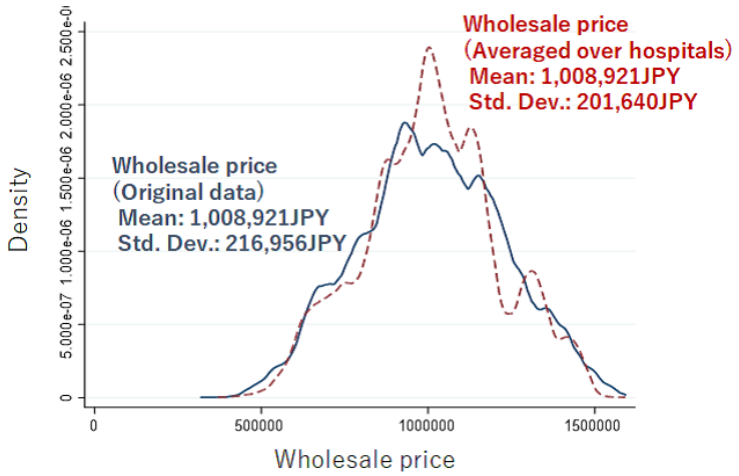
To check the appropriateness of the comparison group used in the reduced-form analyses, we have performed a so-called placebo test. We assumed that the regulator, in its revision of the reimbursement prices, used the sampled wholesale data from the same five months, but from the even-numbered years. We introduced a new notation, T_y^c, which consists of a set of months during May through September of the year y, which takes even numbers from 2004 to 2014, and replaced T_y with T_y^c in the regression exercises. The "placebo" in this case is the counterfactual sampling period, and allows us to test whether the finding of significant price increase in the sampling period reported in Table 2 are driven by the differences in the trends between the sampling (treated) and non-samling (controlled) periods. Estimation results are shown in Table 3. We have found that the coefficients of the placebo dummy are statistically insignificant or statistically *negative*.

Table 3: Placebo test results

The dependent variable: Wholesale prices (JPY)	(2-1)	(2-2)
Placebo period dummy	1818.93	-14252.18 ***
	(2747.80)	(1643.19)
Time trend	No	Yes
Product dummy	Yes	Yes
Hospital dummy	Yes	Yes
R-squared	0.818	0.936
F value	62.59 ***	201.94 ***
Observation	4,792	4,792

Notes: The dependent variable is the wholesale prices (in Japanese Yen). The explanatory variables are the placebo period variable, which takes the value of 1 when the month belongs to May-September in even-numbered years, and 0 otherwise; the monthly time trend, and the dummy variables specific to products and hospitals. All samples are from even-numbered years. Standard errors are inside parentheses. ***, **, and * indicate $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

Figure 5: Distribution of wholesale prices averaged over hospitals



Notes: The blue solid line represents the distribution of wholesale prices, while the red dashed line represents the distribution of wholesale prices averaged across hospitals.

These reduced-form estimates are indicative to the presence of distortionary incentives driven by the ratcheting scheme on the reimbursement prices. The preliminary analysis presented here, however, may be vulnerable to the choice of controls, primarily because pricing behavior (more precisely, bargaining power conferred in the price negotiation discussed in Sections 2.3 and 3.2) may differ between the treated group (those in the sampling periods) and the control (those in the non-sampling period). The next section thus introduces a structural model of demand and supply behavior. The structural model enables us to understand an economic mechanism underlying the reduced-form estimates.

3.2 Preliminary Analysis on Bargaining

It is known among industry practitioners that medical device is priced on the business-to-business (B2B) basis between device sellers and medical providers, and thus the prices tend to widely differ by B2B transaction. Figure 5 plots the distribution of wholesale prices averaged over hospitals, in addition to the original distribution. The latter has a larger standard deviation, which means that we can see different wholesale prices among hospitals even for the same product and in the same month. This finding is consistent with the hypothesis that the pacemaker price is determined by negotiation between hospitals and device sellers, but also consistent with the one that the device sellers charge prices according to demand elasticities of hospitals. We introduce, in Section 4, a bilateral bargaining model, which nests the model of price discrimination.

4 Estimation Model of Cardiac Pacemakers

This section describes the estimation model we use to analyze the Japanese pacemaker market. Based on the descriptive statistics discussed in the previous section, this section seeks to describe a bilateral Nash bargaining in the pacemakers transactions. The model comprises of two main components. In Section 4.1, we introduce a demand system, derived from a random-coefficient discrete-choice model of hospital decision making. We estimate Japanese demand for cardiac pacemakers at the transaction level, incorporating key product characteristics. Since we do not observe the individual patient behavior, we aggregate across individual patients to obtain the product-level demand, while still allowing for heterogeneity across patients. We then turn to a bilateral Nash bargaining model over the wholesale prices between hospitals and device sellers in Section 4.2.

4.1 Demand

A market is defined as a combination of therapeutic category f, hospital h and time (month) t. With this definition, we assume that there exist no substitution across f.

We use a utility-based random coefficient discrete-choice model to describe pacemaker demand in Japan, following a seminal work by Berry, Levinsohn, and Pakes (1995). We assume that a patient arrives at a hospital to undergo a diagnostic procedure. Since we do not have the patient-level data, we assume that patients exogenously arrive at a hospital. A physician who works for hospital h chooses a treatment $j \in J_{f,h,t}$ for patient i at time t, to maximize the indirect utility, $u_{i,j,h,t}$. The set $J_{f,h,t}$ includes not only implanting a particular pacemaker model, but also the outside option, $j = 0$, for the treatment other than implanting a pacemaker. A similar approach is taken by Iizuka (2007) and Grennan (2013). The indirect utility consists of a deterministic component and a random shock, ϵ_{ijht}, distributed as a Type I extreme value:

$$u_{i,j,h,t} = \delta_{j,h,t} + \epsilon_{i,j,h,t}. \tag{3}$$

The deterministic indirect utility function is given by:

$$\delta_{i,j,h,t} = \alpha(\bar{p}_{f,y} - p_{j,h,t}) + \beta e_i^t(\bar{p}_{f,y}) + \gamma x_{j,h,t} + \xi_{j,h,t}. \tag{4}$$

The first term on the right-hand side of eq.(4), $\bar{p}_{fy} - p_{jht}$, is the markup that hospital h receives when pacemaker j is implanted at time t, as already discussed. The second term, $e_i^t(\bar{p}_{fy})$, represents patient's out-of-pocket expense. While the co-payment usually amounts to 30 percent of $\bar{p}_{fy}$, a portion is subsidized by taxpayers for an expensive medical treatment, such as that involving pacemakers. The eventual out-of-pocket expense is a function of $\bar{p}_{f,y}$, whose function differs by age ($A_{i,t}$) and monthly income ($I_{i,y}$) of patient i at month t of year y. For example, $e_i^t(\bar{p}_{f,y})$ is defined as below for those whose age under 70 years old, and income above 35,000 USD:

$$e_i^t\left(\bar{p}_{f,y}\right) = \begin{cases} e_1 + 0.11 \cdot \bar{p}_{f,y} & if\ A_{i,t} < 70 \text{ and } I_{i,y} > 350,000, \text{ or } A_{i,t} > 70 \text{ and } I_{i,y} > 6,000,000 \\ e_0 & \text{otherwise} \end{cases},$$

where

$$e_0 = 69,890, e_1 = 40,200 \qquad t \in [\text{May 2003, September 2006}].$$
$$e_0 = 77,430, e_1 = 44,400 \qquad t \in [\text{October 2006, April 2014}].$$

