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Induced Physician-Induced Demand

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Abstract

Physicians may change their practices when introducing advanced medical equipment, and, in particular, they tend to overuse it. We investigate further inefficiency arising from physicians at surrounding hospitals. Using the panel data on the Japanese hospitals, we find that there exists a business-stealing effect: Hospitals lose their patients because of MRI adoption by nearby public hospitals, and, to compensate for the loss of patients, physicians take more MRI scans per patient. Our results suggest that the decision to adopt medical equipment needs to be made collectively rather than individually to avoid not only excessive adoption but also further physician-induced demand.

JEL Classification: I11, I12, I19.
Keywords: Physician-induced demand, Business-stealing effects, Externalities.

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1 Introduction

Increasing medical expenditure has attracted attention in many developed countries. In particular, there is an growing concern about the excessive introduction and use of advanced medical equipment. Though such advanced equipment certainly enhances the quality of healthcare, physicians may use it more than necessary, a practice typically known as *physician-induced demand* or supplier-induced demand. Such physicians' opportunistic behavior is driven by the high reimbursement price for physicians, whereas the usage cost and the burden on patients (patients' out-of-pocket expense) are low. As discussed in Baker (2010), physician-induced demand may become more prominent when hospitals newly adopt medical equipment. This paper investigates further inefficiencies arising from the local competition among hospitals. When a hospital purchases medical equipment, the patients attending the surrounding hospitals may switch to that hospital, known as *business-stealing effects* in the industrial organization literature. This business stealing may strengthen the incentive of physician-induced demand at the surrounding hospitals to compensate for their loss of revenue. We call this class of physician-induced demand *induced physician-induced demand*, as the magnetic resonance imaging (MRI) adoption of the surrounding hospitals induces it. Physician-induced demand through this channel is important, because ignoring the indirect effects on the surrounding institutions underestimates the social cost of adoption and taking this channel into account allows us to shed light on designing better healthcare policies.

To this end, we use the administrative data on all medical institutions in Japan, which give an ideal environment to investigate such a new mechanism of physician-induced demand thanks to its institutional features. First, as Japan has achieved universal health coverage since the 1960s, all citizens can go to any medical institution in Japan and receive medical service at the same price for the same medical treatment, regardless of their choice of medical institution. Together with the panel structure of the data which allows us to calculate the change in the number of MRI scanners within a 1 kilometer radius from each medical institution, this institutional feature enables us to examine how MRI adoptions of nearby hospitals affect the numbers of patients and MRI scans taken for the surrounding hospitals. Second and, again, related to the first feature, our environment is free from an endogeneity concern about prices; Because medical prices are fixed and regulated by the government under the Japanese health insurance system, physicians cannot adjust the prices flexibly in response to changes in demand.

We take advantage of these institutional features, and seek to verify our hypothesis, by first examining whether the business-stealing effects exist in the MRI scanning market. Our estimation results show that a hospital loses its patients by up to 4 percentage points for an additional MRI scanner purchased by the surrounding hospitals. These business-stealing effects are found only for MRI purchases by public hospitals. We then investigate whether the hospitals that lose their patients take MRI scans more often to compensate for the reduction in patients. To provide such evidence, we define the *conversion rate* as the fraction of patients who receive MRI scans, and we demonstrate that the conversion rate increases after surrounding public hospitals purchase MRI scanners, which confirms the existence of *induced physician-induced demand*. In particular, our estimation results shows that hospitals take roughly the same number of MRI scans, regardless of the change in the number of patients. One may worry that this induced physician-induced demand might be overestimated, if increases in both the conversion rate and the number of surrounding MRI scanners are driven by the increase in local demand, which is unobserved. However, our data reveal that purchases of MRI scanners by public hospitals are not correlated with the change in local demand, which circumvents the endogeneity concern in our analysis. Taking advantage of those findings, we further quantify physician-induced demand in a more general sense: how physicians change their behavior when the number of patients changes, exogenously. We take an instrumental variable (IV) approach, using the MRI purchases of public hospitals as an instrument for the number of patients, and confirm that physicians take MRI scans more often when the number of patients decreases. We further quantify the increase in healthcare expenditure due to this physician-induced demand. Our estimates suggest that total annual healthcare expenditure increases up to ¥12 billion (Japanese yen).

This paper contributes to two strands of literature. First, we contribute to the literature on supplier-induced demand by adding an eloquent evidence of its existence and by revealing a new mechanism, externalities from the surrounding medical institutions, which has not yet been explored in previous studies. Supplier-induced demand has been studied extensively both in the context of the healthcare industry (Kessler and McClellan, 1996; Chandra and Staiger, 2007; Geruso and Layton, forthcoming) and outside healthcare industry (Balafoutas et al., 2013). Debate on the magnitude of induced demand and even on its existence is still ongoing (Dranove and Wehner, 1994; Chandra and Staiger, 2007; Currie and MacLeod, 2008). We provide an new piece of evidence of physician-induced demand and quantify its economic significance by investigating the MRI scanning market, where Baker (2010) and Clemens and Gottlieb (2014) also find physician-induced demand. We also exploit the unique features of the Japanese healthcare system to quantify its existence and magnitude, as Iizuka (2012) and Shigeoka and Fushimi (2014) do. In terms of the mechanism, Johnson (2014) classified the existing studies into three groups based on the sources of identification: (i) patients' income shocks (Fuchs, 1978; Cromwell and Mitchell, 1986), (ii) changes in physician fees (Rice, 1983; Nguyen and Derrick, 1997; Dafny, 2005), and (iii) variations in patient information (Currie et al., 2011; Angott et al., 2019). Although all existing studies view physician-induced demand as a phenomenon at each institution, this paper attempts to identify physician-induced demand from interactions and competition among medical institutions.

The second strand of literature that this paper contributes to focuses on hospital competition. Many studies have been conducted on how hospital competition affects healthcare quality, which Katz (2013) summarizes. For example, Dranove, Shanley and Simon (1992); Kessler and McClellan (2000); and Bloom, Propper, Seiler and Van Reenen (2015) find that hospital competition increases healthcare quality. Though the business-stealing effect is a central issue related to competition and is studied intensively both theoretically (Mankiw and Whinston, 1986) and empirically (Davis, 2006), not much attention has been paid to the business-stealing effect in the healthcare industry. This paper, therefore, is the first to establish some evidences that hospital competition creates business-stealing effects, which further induces physician-induced demand.

This paper is organized as follows. Section 2 describes the institutional background and the data. We use the Japanese MRI scanning market to show in the first part of Section 3 that there are business-stealing effects by MRI purchases of surrounding hospitals and these business-stealing effects cause further physician-induced demand there, which verifies our induced physician-induced demand hypothesis. Taking advantage of our finding in the first half of section 3, we attempt to identity more broadly defined physician-induced demand in the subsequent section. Section 4 provides various robustness check to address some concerns in our approach taken in Section 3. Section 5 concludes.

2 Institutional Background and Data

2.1 Institutional Background

Healthcare System in Japan. Since 1961, Japan has achieved universal health coverage like many Organization for Economic Co-operation and Development countries. Under the Japanese healthcare system, every citizen in Japan is insured, and two types of insurance programs are available in Japan. If a citizen's employer offers its own insurance program, the employee enroll in it, which is called "Employee Health Insurance" (*Kenko-Hoken*). Dependents of the employee may also enroll in the program. Citizens not enrolled in Employee Health Insurance must enroll in so-called "National Health Insurance" (*Kokumin-Kenko-Hoken*). Both insurance programs offer the same insurance, and, regardless of their insurance program, when the insureds (patients) receive medical services at medical institutions, the patients pay 30% of the healthcare fee and their insurers cover the remainder.[1] The Japanese health care system has two notable features: (i) "free access," and (ii) fee-for-service (FFS) payment.

