The Welfare Consequences of Free Entry in Vertical Relationships: The Case of the MRI Market*

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Abstract

This paper considers policy design in markets with vertical relationships by studying how upstream competition affects downstream entry and social welfare in the context of MRI adoption. We build and estimate a model where MRI manufacturers sell MRIs in the upstream market, whereas medical institutions purchase MRIs to provide medical services to patients in the downstream market. Simulation results suggest that the current free-entry policy in Japan leads to excess MRI adoption. Regulating medical institutions' MRI adoption, taxing MRI purchases, or softening competition among MRI manufacturers would increase social welfare substantially by mitigating the business-stealing effect in the downstream market.

JEL Classification: L51, I11, I18.
Keywords: Vertical relationships, Free entry, MRI industry, Healthcare market.

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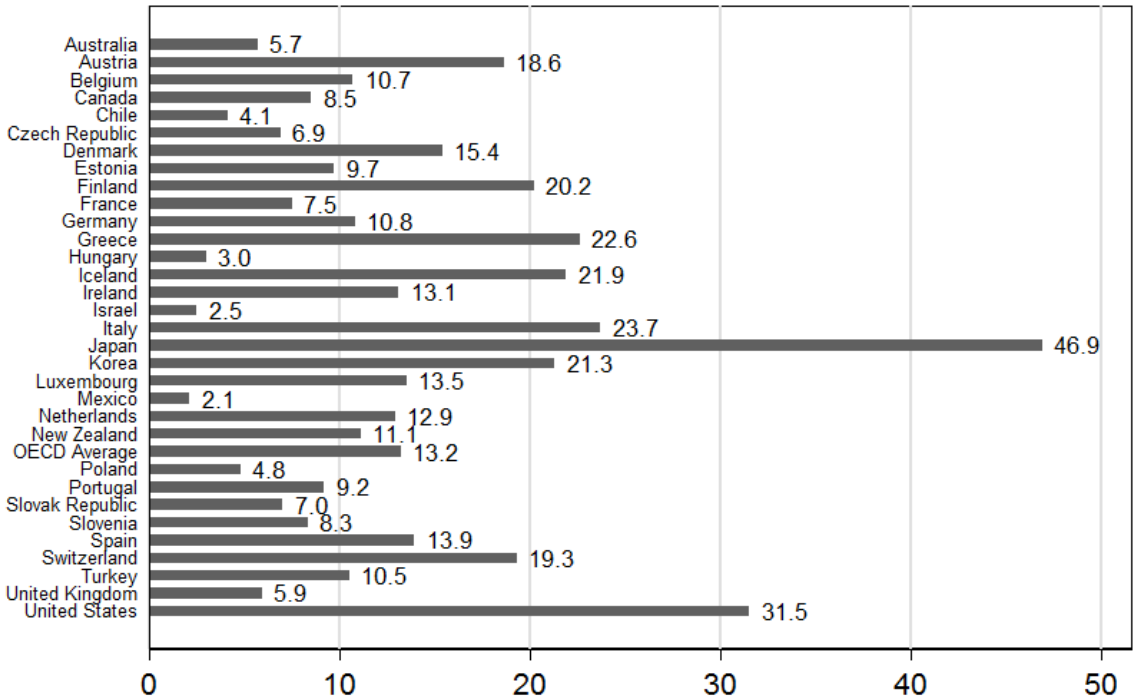
1 Introduction

It is well known that firms' entry incentives are not necessarily aligned with social welfare maximization because firms account for neither the business stealing effect on their competitors nor consumer surplus. Such inefficiencies have been extensively studied both theoretically (e.g., Mankiw and Whinston, 1986; Suzumura and Kiyono, 1987) and empirically (e.g., Berry and Waldfogel, 1999; Ferrari, Verboven and Degryse, 2010). Although these inefficiencies hinge on the cost of entry, little attention has been paid to an important determinant of entry costs: how intermediate products necessary for entry are supplied. Understanding vertical relationships between suppliers of intermediate products and entrants in the final goods market is essential for assessing inefficiencies, because competition in the upstream market influences entry costs and the number of entrants, which ultimately affect social welfare.

A medical arms race, the proliferation of expensive medical technology and devices, is an interesting example involving such vertical relationships. Medical equipment is often supplied in oligopolistic markets and the adoption behavior of medical institutions can be seen as entry. To attract patients, medical institutions adopt new technology as long as the benefit exceeds the cost of adoption, which may result in unnecessary duplication of costly medical devices. Medical arms races have indeed caused significant concern about increasing healthcare expenditures in many countries. This paper examines the production, adoption and utilization of magnetic resonance imaging scanners (hereinafter MRIs) and considers potential policy design in the MRI market, as MRIs are among the most expensive medical devices and MRI adoption is frequently cited as an example of a medical arms race (e.g., Baker, 2010; Sari, 2007; Schmidt-Dengler, 2006).

An international comparison of the number of MRIs per million residents across OECD countries in Figure 1 gives us insight into the relationship between the medical arms race and healthcare regulation. As shown in the figure, the top two countries are Japan and the U.S. Both have far more MRIs per million people than the OECD average which is 13.2, whereas European countries, such as France and Germany, have fewer MRIs per capita than the OECD average. One of the most important distinctions between these two types of countries is the existence of regulation on the adoption of expensive medical devices to mitigate medical arms races. Medical institutions in Japan and the U.S. can decide whether to adopt an MRI based on their own assessments, whereas many European countries regulate MRI adoption. These observations immediately raise questions about whether the medical

Figure 1: The number of MRIs per million residents across OECD countries



arms races in Japan and the U.S. create unnecessary duplication of costly medical devices, and whether regulations in European countries achieve socially efficient allocation of MRIs.

Regulations that are not optimally designed may result in underprovision of MRIs. On the other hand, in the absence of regulation, medical institutions may adopt more than the socially optimal number of MRIs, as theoretically shown in Mankiw and Whinston (1986). They consider a free-entry model with fixed cost of entry and show that there is a tendency toward excessive entry due to the business-stealing effect. Their model is potentially applicable to the MRI industry in countries without regulation, because, in these countries, medical institutions can provide MRI-associated services upon purchasing an MRI, which can be viewed as free entry with large fixed cost. In fact, Chandra and Skinner (2012) note that overprovision of MRIs might occur without regulation and suggest the use of regulation to mitigate excessive adoption. We therefore empirically examine the welfare consequences of MRI adoption with and without regulation.

The framework developed by Mankiw and Whinston (1986), however, is not sufficient when considering the MRI industry, as it does not model the upstream market, i.e., com-

petition among MRI manufacturers. If the upstream market is a monopoly and there is no competition, the monopolistic MRI manufacturer has an incentive to set high prices for MRIs, which impedes MRI adoption. On the other hand, if the upstream market is perfectly competitive, the MRI prices approach the marginal cost, which facilitates MRI adoption. Thus, the excessiveness or insufficiency of the adoption in the downstream market depends crucially on the mark-ups that the upstream firms charge. The differences between mark-ups in Japan and in the U.S. suggest that competition among MRI manufacturers affects medical institutions' adoption of MRIs. The number of MRI manufacturers in Japan is greater than that in the U.S. and the Japanese Fair Trade Commission documented in 2004 that the price of MRIs in Japan was 25% lower than the price in the U.S.[1] The lower price in Japan may have been a consequence of severe competition in the upstream market, which accelerates the medical arms race. To assess the welfare implications of the medical arms race, therefore, we explicitly model the upstream market where MRI manufacturers sell MRIs to medical institutions.

To proceed to the empirical analysis, we construct a novel dataset that contains a complete list of medical institutions, the characteristics of the MRIs that each medical institution owns, the number of patients treated in each medical institution, the patients' co-payments and the reimbursement amount for medical institutions in Japan. Although our general framework is not restricted to the study of the Japanese market, there are two advantages that make the Japanese market more appealing than the U.S. for this analysis. First, medical prices are regulated by the government in Japan; thus, patient co-payments and medical institution reimbursements can be perfectly observed, which is crucial for welfare analysis. On the other hand, in the U.S., it is hard to obtain the data on co-payment for each patient and the reimbursement price for medical institutions, due to the lack of a unified health insurance system. Second, in our Japanese data, we observe the number of patients, which is a key variable in quantifying the business-stealing effects of MRI adoption, from a random sample of all medical institutions that offer MRI scans. In the U.S., other institutions besides hospitals (such as freestanding imaging centers) provide MRI scanning service, which makes it difficult for researchers to assess the number of patients treated there.

In the empirical analysis, we build and estimate a vertical industry model. In the upstream market, MRI manufacturers compete in quantity and medical institutions strategically decide whether to adopt an MRI or not. In the downstream market, MRI-equipped

[1] There are five MRI manufacturers operating in the U.S., whereas there is one additional domestic firm in addition to those five firms operating in Japan.

medical institutions provide MRI scanning services for patients and patients decide whether to visit a medical institution and if so, which one. The number of patients helps us identify the parameters for MRI scanning demand, whereas free-entry conditions for medical institutions and optimality conditions for MRI manufacturers help us identify the parameters for MRI production cost.

The estimated parameters are then used to conduct counterfactual simulations in order to quantify the effect of potential policy interventions. Motivated by Figure 1, we first hypothetically introduce French-style regulation which limits the number of MRIs per million people in each region. We consider three scenarios: one having the same limit as France's regulation (7.5 MRIs per million people) and two levels of looser regulation (10 and 23 MRIs per million people).[2] In all scenarios, consumer surplus would decrease because fewer medical institutions would adopt MRIs and consumers' hospital choices would be limited. On the other hand, MRI producer surplus would increase because the business-stealing effects are mitigated.[3] The change in producer surplus would outweigh the change in consumer surplus, leading to an increase in social welfare. Second, we hypothetically introduce a sales tax on MRIs, as entry taxes and licensing fees are frequently discussed as effective policy interventions in the literature on free entry. Our results indicate that such a sales tax with an appropriate redistribution of tax revenue would be Pareto improving.

We further examine the effect of upstream market competition on social welfare by considering two hypothetical cases. First, all MRI manufacturers proportionally reduce their quantity to maximize the industry profit, keeping their current market shares constant. Second, all manufacturers hypothetically merge, allowing for production reallocation. The first scenario would yield similar results to those generated by French-style regulation. Even though allowing a cartel is anti-competitive, social welfare would increase as MRI producers internalized business-stealing effects in the downstream market. This finding reveals a mechanism that determines how upstream market competition affects social welfare and provides new insight into antitrust policies. In the second scenario, we observe further improvement in social welfare due to production reallocation. By allowing MRI manufacturers to reallocate their production, they are able to further internalize business-stealing effects among products.

Our contribution is threefold. First, this paper makes a substantial contribution to the empirical literature on vertical markets and firms' entry. The recent empirical literature on

[2]We assume that market share stays the same under this hypothetical regulation.

[3]In the model, we assume zero-profit conditions for the medical institutions. Therefore, social welfare is defined by the sum of consumer welfare and the MRI producer surplus.

vertical markets, including Crawford and Yurukoglu (2012), Gowrisankaran, Nevo and Town (2015), Grennan (2013), Ho and Lee (forthcoming), Mortimer (2008) and Villas-Boas (2007), has extensively studied how competition and negotiation among upstream and downstream firms affect social welfare. Their models take market structure as given in the sense that they do not explicitly model firms' entry. On the other hand, the empirical literature on firms' entry, including Berry and Waldfogel (1999, 2001), Ferrari, Verboven and Degryse (2010), Jia and Pathak (2015), Maruyama (2011) Mazzeo (2002), Seim (2006), and Tamer (2003), has examined how firms' entry affect market outcomes and social welfare, given entry costs. This paper is the first empirical paper that combines these two aspects. We endogenize the entry cost as an outcome of upstream market competition and see how the degree of upstream market competition affects downstream firms' entry and social welfare.