The vector, x_{jht}, on the right-hand side of eq.(4) contain the dummy variables specific to product, hospital, month and year. While we have several dimensions of observed product characteristics, including battery voltages, battery capacity and expected lifetime, these characteristics are subsumed by product-specific dummy variable. Nevertheless, we use the characteristics variables to address econometric issues, as discussed in the next section. An unobservable time fluctuation in the hospital preference for the product is denoted by $\xi_{j,h,t}$ with the property that $E\left[\xi_{j,h,t}\right] = 0$. Note that persistent unobserved heterogeneity at the product-hospital level is controlled for by the inclusion of this dummy variable. The distributional assumption on $\epsilon_{i,j,h,t}$ yields the well-known closed-form probability of the choice of device j as follows:

$$s_{i,j,h,t} = \frac{\exp\left(\delta_{i,j,h,t}\right)}{1 + \sum_r \exp\left(\delta_{i,r,h,t}\right)},$$

The market share of device j that purchased by hospital h is thus obtained by integrating out patients demographics:

$$s_{j,h,t} = \int_a \int_b \int_c s_{i,j,h,t} dF\left(c\right) dG\left(b\right) dH\left(a\right),$$

where $dF\left(a\right)$ and $dG\left(b\right)$ represent respective empirical distributions of age and income for Japanese population for each year y [4], and $dH\left(c\right)$ is the standard normal distribution. To approximate the integral, we draw 1000 random observations independently from the respective distributions.

The market share is calculated as a fraction of the potential market size, $M_{h,t}$. Thus, the quantity demanded is written as $q_{j,h,t}(\mathbf{p}_{f,h,t}, \bar{p}_{f,y}) \equiv M_{h,t} \cdot s_{j,h,t}$, in which $\mathbf{p}_{f,h,t}$ is the vector, whose j-th component is $p_{j,h,t}$. We take the size of the potential market as the number of patients with heart diseases for hospital h and month t. According to the Ministry of Health, Labor and Welfare, the number of inpatients who develop heart diseases amounts to more than five percent of total Japanese population in 2014.[5]

We normalize the mean utility of the outside option is zero. Demand parameters enable us to calculate the welfare measure. Grennan (2013) provides a careful explanation on how to interpret the surplus based

[4] The data are taken from *Patient Survey* and *Comprehensive Survey of Living Conditions* of respective years. The detailed data description is in the appendix.

[5] We employ in our preliminary analysis the number of hospital beds as another indicator of potential market size, $M_{h,t}$. This alternative assumption makes little change to the estimates we will report in Section 6.

on the utility function (4). We essentially adopt his approach to assume that incentives of physicians and those of hospitals are aligned with one another. Thus, we take the hospital surplus as:

$$\begin{aligned}
&\pi^H_{f,h,t}(\mathbf{p}_{f,h,t}, \bar{p}_{f,y}; J_{f,h,t}) \\
&\equiv M_{h,t} * \int_a \int_b \int_c \left[\sum_{k \in J_{f,h,t}} \int_{\{i | k = \text{argmax}_{k' \in J_{f,h,t}} u_{i,k',h,t}\}} \frac{u_{i,k',h,t}}{\alpha} df(\epsilon) \right] dF(c)\, dG(b)\, dH(a) \\
&= \frac{M_{h,t}}{\alpha} * \int_a \int_b \int_c \log \left[1 + \sum_r \exp\left(\delta_{r,h,t} + \mu_{i,r,h,t}\right) \right] dF(c)\, dG(b)\, dH(a).
\end{aligned}$$

We follow the estimation methods detailed in Berry, Levinsohn and Pakes (1995); we use instruments discussed in the next section to compute the estimates from the two-step GMM. We follow Nevo (2000) for the numerical search technique and for the construction of standard errors. We will discuss the estimation result in Section 6.

4.2 A Bilateral Bargaining Model

This section describe a model of pricing with competition and bargaining in the Japanese pacemaker market. We set up a bilateral Nash bargaining problem between a hospital and a device seller over the determination of the wholesale prices. We assume that hospital h and device seller m negotiate simultaneously to set wholesale prices, $p_{j,h,t}$ for $j \in J_{m,f,h,t}$, where $J_{m,f,h,t}$ is a set of products owned by seller m. Each hospital in the data set negotiates with a seller separately, leading to an outcome of the bilateral Nash bargaining solution. The outcome forms a Nash equilibrium. This accords with the idea proposed by Horn and Wolinsky (1988).

Based on the discussion made in Section 2.2, the model comprises two regimes to incorporate the unique feature of the regulatory ratchet rule. The two regimes are the sampling period (i.e., $\Phi_t = 1$) when $t \in T_y$, and the non-sampling period ($\Phi_t = 0$) otherwise, in which Φ_t is the dummy variable. When $\Phi_t = 0$, the reimbursement prices are exogenous to the negotiated prices. Thus, the model is given by the following static bilateral Nash bargaining model:

$$\begin{aligned}
\max_{\{p_{jht}\}_{j \in J_{mfht}}} \quad & \left[v^M_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}) + \delta \Phi_t V^M_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}) \right]^{1 - b^h_{mft}} \\
& * \left[v^H_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}) + \delta \Phi_t V^H_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}) \right]^{b^h_{mft}}. \quad (5)
\end{aligned}$$

where

$$\begin{aligned}
v^M_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}) &\equiv \pi^M_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}; J_{fht}) - \pi^M_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}; J_{fht} \backslash J_{mfht}) \\
&= \pi^M_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}; J_{fht}) = \sum_{k \in J_{mfht}} q_{kht}(p_{kht} - c_{kht}), \\
v^H_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}) &\equiv \pi^H_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}; J_{fht}) - \pi^H_{mfht}(\mathbf{p}_{fht}, \bar{p}_{fy}; J_{fht} \backslash J_{mfht})
\end{aligned}$$

b^h_{mft} represents the bargaining parameter assigned to hospital h, when it deals with m for device j at time t. Note that the parameter is allow to differ by device seller m, therapeutic category f and time t. The wholesale price is set the same if the products belong to the same therapeutic category. The per-period payoff of multi-product device seller m is given by $\pi^M_{m,f,h,t}(\mathbf{p}_{f,h,t}, \bar{p}_{f,y}; J_{f,h,t}) = \sum_{j \in J_{m,f,h,t}} q_{j,h,t}(\mathbf{p}_{f,h,t}, \bar{p}_{f,y})(p_{j,h,t} - c_{j,h,t})$, and that of hospital h is given by $\pi^H_{fht}(\mathbf{p}_{fht}, \bar{p}_{fy}; J_{fht})$, which is defined in the previous section. We assume that h and m stop trading each other at the disagreement state. The disagreement payoff for device seller m in dealing with hospital h is zero, whereas that for h is denoted by $\pi^H_{fht}(\mathbf{p}_{fht}, \bar{p}_{fy}; J_{fht} \backslash J_{mfht})$. The choice set for hospital h at the disagreement state narrows by $J_{m,f,h,t}$, which is the set of device that h and m had dealt with when they negotiated.