First and most important, patients have free access, which means they can go to any medical institution in Japan, unlike the U.S. healthcare system which allows patients, in principle, to go only to medical institutions belonging to the network of their health insurer. Furthermore, unlike countries such as France, the United Kingdom, and the

[1] There are some exceptions. For example, the co-payment is 20% for patients aged 70 or older. Furthermore, insurers subsidize some expensive medical treatments.

Netherlands, there is no general practitioner system in Japan and, thus, people generally go directly to specialized medical institutions when they get sick. These aspects are particularly relevant to this paper, as patients may change their choices of medical institution because of MRI adoption by nearby hospitals. Second, healthcare fees are regulated in Japan and are set by the government with biannual revisions, and the government sets a fixed fee for each medical treatment in an FFS payment system, patients pay for each medical treatment they receive, and physicians receive payment for each treatment they provide. Since 2003, some hospitals have started adopting the DPC (Diagnosis Procedure Combination) payment system, where patients' payment is based on diagnosis categories and diagnosis groups rather than on each treatment they receive, as in FFS. Healthcare service providers are paid a flat-rate prospective fee per day of an inpatient hospital stay for certain DPC services and are paid FFS for non-DPC services. The Japanese government encourages hospitals to shift from FFS to DPC to reduce medical expenses. However, the FFS payment system remains the most popular payment system during our sample period and we discuss this point thoroughly in Section 4.2.

In Japan, medical institutions are formally divided into two main categories, hospitals and clinics, depending solely on the number of beds. A medical institution with less than 20 beds is classified as a clinic. Otherwise, it is classified as a hospital. Most of MRI scanners are owned by hospitals, which restrict our attention to hospitals rather than clinics. In general, clinics provide basic treatment whereas hospitals provide advanced and specialized treatment. Furthermore, in terms of the ownership of medical institutions, there are 28 classifications in the Japanese official statistics, based on the founder of hospitals, such as some national government organizations, local municipalities, medical corporations and so on. We re-classify them as either public or private based on ownership information.[2] Notice that, despite such variation in medical institutions' ownership, the insureds must pay the same fees for the same medical treatment in Japan, regardless of their medical institution choices.

[2]We classify medical institutions as public if they are owned by the Japanese government, local municipalities, or any public institutions. Otherwise, we classify them as private.

The MRI Scanning Market MRI is one of the medical imaging techniques that enables the scanning of body tissues. In particular, it is a useful tool for identifying diseases in the brain, other organs and soft tissues and it is used mainly in neurosurgery, neurology, and orthopedics.[3] Thus, the average patient whose co-payment is 30% must pay approximately ¥7,000 ($65) for a high tesla MRI scanning service and ¥5,800 ($ 54 USD) for a low-tesla MRI scanning service.[4] This feature may change physicians' incentive of physician-induced demand and thus we discuss it thoroughly in Section 4.2.

Lastly, neither regulations nor subsidies are affecting medical institutions' MRI adoption. According to Ho, Ku-Goto and Jollis (2009), the United States is in a similar situation where there is no effective regulation on MRI adoption. On the other hand, many European countries, including France and Germany, have regional restrictions to discourage excessive adoption of expensive medical equipment see (see König, 1998, for details of the regulations).

2.2 Data

2.2.1 Overview

We use the administrative data on Japanese medical institutions, called *Static Survey of Medical Institutions*. The Japanese Ministry of Health, Labor and Welfare conducts this survey every three years. In the data, we observe basic information on medical institutions, such as address, establishing organization (ownership), number of beds, clinical specialty, and numbers of outpatients, inpatients, and doctors for each clinical special-

[3] MRI scanners use magnetic fields and radio waves and thus, naturally, one of the most important characteristics of an MRI is the field strength of its magnet, which is measured in tesla. Although there are some exceptions, a higher-tesla machine is basically better than one with lower tesla, because a higher-tesla machine allows doctors to take higher-quality images in less time. Although the most popular MRI is a 1.5-tesla machine, the field strength varies by machine, typically ranging from 0.2 to 3 tesla. In the MRI treatment market, the regulated reimbursement price depends on the MRI's tesla. If an MRI's magnetic strength is 1.5 tesla or higher, medical institutions typically receive about ¥23,400 for each treatment. Otherwise, the reimbursement price is ¥19,200. Here, the reimbursement prices are imputed in the following way: First, if the MRI field strength is less than 1.5 tesla, the sum of the fee for undergoing an MRI scan and the standard consultation fee is ¥19,200. For a high-tesla MRI, the fees typically include more components and it is not clear how to calculate the average reimbursement price. Thus, we calibrate these high-tesla fees by matching the average reimbursement prices to those reported in Imai, Ogawa, Tamura and Imamura (2012).

[4] 1 U.S. dollar = ¥108.3 as of February 2, 2020.

ity, as well as MRI ownership and usage, for all medical institutions in Japan.[5] Our sample period is from 2005 through 2014, and Table 1 describes summary statistics for the variables employed in this paper. We can see that of the 9,223 hospitals in 2005, 3,004 own at least one MRI scanner, whereas of the 8,632 hospitals in 2014, 3,033 own at least one MRI scanner. The data also identify the number of inpatients and outpatients for each medical department, separately. Throughout this paper, we focus on patients in the neurosurgery, neurology and orthopedics department, unless otherwise noted. The second and third row show the average number of patients, the sum of inpatients and outpatients, that each private and public hospital admit. In our sample, public hospitals tend to attract more patients. Note that private hospitals own about two-thirds of the MRI scanners. The aggregate number of MRI scanners is stable over time. However, at the hospital level, adoption and abandonment happened frequently. The seventh row shows the fraction of hospitals that experienced any change in the number of MRI scanners among hospitals that owned MRI scanners in the survey year or the previous survey year. We find that about 25% of the hospitals newly adopt or abandon MRI scanners between each survey year.

The lower panel of Table 1 shows the utilization of MRI scanners. The utilization rate of MRI scanners is well documented to be low in Japan. In fact, suppose a hospital operates 22 days per month, 8 hours a day and one MRI scan takes 30 minutes to complete. Then, the maximum number of MRI scans per month (physical capacity) would be 352. Table 1 shows that the median utilization rate of an MRI scanner is slightly less than 50%.

Furthermore, using address information, we calculate distance among hospitals—in particular, distance among hospitals that own MRI scanners. Table 2 shows the average number of MRI scanners within 1 kilometer from each hospital that is equipped with MRI scanners. In Panel (A), we look at all hospitals that are equipped with MRI scanners and count the number of MRI scanners within 1km except their own scanners. We also show the breakdowns for the number of MRI scanners owned by public and private hospitals, separately. In Panels (B1) and (B2), we also compute the same statistics from

[5] The survey is conducted in September, and the units for the numbers of outpatients, inpatients, and so on are person per month.

Table 1: Descriptive Statistics

	2005	2008	2011	2014
Number of hospitals	9,223	9,047	8,814	8,632
Average number of patients				
at private hospitals	2,174	2,002	1,941	1,890
at public hospitals	2,854	2,514	2,413	2,354
Number of hospitals equipped with MRIs	3,004	2,990	3,124	3,033
Number of private hospitals equipped with MRIs	1,897	1,896	2,036	1,995
Number of public hospitals equipped with MRIs	1,107	1,094	1,088	1,038
Fraction of hospitals adopting or abandoning MRIs	0.26	0.26	0.24	0.24
Number of MRI scans (per MRI scanner)				
Mean	189	198	195	193
25%	86	89	81	78
50%	169	175	176	170
75%	270	283	283	280

Note: This table provides summary statistics of the data on hospitals and MRI scanners for each sample year. The first seven rows in the upper panel show the number of hospitals, average number of patients visiting private hospitals, average number of patients visiting public hospitals, number of hospitals that own an MRI scanner, number of private hospitals that own an MRI scanner, number of public hospitals that own an MRI scanner, fraction of hospitals that change the number of MRI scanners they own between the current sample year and the previous sample year, respectively. The lower panel of the table shows the mean and the quartiles of the number of MRI scans per MRI among the hospitals in the data.

the viewpoints of private and public hospitals equipped with at least one MRI scanner, respectively. In all panels, the standard deviations are reported in the parentheses.