Second, by doing so, we also contribute to the theoretical literature on firms' entry by showing that introduction of the vertical structure of markets may reverse welfare implications in the existing literature. Building upon a seminal paper by Mankiw and Whinston (1986), Ghosh and Morita (2007) introduce vertical structure of markets to the literature. They consider free entry in the upstream market with a fixed number of downstream firms, whereas we focus on the effect of upstream market competition given free entry in the downstream market.

Finally, this paper is related to the growing literature of health economics, in particular, the literature focusing on new technology adoption and the medical arms race. Existing papers such as Baker (2001) and Baker and Phibbs (2002) suggest the existence of strategic interaction among hospitals and of inefficiency that arises from the medical arms race. Schmidt-Dengler (2006) introduces a structural approach to show that the business-stealing effect is one important source of inefficiencies. However, the existing literature lacks welfare analysis due to the limited availability of patient-level data. To the best of our knowledge, Zabinski (2014) is the first to attempt to quantify social welfare using data from the robotic surgery industry. Our paper expands the literature by examining how regulations affect social welfare; we also quantify the welfare consequences of the medical arms race.

This paper is organized as follows: Section 2 describes the institutional background and our novel data, and provides some summary statistics and motivating facts for the modeling framework. Section 3 then provides a theoretical model, which provokes our empirical study, and an empirical model, which is customized to study the data we have in hand. We discuss empirical implementation and identification in Section 4. The estimation results and the counterfactual simulation are given in Section 5. Section 6 concludes.

2 Institutional Background and Data

In order to motivate our model, this section first provides a brief overview of the health care system and the MRI industry in Japan. After that, we describe our data.

2.1 Background

Health Care System in Japan Since 1961, Japan has had universal health coverage (like many OECD countries), which implies that every citizen in Japan is insured. Roughly speaking, there are two types of insurance programs available in Japan and they depend on the citizen's employer. If a citizen's employer offers its own insurance program, then he/she must enroll in it. This is called "Employee Health Insurance" (*Kenko-Hoken*). Otherwise people enroll in so-called "National Health Insurance" (*Kokumin-Kenko-Hoken*). Regardless of their insurance programs, when the insured (patients) receive medical services at medical institutions, the patients must pay 30% of the health care fee and the rest should be covered by their insurers.[4] The Japanese health care system has several notable features: (i) "free access," (ii) fee-for-service (FFS) payment, and (iii) a lack of regulation of medical institutions' adoption of MRIs.

First and most importantly, Japanese patients have "free access", which means that they are allowed to go to any medical institution in Japan, unlike the U.S. system which only allows patients to go to medical institutions belonging to their health insurers' network. Thus, except in a few rare cases, patients can choose to go to whichever medical institution they like, in principle. Furthermore, unlike countries such as France, the U.K., and the Netherlands, there is no general practitioner system in Japan and thus it is common for people to go directly to specialized medical institutions when they get sick. This aspect is particularly relevant to the model presented in Section 3, because patients' choice of medical institution does not depend on home doctors' advice but rather on their own preference.

Second, health care fees are regulated in Japan and are set by the government with biannual revisions. In a fee-for-service (FFS) payment system, medical treatments are unbundled and patients must pay for each medical treatment.[5] Medical institutions are formally divided into two main categories in Japan: hospitals and clinics. The distinction depends entirely

[4]There are some exceptions. For example, if patients are more than 70 years old, their co-payment is 20%. Furthermore, insurers subsidize some expensive medical treatments.

[5]As of 2015, some hospitals have started using the DPC (Diagnosis Procedure Combination) payment system, because the Japanese government encourages hospitals to shift to DPC in order to reduce medical expenses. However, the time period that our sample comes from is 2008 and at that time most medical institutions used fee-for-service payment.

on the number of beds. If a medical institution has less than 20 beds, it is classified as a clinic. Otherwise, it is called a hospital. About 80% of hospitals and around 95% of clinics are privately owned, which enables us to safely assume that medical institutions maximize their profits in our model. Even though there is such wide variation in medical institutions' patient capacity, the insured must pay, in principle, the same fees for the same medical treatment in Japan, regardless of their medical institution choices.

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

The MRI Industry in Japan MRI (Magnetic Resonance Imaging) 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. MRIs 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 machice 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 around 23,400 JPY for each treatment. Otherwise, the reimbursement price is 19,200 JPY.[6] Thus, the average patient whose co-payment is 30% must pay approximately 7,000 JPY (60 USD) for a high-tesla MRI scanning service and 5,800 JPY (49 USD) for a low-tesla MRI scanning service.[7]

There are six MRI manufacturers operating in Japan; Five of them are globally operated and one of them is domestically operated. The five global MRI producers include GE Healthcare Japan (GE), Hitachi Medical Corp. (Hitachi), Philips Electronics Japan (Philips), Siemens Healthcare Japan (Siemens) and Toshiba Medical Systems (Toshiba).

[6]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 JPY. For 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).

[7]1 USD = 117.4 JPY as of January 19, 2016.

The single domestic producer is Shimadzu Corp (Shimadzu).[8] Even though MRI machines are among the most expensive pieces of medical equipment, it seems that the Japanese market offers relatively lower prices due to severe price competition induced by the three Japanese manufacturers – Hitachi, Shimadzu and Toshiba. In fact, the Japan Fair Trade Commission (2005) documented that the average MRI price in Japan was about 25% lower than the price in the U.S., and the U.S. price is typically much lower than that in EU countries. This industry structure could be one of the reasons why there are so many MRIs in Japan.

2.2 Data

Data Overview The datasets used in this paper come from various sources. First of all, we obtained a complete list of hospitals in Japan based on a series of books, *Byouin Jyouhou* (Hospital Information), with help of Freeill Corp, and a complete list of clinics that focus on neurosurgery, neurology and orthopedics in Japan. Second, we manually collected a complete list of medical institutions that own at least one MRI based on a series of monthly-published books, *Gekkan Shin Iryo* (New Medical Care). Third, we also used a survey of medical institutions, asking which model of MRI they own, the timing of their purchases, reasons for purchasing, utilization of their MRIs, and so on. Roughly 20% of the medical institutions that own MRIs responded and Hashimoto and Bessho (2011) show that the samples represent the population well. Therefore, in this paper, we assume that samples are drawn randomly. Finally, the municipality-level average income and population data are obtained from the 2010 census, as the Japanese government conducts a census every five years and the 2010 census is closest in time to the year our MRI data was collected.

Descriptive Statistics Table 1 shows, by institution type, the number of Japanese medical institutions that own low- and high-tesla MRIs or no MRIs. This paper only deals with the medical institutions that potentially adopt MRIs. Therefore, we use all hospitals in Japan and all clinics that focus on neurosurgery, neurology and orthopedics. As demonstrated in the first row, there are 2,673 large hospitals in Japan. Among them, 1,366 hospitals, more than half of them, own at least one high-quality MRI and 813 hospitals have a low-quality MRI. This pattern is completely reversed for small hospitals and clinics. Most of them do not own high-quality MRIs, though a non-negligible portion of them still have low-quality

[8] Shimadzu was also globally operated but the firm halted its sales of MRI scanners outside the Japanese market in 1999 and has not resumed them.

Table 1: MRI Ownership by Medical Institution Type

	No MRI	Owning MRI Low	Owning MRI High	Total
Hospitals				
Large ($\geq$ 100 beds)	494	813	1,366	2,673
Small ($<$ 100 beds)	5,001	906	286	6,193
Sub Total	5,495	1,719	1,652	8,866
Clinics (Only neurology, neurosurgery and orthopedics)				
	12,958	1,115	252	14,325
Total	18,453	2,834	1,904	23,191

Note: This table represents the number of medical institutions without and with low- and high-tesla MRIs by the category of medical institutions. The category "Clinics" only includes the clinics that focus on neurology, neurosurgery, and orthopedics, as these clinics are the main users of MRIs.

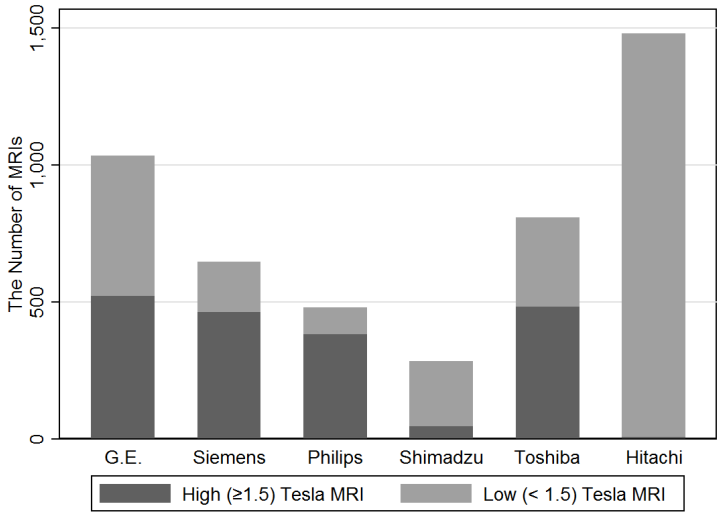
MRIs.

Next, Figure 2 depicts the market share. Though there are some differences in selling low-quality MRIs, *four* global MRI manufacturers produce very similar numbers of high-quality MRIs. In contrast, Hitachi, one of the global MRI manufacturers, has the largest share among six MRI producers and almost 99% of Hitachi's share comes from the sales of low-quality MRIs, when decomposing Hitachi's market share into the low-quality and high-quality segments. A similar pattern is observed in the market share composition for Shimadzu. Notice that the global market share looks slightly different from this graph. In many OECD countries, GE, Philips and Siemens each account for 25% of the market share, respectively, whereas Toshiba typically accounts for 10 to 15% and Hitachi accounts for 5%. Thus, Japan's unique market share structure could be due to the severe competition in Japan, in particular for the segment of low-quality MRIs.

Third, Panel (a) of Figure 3 shows the relationship between the number of MRIs and population for each market. Here we define the market as a geographically distinct medical administration area, called *Niji-Iryoken*, based on the Medical Care Act, excepting some large cities (cities designated by government ordinance and 23 Tokyo special districts) where we use municipalities for the market definition.[9] There are about 1,700 municipalities in Japan and our process results in 523 markets. The figure suggests there is a linear relationship

[9]These definitions are based on an approximation of patients' behavior. In large cities, there are sufficient choices nearby and thus people tend to go to local hospitals. On the other hand, in rural areas, there are not many medical institutions nearby and thus people tend to choose medical institutions that cover larger geographical areas, which correspond to the medical administration areas.