When $\Phi_t = 1$, the wholesale prices at time t influence the future reimbursement prices through the ratchet rule specified by eqs.(1) and (2): an increase in p_{jht} does not necessarily decrease the overall payoff for the device seller; it reduces the seller's payoff at month t, but could increase its payoffs at year $y+1$ and $y+2$. Thus, it is reasonable to assume that when $\Phi_y = 1$, seller m and hospital h negotiate the price at t, considering its effects not only on the current respective payoff, v^M_{mfht} and v^H_{mfht}, but also on the future payoffs for the subsequent two years.[6] Future payoffs can be formulated as follows.

$$
\begin{aligned}
&V^M_{mfht}(\mathbf{p}_{fht}) \\
&= \sum_{s=1,2} \delta^{t(s-1)} \sum_{t \in \Psi_{y+s}} \left\{ \pi^M_{mfht}\left(\mathbf{p}^{'}_{fht}, \bar{p}_{y+1}(\mathbf{p}_{fht}); J_{fht}\right) - \pi^M_{mfht}\left(\mathbf{p}^{'}_{flt}, \bar{p}_{y+1}(\mathbf{p}_{fht}); J_{fht} \backslash J_{mfht}\right) \right\} \\
&= \sum_{s=1,2} \delta^{t(s-1)} \sum_{t \in \Psi_{y+s}} \sum_{k \in J_{mfht}} q_{jht}\left(\mathbf{p}^{'}_{flt}, \bar{p}_{y+1}\right)(p_{kht} - c_{kht}),
\end{aligned}
\tag{6}
$$

and

$$
\begin{aligned}
&V^H_{mfht}(\mathbf{p}_{fht}) \\
&\equiv \sum_{s=1,2} \delta^{(s-1)t} \sum_{t \in \Psi_{y+s}} \left[\pi^H_{mfht}\left(\mathbf{p}^{'}_{fht}, \bar{p}_{fy+s}(\mathbf{p}_{fht}); J_{fht}\right) - \pi^H_{mfht}\left(\mathbf{p}^{'}_{flt}, \bar{p}_{f,y+s}(\mathbf{p}_{fht}); J_{fht} \backslash J_{mfht}\right) \right],
\end{aligned}
\tag{7}
$$

We assume that both hospitals and sellers have perfect foresight with the common monthly discount factor δ being equal to 0.95. Note that $\mathbf{p}^{'}_{fht}$ is a vector of the future wholesale prices, corresponding to the current prices, $\mathbf{p}_{fht}$. The set of months at the fiscal year $y+s$ is denoted by Ψ_{y+s}.

The first order necessary condition is derived as follows:

$$
\begin{aligned}
&q_{jht} + \sum_{k \in J_{mfht}} \frac{\partial q_{kht}}{\partial p_{jht}}(p_{kht} - c_{kht}) + \delta \Phi_t r_{jht} \frac{\partial V^M_{mfht}}{\partial \bar{p}_{fy+1}} \\
&= -\frac{b^h_{mft}}{1 - b^h_{mft}} \frac{\frac{\partial v^H_{mfht}}{\partial p_{jht}} + \delta \Phi_t r_{jht} \frac{\partial V^H_{mfht}}{\partial \bar{p}_{fy+1}}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}} \left\{ \sum_{k \in J_{mfht}} q_{kht}(p_{kht} - c_{kht}) + \delta \Phi_t V^M_{mfht} \right\}.
\end{aligned}
$$

[6] In this section, we do not consider the effects on the payoffs at year $y+3$ and afterwards.

where $r_{jht} \equiv \frac{\partial \bar{p}_{y+1}}{\partial p_{jht}}$.

This can be rewritten as

$$\begin{aligned}
&\sum_{k \in J_{mfht}} \left\{ \frac{\partial q_{kht}}{\partial p_{jht}} + \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\frac{\partial v^H_{mfht}}{\partial p_{jht}} q_{kht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}} + \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\delta \Phi_t r_{jht} \frac{\partial V^H_{mfht}}{\partial \bar{p}_{fy+1}} q_{kht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}} \right\} (p_{kht} - c_{kht}) \\
&= -q_{jht} - \delta \Phi_t r_{jht} \frac{\partial V^M_{mfht}}{\partial \bar{p}_{fy+1}} - \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\delta \Phi_t \frac{\partial v^H_{mfht}}{\partial p_{jht}} V^M_{mfht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}} - \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\delta^2 \Phi_t r_{jht} \frac{\partial V^H_{mfht}}{\partial \bar{p}_{fy+1}} V^M_{mfht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}}.
\end{aligned} \tag{8}$$

For the sake of convenience, we rewrite a part of LHS as follows.

$$\begin{aligned}
&\frac{b^h_{mft}}{1-b^h_{mft}} \frac{\frac{\partial v^H_{mfht}}{\partial p_{jht}} q_{kht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}} \\
&= \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\frac{\partial v^H_{mfht}}{\partial p_{jht}} q_{kht}}{v^H_{mfht}} + \left\{ \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\frac{\partial v^H_{mfht}}{\partial p_{jht}} q_{kht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}} - \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\frac{\partial v^H_{mfht}}{\partial p_{jht}} q_{kht}}{v^H_{mfht}} \right\}.
\end{aligned} \tag{9}$$

Inserting (9) into (8) gives

$$\begin{aligned}
(\mathbf{\Omega} + \mathbf{\Lambda} + \mathbf{\Lambda_1})(\mathbf{p} - \mathbf{c}) &= -\mathbf{q} - \mathbf{v} \\
\Leftrightarrow \ \mathbf{p} &= \mathbf{c} - (\mathbf{\Omega} + \mathbf{\Lambda} + \mathbf{\Lambda_1})^{-1}(\mathbf{q} + \mathbf{v}).
\end{aligned} \tag{10}$$

For each f and t, $\mathbf{\Omega}$, $\mathbf{\Lambda}$ and $\mathbf{\Lambda_1}$ are $J_{ft} \times J_{ft}$ matrices with

$$\begin{aligned}
\mathbf{\Omega}(j,k) &= \frac{\partial q_{kht}}{\partial p_{jht}}, \\
\mathbf{\Lambda}(j,k) &= \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\frac{\partial v^H_{mfht}}{\partial p_{jht}} q_{kht}}{v^H_{mfht}}, \\
\mathbf{\Lambda_1}(j,k) &= \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\frac{\partial v^H_{mfht}}{\partial p_{jht}} q_{kht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}} - \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\frac{\partial v^H_{mfht}}{\partial p_{jht}} q_{kht}}{v^H_{mfht}} + \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\delta \Phi_t r_{jht} \frac{\partial V^H_{mfht}}{\partial \bar{p}_{fy+1}} q_{kht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}},
\end{aligned}$$

and $\mathbf{v}$ is $J_{ft} \times 1$ vectors with

$$\mathbf{v}(j) = \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\delta \Phi_t \frac{\partial v^H_{mfht}}{\partial p_{jht}} V^M_{mfht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}} + \delta \Phi_t r_{jht} \frac{\partial V^M_{mfht}}{\partial \bar{p}_{fy+1}} + \frac{b^h_{mft}}{1-b^h_{mft}} \frac{\delta^2 \Phi_t r_{jht} \frac{\partial V^H_{mfht}}{\partial \bar{p}_{fy+1}} V^M_{mfht}}{v^H_{mfht} + \delta \Phi_t V^H_{mfht}}.$$

During non-sampling periods ($\Phi_t = 0$) or without any dynamic incentives for sellers and buyers ($\delta = 0$), (10) is reduced to

$$\mathbf{p} = \mathbf{c} - (\mathbf{\Omega} + \mathbf{\Lambda})^{-1}\mathbf{q}.$$

5 Identification

This section addresses identification issues when estimating the models of demand and bilateral bargaining (5), discussed in the previous section. In the demand estimation, we employ three sets of instruments. One is

the purchase price to a domestic seller, c_{jht}. We assume in the estimation that c_{jht} is exogenous to the price negotiation process. This assumption however is not innocuous, if the wholesaler received ex-post rebates from manufacturers after the negotiation with hospitals completed. To check the validity of this instrument, we run a simple correlation between c_{jht} and the estimated demand residuals obtained by use of a set of instruments, not including c_{jht}. We find that the correlation coefficient is estimated to be not significant both economically and statistically.

