Free Entry and Social Inefficiency in Vertical Relationships: The Case of the MRI Market*

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Abstract

This paper quantifies the social inefficiency that arises from the medical arms race in the context of MRI adoption. We construct a novel dataset that contains a complete list of medical institutions and includes their characteristics, MRI ownership and utilization information, and data on patient co-payments and medical institution reimbursements. Using the data, the paper builds and estimates a vertical industry model where MRI manufacturers sell MRIs and hospitals purchase MRIs ("free entry") in the upstream market, and hospitals provide medical services to patients in the downstream market. The estimated model allows us to evaluate potential policy interventions. Simulation results suggest that the current "laissez-faire" policy in Japan leads to excess MRI adoption, resulting in lower social welfare compared the regulation style used in France. Furthermore, softening competition in the upstream market via collusive agreement or mergers among upstream firms would increase social welfare substantially by reducing excess MRI adoption and mitigating the business-stealing effect in the downstream market. These findings shed light on the mechanism behind the social inefficiency of medical arms races and offer new insight into antitrust policies in industries with vertical structure.

Keywords: Vertical relationship, Free entry, MRI industry, Healthcare market
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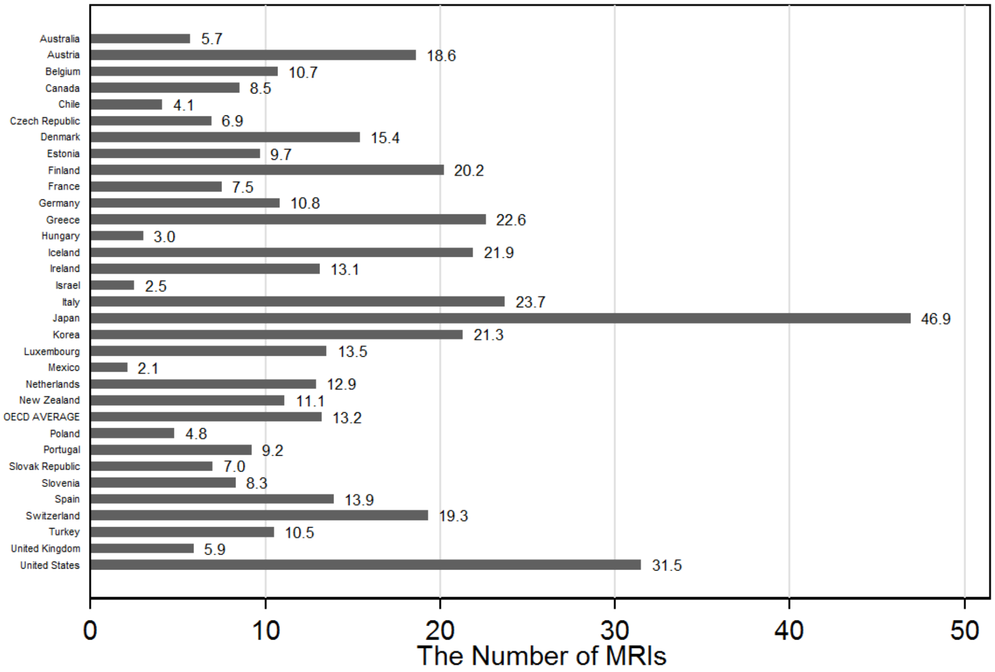
1 Introduction

The medical arms race, the proliferation of expensive medical technology and devices, has been a major concern related to increasing healthcare expenditures in many countries. To attract patients, medical institutions adopt new technology as long as the benefit exceeds the cost of adoption. From a social welfare point of view, however, such competition among medical institutions may result in unnecessary duplication of costly medical devices. This paper examines this potential inefficiency arising from the medical arms race in the context of adoption of magnetic resonance imaging scanners (hereinafter MRIs), as MRIs are among the most expensive medical devices and MRI adoption is frequently cited as an example of the medical arms races (Schmidt-Dengler (2006), Sari (2007), and Baker (2010)).