Table 2 shows the difference in the MRI purchase patterns between private hospitals and public hospitals. First, the number of MRI scanners within 1 kilometer from a public hospital is smaller than that from a private hospital. We can see this distinction by comparing the numbers in the first rows of Panels (B1) and (B2). This difference implies that public hospitals purchase MRI scanners in regions where MRI scanners are sparse. For example, in 2005, a private hospital has 0.76 MRIs owned by other hospitals within 1 kilometer whereas a public hospital has only 0.50, on average. Furthermore, the ratios of the third row to the second row of Panels (B1) and (B2) tell us that the entry decision of public hospitals differs from that of private hospitals. For instance, in Panel (B1) of 2005, the number of MRI scanners owned by public hospitals within 1 kilometer from public hospitals equipped with MRI scanners is about one-third $\left(\frac{0.13}{0.37}\right)$ of the number of MRI scanners owned by private hospitals whereas the rate is about one-half $\left(\frac{0.24}{0.52}\right)$ when we focus on the Panel (B2). This observation implies that public hospitals tend to purchase MRI scanners in the area with a smaller number of MRI scanners—in particular

Table 2: The Number of MRIs within 1 Kilometer (by Wwnership)

	2005	2008	2011	2014
Panel (A): From hospitals equipped with MRI scanners				
Number of MRI scanners within 1km	0.66	0.63	0.69	0.60
	(1.29)	(1.35)	(1.44)	(1.18)
...owned by private hospitals	0.46	0.43	0.48	0.44
	(0.99)	(0.96)	(1.07)	(0.97)
...owned by public hospitals	0.20	0.20	0.21	0.17
	(0.61)	(0.71)	(0.72)	(0.54)
Panel (B1): From private hospitals equipped with MRI scanners				
Number of MRI scanners within 1km	0.76	0.74	0.80	0.69
	(1.40)	(1.48)	(1.59)	(1.27)
...owned by private hospitals	0.52	0.48	0.56	0.50
	(1.04)	(1.01)	(1.15)	(1.03)
...owned by public hospitals	0.24	0.25	0.25	0.19
	(0.67)	(0.80)	(0.79)	(0.58)
Panel (B2): From public hospitals equipped with MRI scanners				
Number of MRI scanners within 1km	0.50	0.44	0.49	0.43
	(1.08)	(1.06)	(1.09)	(0.98)
...owned by private hospitals	0.37	0.33	0.36	0.31
	(0.90)	(0.86)	(0.89)	(0.85)
...owned by public hospitals	0.13	0.11	0.14	0.12
	(0.47)	(0.50)	(0.54)	(0.45)

Note: This table provides summary statistics of the number of surrounding MRI scanners from each hospital. Panel (A) shows the average number of MRI scanners and its standard deviation (in parentheses) from each hospital that owns an MRI scanner. Panels (B1) and (B2) show the same statistics from each private hospital and public hospital, respectively. In each panel, the first row shows the total number of MRI scanners within 1 kilometer distance. The second and third rows show the number of MRI scanners within 1 kilometer distance owned by private hospitals and public hospitals, respectively.

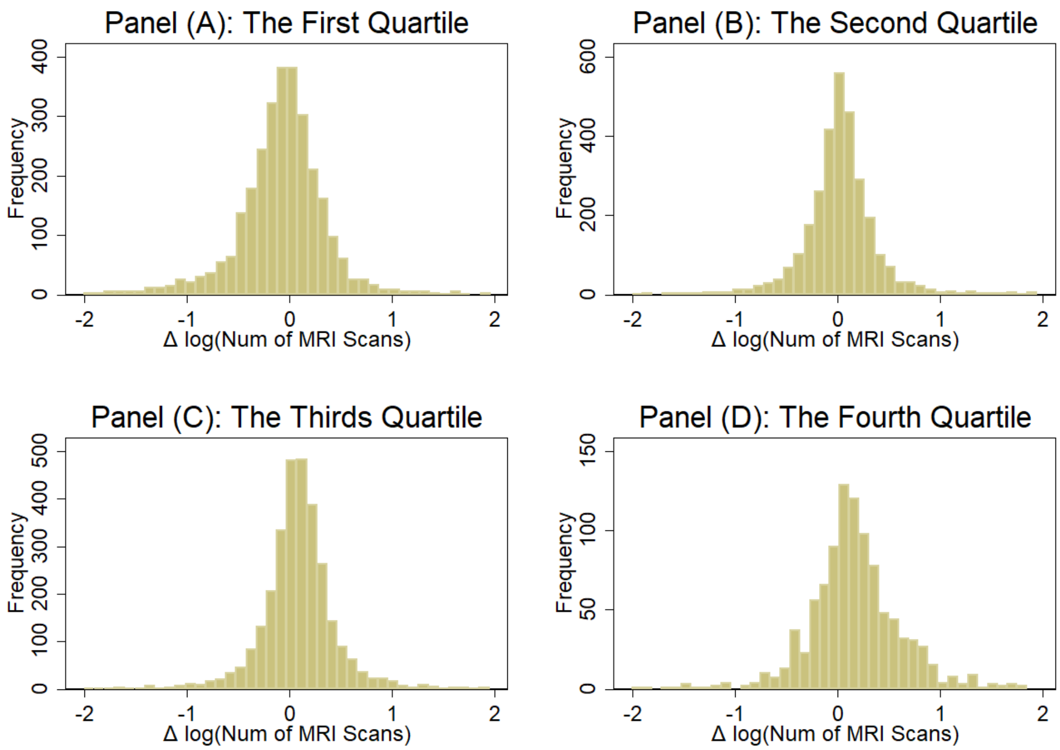
MRI scanners owned by public hospitals.

2.2.2 Motivating Observations

To motivate our empirical analysis, we provide two pieces of evidence in this subsection for why we suspect new purchases of MRI scanners by nearby hospitals may further induce physician-induced demand. Unfortunately, as discussed in the literature, identifying the *total* physician-induced demand is difficult because, given a set of patients, we do not know what the appropriate number of MRI scans would be and thus cannot determine how excessive the number of MRI scans taken in the observed data. However, we may still be able to determine whether physicians engage in physician-induced demand by looking at the *changes* in the environment that are unrelated to the patients' conditions. If physicians change the number of MRI scans in response to such changes in the environment, it implies that physicians take MRI scans not to suit patient's interest but to suit their own, which allows us to quantify the induced demand. We, therefore, focus on how physicians change their decisions on taking MRI scans. In the remainder of this section, we show descriptive evidence on how the MRI usage and conversion rate—defined as the percentage of patients that result in taking MRI scans—change when nearby hospitals purchase new MRI scanners. If the severity distribution of patients does not change before and after nearby hospitals purchase new MRI scanners, the increase in the conversion rate after the nearby introduction of MRI scanners supports our hypothesis of induced physician-induced demand. Subsection 4.1 thoroughly examines the assumption that the distribution of severity does not change .