Figure 2: MRI Market Share in Japan



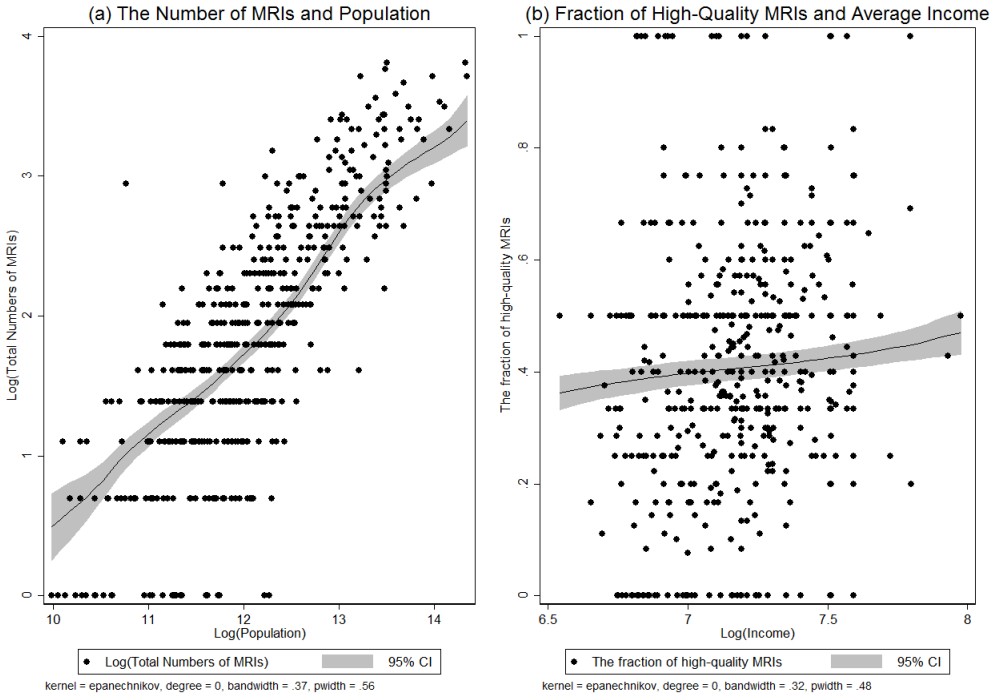
Note: This figure represents the number of MRIs sold by each MRI manufacturer. Gray bars indicate the sales for low-tesla MRIs, while black bars indicate the sales for high-tesla MRIs.

between the logarithm of population and the logarithm of the number of MRIs, implying that the population is one of the most important determinants for the number of MRIs in the market. Although the average income is another important factor that affects MRI adoption, it affects the proportion of low- and high-quality MRIs purchased rather than the the total number of MRIs in the market, as indicated in Panel (b) of Figure 3. Even though the slope is not very steep, it is still positive and statistically significant, which suggests that high-quality MRIs are preferred by high-income people and medical institutions take this preference into account when purchasing MRIs.

Lastly, Figure 4 shows the utilization rates for high- and low-quality MRIs. Utilization is defined as the number of patients treated per week divided by the physical capacity of a MRI scanner.[10] Panel (a) demonstrates the utilization rates of medical institutions adopting high-quality MRIs, whereas Panel (b) demonstrates the utilization rates of medical institutions adopting low-quality MRIs. Each dot denotes a medical institution, while the horizontal and vertical axes shows the logarithm of population of the market where the medical institution is located and the utilization rate, respectively. There are two important observations. First, in both panels, medical institutions do not fully utilize their MRIs, suggesting that MRI adoption could be excessive in Japan because the same number of patients could be treated

[10]We compute that the physical capacity of an MRI scanner is 132 per week, assuming that medical institutions operate 8 hours per day, 5.5 business days per week, and that each scan takes approximately 20 minutes.

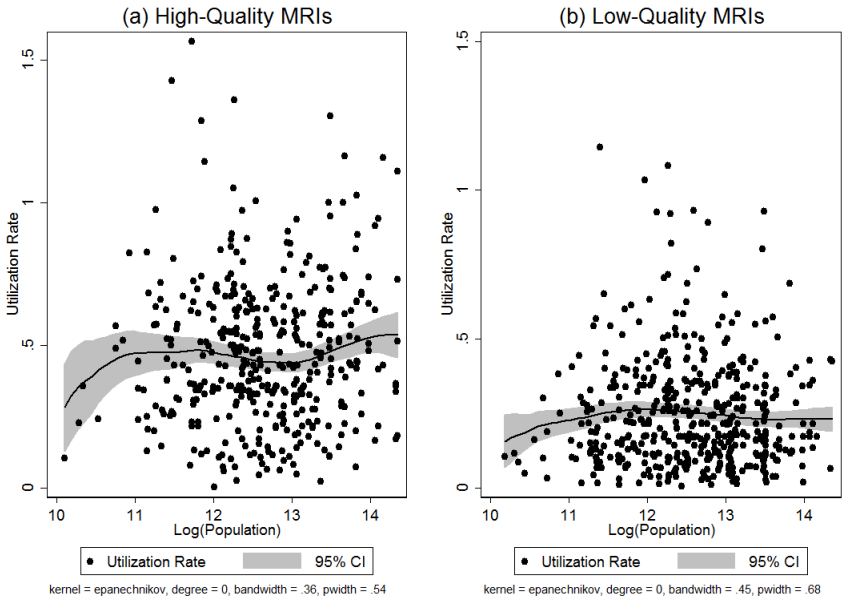
Figure 3: The Effects of Population and Income on MRI Adoption



Note: Panel (a) shows the relationship between the logarithm of population and the logarithm of the number of MRIs in each market. Panel (b) shows the relationship between the logarithm of average income and the fraction of high-tesla MRIs in each market. Each dot represents one market. In each panel, using a non-parametric approximation, we show the fitted value as a black solid line and the 95% confidence interval as a shaded region.

with fewer MRIs. Furthermore, the utilization rates of low-quality MRIs are lower than those of high-quality MRIs, which may reflect the fact that low-quality MRIs are relatively cheap compared to high-quality MRIs and even these low utilization rates are enough to cover the adoption costs. In fact, the average numbers of patients for high- and low-tesla MRIs per week are 64.2 and 34.9, respectively, implying that the average utilization rates for them are 48.6% and 26.4%, respectively. Second, even though the total number of MRI scans increases in population, the utilization rates are roughly constant. As the population increases, the total number of MRIs also increases as in Figure 3, which makes the utilization rates nearly constant regardless of the population.

Figure 4: Utilization Rates for MRIs



Note: Panel (a) shows the relationship between the logarithm of population and the utilization rate of high-tesla MRIs at each medical institution. Panel (b) shows the relationship between the logarithm of population and the utilization rate of low-tesla MRIs at each medical institution. Each dot represents one medical institution. In each panel, using a non-parametric approximations, we show the fitted value as a black solid line and the 95% confidence interval as a shaded region.

3 The Model

The goal of this section is twofold. The first goal is to develop a theoretical model of a vertical industry with free entry in the downstream market and show that the social efficiency of the whole economy hinges on the degree of competition in the upstream market. More specifically, we prove that (i) when the upstream market is monopolized, social welfare is improved by *increasing* the degree of upstream market competition, and (ii) when the upstream market is perfectly competitive, social welfare is improved by *decreasing* the degree of upstream market competition. The second goal is to develop and present an empirically tractable model, which we later use with the data. Though the intuition behind our theoretical and empirical models is the same, as is their takeaway message, the theoretical model is different from the empirical model with respect to (i) the downstream prices and (ii) the heterogeneity in both products and firms. Regarding the downstream prices, even though the medical price is fixed in Japan as explained in the previous section, our theoretical model allows the downstream price to be an equilibrium outcome of the competition

of downstream firms. On the other hand, our empirical model includes rich heterogeneity in upstream and downstream products and cost structures, whereas our theoretical model considers a homogeneous environment to derive clear analytical results. Readers who are interested in empirical analysis can proceed directly to Section 3.2.

3.1 The Theoretical Model

We consider an industry that consists of an upstream market and a downstream market. The upstream firms produce an intermediate product which is required for the downstream firms to produce the final product for consumers. In our MRI context, the upstream firms are MRI manufacturers that produce MRIs as intermediate products and the downstream firms are medical institutions that provide MRI scanning services for patients. We consider the following three-stage game. In the first stage, N_u identical upstream firms, a finite and fixed number, simultaneously decide the quantity of a homogeneous intermediate product. All upstream firms possess exactly the same production technology, which is characterized by the linear cost function $c_u(q) = Kq$, where K is fixed and constant. In the second stage, the price of the intermediate product p_u is realized and a large (infinite) number of identical potential entrants make their entry decisions.[11] Upon entry, each downstream firm purchases one unit of intermediate product which costs p_u and thereby obtains access to a technology. This is characterized by the cost function $c_d(q)$. We assume that $c_d(\cdot)$ is continuous, $c_d(0) = 0$, $c_d'(\cdot) \geq 0$, and $c_d''(\cdot) \geq 0$ for all $q \geq 0$. Lastly, in the third stage, these downstream firms that enter the market play an oligopoly game, for which we do not specify the mode of competition. This model is a natural extension of that of Mankiw and Whinston (1986) and Suzumura and Kiyono (1987) where they do not consider the upstream market. They treat the entry costs as exogenously given and fixed, whereas our model endogenizes the entry cost of downstream firms as an equilibrium result of competition among upstream firms.

We characterize the subgame perfect equilibrium using backward induction. In the third stage, given that N_d firms have entered the final product market in the second stage, we assume that the equilibrium is symmetric and denote $q(N_d)$ to be the equilibrium output per downstream firm. Knowing what would happen if N_d firms entered the final product market and given the first stage total production quantity, Q_u, we assume that the equilibrium intermediate product price p_u is characterized by the following assumption:

[11] Though we do not explicitly specify the exact mechanism that determines prices here, this price determination can be through negotiation or bargaining.

Assumption 1 (Free-Entry Equilibrium) *Suppose Q_u is the aggregate output in the first stage and $P(\cdot)$ denotes the inverse demand function in the final product market, then*

$$P(Q_u \cdot q(Q_u)) \cdot q(Q_u) - c_d(q(Q_u)) - p_u = 0.$$

This assumption corresponds to the free-entry assumption in Mankiw and Whinston (1986) and states that all firms obtain exactly zero profit in a free-entry equilibrium.[12] Since each entry requires one unit of intermediate product, the number of entrants must be equal to the aggregate output of the intermediate product Q_u in an equilibrium. Given the aggregate output Q_u, what would happen in the third stage can be rationally expected and $Q_u \cdot q(Q_u)$ will be the total final production amount in the third stage. The first term, therefore, is the revenue of each downstream firm and the second term is the production cost, whereas the third term represents the entry cost. This assumption also guarantees the market clearing for the intermediate product by having the price of the intermediate product equal the profit earned by the entrants in the third stage.

Social Welfare and Competition in the Upstream Market We begin our analysis by defining social welfare as a function of the number of upstream firms, N_u. For the sake of the tractability of our analysis, we ignore the integer problem and treat the number of firms as continuous like Mankiw and Whinston (1986). Given all primitives, we first characterize the equilibrium aggregate output of the intermediate product. Since the first stage is quantity competition with symmetric firms, the equilibrium must be symmetric and, therefore, $Q_u = N_u \cdot q_u$, where q_u denotes the output per upstream firm. The equilibrium production quantity is characterized by the first-order condition given by

$$\frac{\partial p_u}{\partial Q_u} q_u + p_u - K = 0.$$

Now, we can define social welfare as a function of the number of upstream firms, which is given by

$$W(N_u) = \int_0^{Q_u \cdot q(Q_u)} P(s)ds - Q_u \cdot c(q(Q_u)) - Q_u \cdot K$$
$$\text{subject to } Q_u = N_u \cdot q_u \text{ and } \frac{\partial p_u}{\partial Q_u} q_u + p_u - K = 0.$$

Proposition 1 *Suppose Assumptions 1 and MW1-3, which are the assumptions on the*

[12] Having exactly zero profit may seem to be a strong assumption because the typical free-entry conditions simply state that the marginal entrant obtains non-negative profit and no additional entry is profitable. We discuss this issue later when we describe our empirical model.

downstream market and the same as those in Mankiw and Whinston (1986), in Appendix A hold. If the upstream market is monopolized by one firm, then

$$\frac{\partial W}{\partial N_u} > 0.$$

Moreover, if the price in the upstream market is equal to the marginal cost, then

$$\frac{\partial W}{\partial N_u} \leq 0 \text{ if } p_u = K \text{ with strict inequality if } p(Q_u \cdot q(Q_u)) - c'(q(Q_u)) > 0.$$

Proof: See Appendix A.