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



Source: OECD Health Statistics 2013.
Belgium, Germany and Switzerland only include MRIs in hospitals. The data is not available for Norway and Sweden.

An international comparison of the number of MRIs per million people 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 the U.K., 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. 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 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 MRIs than socially optimal, 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 a MRI, which can be viewed as free entry with large fixed cost. 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., competition 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. Modeling the upstream market may help us understand the difference in MRI adoption between Japan and the U.S. 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 is 25% lower than the price in the U.S.[1] The lower price in Japan may be 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-payment 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 collect 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 a MRI or not. In the downstream market, MRI-equipped 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

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[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.

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 two scenarios: one with regulations just like France's (7.5 MRIs per million people) and a slightly looser regulation (10 MRIs per million people).[2] In both scenarios, consumer surplus would decrease because fewer medical institutions 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. Moreover, the looser regulation would perform better than the tighter one, suggesting that the regulator must take into account the trade-off between these two effects to maximize social welfare.

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 internalize 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 real-

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[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.

locate their production, they are able to further internalize business-stealing effects among products.

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 our data 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 in 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] There are several notable features of the Japanese health care system: (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

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[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.

are allowed to go to any medical institutions in Japan, unlike the U.S. system which only allows patients to go to hospitals belonging to their health insurers' network. Thus, except in a few rare cases, patients can choose to go to whichever medical institutions they like, in principle. Furthermore, unlike some other 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 straight 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 institutions do not depend on home doctors' advice but rather on their own will.

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] Thus, regardless of their medical institution choices, the insured must pay the same fees for the same medical treatment in Japan.

Lastly, there are neither regulations nor subsidies affecting medical institutions' MRI adoption. Though this is not directly related to the health care system in Japan, medical institutions are formally divided into two big categories there: hospitals and clinics. The distinction depends purely 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. In many cases, hospitals have multiple clinical departments, whereas clinics have only one or a couple of clinical departments closely related to each other. This paper only deals with the medical institutions that potentially adopt MRIs. Therefore, we use all hospitals in Japan and about 15,000 clinics that focus on neurosurgery, neurology and orthopedics.

The MRI Industry in Japan MRI (Magnetic Resonance Imaging) is one of the medical imaging technique that enables the scanning of body tissues. In particular, it is a useful

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[5] As of 2015, some hospitals have started using the because the Japanese government encourages hospitals to shift to DPC (Diagnosis Procedure Combination) payment system 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.

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), and the single domestic producer is Shimazu Corp (Shimazu). 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. 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 potential reasons why there are so many MRIs in Japan.

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[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 taking a MRI scan and the standard consultation fees is 19,200. For high-tesla MRI, the fees typically include more components and it is not clear how to calculate the average reimbursement prices. Thus, we calibrate this 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.

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 2010 Census, as the Japanese government conducts Census every five years and 2010 is the closest year to our MRI data.

Descriptive Statistics Table 1 shows the numbers of large and small hospitals and clinics, depending on MRI ownership. 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 MRIs.