Observation 1: Small pass-through from the number of patients to the number of MRI scans When a hospital faces a decreased number of patients compared with the previous period, does it proportionally take less MRI scans? To answer this question, we examine the relationship between the changes in the number of patients and the number of MRI scans. Here, we restrict the sample to hospitals that did not adopt or abandon MRI scanners between $t-1$ and t. We first compute the distribution of the change in the number of patients at each hospital, and then, using the quartile of this distribution, we classify the hospitals into Groups A, B, C, and D. Note that the quartiles of the distribution of the change in the logarithm of number of patients are negative 0.16, negative 0.03 and 0.09, implying that the hospitals in Group A experience a sharp decrease in the number of patients, whereas the hospitals in Group D experience an increase in the number of patients. Figure 1 shows the distribution of the change in the logarithm of the number of MRI scans in each group. The mean values for Groups A, B, C, and d are negative 0.38, negative 0.09, 0.03 and 0.38, respectively. Despite the large variation in the number of patients, Figure 1 shows that the number of MRI scans is centered around 0 for all groups. In fact, the medians of each group are negative 0.01, 0.04, 0.07 and 0.13, which have much smaller differences than negative 0.38, negative 0.09, 0.03 and 0.38. Those differences show that the extent of pass-through from the change in the number of patients to the

Figure 1: Changes in the Number of MRI Scans



Note: Each panel shows the distribution of the change in the logarithm of the number of MRI scans within each quartile group. The quartile group is defined based on the change in the number of patients at each hospital and Panels (A), (B), (C) and (D) correspond to the first, second, third and fourth quartile group, respectively.

number of MRI scans is small.

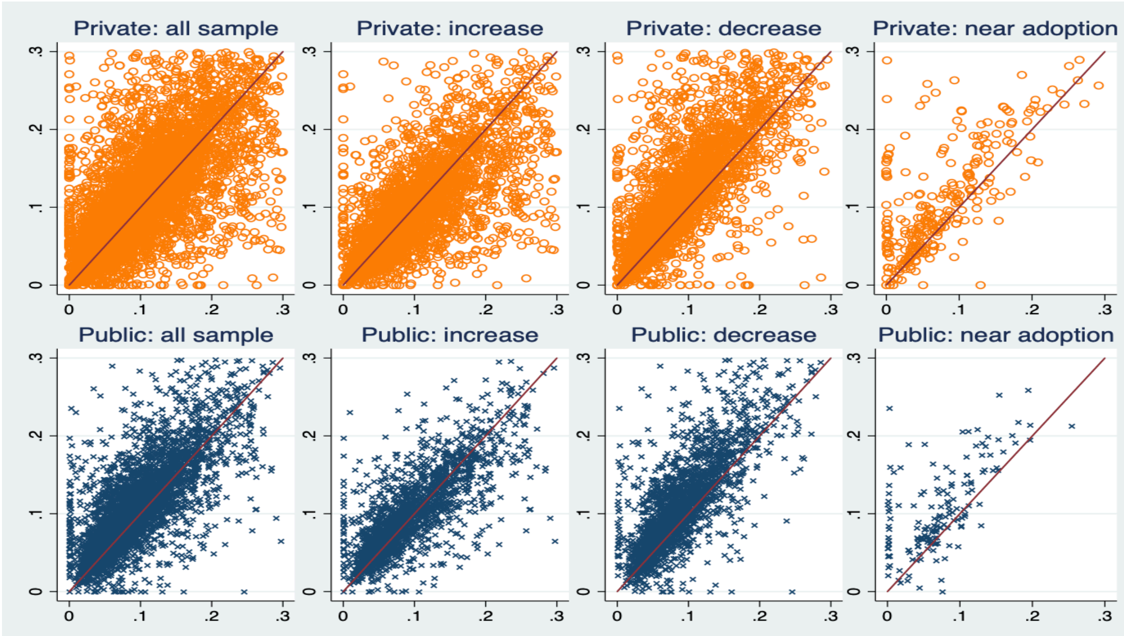
Observation 2: Changes in the conversion rate The first observation suggests that the fraction of patients who receive MRI scans is affected by the number of patients. To examine this possibility, we now see the change in the MRI conversion between time $t-1$ and t in Figure 2. Here, the MRI conversion rate is defined as the fraction of patients who receive MRI scans. If there is no physician-induced demand, i.e., physicians take MRI scans based solely on the patients' condition, this conversion rate would not change unless the distribution of patients' severity changes.

For each of the eight panels in the figure, the horizontal axis shows the conversion rate in the previous period, and the vertical axis shows the conversion rate in the current period. Orange circles in the top four panels represent private hospitals, and navy crosses in the bottom four panels represent public hospitals. The two panels in the first column use all hospitals, whereas the rest use only a subset of the hospitals to draw the scatter plots as data. The panels in the second, third, and fourth columns use the hospitals that face an increasing number of patients, a declining number of patients, and the increase in the number of MRI scanners owned by surrounding hospitals located within 1 kilometer, respectively.

From the panels in the first column, we can see that the conversion rate does not change over time on average, as most of the orange circles and the navy crosses are distributed symmetrically around the 45-degree line. In the next two panels where hospitals face increasing demand, we can again see that the conversion rates do not change over time. However, in the next two panels where hospitals face decreasing demand, we can see that many hospitals are above the 45-degree line, implying that they take more MRI scans per patient. Of course, one cannot interpret this observation solely as evidence of physician-induced demand, because we do not know why demand has decreased for these hospitals. So, we further plot the same graph for hospitals where at least one surrounding hospital located within 1 kilometer purchases MRI scanners. Now we can clearly see that most hospitals are above the 45-degree line, implying that physicians at these hospitals are likely to take more MRI scans, given the same number of patients. Perhaps these hospitals are likely to lose their patients due to the business-stealing effects, and, to maintain the same level of revenue from MRI scanning, they take MRI scans more than they did before.

Of course, as mentioned earlier, there are several concerns for this graphical evidence. First, we do not control any hospital characteristics, and thus, in our main analysis, we include the hospital fixed effects to purely examine the effects caused by the MRI purchase of surrounding hospitals in Section 3.1. Second, there might be an endogeneity concern for MRI adoption of surrounding hospitals. This concern arises because if an unobserved factor increases the demand for the MRI scanning service in that area, it would affect both (i) the MRI conversion rates, as the number of MRI scans would increase, and (ii) the MRI adoption behavior of surrounding hospitals. Thus, we address such a concern in Section 3.1.3. Third, the severity distribution of patients could be dif-

Figure 2: Changes in MRI Conversion Rates



Note: Each scatter plot shows the MRI conversion rate where the x-axis and y-axis shows the MRI conversion rate at $t-1$ and t, respectively. Each dot represents a hospital. The scatter plots in the first and second rows show the conversion rate of private hospitals and public hospitals, respectively. The scatter plots in the first, second, third, and fourth columns show the conversion rate of all hospitals, hospitals facing an increasing number of patients between period $t-1$ and t, hospitals facing a decreasing number of patients between period $t-1$ and t, and hospitals facing new MRI adoption by surrounding hospitals.

ferent when surrounding hospitals purchase MRI scanners, because some patients who have a serious illness might tend to remain in the same hospital (as the early MRI adopter could be a good hospital), and thus, the MRI conversion rate could increase. To address such concern, we conduct various robustness checks in Section 4.1.

3 Empirical Strategy and Results

The objective of this section is twofold. First, we show that a phenomenon that we call *induced physician-induced demand* in Section 3.1. Although there are many potential identification sources for physician-induced demand, such as changes in the reimbursement system and information structure, this paper proposes the externalities from nearby hospitals as a primary source of identification for physician-induced demand. More specifically, we focus on business-stealing effects: A hospital may lose its patients when nearby hospitals introduce MRI scanners and, as a response to the declined demand, the hospital may take more MRI scans per patient, even unnecessarily. We also address the endogeneity concern for the purchases of MRI scanners by surrounding hospitals.

Second, we quantify the physician-induced demand in a more general context as a phenomenon that physicians over-treat in response to a reduction in demand. When thoroughly examining our induced physician-induced demand hypothesis, we find that public hospitals' MRI purchase decision would be suitable for an instrument. We use this instrument and attempt to identify more broadly defined physician-induced demand in Section 3.2.

3.1 Testing Induced Physician-Induced Demand Hypothesis

3.1.1 Business-Stealing Effects

Throughout this paper, subscripts h and t denote the indices of each individual hospital and period, respectively. Let $M_{h,t}$ and $M_{-h,t}$ denote the number of MRI scanners owned by hospital h and by surrounding hospitals, respectively.[6] Also, let $N_{h,t}$ denote the number of patients at the relevant medical departments, which we explain in Section 2, in hospital h at period t.