This proposition states that the number of downstream firms is socially insufficient if the upstream market is a monopoly, and socially excessive if the upstream market is perfectly competitive. The result suggests that, even in a very simple homogeneous setting like that of Mankiw and Whinston (1986), the sufficiency or excessiveness depends on the degree of competition in the upstream market. It also suggests that ignoring the upstream market would overestimate inefficiency. Furthermore, as argued in Mankiw and Whinston (1986), product differentiation may reverse this bias toward excessive entry and make theoretical prediction ambiguous. In the next subsection, therefore, we build a sufficiently rich model that captures important features of the MRI industry: its vertical structure, the heterogeneity of both upstream and downstream firms and product differentiation among MRIs, which are the key components of the welfare analysis.

3.2 The Empirical Model

Given our motivation and institutional background, this section describes a structural model that explicitly takes into account the vertical structure of the MRI industry. Our model has three sets of players: (i) MRI manufacturers that produce high- and low-quality MRIs and compete in quantities in each geographical market, (ii) medical institutions, namely hospitals and clinics, that purchase MRIs to offer medical services for patients in the downstream market, and (iii) patients who need to undergo MRI scans to find and cure their diseases.

In order to formally describe our model, we first introduce several notations. Each geographical market is denoted by a subscript $m \in \mathcal{M}$ and characterized by its population, pop_m, and the average weekly income level, y_m. Following the standard definition used by the Japanese government, the medical institutions are categorized into three sets, $\{c, s, l\}$, where c denotes clinics that have less than 20 beds, s denotes small hospitals that have less than 100 beds, and l denotes large hospitals that have 100 beds or more. Each MRI producer $f \in \mathcal{F}$ sells two types of MRI, $q \in \{\mathrm{L}, \mathrm{H}\}$, where L denotes low-tesla MRIs (less than

1.5 tesla) and H denotes high-tesla MRIs (1.5 tesla or higher). This simplification tremendously eases computational complexity, but still introduces sufficient product differentiation, because these two types of MRI correspond to the reimbursement rates, as is explained in Section 2.

MRI manufacturers decides the production quantities and prices for MRIs with different level of Tesla in each geographical market. Each medical institution is different in the characteristics, e.g., the size of the institution and makes its adoption decision independently. When consumers need a MRI scan, they face a choice of medical institutions and this is a result of manufacturers' production decisions and medical institutions adoption decisions. From consumers' perspective, each MRI scan is differentiated by the characteristics of the MRI and those of the hospital. Although it is natural to use a differentiated product approach in a continuous fashion, e.g., treating level of Tesla and the size of medical institutions as continuous variables, such an approach introduces a complication in the second stage adoption game played by medical institutions. Thus, to keep the empirical tractability, we introduce the concept of a *segment*, which is defined as a Cartesian product of hospital types and MRI types, and is described in Table 2. This is similar to the firm type introduced by Mazzeo (2002) and the firm location introduced by Seim (2006). This segmentation captures the differentiation in a discrete fashion and means that from consumers', hospitals' and MRI manufacturers' perspectives, they can at least distinguish among MRIs with different tesla ratings, different hospital types, and the combination of these. From the medical institutions' perspective, each institution has three choices: to adopt a high-tesla MRI, to adopt a low-tesla MRI or to stay out of the MRI treatment market. Hospitals make their decisions strategically based on their characteristics and the perceived differentiation among consumers. Given this structure, MRI manufacturers and hospitals treat MRIs in different segments differently. MRI manufacturers also strategically decide what quantity to supply in each segment. The price of an MRI can differ in each segment.

Table 2: Concept of Segment

		Hospitals	
	Clinics	Small	Large
	(c)	(s)	(l)
Low-tesla MRI	1	3	5
High-tesla MRI	2	4	6

Note: This table visualizes how we define the segment.

3.2.1 Patient Demand for MRI Scanning Services

We first present the patients' demand for MRI scanning services in the downstream market. Our model is closely related to the discrete choice models proposed by Berry (1994) and Berry, Levinsohn and Pakes (1995). Ho (2006, 2009) applied their methodology to the health economics literature to study the welfare effects of restricted hospital choice in the U.S. and the determinants of hospital networks offered by managed care health insurers, respectively. The indirect utility for patient i in market m choosing medical institution j is defined by

$$u_{ijm} = \begin{cases} \alpha \log(y_m - \delta b_t) + \boldsymbol{I}_j' \boldsymbol{\beta} + d_{jm} + \xi_m + \epsilon_{ijm}, & \text{if } j \neq 0 \\ \alpha \log(y_m) + \epsilon_{i0m}, & \text{otherwise,} \end{cases}$$

where y_m denotes the average income in market m, δb_t denotes the medical treatment price that patients must pay for taking an MRI scan, $I_j = (i_{t_1 j}, \cdots, i_{t_T,j})$ denotes a vector of the indicator variables when hospital j is type t, ξ_m denotes a market-specific random effect, and ϵ_{ijm} is a random utility shock.[13] The first term expresses the mean utility per monetary unit, while the second term expresses the utility from the segment to which medical institution j belongs. ξ_m captures region-m-specific effects, as there might be some region-specific factors, such as weather, food and other region-m-specific omitted variables that potentially affect the probability of becoming sick. All other idiosyncratic factors, such as the distance between patient i' home and medical institution j, are included in ϵ_{ijm}.

We specify consumer preference as a three-level nested logit model: potential patients first decide whether they will go to a hospital or not. Then, if they decide to go, they must choose a segment sg and, finally, they must decide which hospital or clinic j to visit among the medical institutions in segment sg. Mathematically, we assume that ϵ_{ijm} is decomposed into three parts:

$$\epsilon_{ijm} = \varepsilon_{igm} + (1 - \lambda_2)\varepsilon_{i,sg,m} + (1 - \lambda_1)\varepsilon_{ijm},$$

where ε_{igm} corresponds to the first decision, that of whether to go to a medical institution or not, $\varepsilon_{i,sg,m}$ is the segment-specific utility shock, and ε_{ijm} denotes the hospital or clinic j-specific random utility shock. The first nest captures the individual's state: healthy or sick. Sickness corresponds to a high value of ε_{igm}. The second nest captures the seriousness of the symptoms and diagnoses of patients. For example, a high value of $\varepsilon_{i,6,m}$ leads to

[13] As empirically studied by Iizuka (2012), there may exist agency problems and some demand might be driven by physicians. (The latter is known as physician-induced demand.) However, such an aspect is out of the scope of this paper due to the data limitations.

a high demand for an MRI scan in a large hospital with a high-tesla MRI. The final nest captures the idiosyncratic heterogeneity in consumer preference within a given segment, such as the distance to the hospital. Although the importance of the distance to the hospital is emphasized by Gowrisankaran, Nevo and Town (2015) and Ho and Pakes (2014), we do not explicitly take it into account in our utility function specification, due to the lack of the patient-level data. However, as Einav, Finkelstein, and William (2016) note, the distance to the hospital in our setting may not be as crucial as in those papers, because patients visit hospitals just for "one time" to take a MRI scan rather than attending there repeatedly.

From a technical point of view, patients can go to any hospital in Japan. From a practical point of view, however, it is not very common for patients to go to medical institutions in other geographical markets. Therefore, the choice set for patient i living in market m is denoted by $\mathcal{J}_{im}$, and we include all available hospitals and clinics in market m. This market definition, together with the previous indirect utility function specification, allows us to define the market share for medical institution j in market m in a given week as

$$s_{jm} = \int_{A_j(\alpha,\boldsymbol{\beta},\boldsymbol{\lambda}} f(\varepsilon)d\varepsilon, \quad \text{with} \quad A_j(\alpha,\boldsymbol{\beta},\boldsymbol{\lambda}) = \{\varepsilon | u_{ijm} \geq u_{jkm}, \forall k \neq j\}, \tag{1}$$

where A_{jm} denotes the set of patients who choose medical institution j to provide MRI scanning services and s_{jm} denotes the market share for medical institutions j, which is integral over population.

3.2.2 Medical Institutions' MRI Adoption

The profit maximization problem for medical institution j in market m is given by

$$\max_{(a_{jm},f)\in\{0,L,H\}\times\mathcal{F}} \pi_{jm}(a_{jm},\vec{a}_{-jm}) + \epsilon_{jm}^{a_{jm},f},$$

where a_{jm} denotes an action, $\pi_{jm}(a_{jm},\vec{a}_{-jm})$ denotes a profit function that depends not only on j's own action a_{jm} but also on the actions of other medical institutions $\vec{a}_{-jm}$ in the same geographical market and $\epsilon_{jm}^{a_{jm}}$ denotes an action specific random term that affect j's profit. Here, we assume $\epsilon_{jm}^{af} \sim N(0,\sigma_\varepsilon)$. For each medical institution, $a_{jm} = 0$ means that no MRIs were purchased, and a_{jm} = L or H means that a low- or high-tesla MRI was purchased, respectively, i.e., our model endogenizes medical institutions' MRI choices upon entry, as in Mazzeo (2002).[14] The profit function for each medical institution j in market m is specified

[14] We assume that each medical institution purchases at most one MRI. In our data, 83% of them have just one MRI. Moreover, even though 17% of them have multiple MRIs, some of them own a second MRI for backup purposes or keep an old one due to high scrapping costs.

as

$$\pi_{jm}(a_{jm}, \vec{a}_{-jm}) = \begin{cases} \text{pop}_m \cdot s_{jm}(a_{jm}, \vec{a}_{-jm}; \xi_m) b_t - p_{ftm}, & \text{if } a_{jm} \neq 0, \\ 0, & \text{otherwise,} \end{cases}$$

where pop_m is the population in market m, which is observed in the data; $s_{jm}(a_{jm}, a_{-jm})$ is the market share for j defined in equation (1); b_t is the per-patient monetary transfer from the insurer to a medical institution, which depends on the quality of MRI; and p_{tm} is the MRI price for segment t in market m. We normalize the profit for not adopting MRI as zero, reflecting the fact that medical institutions that do not have MRIs cannot earn any profit from MRI-related services.[15] On the other hand, medical institutions that purchase MRIs can earn some profits: the revenue, the number of treated patients, $\text{pop}_m \cdot s_{jm}(a_{jm}, \vec{a}_{-jm})$, multiplied by the price per treatment, b_t, minus the costs of adopting MRI technology, summarized in p_{tm}. We can rewrite the profit function using only the total number of medical institutions that adopt MRI technology in each segment. Now the post-entry profit function for a medical institution in segment t in market m is given by

$$\tilde{\pi}_{tm}(\vec{Q}_m) = \text{pop}_m \cdot s_{tm}(\vec{Q}_m) \cdot b_t,$$

where $\vec{Q}$ is a vector of total number of MRIs in each segment, i.e., $\vec{Q}_m = (Q_{1m}, Q_{2m}, \cdots, Q_{6m})$. This feature allows us to derive the inverse demand function for MRIs in market m. Given the number of MRIs in other segments, medical institutions' willingness to pay for MRIs in segment t must be identical to the post-entry profit and be decreasing in Q_{tm}. Though the existing literature often models the profit function in a reduced-form fashion, our model of the downstream market enables us to express the post-entry profit in a structural fashion. This approach allows us to conduct richer sets of counterfactual analyses.