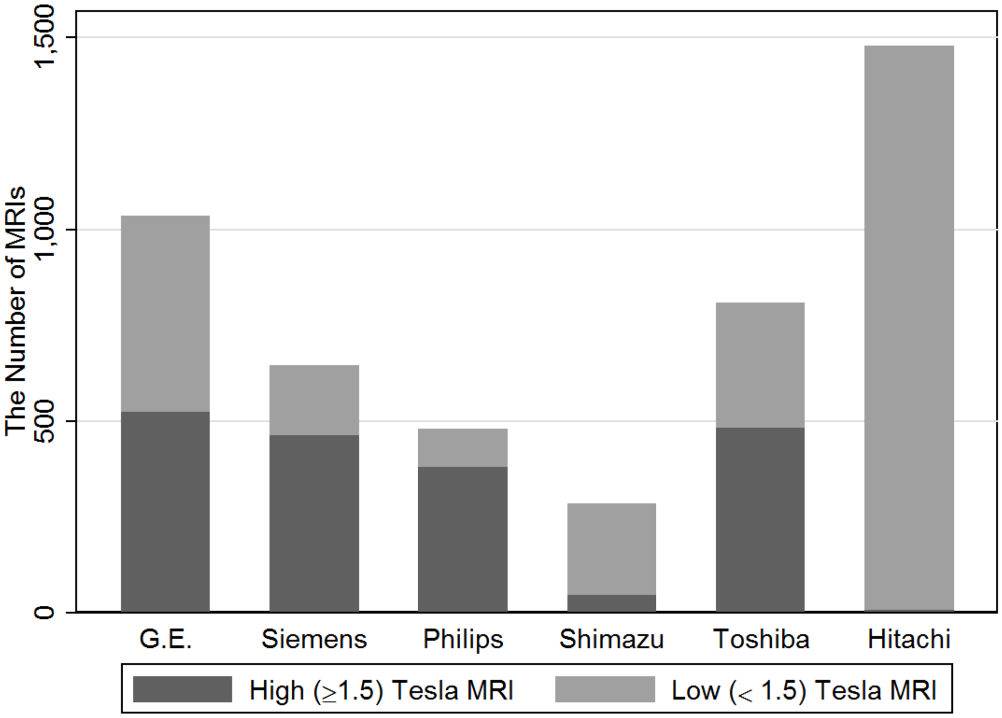
Next, Figure 2 depicts the market share. Though there are some differences in selling low-quality MRIs, *four* global MRI manufacturers produce very similar numbers of high-quality MRIs. In contrast, Hitachi, one of the global MRI manufacturers, has the largest share among six MRI producers and almost 99% of Hitachi's share comes from the sales of low-quality MRIs, when decomposing Hitachi's market share into two segments. A similar pattern is observed in the market share composition for Shimazu. Notice that the global market share

Table 1: MRI Ownership by Hospital Type

	No MRI	Owning MRI Low	Owning MRI High	Total
Hospitals				
Big (≥ 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

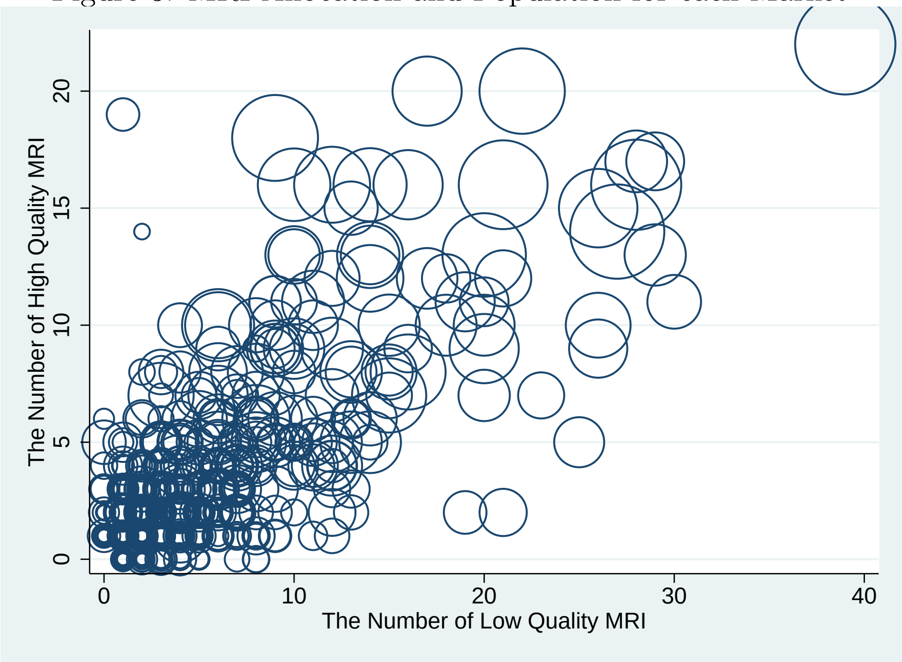
looks slightly different from this graph. In many OECD countries, GE, Philips and Siemens each accounts for 25% of the market share, respectively, whereas Toshiba typically accounts for 10 to 15% and Hitachi accounts for 5%. Thus, this unique market share could be due to the severe price competition in Japan, in particular for the segment of low-quality MRIs.