To examine the business-stealing effects of MRI purchases by surrounding hospitals, we use the following model:

$$\Delta \log \left(N_{h,t}\right) = \delta \Delta \log \left(M_{-h,t} + 1\right) + \text{controls} + \epsilon_{h,t}, \tag{1}$$

where ΔX_t denotes the first difference of X_t (i.e., $X_t - X_{t-1}$), and $\epsilon_{h,t}$ is an error term. As for control variables, we include year fixed effects, the change in the number of hospital beds, the number of MRIs that hospital h owns at $t-1$, the number of patients at the relevant medical department at $t-1$, and the number of MRI scans taken at hospital h at $t-1$.[7] We are interested in the coefficient for $\Delta \log \left(M_{-h,t} + 1\right)$, namely δ. A negative

[6] Here, the hospitals of surrounding hospital h are defined as the hospitals within 1 kilometer radius from hospital h.

[7] As we take first difference of the variables, we do not include hospital fixed effects, because hospital fixed effects are differenced out. This specification is more general than estimating a fixed-effect model

value of δ implies that more MRI scanners at surrounding hospitals negatively affect the patients from hospital h—i.e., there indeed is a business-stealing effect. Note that we add one to $M_{-h,t}$ when taking logarithm to avoid log(0) when constructing the variable.

In addition to this baseline specification, we adopt another specification where we allow for a heterogeneous business-stealing effect. As it is natural to assume that the MRI adoption incentives differ between private hospitals and public hospitals, the resulting business-stealing effects may differ. Private hospitals may be closer to profit-maximizing entities and, thus, their adoption decision may better reflect local demand for MRI scanning or they may have higher incentive to steal patients from nearby hospitals, which results in a lower or higher business-stealing effect compared with the adoption of MRI at public hospitals. Also, the MRI adoption decisions of public hospitals may be less sensitive to local demand, as they may care less about the profitability of MRI, which may result in a higher business-stealing effect. Depending on what effect exists/is dominant, we would expect a heterogeneous effect of the business-stealing effect determined by the owner of the MRI scanners. To capture this heterogeneity, let $M_{-h,t}^{Pub}$ and $M_{-h,t}^{Pri}$ denote the numbers of MRI scanners purchased by surrounding public hospitals and by surrounding private hospitals, respectively. And, we estimate the following equation:

$$\Delta \log\left(N_{h,t}\right) = \delta_{pub}\Delta \log\left(M_{-h,t}^{Pub}+1\right)+\delta_{pri}\Delta \log\left(M_{-h,t}^{Pri}+1\right)+\text{controls}+\epsilon_{h,t}. \qquad (2)$$

Note that we include the first difference of the number of beds to control for change in hospital size, and inclusion of this variable may create a simultaneity issue. To address this concern, we run both ordinary least squares (OLS) regression and IV regression with the lagged value of the number of total outpatients, inpatients, and hospital beds as the instrument for the first difference of hospital beds.

Table 3 depicts the results. The first four columns present OLS estimation results, whereas the last four columns present IV estimation results. In the regression, we use only the hospitals that owned MRI scanners both at period $t-1$ and t. As we expect that public and private hospitals are affected by MRI adoption of surrounding hospitals

on the level of the variables, as it allows for time-specific growth rate of the number of patients.

differently and the substitution between public and private hospitals is different. The first and fifth columns show the baseline specification corresponding to Equation (1) by using all hospitals that own MRI scanners, whereas the rest of the columns correspond to Equation (2). we estimate the business-stealing effect *to* public and private hospitals separately. The second and sixth columns show the results using observation only when h is a private hospital, the third and seventh columns show the results using observation only when h is a public hospital, and the fourth and eighth columns show the results using all hospitals, respectively.

Table 3: Business-Stealing Effects

Dependent Var: $\Delta \log(N_{h,t})$	(i) OLS All	(ii) OLS Private	(iii) OLS Public	(iv) OLS All	(v) IV All	(vi) IV Private	(vii) IV Public	(viii) IV All
$\Delta \log(M_{-h,t} - 1)$	-.031*				-.035*			
	(.018)				(.018)			
$\Delta \log(M^{Pub}_{-h,t} + 1)$		-.067*	-.055	-.062**		-.065*	-.053	-.060**
		(.036)	(.040)	(.027)		(.036)	(.043)	(.027)
$\Delta \log(M^{Pri}_{-h,t} + 1)$		-.000	.001	.000		-.007	-.016	-.006
		(.032)	(.028)	(.024)		(.034)	(.031)	(.025)
$\Delta Beds_{h,t}$	.001***	.002***	.001***	.001***	-.000	-.001	-.002**	-.000
	(.000)	(.001)	(.000)	(.000)	(.001)	(.001)	(.001)	(.001)
Fixed Effects								
Time	√	√	√	√	√	√	√	√
N	7,375	4,668	2,707	7,375	7,375	4,668	2,707	7,375
R^2	.075	.064	.110	.075	.069	.055	.071	.069

Note: Standard errors in parentheses and significance levels are denoted by <0.1 (*), <0.05 (**), and <0.01 (***). All specifications include the number of MRI scanners hospital h owns at $t-1$, the number of patients at the relevant medical department at $t-1$, the number of MRI scans taken at hospital h at $t-1$, and a constant term, as control variables.

First, the estimation results corresponding to Equation (1) show the negative and statistically significant effect of $\log\left(M_{-h,t} + 1\right)$, suggesting that there exist business-stealing effects. By comparing these results with the results corresponding to Equation (2), we can see that the business-stealing effects results from MRI scanner adoption of public hospitals. Though estimated coefficients for specification Equation (2) have similar magnitude, the levels of significance are different. This difference may be due to the number of observations used in the estimation. It is natural to expect the statistics to have the highest power when more observation is used. In fact, the level of significance gets higher as the number of observations increases. Therefore, we believe that the results presented in the fourth and eighth columns are the most reliable.[8] The coefficient on the number of hospital beds is positive and statistically significant in the OLS specification but negative or statistically insignificant in the IV specification, which suggests that the size of the hospital is correlated with the number of patients in the relevant medical department but does not have any causal effect.

In terms of the economic significance, when the number of nearby public hospitals with MRI scanners increases from zero to one, the number of patients at the relevant medical department decreases by 4.2% ($\delta_{pub} \times (\log(2) - \log(1)) = 0.042$), which is a significant loss for hospitals. In the next subsection, we further examine how hospitals react to such a loss in patients.

3.1.2 Induced Physician-Induced Demand

Given our finding in the previous section—there do exist business-stealing effects from public hospitals' MRI scanner purchases— now we are interested in how these business-stealing effects are translated into the changes in the use of MRI scanners. Do the hospitals facing fewer patients due to the business-stealing effects take more MRI scans than they did before to compensate for their foregone revenue? To study this question, we define a new variable, the *MRI conversion rate*. Let $S_{h,t}$ denote the number of MRI scans taken in hospital h at time t, and the MRI conversion rate is defined as the fraction of patients that receive MRI scans—i.e.,

$$CR_{h,t}^{MRI} = \frac{S_{h,t}}{N_{h,t}}.$$

The conversion rate is meant to capture physician-induced demand. Suppose the physicians take MRI scans based solely on the severity of the condition of patients, then the conversion rate should be constant regardless of other factors as long as the distribution

[8] One may worry that the business-stealing effect *to* public hospitals and *to* private hospitals are different. By comparing the results in the second and third, or sixth and seventh, one may conclude that the former does not exist while the latter exists. We also performed a formal test using all observation but we could not reject the null hypothesis that the effect *to* public hospitals and the effect *to* private hospitals are the same.