As is clear from the expression, the model introduces strategic interaction among medical institutions in a given geographical market, because many previous studies, such as Schmidt-Dengler (2006) and Hashimoto and Bessho (2011), find that there are business-stealing effects in the MRI scanning service industry. If an additional entrant medical institution k adopts MRI technology, the market share for the incumbent medical institutions would decrease. This effect is called the *business-stealing effects*. The magnitude of this effect should depend on the segments of medical institution k and of the incumbents. Our model allows for heterogeneous business-stealing effects within and across segments in a given market,

[15] There might be some indirect effects for not offering MRI scanning services, such as reputation "loss." However, this effect is hard to quantify and the literature still has not found hard evidence of it. Therefore, this model avoids dealing with such effects.

One might worry about the heterogeneity of medical institutions within a segment, i.e., even within a given segment the degree of substitution could be different. We introduce two type of heterogeneity within a segment: idiosyncratic consumer preference, captured by ϵ_{ijm}, and idiosyncratic action specific unobserved profitability of medical institutions, captured by ϵ_{jm}^{af}. However, we do not explicitly model geographical heterogeneity. For example, in the segment comprised of large hospitals owning high-tesla MRIs, if two institutions are near to each other, we would expect the substitution rate to be different than if the two institutions were far away from each other. Such heterogeneity is intentionally omitted here in order to keep our model tractable. Though models having such heterogeneity will better approximate the reality, this heterogeneity enormously increases the state space. Our model uses only the total number of medical institutions that adopt MRI technology in each segment. In this sense, our adoption game as played by medical institutions is similar to the entry model of Bresnahan and Reiss (1991), which assumes that firms are completely homogeneous. Our model partially allows us to have heterogeneity by introducing segmentation and, more crucially, when our segmentation becomes more detailed, our model approaches the model that fully takes heterogeneity into account. Therefore, although our way of introducing strategic interaction may look restrictive, this simplification dramatically reduces computational complexity and can be easily extended to introduce more heterogeneity.[16]

As pointed out by Schmidt-Dengler (2006), medical institutions have an incentive to adopt MRI technology in order to enhance their reputations and attract additional non-MRI patients as well. In other words, adopting MRI technology has some externalities for other illnesses and thus our normalization might no longer hold. However, this model allows such an effect as well, because p_{tm} can be seen as the real cost of adoption netting out all such effects, rather than a nominal MRI price. Therefore, in essence, by observing (i) medical institutions' adoption decisions, (ii) pop_m, and (iii) b_t in our data, we recover the difference in profits that occurs medical institutions adopt (or do not adopt) MRI technology, which is summarized in p_{tm}. We further discuss this issue in the subsequent subsection where we discuss the marginal cost of MRI production.

3.2.3 Competition Among MRI Producers

Each manufacturer sets the price and production quantity of MRIs for each segment and in each market. Let $\boldsymbol{p}_{fm} = (p_{1fm}, p_{2fm}, \cdots, p_{Tfm})$ and $q_{fm} = (q_{t_1fm}, \cdots, q_{t_6fm})$ denote the

[16]For example, if we categorize the medical institutions into two groups – centrally located and non-centrally located – we can increase the number of segments from six to twelve.

prices and production quantities manufacturer f sets in market m. Then, MRI manufacturer f's profit is given by

$$\pi_f(\boldsymbol{p}_f, \boldsymbol{p}_{-f}) = \sum_m \sum_t \left(p_{ftm} q_{tfm}(\boldsymbol{p}_m, \boldsymbol{\epsilon}_m) - mc_{tfm} q_{tfm}\right)$$

where $q_{tfm}(\boldsymbol{p}_m, \boldsymbol{\epsilon}_m)$ denotes the sales quantity of manufacturer f in segment t in market m under price vector $\boldsymbol{p}_m$ and the action specific random profit $\boldsymbol{\epsilon}_m$. Also, mc_{tfm} denotes the marginal cost of producing one unit of MRI for firm f in segment t in market m. As in the discussion of p_{tm}, this marginal cost captures the real cost of MRI production, netting out all costs and benefits. Alternatively, we could model all relevant effects and costs such as the privilege effects and installation costs. However, the data only allows us to infer the difference in profits with and without the marginal MRI. Therefore, such effects cannot be separately identified. For our counterfactual analysis, separate identification is not crucial because only the difference between the real cost of MRI production and the real benefit of MRI adoption matters to our welfare analysis.

Here we assume constant marginal costs and specify that the marginal cost is decomposed into two parts

$$mc_{tfm} = mc_{tf} + e_{tfm},$$

where mc_{tf} denotes the deterministic part of the marginal cost and e_{tfm} denotes the stochastic part of the marginal cost, which follows a normal distribution, $N(0, \sigma_e^2)$. To reduce the number of parameters, we further put a specific function assumption on mc_{tf}: $mc_{tf} = mc_f^L + mc_t$ for low-tesla MRIs and $mc_{tf} = mc_f^H + mc_t$ for high-tesla MRIs. Note that we allow the deterministic part of the marginal cost, mc_{tf}, to be different among segments. We treat the marginal cost in this way to capture the net cost of MRI adoption. The MRI purchase price is not the only cost hospitals pay; MRI installation also carries a cost. Also, MRI adoption may have indirect benefits to hospitals such as reputation enhancement. Since we only observe medical institutions' adoption decisions and number of patients, what we can infer from the data is the net cost of MRI adoption that includes all those costs and benefits. By allowing the marginal cost to be different depending on the segment, we allow the possibility that those costs and benefits may be different among medical institutions.

3.2.4 Information Structure, Multiplicity and Model Discussion

We model manufacturers and medical institutions behaviour as a complete information game. The timing of the game is as follows.

1. ξ_m, $\{\epsilon_{jm}^{tf}\}_{t\in T, f\in\mathcal{F}, j\in\mathcal{J}}$ and $\{e_{tfm}\}_{t\in T, f\in\mathcal{F}}$ realize and all manufacturers and medical institutions observe the realization.

2. Manufacturers set their production quantities in each segment in each market.

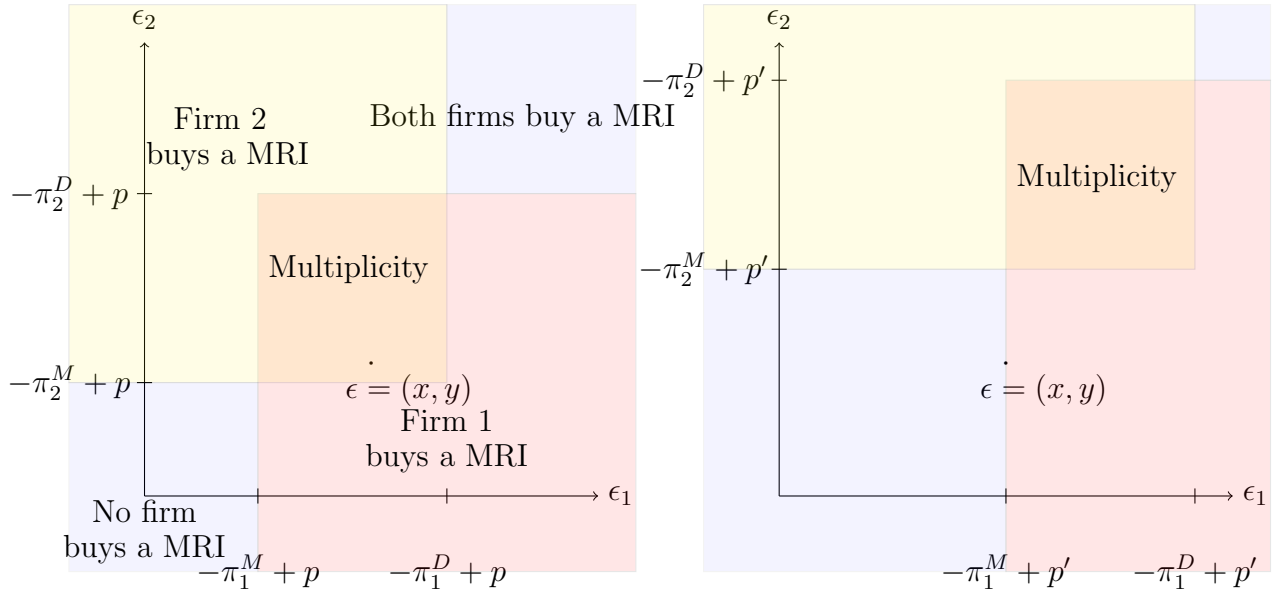
3. Manufacturers set their prices of MRIs in each segment in each market after observing all manufacturers production quantities.

4. Medical institutions make their adoption decisions.

Since this is a complete information game with multiple stages, we use Subgame-Perfect Nash Equilibrium as a solution concept. Here an equilibrium is characterized by the optimality of manufacturers' quantity decisions, pricing decisions and the adoption decision of medical institutions. In the adoption stage, no medical institution can improve its profit by changing its behaviour given the adoption decisions of other medical institutions and the prices of MRIs. In the price and quantity setting stage, no manufacturer can increase its profit by changing neither the prices or the quantities given other manufacturers decisions and the optimal behaviour of medical institutions in the next stage.

Here, one might worry about the multiplicity of equilibria in the adoption stage. Since the adoption model is similar to those with Tamer (2003) and Ciliberto and Tamer (2009), there do exist multiple equilibria in terms of the adoption behaviour with generic prices of MRIs. However, such multiplicity does not arise, at least, on the equilibrium path. Given the production quantity, the existence of multiple equilibria in adoption behaviour implies suboptimal pricing. Suppose there is a monopolist who sells one MRI to two potential entrants (medical institutions). Let π_j^M π_j^D denotes the profit of medical institution as a monopolist and duopolist in the MRI treatment (downstream) market, respectively. Suppose the realization of unobserved profitability, $\epsilon = (\epsilon_1, \epsilon_2)$, is (x, y). Figure 5 illustrates the situation. For a generic price of a MRI, p, there may exist multiple equilibria in medical institutions' adoption decision as in Tamer (2003), which is illustrated in the left panel of Figure 5. In such a situation, however, the monopoly MRI manufacturer can increase its profit by increasing the price of MRI. In the left panel of Figure 5, $p < \pi_1^M + x$. By revising the price to $p' = \pi_1^M + x$, the manufacturer still sells one MRI and the profit increases. In other word, given the production decisions, manufacturers have an incentive to set the highest prices of MRI that clear the market, which eliminates multiplicity in the adoption behaviour. There may still exist multiple equilibrium in the manufacturers' production decisions. We discuss this issue more in 4.

Figure 5: Multiplicity and Endogenous Entry Cost



In this paper, we model the game as a complete information game. Alternatively, we could have modelled it as an incomplete information game by assuming ϵ_{jm}^{af} to be private information of medical institution j. Since these two models are mutually exclusive, we need to select one of them. We believe that our modelling is reasonable because, as discussed in Section , the model fits the data well. In simple entry games without the vertical structure of industry, Grieco (2014) provides a method to incorporate flexible information structure that nests both pure complete information and pure incomplete information. In the future work, we may construct a similar method with a vertical structure.