The other set of instruments used for demand estimation is from the idea of Berry, Levinsohn and Pakes (1995); the number of other devices available in the market, and the sum of characteristics observed in the market. Remember that the market is defined by a triple of therapeutic function-hospital-month.

The final candidate for the instruments is the distance between the hospital and the nearest wholesaler's office. The distance can increase supply costs including transportation costs, which has a possible positive impact on the wholesale price.

On the supply side, we estimate the Nash bargaining parameter, b^h_{mft}. To get an idea on identification, we explain the case where $J_{mfht} = \{j\}$. Denote hospital's bargaining power for device j is given by b^h_{jt}, and it is derived as follows:

$$b^h_{jt} = \frac{B^h_{jt}}{1 + B^h_{jt}},$$

and

$$B^h_{jt} = -\frac{W^H_{jht}}{W^M_{jht}} \cdot \frac{\frac{dW^M_{jht}}{dp_{jht}}}{\frac{dW^H_{jht}}{dp_{jht}}}, \tag{11}$$

where $W^M_{jht} \equiv q_{jht}(p_{jht} - c_{jht}) + \delta \Phi_t V^M_{jht}$ is the profits obtained by producer m over two years, and W^H_{jht} is those by hospital h, as defined in Section 4.2. Based on the discussion therein, the following conditions are likely to hold; $\frac{dW^M_{jht}}{dp_{jht}} > 0$ and $\frac{dW^H_{jht}}{dp_{jht}} < 0$.

One needs to be careful when estimating B^h_{jt} in the absence of the data on marginal costs. This is because if the marginal-cost estimate is biased downwardly, W^M_{jht} is over-estimated, leading to underestimation of B^h_{jt}. Having the data on marginal costs helps us identify B^h_{jt}. We examine this issue in Section 6.2.1.

6 Estimation Results

This section presents the results of estimating the models of demand and bilateral bargaining (5) based on monthly data covering 2003 to 2014. We first discuss estimates for demand, then turn to estimated distribution of the bargaining parameters.

6.1 Demand Estimates

Table 4 examines the relationship between the wholesale price, which is the endogenous variable in our demand estimation, and various sets of the instrumental variable candidates discussed in Section 5. Estimation results show that both reimbursement and purchase prices have a positive impact on wholesale prices, which is consistent with a direct implication from our model in eq. (5). However, the results of specification (b) and (d) shows that the number of competing products does not have effects predicted from the model. In particular, the existence of products provided by other manufacturers does not significantly decrease the wholesale price. Finally, the results of specification (c) and (d) shows that the distance from the nearest wholesaler's office significantly increases the wholesale price as predicted. The hypothesis that all coefficients of the instruments are zero is rejected in all specifications. With the significantly estimated coefficients and the highest F value, we use the sets of the instruments in specification (c) hereafter.

Table 5 reports the estimation results for the utility function parameters in eq. (4). Specifications (a)–(d) in the table correspond to the sets of instruments shown as (a)–(d) in Table 4. Without any instruments, we find a positive effect of hospital's markup, and a negative effect of out-of-pocket expenses. However, the coefficient of hospital's markup is not significantly estimated. On the other hand, we can see a significantly positive impact of hospital's markup in the specifications with the instruments. In addition, the negative effect of out-of-pocket expenses is significantly estimated, and the coefficient is larger than that estimated without any instruments. These results are consistent with the findings in previous studies including Iizuka (2007). There are few differences in the results among the specifications (a)-(d). Again, we follow the results of specification (c).

The distribution of the estimated elasticities with respect to wholesale prices has a mean of -0.82 and a standard deviation of 0.19, as shown in Figure 6.

6.2 Bargaining Estimates

With our data and the demand estimates, we recover hospital's normalized bargaining parameters, b^h_{mft}, based on eq. (11). We characterize b^h_{mft} as a flexible functional form, and represent it by dummy variables specific to producer, product, hospital, month and year. Figure 7 classifies b^h_{mft} into the sampling ($\Phi_t = 1$) and non-sampling ($\Phi_t = 0$) periods. We cannot see much differences between them. The mean of the estimates is 0.85, indicating that hospitals have higher bargaining power.

We also decompose the b^h_{mft} estimates into three components; year-, hospital-, and product-fixed effect components. Figure 8 summarizes the estimates. Two observations are made in this exercise. One is that the values of estimated year-fixed effect is on the upward trend over the study period as shown in Panel A: and the other is that the estimated hospital fixed effects have larger dispersion (whose standard error is 0.048), relative to the product-fixed effects (0.022) as shown in Panel B and C. The latter observation implies that bargaining is indeed an important theoretical framework to explain the wholesale prices of

Table 4: Demand estimates: wholesale price and the sets of instruments

	Dependent variable: wholesale price (in million JPY)			
Specification:	(a)	(b)	(c)	(d)
Reimbursement price	0.216 ***	0.216 ***	0.218 ***	0.217 ***
(in million JPY)	(0.027)	(0.027)	(0.027)	(0.027)
Purchase price	0.392 ***	0.393 ***	0.387 ***	0.388 ***
(in million JPY)	(0.010)	(0.010)	(0.010)	(0.010)
# of products provided by the same manufacturer		0.001 *		0.001 *
		(0.001)		(0.001)
# of products provided by other manufacturers		0.000		0.000
		(0.000)		(0.000)
Distance from the nearest wholesaler's office			0.011 ***	0.011 ***
			(0.002)	(0.002)
Year dummy	Yes	Yes	Yes	Yes
Month dummy	Yes	Yes	Yes	Yes
Product dummy	Yes	Yes	Yes	Yes
Hospital dummy	Yes	Yes	Yes	Yes
R-squared	0.953	0.953	0.953	0.953
F value (H0: all coefficients of IVs are zero)	496.41 ***	494.15 ***	531.86 ***	529.24 ***
Observation	10,792	10,792	10,740	10,740

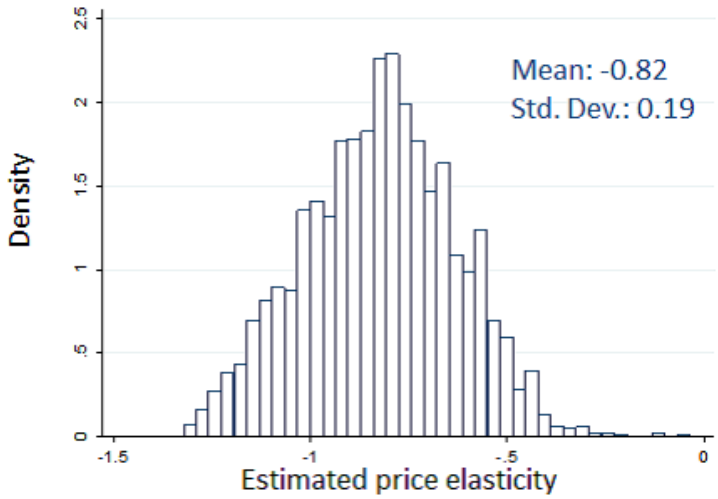
Notes: The dependent variable is the wholesale prices (in Japanese Yen). The explanatory variables include the sets of the instrumental variables discussed in Section 5: the purchase price, c_{jht}, the number of products provided by the manufacturer, the number of products provided by the other manufacturers, and the distance between the hospital and the nearest wholesaler's office. Specifications (a) through (d) use different sets of instruments, along with the exogenous reimbursement price and the dummy variables for years, months, products and hospitals. Standard errors are inside parentheses. ***, **, and * indicate $p < 0.01$, $p < 0.05$, and $p < 0.1$, respectively.