of the severity remains the same. Therefore, we can test whether the business-stealing effect induces PID by estimating the following two specifications:

$$\Delta CR^{MRI}_{h,t} = \beta_{pub}\Delta\log\left(M^{Pub}_{-h,t}+1\right)+\beta_{pri}\Delta\log\left(M^{Pri}_{-h,t}+1\right)+\text{controls}+\epsilon_{h,t}, \tag{3}$$

and

$$\begin{aligned}\Delta CR^{MRI}_{h,t} \quad = \quad & \beta_{pub}\Delta\log\left(M^{Pub}_{-h,t}+1\right)+\beta_{pri}\Delta\log\left(M^{Pri}_{-h,t}+1\right)\\ & +\gamma_{pub}\Delta\log\left(M^{Pub}_{h,t}+1\right)\times P_h+\gamma_{pri}\Delta\log\left(M^{Pri}_{h,t}+1\right)\times P_h\\ & +\text{controls}+\epsilon_{h,t},\end{aligned} \tag{4}$$

where P_h is an indicator variable, taking a value of one if hospital h is a public hospital and of zero otherwise, and controls include P_h, the lagged values, values at $t-1$, of the number of hospital beds, MRI scans, patients in the relevant medical department, and MRI scanners owned by hospital h. The sign of βs and γs allow us to test the existence of the induced physician-induced demand. When estimating Equation (3), we separately run the regression using observation of private hospitals, public hospitals, and all hospitals, whereas we use all observations when estimating Equation (4). When we estimate the model, we restrict our sample to hospitals that owned and used MRI scanners in both period $t-1$ and t. Furthermore, because the construction of CR^{MRI}_{ht} involves division, the variable contains extreme values. To avoid the results to be driven by those outliers, we drop 5% of the tail observations. Table 4 depicts the estimation results.

The first three columns of Table 4 show the results corresponding to Equation (3) and present the results using observation when h is a private hospital, observation when h is a public hospital, and all observation, respectively. As in the results in Table 3, all three columns show similar qualitative results with different significance levels. The results in those three columns clearly indicate that the adoption of MRI scanners at pubic hospitals has a statistically significant effect. However, it is hard to conclude whether private hospitals and public hospitals are affected differently. To examine this issue, we estimate the model corresponding to Equation (4). The fourth column presents the result. The

Table 4: Induced Physician-Induced Demand

Dependent Var: $\Delta CR_{h,t}^{MRI}$	(i) Private	(ii) Public	(iii) All	(iv) All
$\Delta \log(M_{-h,t}^{Pub})$	.011***	.006	.009***	.011***
	(.003)	(.005)	(.003)	(.003)
$\Delta \log(M_{-h,t}^{Pri})$	-.005*	-.000	-.003	-.004
	(.003)	(.004)	(.002)	(.003)
Public $\times \Delta \log(M_{-h,t}^{Pub})$				-.004
				(.006)
Public $\times \Delta \log(M_{-h,t}^{Pri})$				.003
				(.005)
Fixed Effect				
Time	√	√	√	√
N	3,960	2,562	6,522	6,522
R^2	.022	.048	.032	.032

Note: Standard errors in parentheses and significance levels are denoted by <0.1 (*), <0.05 (**), and <0.01 (***). All specifications include an indicator for public hospitals, the number of hospital beds at $t-1$, MRI scans at $t-1$, patients in the relevant medical department at $t-1$, and MRI scanners owned by hospital h at $t-1$ and a constant term, as control variables.

coefficient on $\Delta M_{-h,t}^{Pub}$ is still estimated as positive and statistically significant at 5% level, and we cannot reject the hypothesis that the effect is the same to private hospitals and to public hospitals.

The estimated value of β_{pub} suggests that the conversion rate increases 0.8% when the number of nearby public hospitals increases from zero to one ($\beta_{pub} \times (\log(2) - \log(1)) = 0.0076$). The average conversion rate conditional on having MRI scanners is 14.6%. Therefore, 0.8% increase in conversion rate can be interpreted as 5.2% increase from the average conversion rate (0.8%/14.6%). Together with the finding in Section 3.1.1, the estimated coefficients suggest that hospitals keep the number of MRI scans constant regardless of the number of patients visiting the hospitals—i.e., MRI adoption by nearby public hospitals reduces the number of patients but hospitals increase the conversion rate so that the number of MRI scans remains the same. This observation is consistent with anecdotes from interviews with physicians indicating an implicit quota imposed by hospital managers for the number of MRI scans.

3.1.3 Addressing an Endogeneity Concern

Our results presented in the previous sections may potentially suffer from endogeneity of MRI purchases, because MRI purchases could be driven by unobserved changes in the demand for MRI scanning. For example, if a large-scale nursing home were built in one area, the elderly population would increase as would the demand for MRI scanning service. Expecting such an increase in demand, hospitals might purchase MRI scanners and, at the same time, the conversion rate might increase without any physicians' opportunistic behavior.

Such a mechanism would lead to an overestimation of induced physician-induced demand. In particular, the estimated business-stealing effect in Table 3 and the estimated PID in Table 4 may be upward biased, which may explain why new MRI purchases of private hospitals do not create a business-stealing effect. Private hospitals may care more about the profitability of MRI purchases and take the local demand growth into their purchase decision more than public hospitals do. However, even with such possible upward biases, we do find a business-stealing effect for new MRI purchases of public hospitals. The MRI purchase decision of public hospitals may not be correlated with the local demand growth for a variety of reasons—e.g., local government may constraint the budget of public hospitals, public hospitals may have a more rigid decision process than private hospitals, the bureaucratic management structure at public hospitals means it may take longer to reach a decision, public hospitals are less sensitive to the profitability of a new purchase, etc.

Our estimation result in Table 3—the public hospitals steal patients from surrounding hospitals—is consistent with this possibility that public hospitals do not respond to the change in demand immediately when purchasing MRI scanners, which ends up with stealing patients from hospitals that enter the market beforehand. If the MRI purchase decision of public hospitals is not correlated with the change in unobserved local demand, at least, the results for the coefficients on the effect of public hospitals' MRI purchases in Table 3 and Table 4 are consistent.

To examine the validity of our results, we investigate the MRI adoption decision of private and public hospitals. Let $D_{h,t}$ denote an indicator that takes a value of one if the difference of the number of MRI scanners owned by hospital h increases at period t—i.e., $D_{h,t} = 1$ implies new MRI adoption, takes a value of negative one if the difference of the number of MRI scanners owned by hospital h decreases at period t, and takes a value of zero if there is no change in the number of MRI scanners. We adopt the following empirical specification, and we estimate an ordered logit model with hospital random effects. Formally, a latent variable $D^*_{h,t}$ is specified as

$$D^*_{h,t} = \zeta_1 \log(N_{h,t-1}) + \zeta_2 M_{h,t-1} + \zeta_3 \log(N_{-h,t-1}) + \text{controls} + \mu_h + \epsilon_{h,t}, \tag{5}$$

where $N_{-h,t-1}$ denotes the number of patients at the surrounding hospitals of h at the relevant medical departments, μ_h denotes hospital random effects, and controls include $\Delta \log\left(M^{Pri}_{h,t-1} + 1\right)$, $\Delta \log\left(M^{Pub}_{h,t-1} + 1\right)$, the lagged value of the number of hospital beds, the lagged value of total outpatients and inpatients at all medical departments, and the time-fixed effects. $D_{h,t}$ takes a value of either -1, 0, or 1, depending on the value of $D^*_{h,t}$ as

$$D_{h,t} = \begin{cases} -1, & \text{if } D^*_{h,t} \leq \underline{c}, \\ 0, & \text{if } \underline{c} < D^*_{h,t} < \bar{c}, \\ 1, & \text{if } D^*_{h,t} \geq \bar{c}. \end{cases}$$

The purpose of this specification is to infer the MRI purchase decision of private and public hospitals to see whether an endogeneity issue exists. Our primary focus is to determine whether ζ_3 is estimated as significantly different from zero for pubic hospitals. If so, it rejects the hypothesis that public hospitals' MRI purchase decision is not correlated to unobserved changes in demand in nearby hospitals, which violates the validity of our argument in previous sections.