4 Empirical Implementation and Identification

There are three sets of parameters of interest: (i) the downstream demand parameters, $(\alpha, \beta, \gamma_1, \gamma_2)$, (ii) MRI manufacturers' marginal cost, $\{\text{mc}_{tf}\}_{t=L,H,f=1,\cdots,F}$, and (iii) three variances of distributional assumptions for the private information of medical institution σ_ϵ^2, the unobserved demand σ_ξ^2 and the marginal cost σ_e^2. Let θ denote the vector of the parameters of interest. Given the parameter values, the model predicts two sets of moments: (a) market share for each hospital and clinic in the downstream market, which enables us to identify (i) and one of the parameters in (iii), and (b) market share for each MRI manufacturer and its variance across markets, which enables us to identify (ii) and the other two of the parameters in (iii). Roughly speaking, the latter set of moments contains the same information

as the adoption decisions of medical institutions. Essentially, there are two possible ways to estimate our model: estimating all parameters jointly, and estimating the downstream demand parameters first and then the upstream cost parameters, separately. Although efficiency might be improved by employing the former approach, we take the second approach to reduce computational complexity. More precisely, we first estimate some of the downstream demand-side parameters, $\theta_1 = (\alpha/(1-\lambda_2), \beta_2/(1-\lambda_2), \cdots, \beta_6/(1-\lambda_2), (\lambda_1-\lambda_2)/(1-\lambda_2))$, using the MRI utilization data, denoted by (a). Given the estimated parameters in the first stage, $\hat{\theta}_1$, we construct the objective function with respect to the remaining parameters, $\theta_2 = (\{\mathrm{mc}_{tf}\}_{t=1,\cdots,6,\ \forall f}, \lambda_2, \sigma_\xi, \sigma_\varepsilon)$, and estimate these parameters using market shares for MRI producers (or adoption decisions of medical institutions), denoted by (b).

4.1 Estimating Parameters in Patients' Demand

The demand estimation follows a standardized procedure.[17] The nested logit structure induces the following closed-form solution for the market share of each medical institution:

$$\begin{aligned}\ln(s_{jm}) - \ln(s_{0m}) &= \alpha \log(y_m - \delta b_t) + \boldsymbol{\beta I}_j + \xi_m + \xi_{jm} \\ &\quad + \lambda_1 \ln(\text{within share in the segment})_j \\ &\quad + \lambda_2 \ln(\text{Total number of patients in region } m \text{ divided by the population}).\end{aligned}$$

$$\ln(s_{jm}) = \frac{\alpha \log(y_m - \delta b_t) + \boldsymbol{\beta I}_j + \xi_m}{1-\lambda_2} + \frac{\lambda_1 - \lambda_2}{1-\lambda_2} \log(\text{within share in the segment})_j + \text{Market-Specific Constant}.$$

Based on this closed-form solution, our estimation equation can be rearranged as

$$\ln(NP_{jm}) = \frac{\alpha \log(y_m - \delta b_t) + \boldsymbol{\beta I}_j}{1-\lambda_2} + \frac{\lambda_1 - \lambda_2}{1-\lambda_2} \log(w_{jm}) + F_m + \eta_{jm}, \tag{2}$$

where NP_{jm} denotes the number of patients that clinic/hospital j treats per week, w_{jm} denotes the market share within the same segment, F_m is a market-specific fixed effect and η_{jm} denotes the error term.[18] This fixed effect estimator gives us consistent estimates of $\frac{\alpha}{1-\lambda_2}$, $\frac{\boldsymbol{\beta}}{1-\lambda_2}$ and $\frac{\lambda_1-\lambda_2}{1-\lambda_2}$ and, more importantly, incorporates the possible measurement error in

[17] See Verboven (1996) for a detailed discussion and derivation of the nested logit model.

[18] In the model, all medical institutions in the same segment are *ex ante* identical and, therefore, the market share within the segment is equal to the inverse of the number of clinics/hospitals in the same segment.

the number of patients.[19] Our model predicts that the number of patients for two medical institutions in the same segment in a given market must be exactly the same. This is not the case in the data, however, and we assume that the variations are attributed to the measurement errors that are orthogonal to other variables, i.e., the number of patients in the data must be equal to the number of patients predicted by the model plus the measurement errors.

4.2 Estimating Parameters in the Upstream Market

In the upstream market, the manufacturers set their prices and quantities. Once the production quantities are set, the profit maximizing prices of MRIs are set to clear the market. Since the market clearing prices are determined through the adoption decisions of medical institutions, we can express the market clearing prices as a function of quantities and the realization of ϵ_{jm}^{tf}s. Let $p_{tfm}(\boldsymbol{q}_m, \boldsymbol{\epsilon}_m)$ denote the market clearing price, then we can express the profit of manufacturer f in market m as

$$\pi_{fm}(\boldsymbol{q}_m, \boldsymbol{\epsilon}_m) = \sum_t \left(p_{tfm}(\boldsymbol{q}_m, \boldsymbol{\epsilon}_m) - mc_{tfm}\right) q_{tfm}.$$

Therefore, the optimality on the quantity decision implies

$$\pi_{fm}(q_{fm}; q_{-fm}, \boldsymbol{\epsilon}_m) \geq \pi_{fm}(q'_{fm}; q_{-fm}, \boldsymbol{\epsilon}_m) \quad \forall q'_{fm} \text{ and } \forall f,$$

which means that no MRI manufacturer has an incentive to change its output, given the output level of other manufacturers. In many markets, as shown in Section 2.2, q_{tfm} ranges from zero to 10 and this discreteness prevents us from using first-order conditions to estimate this model. Thus, instead of using first-order conditions, we use inequality conditions to derive the likelihood.[20] Specifically, the inequality condition is decomposed into two conditions:

$$\pi_{fm}(q_{fm}; q_{-fm}, \boldsymbol{\epsilon}_m) \geq \pi_{fm}((q_{tfm} + 1, q_{-tfm}); q_{-fm}, \boldsymbol{\epsilon}_m), \tag{3}$$

$$\pi_{fm}(q_{fm}; q_{-fm}, \boldsymbol{\epsilon}_m) \geq \pi_{fm}((q_{tfm} - 1, q_{-tfm}); q_{-fm}, \boldsymbol{\epsilon}_m). \tag{4}$$

[19] We need not use instrumental variables for co-payments nor for the market share within a segment. As co-payments are set by the government and market share within the segment here is deterministic number, there are no worries for endogeneity in prices nor in the market share within the segment.

[20] Our estimation procedure implicitly assumes that there is no multiplicity of equilibrium. Although Cournot competition typically yields a unique equilibrium outcome, the discreteness of the number of MRIs in our model potentially leads to a multiple equilibrium problem. However, when we compute equilibria using the estimated model, manufacturers' production quantities are unique in more than 80% of the cases. Even if the computed quantities are different in two different equilibria, the difference is typically very small – just one or two units. Thus, we believe that multiplicity is not a serious issue in our model.

Rearranging inequality (3) gives us the intuitive inequality

$$\begin{aligned}\overbrace{\mathrm{mc}_{tf} + e_{tfm}}^{\mathrm{mc}_{tfm}} \;\geq\;& p_{tfm}((q_{tfm}+1, q_{-tfm}, \boldsymbol{\epsilon}_m), q_{-fm}) \\ &- q_{tfm}[p_{tm}(q_m, \boldsymbol{\epsilon}_m) - p_{tm}((q_{tfm}+1, q_{-tfm}), q_{-fm}, \boldsymbol{\epsilon}_m)] \\ &- \boldsymbol{q}_{-tfm}[\boldsymbol{p}_{-tm}(q_m, \boldsymbol{\epsilon}_m) - \boldsymbol{p}_{-tm}((q_{tfm}+1, q_{-tfm}), q_{-fm}, \boldsymbol{\epsilon}_m)].\end{aligned}$$

The left-hand side is the marginal cost of producing an additional MRI, while the right-hand side is the marginal revenue of producing an additional MRI, which is decomposed into three terms. The first term is the additional revenue from selling one more MRI in segment t at the new price. The second term is the revenue loss from the decrease in the MRI price in segment t. Holding other manufacturers' production constant, producing one additional MRI leads to a decrease in the price in segment t and the new price will be applied to all units sold in segment t. Thus, we need to multiply the original units sold by the difference between the old and new prices. The last term is the revenue loss from the decrease in MRI prices in segments other than t. Because one additional MRI will be adopted in segment t, medical institutions in other segments will face lower demand and thus their willingness to pay for MRIs will be decreased. Therefore, the sum of these three terms is the marginal revenue and, redefining the right-hand side of inequality as $\mathrm{MR}_{tfm,+1}$, we obtain

$$e_{tfm} \geq \mathrm{MR}_{tfm,+1} - mc_{tf}. \tag{5}$$

The other inequality (4) also yields a similar inequality condition and combining these two conditions yields

$$\mathrm{MR}_{tfm,+1} - mc_{tf} \leq e_{tfm} \leq \mathrm{MR}_{tfm,-1} - mc_{tf}, \forall\ t, f, \text{ and } m.$$

If ξ_m and $\boldsymbol{\epsilon}_m$ is known, the inequality above enables us to calculate the likelihood

$$\mathbf{P}\left(\mathrm{MR}_{tfm,+1}(\xi_m, \boldsymbol{\epsilon}_m) - mc_{tf} \leq e_{tfm} \leq \mathrm{MR}_{tfm,-1}(\xi_m, \boldsymbol{\epsilon}_m) - mc_{tf}\right),$$

together with the normality assumptions for e_{tfm}. However, in this study, the unobserved market-specific effect ξ_m cannot be fully recovered from the demand estimation due to the measurement errors and $\boldsymbol{\epsilon}_m$ is not observed to econometricians. To construct a likelihood function of the data, we need to write a joint likelihood of all unobservable, e, ϵ, ξ. However, getting a closed form expression for such a likelihood function is difficult. Thus, we use a simulated maximum likelihood method to compute the likelihood of the data. The procedure is as follows. First, simulate an m-dimensional vector of ξ and $m \times T \times \mathcal{F} \times N^e$-dimensional

value of ϵ N times, denoted by ξ^n_{seed} and ϵ^n_{seed}. We fix those values throughout this estimation procedure. Then, estimate the downstream demand and obtain a set of parameters, $\hat{\theta}_1$, that does not depend on the second stage. Then, given θ_2, calculate the likelihood

$$\mathbf{P}\big(\mathrm{MR}_{tfm,+1}(\xi^n_{seed}, \epsilon^n_{seed}) - mc_{tf} \leq e_{tfm} \leq \mathrm{MR}_{tfm,-1}(\xi^n_{seed}, \epsilon^n_{seed}) - mc_{tf}\big)$$

and evaluate the log-likelihood of the data

$$L^n = \sum_m \left[\sum_{f,t} \log \mathbf{P}\big(\mathrm{MR}^n_{tfm,+1} - mc_{tf} \leq e_{tfm} \leq \mathrm{MR}^n_{tfm,-1} - mc_{tf}\big) \right].$$

We repeat this procedure to find the parameter that solves the maximization problem

$$\hat{\theta}_{2,MLE} = \arg\max_{\theta_2} \frac{1}{N} \sum_{n=1}^{N} L^n(\theta_2|\hat{\theta}_1). \tag{6}$$

5 Results

5.1 Estimation Results

Demand parameters Table 3 shows the results for the first-stage demand estimation. The first row presents the coefficient for the logarithm of income minus price. As expected, the estimation result for this coefficient is positive and statistically significant, implying that the out-of-pocket expenditure negatively affects the demand for MRI scanning services. This finding is consistent with the literature, e.g., Bhattacharya et al. (1996) and Shigeoka (2014), who show that an increase in out-of-pocket expenditure reduces the demand for medical care using the Japanese data. As β_1 (the coefficient for clinics with low-tesla MRI) is normalized to zero, β_2 through β_6 can be seen to represent consumers' preferences for each type of clinic/hospital compared to clinics that own low-tesla MRIs. Our results indicate that small hospitals with low-tesla MRIs are less preferred than clinics with low-tesla MRIs, whereas other segment types are more preferred. In general, the estimated coefficients suggest that imaging with high-tesla MRIs is more appreciated by high-income patients, because βs for high-tesla MRI is high and the difference in βs is more important than the difference in co-payments for high-income patients relative to low-income patients when they make their choices. This observation is consistent with Panel (b) in Figure 3. Knowing that high-income patients have such strong appreciation for high-tesla MRIs, medical institutions tend to enter the market by purchasing high-tesla MRIs in relatively wealthy markets.