Figure 2: MRI Market Share in Japan



Lastly, Figure 3 shows the relationship among the numbers of high- and low-quality 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 big cities (cities designated by government ordinance and 23 Tokyo special districts) where we use municipalities for the market definition.[8] There are about 1,700 municipalities in Japan and our process results in 523 markets. The radius of the circle denotes the population of the market, while x and y axes denote the numbers of low- and high-quality MRIs, respectively. For example, the circle in the top-right denotes the city with the highest population, because the radius is the biggest, and with about 40 high-quality MRIs and 22 low-quality MRIs. Roughly speaking, the numbers of high- and low-quality MRIs increase proportionally with population, although they are not perfectly correlated.

Figure 3: MRI Allocation and Population for each Market



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

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[8] These definitions are based on an approximation of patients' behavior. In big cities, there are enough nearby choices 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 with larger geographical areas, which correspond to the medical administration areas.

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. Those readers who are interested in empirical analysis can proceed directly to Section 3.2.

3.1 The Theoretical Model

We model the industry as a three-stage game.[9] In the first stage, N_u identical upstream firms, a finite and fixed number, simultaneously decide the quantity of homogeneous intermediate product that is required for the downstream firms to enter into the final good market. All upstream firms possess exactly the same production technology, which is characterized by the cost function, $c_u(q)$. In the second stage, the price of the intermediate product, p_u, is realized and a large (infinite) number of identical potential entrants decide whether to enter the industry by purchasing one unit of the intermediate product. Upon entry, each downstream firm obtains access to a technology, characterized by the cost function $c_d(q)$. Lastly, in the third stage, these downstream firms that enter the market play an oligopoly game. This model is a natural extension of Mankiw and Whinston (1986) which does not consider the upstream market. They treat the entry costs as exogenously given and fixed. Our model endogenizes the entry cost of downstream firms as an equilibrium result of competition among upstream firms.

We list all assumptions about the upstream market that are necessary for our results.[10]

Assumption 1. $c_u(q) = Kq$ where K is a fixed constant.

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[9] Our model is similar to that of Ghosh and Morita (2007) in the sense that both incorporate vertical structure into Mankiw and Whinston (1986). Ghosh and Morita (2007) considers free entry in the upstream market with a fixed number of downstream firms, whereas our model focuses on the effect of upstream market competition with free-entry in the downstream market.

[10] See Appendix A for the assumptions on the downstream market, which are the same as those in Mankiw and Whinston (1986).

Assumption 2. The equilibrium in the first stage is symmetric and we define q_u to be the equilibrium output per upstream firm.

Since we introduced an upstream market, we must have a market-clearing assumption in the intermediate good market, as well as in the downstream market.

Assumption 3 (*Free-Entry Equilibrium*). Suppose the aggregate output of the intermediate good is Q_u, then $P(Q_u q_{Q_u})q_{Q_u} - c_d(q_{Q_u}) = p_u$.