Table 5: Demand estimates: utility function parameters

	w/o instruments	w/ instruments			
		(a)	(b)	(c)	(d)
Hospital's markup	0.20	0.84 ***	0.85 ***	0.89 ***	0.90 ***
(in million JPY)	(0.09)	(0.25)	(0.25)	(0.26)	(0.26)
Out-of-pocket expense	-31.66 **	-75.04 **	-75.84 **	-79.06 **	-79.80 **
(in million JPY)	(28.54)	(32.29)	(32.29)	(32.44)	(32.43)
Year dummy	Yes	Yes	Yes	Yes	Yes
Month dummy	Yes	Yes	Yes	Yes	Yes
Product dummy	Yes	Yes	Yes	Yes	Yes
Hospital dummy	Yes	Yes	Yes	Yes	Yes
R-squared	0.710	0.709	0.709	0.704	0.704
Sargan chi2			1.22	0.15	1.35
Observation	10,792	10,792	10,792	10,740	10,740

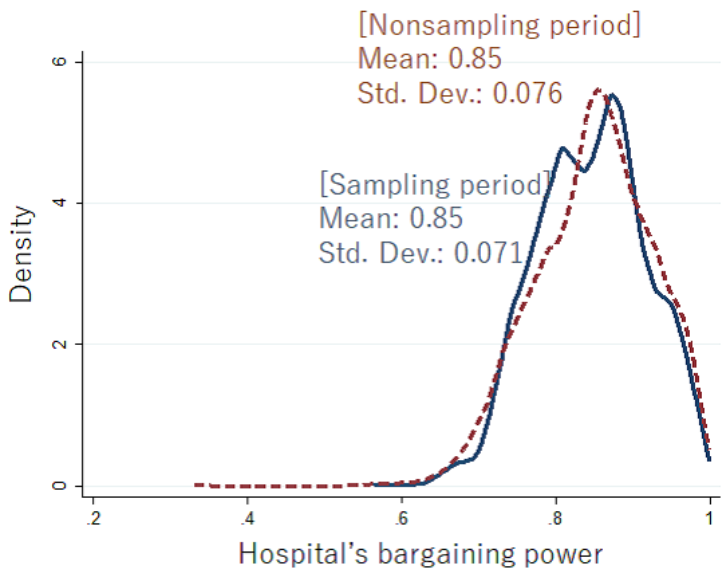
Notes: The table reports the estimated parameters of the utility function in Eq. (4). The explanatory variables include the hospital markup and patients' out-of-pocket expenses, along with dummy variables for years, months, products, and hospitals. The first column presents the estimates without any instrumental variables, while the remaining columns present the estimates with different sets of instruments. Specifications (a) through (d) in the table use the corresponding sets of instruments from (a) through (d) in Table 4.

Figure 6: Estimated elasticities with respect to wholesale prices



Notes: The figure shows the distribution of the estimated elasticities with respect to wholesale prices.

Figure 7: Estimated bargaining power parameters



Notes: The blue solid line represents the distribution of the estimated bargaining power parameters during the sampling period, while the red dashed line represents the distribution during the nonsampling period.

cardiac pacemakers in Japan. It also corroborates with the finding that differentiated-product Bertrand competition, in which hospitals are assume to have no bargaining power, fits the data poorly, as shown in Figure 9.

6.2.1 Estimation without cost data

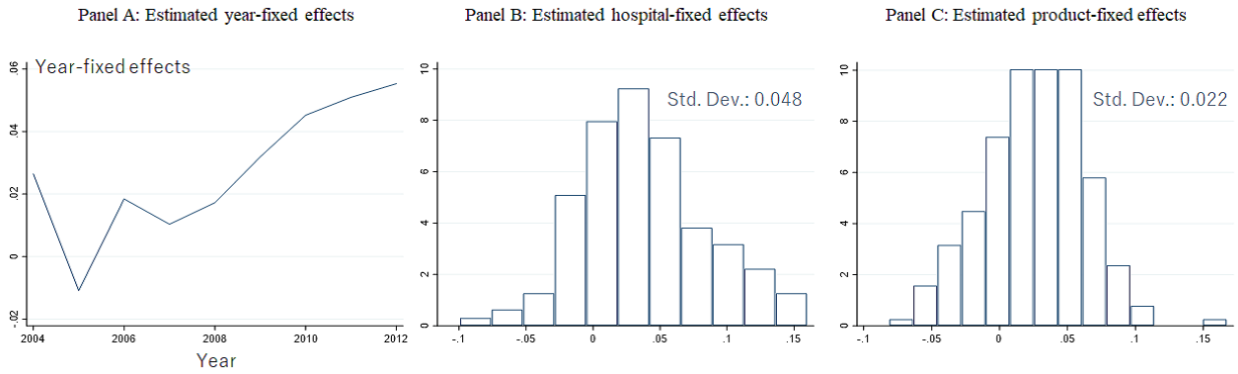
Even without the data on marginal costs, we can estimate the bargaining parameters, under some additional assumptions. Previous studies, including Grennan (2013), take this identification strategies. This strategy, however, sometimes relies on the doubtful assumptions, and can lead to the biased estimates of bargaining parameters. In particular, as discussed in Section 5, if the marginal-cost estimate is biased downwardly, our bargaining parameters, b^h_{mft}, will be underestimated.

In this subsection, we follow the strategy of Grennan (2013), and estimate our bargaining parameters without the cost data. Comparing the results with those with the cost data, we show that having the data on marginal costs is very important for identifying b^h_{mft}.

Focusing on our interest here, for avoiding technical difficulties, we estimate bargaining parameters only for non-sampling periods in this subsection. To get an idea on identification, we explain the case where $J_{mfht} = \{j\}$ again. Eq. (11) can be rewritten as follows.