Table 3: Demand Parameters

	Estimates	Std. Err.
$\alpha/(1-\lambda_2)$: log(Income - Price)	11.27**	4.50
$\beta_2/(1-\lambda_2)$: Clinic with high MRI	1.57***	0.34
$\beta_3/(1-\lambda_2)$: Small hospital with low MRI	-0.24*	0.14
$\beta_4/(1-\lambda_2)$: Small hospital with high MRI	1.37***	0.36
$\beta_5/(1-\lambda_2)$: Large hospital with low MRI	0.475***	0.13
$\beta_6/(1-\lambda_2)$: Large hospital with high MRI	1.80***	0.31

Note: This table reports the fixed-effect regression results for equation (2). Significance levels are denoted by $*(<0.1), **(<0.05)$, and $***(<0.01)$.

Cost parameters Given the demand estimates, the cost parameters are estimated and demonstrated in Table 4. The estimated cost parameters, roughly speaking, reflect the market shares of the MRI producers, because the relative rankings of market share and marginal cost correspond under Cournot competition. Thus, low market share should be attributed to high marginal cost. GE, the company that has the largest market share for high-tesla MRIs, has the lowest estimated marginal cost for high-tesla MRIs, while Hitachi, the company that has the largest market share for low-tesla MRIs, has the lowest estimated marginal cost for low-tesla MRIs. Other parameters are reported in Table 8 in Appendix B.

Table 4: Estimates for Cost Parameters

	High-Tesla MRI		Low-Tesla MRI	
	Est.	Std. Err.	Est.	Std. Err.
G.E.	4.16***	0.056	2.27***	0.024
Siemens	4.32***	0.069	2.24***	0.037
Philips	4.99***	0.070	2.20***	0.048
Shimadzu	6.05***	0.154	1.89***	0.038
Toshiba	3.58***	0.080	2.24***	0.025
Hitachi	7.17***	0.842	2.12***	0.023

Note: This table reports the MLE estimates defined by (6). The unit is translated to million Japanese Yen per week. Significance levels are denoted by $*(<0.1), **(<0.05)$, and $***(<0.01)$.

5.2 Policy Simulations

5.2.1 Decomposing the Effects of Regulation and Competition

We conduct three sets of counterfactual experiments to disentangle two components: the effects of quantity regulation and taxation, and the effects of competition in the upstream market. We first briefly explain what our counterfactual simulations are and provide further details later when we show the results.

In the first set of experiments, we begin by introducing French-style regulation on quantity, whereby 7.5 MRIs are allowed for every one million people. As this number is extremely small compared to the current Japanese number, which is close to 47 per million people, we also allow this number to be 10 and 23 for every one million people, in order to illustrate how the tightness of regulation affects consumer and producer surplus.[21] Second, we introduce a hypothetical sales tax on MRIs to reduce the medical arms race. As anecdotal evidence shows that the MRI prices in Japan are about 25% lower than those in the U.S., our hypothetical tax ratio is set to 30% to roughly approximate the prices in the U.S. The third set of counterfactual experiments examines how the degree of upstream market competition affects welfare. As the Japan Fair Trade Commission (2005) documented, the Japanese MRI market is more competitive than that of other countries, possibly due to severe competition among Japanese MRI producers. Thus, we first reduce the effect of such competition by merging three Japanese firms. Additionally, we also evaluate welfare under situations that allow for a cartel and for merging all six firms.

Table 5 summarizes the welfare implications for each case. The first column, labeled CV, shows compensating variation, which indicates how much consumers must be compensated for being indifferent between the current situation and the counterfactual one. On the other hand, the second through the seventh columns show each MRI producer's surplus and the eighth column sums them up. The ninth column describes the total profit of medical institutions. The tenth and eleventh columns, under Government, show the changes in insurer spending and tax revenue that result from imposing a sales tax. The last column, labeled Social Welfare, sums up compensating variation and MRI producer surplus. Similarly, Table 6 summarizes the numbers of low- and high-tesla MRIs sold by each MRI manufacturer under these counterfactual scenarios, while Table 7 demonstrates the utilization rate in each counterfactual scenarios and the changes in the number of patients compared to the current no regulation situation. In our data, the average utilization rates for low-tesla and high-tesla

[21] German adoption regulation is set at about 10 MRIs per million residents, while 23 MRIs per million residents roughly corresponds to one half of the current Japanese MRI adoption rate.

MRIs are about 25% and 50%, respectively, and thus, in all scenarios except for quantity regulation, we assume that the utilization rate cannot exceed 100%, which is four and two times more than the current level, respectively.

Table 5: Welfare change based on the degree of upstream market competition

	CV	Producer Surplus							Profit of	Δ Gov.	Tax	Social
		GE	Siemens	Philips	Shimadzu	Toshiba	Hitachi	Total	Medical Institution	Spending	Revenue	Welfare
Current	-	1.054	0.624	0.435	0.180	0.884	1.036	4.214	0.948	-	-	5.162
Regulation 7.5	-2.255	1.905	1.300	1.072	0.469	1.739	1.786	8.271	0.035	-0.781	-	6.832
Regulation 10	-1.988	1.863	1.283	0.979	0.442	1.763	1.885	8.215	0.055	-0.613	-	6.894
Regulation 23	-0.815	1.510	1.010	0.762	0.359	1.363	1.523	6.528	0.525	-0.262	-	6.500
Tax 30%	-0.520	0.656	0.402	0.251	0.095	0.573	0.809	2.787	0.770	-0.198	3.840	7.075
JPN Merge	-0.340	1.570	1.124	0.998		2.000		5.693	0.845	-0.104	-	6.302
Cartel	-1.247	1.471	1.081	0.793	0.266	1.352	1.391	6.354	0.041	-0.411	-	5.560
Monopoly	-2.452				8.351			8.351	0.022	-1.514	-	7.435

Note: This table summarizes the results of the counterfactual simulations. The first column reports the compensating variation (CV), normalized by the current utility level. Thus, a negative CV means that the consumer must be compensated by positive monetary transfer to achieve the current utility level. The second through eighth columns reports producer surplus. The ninth column describes the change in the profit of medical institutions. The tenth column describes the change in the health insurer's spending. The negative numbers indicate spending that is less than the current amount. The eleventh column shows the tax revenue. The last column represents social welfare by summing up CV, the total producer surplus, the change in government spending and the tax revenue. The unit is billion Yen per week.

Table 6: Changes in the Number of MRIs

	GE		Siemens		Philips		Shimadzu		Toshiba		Hitachi		Total		
	L	H	L	H	L	H	L	H	L	H	L	H	L	H	Total
Data	512	523	182	464	99	381	237	47	328	482	1,473	7	2,831	1,904	4,735
Model (Fit)	556	468	156	447	73	365	263	47	344	537	1,388	37	2,780	1,901	4,681
Regulation 7.5	113	123	35	107	17	84	45	10	64	121	301	8	575	453	1,028
Regulation 10	145	150	42	145	18	110	63	14	81	150	381	11	730	580	1,310
Regulation 23	286	301	87	279	40	235	128	28	18	315	796	25	1,354	1,183	2,537
Tax 30 %	436	302	129	311	56	241	191	20	251	335	1034	14	2,097	1,217	3,314
JPN Merge	614	484	245	525	143	483	(1234, 342)						2,236	1,834	4,070
Cartel	125	240	59	241	42	175	102	16	134	267	579	14	1,041	953	1,994
Monopoly	(1755, 77)												1,755	77	1,832

Note: This table summarizes the number of MRIs produced by each manufacturer in the data and under counterfactual scenarios. L and H represent low- and high-tesla MRIs, respectively.

Table 7: Capacity Utilization and Changes in the Number of Patients

	Utilization Rate		Number of Patients		
	Low	High	Low	High	Total
Regulation 7.5	86.5%	103.9%	71.6%	49.5%	58.8%
Regulation 10	77.3%	97.3%	81.2%	61.3%	66.5%
Regulation 23	43.2%	68.5%	84.2%	85.3%	84.8%
Tax 30%	33.8%	69.6%	102.0%	89.1%	94.5%
JPN Merger	27.8%	55.1%	89.4%	106.3%	99.2%
Monopoly	77.0%	92.2%	194.4%	7.5%	86.4%
Cartel	52.1%	75.6%	78.0%	75.8%	76.7%

Note: This table summarizes capacity utilization and changes in the number of patients for each counterfactual scenario. The first and second columns show the utilization rates for low- and high-tesla MRIs, respectively. First we calculate the proportional change, compared to the model prediction, and then multiply by the utilization rates in the data to obtain the utilization rates for each counterfactual scenario. The third through fifth columns represent the number of patients, compared to the model prediction.

Introduction of French-style regulation We first examine the effects of introducing French-style regulation. The second through fourth rows depict the results for regulation specifying 7.5, 10 and 23 MRIs per million people, respectively. The procedure of this policy experiment is as follows: we first calculate the number of MRIs that should be allocated in each geographical market. If the data indicates that the actual number of MRIs is greater than this hypothetical number, we then shrink the market while fixing the market shares constant, i.e., we proportionally reduce each MRI producer's production amount. Thus, roughly speaking, the market share must be the same as the first row, though there might be some differences due to the integer problem.

There are two important observations in these results. First of all, introduction of French-style quantity regulation would increase social welfare in all cases. These welfare gains come largely from the increase in producer surplus: in all cases, the MRI manufacturers would reduce their production amounts and be able to charge much higher prices for MRIs, which would drive up their profits. On the other hand, due to the decrease in the number of medical institutions that adopt MRIs, patients' choice sets would shrink substantially, resulting in a lower consumer surplus. In fact, this decrease in consumer surplus is not only driven by the shrinkage of choice sets, but also driven by the fact that some potential patients decide not to go to medical institutions. For example, only 58.8% of the current patients would

go to the medical institutions under Regulation 7.5, according to the last column in Table 7.[22] Thus the Japanese government must compensate consumers to maintain their current utility level. Overall, the former welfare gain in producer surplus exceeds the latter welfare loss in consumer surplus, as business-stealing effects in the downstream market are very severe in the current situation. This first observation essentially tells us that the current Japanese *laissez-faire* policy on MRI adoption results in excessive adoption of MRIs and social inefficiency.