This assumption corresponds to the free-entry assumption in Mankiw and Whinston (1986). In a free-entry equilibrium, the downstream firm enters as long as the marginal firm obtains non-negative profit. The assumption states that the marginal firm obtains exactly zero profit. Furthermore, it also characterizes how the intermediate good market clears and how the price is realized. Since the number of entrants is equal to the aggregate output of the intermediate good, the profit that the marginal entrant earns in the third stage can be rationally expected given the aggregate output, Q_u, and the mode of competition in the third stage. The market clearing for the intermediate good requires that the price of the intermediate good equals the profit the entrant earns 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 to be continuous as in Mankiw and Whinston (1986). Given all primitives, we define the equilibrium aggregate output of the intermediate good. The first-order condition for the upstream firm is given by

$$\frac{\partial p_u}{\partial N^e} q_u + p_u - K = 0.$$

The aggregate output is characterized by this condition and the free-entry equilibrium number of downstream firms, N^e, is equal to the total output of the intermediate good market, i.e., $N^e = N_u q_u$. Now, we can define social welfare as a function of the number of upstream firms, which is given by

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

Proposition 1 *Suppose Assumptions 1-3 and MW1-5 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

$$\frac{dW}{dN_u} \leq 0 \text{ if } p_u = K \text{ with strict inequality if } p(N^e q_{N^e}) - c'(q_{N^e}) > 0.$$

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 and 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, we build a sufficiently rich model that captures two features of the MRI industry: vertical structure and product differentiation, 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 MRIs and compete in quantities

Table 2: Concept of Segment

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

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 disease.

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 rate, which is explained in Section 2.

MRI manufacturers play Cournot competition in each geographical market. Although it is natural to use a differentiated product approach in a continuous fashion, 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 'segment,' which is defined as a Cartesian product of hospital types and MRI types, and is described in Table 2. 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, different hospital types, and the combination of these. From consumers' perspective, each MRI scan is differentiated by the characteristics of the MRI and those of the hospital From the hospitals' perspective, each hospital 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 the quantity they supply in each segment and the price of an MRI can differ in each segment.

3.2.1 Patient Demand for MRI Scan

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, Levinsohn and Pakes (1995) and used by Nevo (2001) and others. Ho (2006) and Ho (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 patients i in market m choosing medical institution j is defined by

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

where y_m denotes the average weekly 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 region-specific random effect, and ϵ_{ijm} is a random utility shock. The first term expresses the mean utility per monetary unit, whereas the second term expresses the utility from the segment to which medical institution j belongs. Thus, regardless of the identities of medical institutions, patients derive exactly the same mean utility from each segment to which medical institution j belongs. The model also includes ξ_m to capture region-m-specific effects, as there might be some region-specific factors, such as weather or food, that potentially affect the probability of becoming sick.

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, 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 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 whether the patient becomes sick or not. A high value of ε_{igm} can be interpreted as the patient becoming sick. The second nest captures the seriousness of the symptoms and diagnoses of patients. For example, a high value of $\varepsilon_{i,6,m}$, which leads to a high demand for an MRI scan in a large hospital with a high-tesla MRI, can be interpreted as a serious symptom. The final nest captures the idiosyncratic heterogeneity in consumer preference in the same segment, such as the distance to the hospital.

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 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 a set of patients who choose medical institution j to provide MRI scans and s_{jm} denotes a 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

$$\max_{a_{jm} \in \{0, L, H\}} \pi_{jm}(a_{jm}, \vec{a}_{-jm}),$$

where a_{jm} denotes an action and $\pi_{jm}(a_{jm}, \vec{a}_{-jm})$ denotes a profit function that depends on not only j's own action, a_{jm}, but also on the actions of other medical institutions, $\vec{a}_{-jm}$, in the same geographical market. For each medical institution, $a_{jm} = 0$ stands for purchasing no MRIs, and $a_{jm} =$ L or H stands for purchasing low- or high-tesla MRI, respectively. The profit function for each medical institution j in market m is specified as

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

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.[11] 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, summarized in p_{tm}.

As is clear from the expression, the model introduces strategic interaction among medical institutions in the same 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. If a medical institution k, different from j but

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

in the same market m, adopts MRI, patients could choose k as well and thus the market share for medical institution j, s_{jm}, would decreased. The magnitude of this decrease should depend on medical institution k's segment. For example, if both k and j belong to the same segment, we expect that these two medical institutions are equivalent from the patient's perspective and thus strategic interaction plays a large role. On the other hand, if j is a large hospital with a high-quality MRI and k is a clinic with a low-quality MRI, substitution between these two institutions should be relatively small and the decrease in s_{jm} should also be small. In this way, the model captures business-stealing effects across segments.