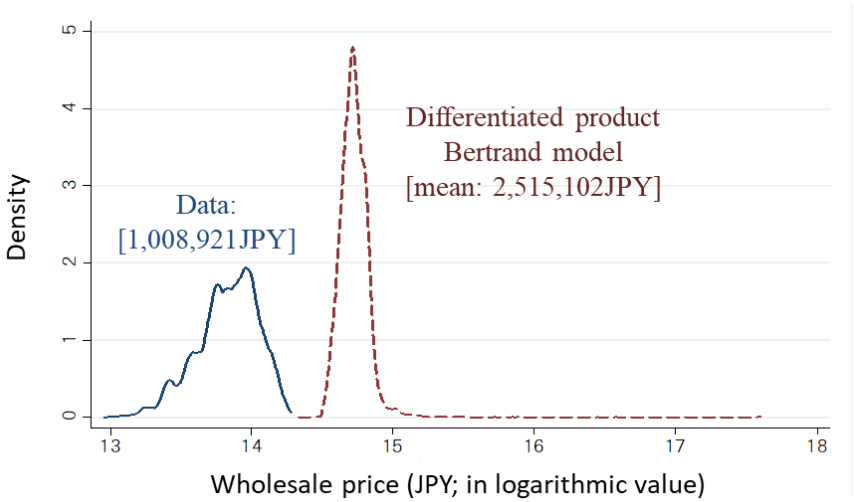
$$\frac{b^h_{jt}}{1-b^h_{jt}} = \frac{\frac{v^H_{jht}}{p_{jht}}}{-\frac{\partial v^H_{jht}}{\partial p_{jht}}} * \left(\frac{p_{jht}}{p_{jht}-c_{jht}} + \frac{\partial q_{jht}}{\partial p_{jht}} \frac{p_{jht}}{q_{jht}} \right).$$

Figure 8: Fixed effects on estimated bargaining parameters



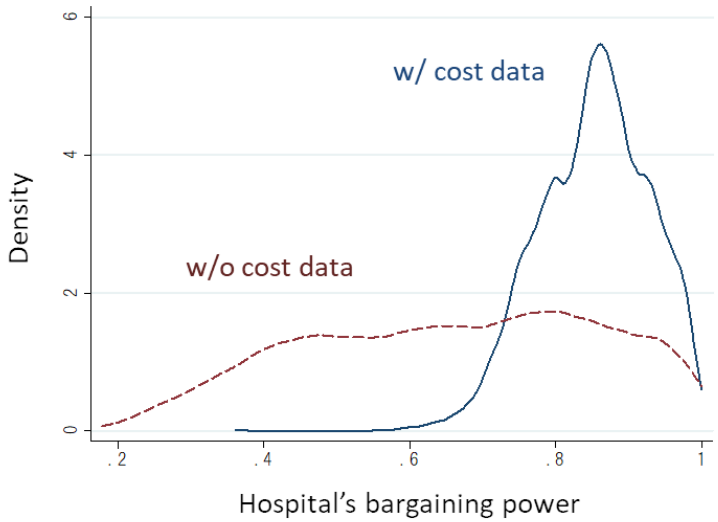
Notes: The figure presents the estimation results from regressing the estimated bargaining power parameters on dummy variables for years, hospitals, and products. Panel A displays the estimated year-fixed effects for each year, while Panels B and C show the distributions of the estimated hospital-fixed effects and product-fixed effects, respectively.

Figure 9: Wholesale prices predicted by the Bertrand model



Notes: The blue solid line represents the distribution of wholesale prices in logarithmic values observed in the data. The red dashed line represents the distribution of wholesale prices in logarithmic values predicted by the differentiated-product Bertrand competition model, where hospitals are assumed to have no bargaining power.

Figure 10: Estimated bargaining power parameters w/o cost data



Notes: The blue solid line represents the distribution of bargaining power parameters estimated using marginal cost data, while the red dashed line represents the distribution of bargaining power parameters estimated without marginal cost data, assuming $c_{jht} = \gamma_j$ and $\frac{b^h_{jt}}{1-b^h_{jt}} = \beta_{jh}\nu_{jht}$.

Clearly, both b^h_{jt} and c_{jht} cannot be identified as free parameters because the number of equations is smaller than the number of parameters. Previous studies impose some restrictions on b^h_{jt} and c_{jht} to decrease the number of estimated parameters. Grennan (2013) specifies the marginal cost by $c_{jht} \equiv \gamma_j$ and the bargaining ability as $\frac{b^h_{jt}}{1-b^h_{jt}} \equiv \beta_{jh}\nu_{jht}$. ν_{jht} is the econometric unobservable term that captures the deviation from the pair-specific bargaining abilities, β_{jh}, which satisfies an orthogonality condition, $E\left[\log \nu_{jht} | z_{jht}\right] = 0$. Rearranging and taking logarithm gives

$$\log \nu_{jht} = \left\{ \frac{\frac{v^H_{jht}}{p_{jht}}}{-\frac{\partial v^H_{jht}}{\partial p_{jht}}} * \left(\frac{p_{jht}}{p_{jht} - \gamma_{jy}} + \frac{\partial q_{jht}}{\partial p_{jht}} \frac{p_{jht}}{q_{jht}} \right) \right\} - \log \beta_{mhy}.$$

Estimation is based on the orthogonality condition, and instruments here are the same as those for our demand estimation. Figure 10 shows the distribution of estimated bargaining parameters with and without cost data. The estimated bargaining parameter without cost data exhibits a smaller mean and greater variation.

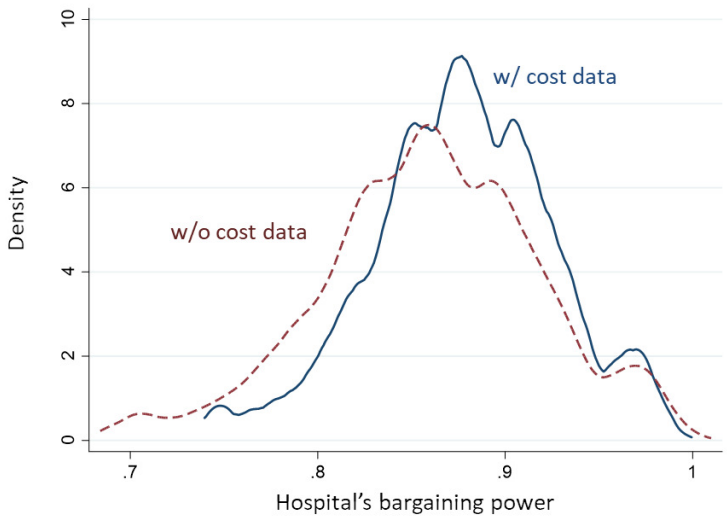
To improve the performance of the estimates, we relax Grennan's assumptions and reformulate them as follows.

$$c_{jht} \equiv \gamma_{jy}, \frac{b^h_{jt}}{1 - b^h_{jt}} \equiv \beta_{mhy}\nu_{jht}. \tag{12}$$

We also allow ν_{jht} to be serially correlated.

$$\nu_{jht} = \rho\nu_{jht-1} + \varepsilon_{jht}. \tag{13}$$

Figure 11: Estimated bargaining parameters w/o cost data (under relaxed assumptions)



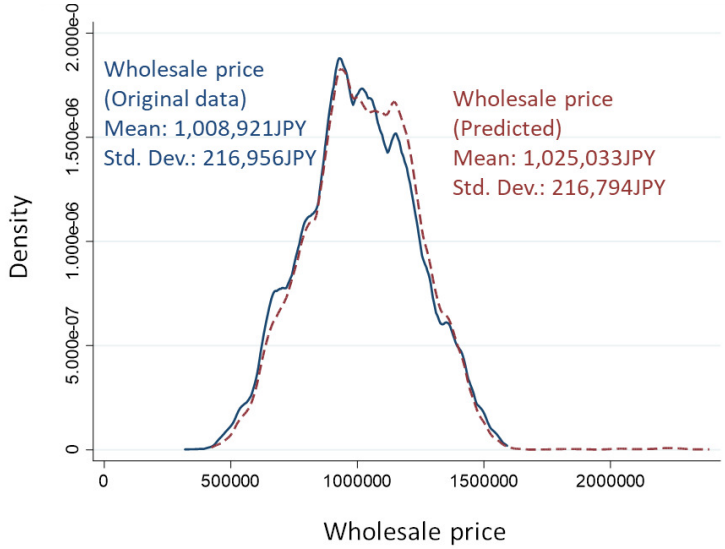
Notes: The blue solid line represents the distribution of bargaining power parameters estimated using marginal cost data, while the red dashed line represents the distribution of bargaining power parameters estimated without marginal cost data, assuming eqs. (12) and (13).