The second observation is that tighter regulation might not necessarily enhance social welfare. When comparing the three regulation levels, the middle one, Regulation 10, achieves the highest social welfare. This observation is particularly important as it points out a limitation of regulation. There is no doubt that the current number of MRIs under *laissez-faire* policy is not optimal. At the same time, tight regulation such as Regulation 7.5 would not provide optimal allocation either. There must exist a level of regulation between 7.5 (French regulation) and 23 (roughly half of the current number of MRIs per million people in Japan) that maximizes social welfare. Therefore, when designing regulation, the government must recognize such a trade-off between consumer and producer surplus and choose an optimal level of regulation.

Introduction of a Sales Tax Another possible policy intervention that could help mitigate the excess adoption of MRIs is direct taxation of MRI sales. As expected, the number of MRIs, consumer surplus and producer surplus would decrease. However, the tax revenue would exceed the sum of these decreases, meaning that this policy could potentially achieve a Pareto-improving allocation by redistributing the tax revenue to producers and consumers. Moreover, note that the decrease in the number of patients is only about 5.5% according to Table 7. Thus, the decrease in consumer surplus is mostly due to the shrinkage of the choice sets rather than the decrease in the number of total patients taking MRI scans.

One important distinction between our paper and the existing literature on free entry is that the tax pass-through rate hinges on the market structure in the upstream market. In the case of perfect competition in the upstream market, the sales tax on MRIs will be fully reflected in the price. However, in the case of monopoly or oligopoly, only some fraction of the tax will be passed, because the monopolistic firm or oligopolistic firms can adjust their quantities. Therefore, when designing policies in vertical markets, policy makers must take

[22]Note that, in the case of Regulation 7.5, the utilization rate for high-tesla MRIs is slightly above 100%, indicating that the capacity constraint would be violated. Thus, the medical institutions might need to operate a little bit longer to implement this hypothetical regulation.

into account the vertical structure of the industry.

Softening Competition in the Upstream Market Finally, we study the impacts of changing the degree of upstream market competition. To illustrate the importance of the degree of upstream market competition, we consider three counterfactual scenarios. First, we merge three Japanese firms together (see JPN Merge, the sixth row of Table 5). Under this scenario, the merged firm would employ the best production technology available among the three Japanese firms in each market. In the second scenario, we allow all firms to collude to maximize the industry profit (see Cartel, the seventh row of Table 5). When working as a cartel, given the current market share, firms proportionally reduce their production amounts to maximize the industry profit, which is referred to as *Proportional Reduction* by Schmalensee (1987). The last scenario allows the merging of all six firms into a monopolist in the upstream market (see Monopoly, the eighth row of Table 5). A newly merged monopolist would be able to employ the best production technology for each market, i.e., the firm that has the lowest marginal cost, including stochastic shocks, produces all high-/low-tesla MRIs for each market. Notice that the difference between Cartel and Monopoly is whether there is an efficiency gain from production reallocation. In the case of a monopoly, the merged firm can employ the best technology and thus reallocate the production to the most efficient firms, whereas, in the case of a cartel, every firm must produce MRIs regardless of the efficiency of their technologies and there are no efficiency gains from product reallocation.

In all cases, softening competition in the upstream market would increase social welfare, although all such exercises are considered to be anti-competitive. The basic mechanism is similar to the introduction of quantity regulation in the downstream market. As the current number of MRIs in Japan is excessive, reducing the number of MRIs mitigates business-stealing effects and results in higher social welfare. Softening competition would allow MRI manufacturers to increase their mark-ups, which would discourage adoption of MRIs by medical institutions. Notice that as the degree of upstream market competition is softened from the current situation to JPN Merger, Cartel and Monopoly, social welfare increases. The softer the competition in the upstream market, the more MRI manufacturers internalize the business-stealing effects in the downstream market when they decide how many MRIs to produce.

In the case where three Japanese firms are merged, the total number of MRIs would dramatically decrease, as indicated in Table 6. This total number of MRIs is slightly larger than the number of MRIs per million people in the U.S. Notably, as demonstrated in Table

6, the number of low-tesla MRIs would substantially decrease in this case, triggering an increase in high-tesla MRI production by foreign firms, in particular, Siemens and Philips. In this way, there would be a shift from low- to high-tesla MRIs and consumers who prefer high-tesla MRIs would be better off, whereas some consumers who prefer low-tesla MRIs would be worse off. Therefore, the decrease in consumer welfare would be relatively small, given the large decrease in the number of MRIs.

A comparison of the results for the Cartel and Monopoly highlights the reallocation effect. In Table 6, when working as a cartel, MRI manufacturers produce more low-tesla MRIs than high-tesla MRIs, as they cannot reallocate their productions. In the case where all manufacturers are merged, the merged MRI manufacturers would produce even more low-tesla MRIs than high-tesla MRIs, further internalizing the business-stealing effect among medical institutions in the downstream market. In other words, under the case of monopoly, the merged firm is able to charge high prices by reducing the production quantity and increasing utilization rates as in Table 7, whereas currently MRIs are not fully utilized by medical institutions and the MRI manufacturers cannot charge such high prices.

Finally we would like to emphasize the importance of regulated medical treatment prices. Dating back to 2008, the difference in MRI scanning and associated prices for high- and low-tesla MRI is relatively small. Thus, if a medical institution can fully utilize the purchased MRI, the maximum revenues from high- and low-tesla MRIs are not so different from the medical institutions' point of view. Knowing this, under the case of monopoly, the merged monopolist tends to produce low-tesla MRI, because the production cost for low-tesla MRIs is much lower than that for high-tesla MRIs and the merged monopolist can fully internalize the business-stealing effect in the downstream market. Therefore, the design of the medical treatment prices may also affect the medical arms races. This could be a good topic for future research.

6 Conclusion

The recent increases in health care expenditures have led to the intense scrutiny of inefficiency arising from the medical arms race. Although the literature attempts to identify the existence of such inefficiencies, there are few papers that attempt to quantify the welfare implications. This paper, therefore, develops and estimates a tractable model of the medical arms race, and quantifies the welfare loss caused by the medical arms race in the context of MRI adoption. Specifically, we model the medical arms race with free entry (no regulation of

MRI adoption) of medical institutions and find that regulation or introduction of a sales tax helps restore efficiency. Furthermore, our model also allows us to quantify how competition in the upstream market affects social welfare. Unlike a common antitrust argument, in an industry with a vertical structure, softening the competition does not necessarily reduce social welfare. These findings shed light on a mechanism that determines how medical arms races result in social inefficiency and offer new insight into antitrust policies in industries with vertical structure.

Appendix A Proof of Proposition 1

Appendix A.1 Assumptions in Mankiw and Whinston (1986)

Assumption MW1. $Nq(N) > \hat{N}q(\hat{N})$ for all $N > \hat{N}$ and $\lim_{N\to\infty} Nq(N) = M < \infty$ for some constant M.

Assumption MW2. $q(N) < q(\hat{N})$ for all $N > \hat{N}$.

Assumption MW3. $P(Nq(N)) - c_d'(q(N)) \geq 0$ for all N where $P(Q)$ denotes the inverse demand function in the final good market and $P'(Q) < 0$.

Appendix A.2 Proof of Proposition 1

$$
\begin{aligned}
\frac{\partial W}{\partial N_u} &= \frac{\partial(Q_u q(Q_u))}{\partial N_u} P(Q_u q(Q_u)) - \frac{\partial Q_u}{\partial N_u} c(q(Q_u)) - Q_u \frac{\partial Q_u}{\partial N_u}\frac{\partial q(Q_u)}{\partial Q_u} c'(q(Q_u)) - \frac{\partial Q_u}{\partial N_u} K \\
&= \frac{\partial Q_u}{\partial N_u} q(Q_u) P(Q_u q(Q_u)) + Q_u \frac{\partial Q_u}{\partial N_u}\frac{\partial q(Q_u)}{\partial Q_u} P(Q_u q(Q_u)) \\
&\qquad - \frac{\partial Q_u}{\partial N_u} c(q(Q_u)) - Q_u \frac{\partial Q_u}{\partial N_u}\frac{\partial q(Q_u)}{\partial Q_u} c'(q(Q_u)) - \frac{\partial Q_u}{\partial N_u} K \\
&= \frac{\partial Q_u}{\partial N_u}\left(P(Q_u q(Q_u)) q(Q_u) - c(q(Q_u)) - p_u\right) + \frac{\partial Q_u}{\partial N_u}(p_u - K) \\
&\qquad + \frac{\partial Q_u}{\partial N_u} Q_u \frac{\partial q(Q_u)}{\partial Q_u}\left(P(Q_u q(Q_u)) - c'(q(Q_u))\right) \\
&= \frac{\partial Q_u}{\partial N_u}\left(-\frac{\partial p_u}{\partial Q_u} q_u + Q_u \frac{\partial q(Q_u)}{\partial Q_u}(P(Q_u q(Q_u)) - c'(q(Q_u)))\right) \\
&= \frac{\partial Q_u}{\partial N_u}\Big(-\frac{\partial q(Q_u)}{\partial Q_u}(P(Q_u q(Q_u)) - c'(q(Q_u))\frac{Q_u}{N_u} - \frac{\partial P(Q_u q(Q_u))}{\partial Q_u} q(Q_u)\frac{Q_u}{N_u} \\
&\qquad + Q_u \frac{\partial q(Q_u)}{\partial Q_u}(P(Q_u q(Q_u)) - c'(q(Q_u)))\Big).
\end{aligned}
$$

When $N_u = 1$, then

$$\frac{\partial W}{\partial N_u} = -\frac{\partial Q_u}{\partial N_u}\frac{\partial P(Q_u q(Q_u))}{\partial Q_u} q(Q_u)\frac{Q_u}{N_u} > 0.$$

Also, if $p_u = K$, then $\frac{dp_u}{dQ_u} q_u = 0$ and, therefore,

$$\frac{\partial W}{\partial N_u} = \frac{\partial Q_u}{\partial N_u} Q_u \frac{\partial q(Q_u)}{\partial Q_u}(P(Q_u q(Q_u)) - c'(q(Q_u))) \leq 0,$$

with strict inequality if $P(Q_u q(Q_u)) - c'(q(Q_u)) > 0$.

Appendix B Remaining Estimated Parameters

Table 8: Estimates for other parameters

	Estimates	Std. Err.
First Stage Parameters		
$(\lambda_1 - \lambda_2)/(1 - \lambda_2)$: First Stage Nest	0.03	0.09
Second Stage Parameters		
β_0: Constant in the indirect utility	-7.27***	0.09
λ_2: Lower nest parameter	0.74***	0.02
mc_3: Small hospitals with low-tesla specific cost	0.24***	0.02
mc_4: Small hospitals with high-tesla specific cost	-0.59***	0.08
mc_5: Large hospitals with low-tesla specific cost	0.90***	0.14
mc_6: Large hospitals with high-tesla specific cost	-0.72***	0.09
σ_ε^H: Variance for low-tesla MRI	0.49***	0.02
σ_ε^L: Variance for high-tesla MRI	0.94***	0.23
σ_ξ: Variance for market random effects	5.49***	0.61
σ_ϵ: Variance for unobserved profitability	0.84***	0.16

Note : This table summarizes the remaining estimation results. The first stage results come from the fixed-effect regression results for equation (2) and the second stage results come from the MLE estimates defined by (6). The unit is in thousand Japanese Yen per week for mc_3, mc_4, mc_5 and mc_6 and million Japanese Yen per week for σ_ε. Significance levels are denoted by $*(< 0.1), **(< 0.05)$, and $***(< 0.01)$.

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