One might worry about the heterogeneity of medical institutions within a segment, i.e., even within the same segment the degree of substitution could be different. For example, in the segment comprised of large hospitals owning high-tesla MRIs, if two institutions are closely located, 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 in this model to keep our model tractable. Though models having such heterogeneity will better approximate the reality, such heterogeneity enormously increases the state space. Our model uses only the total number of medical institutions that adopt MRI in each segment. In this sense, our adoption game played by medical institutions is similar to the entry model of Bresnahan and Reiss (1991), which assume 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 into account heterogeneity. Therefore, although our way of introducing strategic interaction looks restrictive, this simplification dramatically reduces computational complexity and can be easily extended to introduce more heterogeneity.[12]

As pointed out by Schmidt-Dengler (2006), medical institutions have incentive to adopt MRIs in order to enhance their reputations and attract more non-MRI patients as well. In other words, adopting MRI has some externalities for other illnesses and thus our normaliza-

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

tion 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 when medical institutions adopt (or do not adopt) MRI, which is summarized in p_{tm}. We further discuss this issue in the subsequent subsection where we discuss marginal cost of MRI production.

3.2.3 MRI Producers' Competition

Each manufacturer plays a Cournot competition in each segment of market m, meaning that each firm solves the maximization problem

$$\max_{q_f} \ \pi_f(q_f, q_{-f}),$$

where MRI manufacturer f's profit is given by

$$\pi_f(q_f, q_{-f}) = \sum_m \pi_{fm}(q_{1m}, \cdots, q_{Fm}) = \sum_m \sum_t q_{tfm}(p_{tm} - mc_{tfm}).$$

$q_f = (q_{f1}, \cdots, q_{fM})$ and $q_{fm} = (q_{t_1 fm}, \cdots, q_{t_6 fm})$ denote vectors of quantities that manufacturer f produces in each market and quantities that manufacturer f produces for each segment t in market m, respectively, and 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 cost and benefit. Alternatively, we could model all relevant effects and costs such as the privilege effects and installation cost. However, the data only allows us to infer the difference in profits with and without the marginal MRI. Therefore, such effect 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, implying that there are no economies of scale in production. We further specify that the marginal cost is decomposed into two parts

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

where mc_{tf} denotes the deterministic part of marginal cost and e_{tfm} denotes the stochastic part of marginal cost, which follow 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 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 the 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.

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, $\{\mathrm{mc}_{tf}\}_{t=L,H,f=1,\cdots,F}$, and (iii) two variances of distributional assumptions for the marginal cost, σ_ε^2, and unobserved demand, σ_ξ^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, and (b) market share for each MRI manufacturer. 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 Demand Parameters

The demand estimation follows a standardized procedure.[13] The nested logit structure induces the following closed-form solution for the market share of each medical institution

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

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

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

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.[14] 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 the number of patients.

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

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

4.2 Estimating Upstream Supply Parameters

In the upstream market, the manufacturers compete in quantities and the quantities that we observe in the data must satisfy the manufacturers' profit maximization condition

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

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.[15] Specifically, the inequality condition is decomposed into two condition

$$\begin{aligned} \pi_{fm}(q_{fm}; q_{-fm}) &\geq \pi_{fm}((q_{tfm}+1, q_{-tfm}); q_{-fm}), & (2)\\ \pi_{fm}(q_{fm}; q_{-fm}) &\geq \pi_{fm}((q_{tfm}-1, q_{-tfm}); q_{-fm}). & (3) \end{aligned}$$

Rearranging inequality (2) gives us the intuitive inequality

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

The left-hand side is the marginal cost of producing an additional MRI, whereas 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

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[15] 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.