Figure 11 presents the estimates under relaxed assumptions. The distribution of the estimated bargaining parameters fits relatively well, highlighting the importance of adopting reasonable assumptions regarding cost and bargaining parameters.

7 Distortionary Effect of Device Pricing

Based on the primitive estimates obtained in the previous section, we attempt to assess whether and to what extent the endogenous reference pricing rule provides perverse incentives to hospitals and producers. To do so, we simulate eq.(5) by use of the following procedure. At the beginning of our study period of 2003, we take $\overline{p}_{fy}$ and c_{jht} from the data and arbitrary initial values for transaction prices, p^0_{jht}, and calculate producer and hospital surpluses and their disagreement payoffs for each product in all markets at time t. We solve the bilateral bargaining problem, eq.(5), to obtain the Nash equilibrium values of wholesale prices, $\left\{p^1_{jht}\right\}$. We use a convergence criteria; $\sum_{j\in J_{fht}}\left(p^s_{jft}-p^{s-1}_{jft}\right)^2 < 10^{-4}$ for each market. If this criteria is not satisfied for $s=1$, we update the reimbursement price for $\left\{p^1_{jht}\right\}$ by use of eq.(1) and (2), and repeat the above procedure, until the criteria satisfies. We do this simulation until 2013, the period when we can assess the dynamic effect in the next period.

Figure 12: Fitness of the model



Notes: The blue solid line represents the distribution of wholesale prices in the data, while the red dashed line represents the distribution of wholesale prices predicted with our estimates.

7.1 Simulation results

This section quantifies the mechanisms by which the reference pricing scheme influences on agents' incentives. We first simulate our model with actual Φ_t. Figure 12 shows that our model fits the data well.

Then, we consider a counter-factual scenario where no strategic incentives are present on the process of price negotiation between producers and hospitals. This simulation exercise can be done by solving eq. (5) under the assumption that $\Phi_t = 0$. Table 6 reports the simulation results in 2011 and 2012. The difference between the actual prices and the negotiated prices under the counter-factual scenario of no strategic incentives are statistically significance of 0.5 percent. This price difference becomes more pronounced in less competitive environments, reaching 2.3 percent for categories with three pacemaker products or fewer.

The magnitude of this strategic effects depends on the number of competing products. As for every product in all sampling periods, we similarly conduct the simulation exercises to obtain the counter-factual wholesale prices without any strategic incentives, and compare them with the actual prices. Figure 13 examines the relationship between the price differences and the number of competing products. The figure shows that the percentage differences, $\frac{p_{jht} - p_{jht}^{simulated}}{p_{jht}^{simulated}}$, decrease with the number of competing products during the sampling period. As shown in (10), the magnitude of the strategic effects is determined by the values of $\mathbf{\Lambda_1}$ and $\mathbf{v}$. As the number of competing products increases, the value of r_{jht} becomes smaller, which decreases the values of both $\mathbf{\Lambda_1}$ and $\mathbf{v}$.

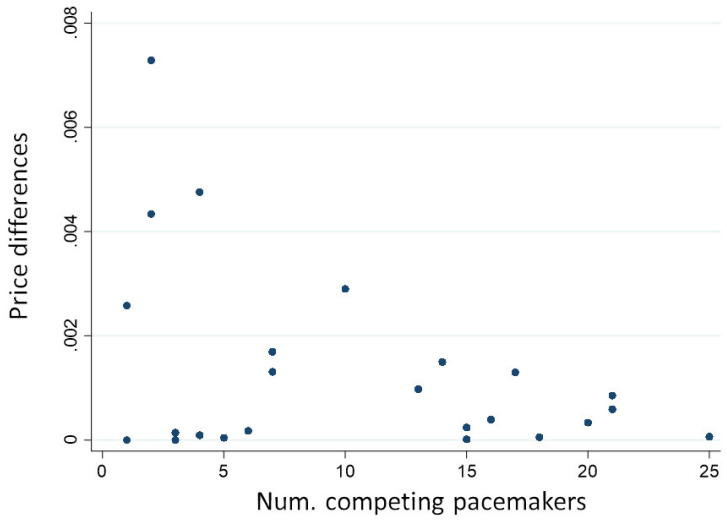
Finally, Table 7 compares some of economic outcomes with and without strategic incentives. As shown in Table 6, strategic incentives have a positive impact on wholesale prices during sampling periods, which

Table 6: Simulation results: Wholesale prices

	Strategic incentives (Data)		No strategic incentives (Simulated values)		Differences (%)	
	Sampling	Non-sampling	Sampling	Non-sampling	Sampling	Non-sampling
Year: 2011						
Reimbursement price	1,086,585	1,078,243	1,086,585	1,078,243		
Wholesale price	916,408	906,924	911,937	906,833	0.49	0.01
Year: 2012						
Reimbursement price	939,423		934,877		0.49	
Wholesale price	776,599		775,024		0.20	

Notes: The table shows simulation results obtained from the two years, 2011 and 2012. The results from the other years show qualitatively the same results, and are available upon request. The sampling period is from May to September of every odd year, whileas the non-sampling period is the rest of the year, during the study period.

Figure 13: Price differences and competition



Notes: The figure shows a scatter plot of the percentage differences in wholesale prices with and without strategic incentives during the sampling period in 2011, $\frac{p_{jht}-p_{jht}^{simulated}}{p_{jht}^{simulated}}$, against the number of competing pacemakers.

Table 7: Simulations Results: Economic Outcomes

		All	Sampling	Non-sampling
Sales	w/ strategic incentives	1.629	1.604	1.636
(unit)	w/o strategic incentives	1.624	1.605	1.629
	diff.	0.29%	-0.11%	0.41%
Seller payoff	w/ strategic incentives	318	339	312
(thousand JPY)	w/o strategic incentives	314	325	311
	diff.	1.29%	4.24%	0.43%
Hospital payoff	w/ strategic incentives	2,203	2,177	2,210
(thousand JPY)	w/o strategic incentives	2,188	2,182	2,189
	diff.	0.67%	-0.21%	0.93%
Medical expenditure	w/ strategic incentives	1,595	1,551	1,606
(thousand JPY)	w/o strategic incentives	1,582	1,546	1,591
	diff.	0.82%	0.35%	0.96%

Notes: The table presents the simulated mean values of economic outcomes with and without strategic incentives during the study period. The sampling period is from May to September of every odd year, whileas the non-sampling period is the rest of the year, during the study period.

apparently decreases demand. At the same time, they also have a positive impact on reimbursement prices, which, in contrast, increases demand. The former effects dominate the latter during sampling periods, and the simulated sales amount with strategic incentives is lower than that without strategic incentives by 0.11%. On the other hand, the sales amount is higher by 0.41% during non-sampling periods. The difference between the simulated sales amount is 0.29% in total.