Table 5 summarizes the results. The first and third columns show the results with observation only when h is a private hospital, whereas the second and the fourth columns show the results with observation only when h is a public hospital. ζ_3, the coefficient on $\log(N_{-h,t-1})$, is estimated not to be significantly different from zero for both private and public hospitals, which supports our argument in previous sections. Furthermore, the

Table 5: MRI Purchase Decisions

	(i) Private	(ii) Public	(iii) Private	(iv) Public
$\log(N_{h,t-1})$	0.32***	0.04	0.29***	0.06
	(0.04)	(0.10)	(0.05)	(0.11)
$M_{h,t-1}$	-2.18***	-2.23***	-2.14***	-2.00***
	(0.11)	(0.17)	(0.13)	(0.19)
$\log(N_{-h,t-1})$	-0.00	-0.08	0.03	-0.03
	(0.03)	(0.05)	(0.04)	(0.06)
$\Delta \log\left(M^{Pri}_{h,t-1}+1\right)$			-0.06	-0.29
			(0.32)	(0.44)
$\Delta \log\left(M^{Pub}_{h,t-1}+1\right)$			-0.01	-0.01
			(0.23)	(0.35)
Fixed Effect				
Year	√	√	√	√
N	5,086	1,624	3,426	1,069

Note: Standard errors in parentheses and significance levels are denoted by <0.1 (*), <0.05 (**), and <0.01 (***). All specifications include the number of hospital beds at $t-1$, total inpatients and outpatients at all medical departments at $t-1$, time fixed effects and a constant term, as control variables.

coefficient on ζ_1, the number of patients in their own hospital, is estimated positive and statistically significant for private hospitals but not significantly different from zero for public hospitals. This observation further suggests that even local demand at their own hospitals does not affect the MRI purchase decisions of public hospitals, consistent with our expectation that the MRI purchase decisions of public hospitals are constrained by non-economic reasons.

3.2 Generalized Physician-Induced Demand

In the previous sections, we quantify physician-induced demand caused by the MRI purchases of surrounding hospitals, which we defined as *induced physician-induced demand*. In the literature, physician-induced demand is more broadly defined as physicians' change in behavior in response to the change in demand—changes in the number of patients. From the previous analysis, we now believe that MRI purchases by surrounding public hospitals can be used as an instrumental variable to the number of patients attending each hospital, because it satisfies exclusion restriction and relevance: Public hospitals do not respond to the potential demand immediately when they purchase MRI scanners and the number of patients would decrease because of the business-stealing effects. Taking advantage of this finding, we attempt to identify this more broadly defined physician-induced demand in this section.

To quantify this physician-induced demand, we adopt the following two stage least squared (2SLS) specification:

$$\Delta CR_{h,t} = \gamma_1 \Delta \log\left(N_{h,t}\right) + \gamma_2 \log(S_{h,t-1}) + \gamma_3 \log(N_{h,t-1}) + \text{controls} + \epsilon_{h,t}, \tag{6}$$

where $\Delta \log\left(N_{h,t}\right)$ is the endogenous variable and controls include $M_{h,t}$, the lagged number of hospital beds, the lagged number of outpatients and inpatients at all medical departments, and time fixed effects. The first-stage regression for $\Delta \log\left(N_{h,t}\right)$ is specified as

$$\Delta \log\left(N_{h,t}\right) = \delta_1 \Delta M_{-h,t}^{Pub} + \text{controls}^{iv} + \varepsilon_{h,t},$$

where controls^{iv} include all control variables in Equation (6).

If γ_1 is negative, then the hospitals increase the conversion rate in response to an exogenous increase in the number of patients, which is an evidence of PID. As we discussed earlier, when physicians take MRI scans solely depending on the conditions of the patients, the conversion rate should remain constant when there is any exogenous change in the number of patients.[9]

Table 6 demonstrates the results for four different specifications with several different control variables. Regardless of the specifications, γ_1 is negative and statistically significant. The lagged value of the number of MRI scans is negative and statistically significant, which suggests regression toward the mean. The lagged value of the number of patients does not have any significant effect.

[9]This argument relies on the assumption that the severity distribution does not change depending on the number of public hospitals with MRI scanners. We investigate whether this assumption is plausible in Section 4.1 more thoroughly.

Table 6: Physician-Induced Demand

Dependent Var: $\Delta CR_{h,t}$	(i) All	(ii) All	(iii) All	(iv) All
$\Delta \log(N_{h,t})$	-.078**	-.084**	-.088**	-.082**
	(.036)	(.037)	(.038)	(.036)
$\log(S_{h,t-1})$		-.005***	-.010***	-.012***
		(.001)	(.003)	(.002)
$\log(N_{h,t-1})$			.009	.009
			(.006)	(.006)
Hospital-size related controls				√
Fixed effect				
Time	√	√	√	√
N	9,405	9,405	9,405	9,405
R^2	.162	.153	.154	.188

Note: Standard errors in parentheses and significance levels are denoted by <0.1 (*), <0.05 (**), and <0.01 (***). All specifications include an indicator for public hospitals, the number of MRI scanners owned by hospital h at $t-1$ and a constant term, as control variables. "Hospital size related controls" includes the number of hospital beds at $t-1$ and the total number of inpatients and outpatients at all medical departments at $t-1$.

3.3 Implications

In the previous subsections, we qualitatively evaluate these two types of physician-induced demands, in terms of the number of MRI scans. Given the estimation results in Sections 3.1 and 3.2, we are able to quantify the number of MRI scans generated by (induced) physician-induced demand. Then, we compute the total amount of reimbursement paid for the excessive MRI scans. As we explain in Section 2.2, healthcare expenditure of MRI scans ranges from ¥19,200 to ¥23,400 for each MRI scan, depending on the details of the actual treatment, and, thus, we use the average of ¥21,300 in our following calculation as the healthcare expenditure per MRI scan.

Panel (A) of Table 7 quantifies the number of MRI scans caused by induced physician-induced demand and associated healthcare expenditure. In Panel (B), we quantify the number of MRI scans caused by broadly defined physician-induced demand and associated healthcare expenditure. In general, an decrease in the number of patients caused by any mechanism unrelated to patients' condition induces physician-induced demand, as discussed in Section 3.2. To quantify this general effect, we use the estimation results from Table 6, where we find that a 1% decrease in the number of patients increases the conversion rate by 0.082%. Here, we look at hospitals that experienced a reduction in the number of patients and quantify their physician-induced demand caused by the changes in the number of patients.

Table 7: Monetary Value of Physician-Induced Demand

	2008	2011	2014
Panel (A): Induced PID			
Induced scans per month	784	1,119	565
Induced payment per month (in million JPY)	¥16.71	¥23.84	¥12.04
Induced payment per year (in billion JPY)	¥0.20	¥0.29	¥0.14
Panel (B): General PID			
Induced scans per month	45,126	30,415	22,909
Induced payment per month (in million JPY)	¥961	¥648	¥488
Induced payment per year (in billion JPY)	¥11.53	¥7.77	¥5.86

Note: This table provides qualitative evaluation of physician-induced demand. Panel (A) describes the estimated physician-induced MRI scans and resulting healthcare expenditure based on the estimates from Table 4, whereas Panel (B) describes the same statistics based on the estimates from Table 6.