Strategic incentives have a positive effect on seller's payoff during both sampling periods and non-sampling periods. In particular, seller's payoff is considerably higher with strategic incentives during sampling periods, because of higher wholesale and reimbursement prices. The difference between the seller's payoff with and without strategic incentives is 1.29% in total. Meanwhile, the strategic effects are not so simple as for hospital payoff. Hospitals benefit from the increase in reimbursement prices during non-sampling periods whereas their payoff is lower during sampling periods due to higher wholesale prices. In total, their payoff is higher by 0.67%.

The positive strategic effects as a whole are at the cost of higher medical expenditures. The difference between the medical expenditures with and without strategic incentives is 0.82% in total. If the results obtained from our analysis of cardiac pacemakers are extrapolated to all medical devices and pharmaceuticals subject to ratcheting benchmarks, it is estimated that Japan's annual medical expenses could be reduced by approximately 5.7 billion yen.

8 Concluding Remarks

With detailed device-level transaction data at hand, along with the intimate knowledge on the target ratcheting scheme in Japan, this paper attempts to empirically investigate the effects of the regulatory benchmarking of target ratcheting on market outcomes. To do so, we describe the Japanese pacemaker market with a multi-period bilateral Nash bargaining model, and quantify implications of the policy by use of structural estimation approach. For this purpose, we also estimate physician's behavior on cardiac pacemakers by use of random-coefficient discrete choice model.

Based on the demand estimates, we then estimate the bargaining model, in which producers and hospitals negotiate over prices of cardiac pacemakers. During the sampling periods, both parties have incentive to influence on the future reimbursement prices by solving a two-period bilateral Nash bargaining model. In other periods, they solve for a static one-period bargaining model. The marginal-cost data for producers help us identify the bargaining parameters in our application. Three observations emerged from the bargaining estimates; (1) The bargaining model estimated in this paper fits the data better than a differentiated-product oligopoly model, the latter which assumes no bargaining power on the side of hospitals; (2) hospitals have higher bargaining power on average than producers, and more so during the sampling period; (3) The wholesale prices under the reference pricing scheme are on average 0.5 percent higher than those under the scenario where no strategic incentives are present.

A Demand estimation: robustness

We perform three sets of robustness checks for the demand estimates. First, we use the number of beds for the potential market size, instead of the number of patients with heart disease. The second stage estimation results are qualitatively similar to our base results. We also estimate with the alternative definition of the outside good share. In this specification, substitution among different types of pacemakers are allowed, and a market is defined as particular hospital in a particular month. Again, the second stage estimation results are very similar to the baseline estimates.

B Data Appendix

The data are supplemented by information on hospital characteristics provided by *Japan Medical Press* (2004-2014), and product characteristics by Nitta and Ishikawa (2014). We also augment the data on retail price, reimbursed by insurers and patients, obtained from Japan Association for the Advancement of Medical Equipment (JAAME).

References

[1] Amano, T., 2016, "Ratcheting, Competition, and the Diffusion of Technological Change: The Case of Televisions under an Energy Efficiency Program," *mimeo*

[2] Ashenfelter, O. C, D. S. Hosken, and M.C.Weinberg, 2015 "Efficiencies brewed: pricing and consolidation in the US beer industry," *RAND Journal of Economics*, 46(2): 328-61

[3] Armstrong, M., and D.E.M. Sappington, "Recent Development in the Theory of Regulation," Ch.3 in *Handbook of Industrial Organization*, Vol.3, edited by M. Armstrong and R. Porter: 1557-1700

[4] Berry, S. T., 1994, "Estimating Discrete-Choice Models of Product Differentiation," *RAND Journal of Economics* 25(2): 242-62.

[5] Berry, S. T., J. Levinsohn and A. Pakes, 1995 "Automobile Prices in Market Equilibrium," *Econometrica* 63(4): 841-90.

[6] Blomqvist, A., 1991 "The Doctor as Double Agent: Information Asymmetry, Health Insurance, and Medical Care," *Journal of Health Economics* 10(4): 411-32.

[7] Brekke, K.R., T.H. Holmas, and O.R.Straume, 2011, "Reference Pricing, Competition, and Pharmaceutical Expenditure: Theory and Evidence from a Natural Experiment," *Journal of Public Economics* 95: 624-38

[8] Chipty, T., and C. Snyder, 1999, "The Role of Firm Size in Bilateral Bargaining: A Study of the Cable Television Industry," *The Review of Economics and Statistics* 81(2): 326-40

[9] Collard-Wexler, A., G. Gowrisankaran, and R. S. Lee, 2016, ""Nash-in-Nash" Bargaining: A Microfoundation for Applied Work," *mimeo*

[10] Crawford, G. S., R. S. Lee, M. D. Whinston, and A. Yurukoglu, 2015, "The Welfare Effects of Vertical Integration in Multichannel Television Markets," *mimeo*

[11] Crawford, G. S. and A. Yurukoglu, 2012, "The Welfare Effects of Bundling in Multichannel Television Markets," *American Economic Review*, 102(2): 643-85

[12] Draganska, M., D. Klepper, and S. B. Villas-Boas, 2010, "A Larger Slice or a Larger Pie? An Empirical Investigation of Bargaining Power in the Distribution Channel," *Marketing Science* 29(1): 57-74

[13] Duggan, M., and F. M. Scott Morton, 1999, "The Distortionary Effects of Government Procurement: Evidence from Medicaid Prescription Drug Purchasing," *Quarterly Journal of Economics* CXXI(1): 1-30

[14] Freixas, X., R. Guesnerie, and J. Tirole, 1985, "Planning under Incomplete Information and the Ratchet Effect," *The Review of Economic Studies*, 52(2): 173-91

[15] Gowrisankaran, G., A. Nevo, and R. Town, 2015, "Mergers When Prices Are Negotiated: Evidence from the Hospital Industry," *American Economic Review* 105(1): 172-203

[16] Grennan, M, 2013, "Price Discrimination and Bargaining: Empirical Evidence from Medical Devices," *American Economic Review* 103(1): 145-77.

[17] Ho, K. and R. S. Lee, 2017, "Insurer Competition in Health Care Markets," *Econometrica* 85(2): 379-417

[18] Horn, H. and A. Wolinsky, 1988, "Bilateral Monopolies and Incentives for Merger," *RAND Journal of Economics 19(3)*: 408-419.

[19] Iizuka, T, 2007, "Experts' Agency Problems: Evidence from the Prescription Drug Market in Japan," *RAND Journal of Economics* 38(3): 844-62

[20] Ito, K., and J. M. Sallee, 2017, "The Economics of Attribute-Based Regulation: Theory and Evidence from Fuel-Economy Standards," forthcoming in *Review of Economics and Statistics*

[21] Lee, R. S., and K. Fong, 2013, "Markov-Perfect Network Formation: An Applied Framework for Bilateral Oligopoly and Bargaining in Buyer-Seller Networks," *mimeo*

[22] Lopez-Casanovas, G., and J. Puig-Junoy, 2000, "Review of the Literature on Reference Pricing," *Health Policy* 54: 84-123

[23] McGuire, T. G., "Physician Agency," Chapter 9 in *Handbook of Health Economics*, Vol. 1, Edited by A. J. Culyer and J. P. Newhouse, 462-536

[24] Ministry of Health, Labour and Welfare, *Patient Survey*, 2004-2015.

[25] Nitta, T. and T. Ishikawa, 2014, "Data Book: Pacemakers ICD· CRT."

[26] Pavcnik, N., 2002, "Do Pharmaceutical Prices Respond to Potential Patient Out-of-Pocket Expenses?," *RAND Journal of Economics* 33: 469-87