Table 7 summarizes the results. Note that we can quantify physician-induced demand generated only by new MRI purchases in Pane (A) or the changes in the number of patients, meaning that we cannot quantify physician-induced demand that has *already* exited. In this sense, one can regard the reported amount as the lower bound of the total PID that exists in the MRI scanning treatment. Panel (A) of Table 7 casts suspicion that induced physician-induced demand cause about 600 to 1,100 scans. These numbers may not seem to be economically significant, because they account for additional induced demand generated only by new MRI purchases of public hospitals, which does not occur frequently. On the other hand, when we calculate induced demand caused by reduced number of patients, Panel (B) of Table 7 shows that physician-induced demand cause about 30,000 to 45,000 MRI scans, which results in unnecessary additional healthcare spending of about ¥4 to ¥6 billion (Japanese yen). This healthcare spending could have been saved if MRI adoption decisions had been made collectively so that business-stealing effects and resulting physician-induced demand were minimal.

4 Robustness Check

4.1 Severity Sorting

In our previous analysis, we assume that the distribution of the severity of patients' condition would not change if nearby hospitals purchase MRI scanners. However, this assumption might not be true. For example, newly equipped hospitals might lack some reputation, and, thus, patients who exhibit more severe symptoms may remain at incumbent hospitals, some patients who exhibits more severe symptoms may want to visit the hospital that has new MRI scanners, or the MRI adoption decision of hospitals itself may depend on such unobserved changes in the severity distribution. In any case, the severity distribution of patients may not be independent from MRI adoption, which may result in upward or downward bias in our estimation results in Tables 4 and 6.

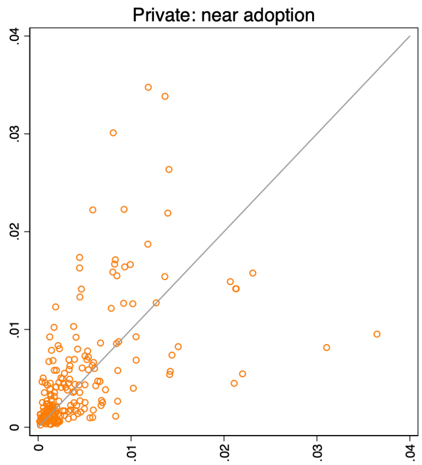
To address these concerns, we first investigate the change in the *surgery conversion rate*, defined as the fraction of the number of all surgeries to the number of patients. This variable can be a proxy for the number of patients with severe symptoms. If patients with severe symptoms tend to remain at the same hospital, the surgery conversion rate would not change after MRI purchases by surrounding hospitals. As one can see from Figure 3, surgery conversion rates do not change for both private and public hospitals, indicating that the severity distribution of attending patients does not change. We also check the robustness by comparing the number of inpatients, because this number can be another proxy for the number of patients with severe symptoms. Figure 4 shows the number of inpatients in $t-1$ and t. As one can see from the figure, they are symmetrically distributed with the 45 degree line, supporting our assumption.

More formally, we estimate a similar model as Equation (3)—i.e.,

$$\Delta y_{h,t} = \beta^{Pub}\Delta \log\left(M_{-h,t}^{Pub}+1\right) + \beta^{Pri}\Delta \log\left(M_{-h,t}^{Pri}+1\right) + \text{controls} + \epsilon_{h,t}, \quad (7)$$

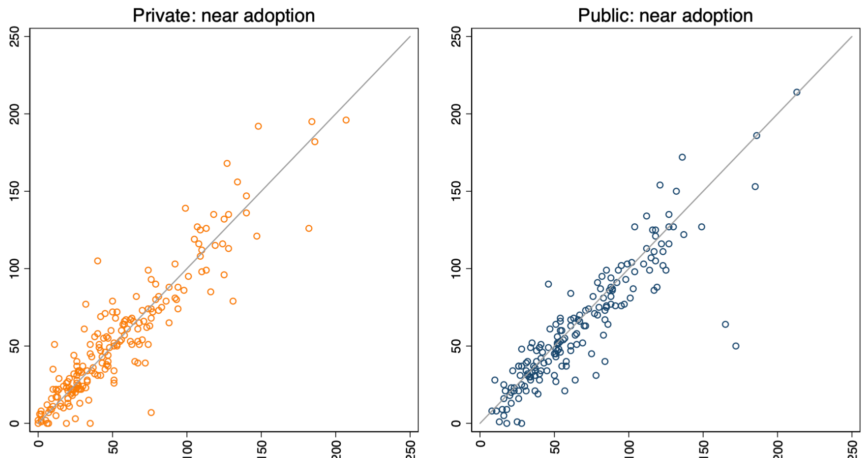
where, as an explained variable, $y_{h,t}$, we use (i) the logarithm of the number of inpatients, (ii) the *computed tomography (CT) conversion rate*, (iii) the *cancer surgery conversion rate*, and (iv) the *all surgery conversion rate*, to check the robustness of our results. Those

Figure 3: Surgery Conversion Rates in $t-1$ and t



Note: Both scatter plots show the surgery conversion rate where the x-axis and y-axis shows the surgery conversion rate at $t-1$ and t, respectively, and each circle represents a hospital. The left panel shows the conversion rate of private hospitals facing new MRI adoption by surrounding hospitals, whereas the right panel shows the conversion rate of public hospitals facing new MRI adoption by surrounding hospitals.

Figure 4: The Number of Inpatients in $t-1$ and t



Note: Both scatter plots show the number of inpatients where the x-axis and y-axis shows the number of inpatients at $t-1$ and t, respectively, and each circle represents a hospital. The left panel shows the number of inpatients at private hospitals facing new MRI adoption by surrounding hospitals, whereas the right panel shows the number at inpatients of public hospitals facing new MRI adoption by surrounding hospitals.

conversion rates are defined analogously as the conversion rate of MRI scans. Table 8 summarizes the estimation results. For all dependent variables, the coefficients on the change in the number of nearby MRI scanners are not significantly different from zero, which strongly supports our assumption that the severity distribution of patients is not correlated with the MRI adoption of nearby hospitals.

Table 8: Severity of Patients' Condition

	(i) log(Inpatients)	(ii) CR^{CT}	(iii) $CR^{CancerSurgery}$	(iv) $CR^{AllSurgery}$
$\Delta \log(M^{Pub}_{-h,t})$	-0.004	.018	.000	.000
	(.013)	(.071)	(.000)	(.000)
$\Delta \log(M^{Pri}_{-h,t})$	-.0015	.049	-.000	-.000
	(.010)	(.065)	(.000)	(.000)
Fixed Effect				
Time	√	√	√	√
N	6,501	6,501	3,965	3,900
R^2	.082	.293	.002	.003

Note: Standard errors in parentheses and significance levels are denoted by <0.1 (*), <0.05 (**), and <0.01 (***). All specifications include an indicator for public hospital, the number of hospital beds at $t-1$, MRI scans at $t-1$, patients in the relevant medical department at $t-1$, and MRI scanners owned by hospital h at $t-1$, and a constant term, as control variables.

4.2 Introduction of Diagnosis Procedure Combination

To prevent over-treatment by doctors, the DPC system has been introduced since 2003 in Japan. Though not many hospitals adopted the DPC system in our sample period initially, the result could be affected, because these hospitals may not have any incentive to engage in creating physician-induced demand. To address this concern, we focus on the number of outpatients, instead of the total number of patients, because the DPC system is applied only to inpatients. We redo the same empirical exercises, replacing the number of total patients with the number of outpatients, and obtain the same results, both qualitatively and quantitatively.

5 Conclusion

We investigate the adoption and usage of MRI scanners, known as one of the typical examples of expensive medical equipment, using panel data on all of the Japanese medical institutions. We find that MRI adoption creates business-stealing effects on nearby hospitals, further inducing physician-induced demand there. In particular, public hospitals do not take into account the local demand for MRI scans when making their MRI purchase decisions. As a result, their MRI purchases cause business-stealing effects and induce physician-induced demand at nearby hospitals. Our results suggest that the decision to adopt expensive medical equipment needs to be made collectively rather than individually to avoid not only excessive adoption but also unnecessary physician-induced demand.

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