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

$$e_{tfm} \geq \mathrm{MR}_{tfm,+1} - mc_{tf}. \tag{4}$$

The other inequality (3) 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 is known, the inequality above enables us to calculate the likelihood

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

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, as we only observe the market share of 20% of medical institutions. In principle, ξ_m can be inferred from both the downstream demand (the number of patients) and upstream demand (the number of medical institutions purchase MRIs). Thus, in order to integrate them out, we use simulated maximum likelihood. The procedure is as follows. First, simulate an m-dimensional vector of ξ for N times, denoted by ξ^n_{seed} and fixed 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

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

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

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

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 scans. This finding is consistent with those of Bhattacharya et al. (1996) and Shigeoka (2014) who show that the 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' preference for each type of clinic/hospital compared to clinics that own low-tesla MRI. Our results indicate that the small hospitals with low-tesla MRIs are considered worse than clinics with low-tesla MRI, whereas other types are seen as better. In general, as coefficients β_2, β_4 and β_6 suggest, imaging with high-tesla MRIs is preferred.

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

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: Significance levels are denoted by $*(<0.1)$, $**(<0.05)$, and $***(<0.01)$.

high-tesla MRIs, has the lowest estimated marginal cost for high-tesla MRIs, whereas 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 7 in Appendix B.

Table 4: Estimates for Cost Parameters

	High-Tesla MRI		Low-Tesla MRI	
	Est.	Std. Err.	Est.	Std. Err.
G.E.	3.59***	0.067	1.71***	0.029
Siemens	3.75***	0.069	2.15***	0.039
Philips	3.99***	0.072	2.33***	0.043
Shimazu	5.05***	0.116	2.20***	0.037
Toshiba	3.58***	0.059	1.87***	0.031
Hitachi	5.17***	0.583	1.40***	0.028

Note 1: Significance levels are denoted by $*(<0.1)$, $**(<0.05)$, and $***(<0.01)$.

Note 2: The unit is million Japanese Yen per week.

5.2 Policy Simulations

5.2.1 Decomposing the Effects of Regulation and Competition

We conduct two sets of counterfactual experiments to disentangle two components: the effects of regulation 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 first introduce French-style regulation on quantity in which 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 for every one million people, in order to illustrate how the tightness of regulation affects consumer and producer surplus. The second 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 welfare implications for each case. The first column, labeled CV, shows that compensating variation, which indicates how much consumers must be compensated for being indifferent between the current and counterfactual situations. On the other hand, the second through the seventh columns show each MRI producer's surplus and the eighth column sums them up. The last column, labeled Social Welfare, sums up compensating variation and MRI producer surplus. As the model imposes the zero-profit condition for hospitals, the profit for hospitals in our model is zero by definition and thus is excluded from Table 5. Similarly, Table 6 also summarizes the numbers of low- and high-tesla MRIs sold by each MRI manufacturer under these counterfactual scenarios.

Introduction of French-style regulation We first examine the effects of introducing French-style regulation. The second and third rows depict the results for regulation specifying 7.5 and 10 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 by fixing the market shares constant, i.e.,

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

		Producer Surplus							Social
	CV	GE	Siemens	Philips	Shimazu	Toshiba	Hitach	Total	Welfare
Current	-	1.065	0.668	0.447	0.186	0.902	1.123	4.390	4.390
Regulation 7.5	2.350	1.953	1.395	1.084	0.494	1.829	1.948	8.701	6.351
Regulation 10	1.948	1.972	1.390	1.085	0.482	1.851	1.887	8.667	6.719
JPN Merge	0.115	1.422	0.964	0.674	1.801			4.860	4.745
Cartel	2.228	2.010	1.444	1.104	0.502	1.881	1.943	8.883	6.595
Monopoly	3.195	11.344						11.344	8.149

Note: The unit for CV (Compensating Variation), PS (Producer Surplus) and Social Welfare is billion Yen per week.

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 for both cases, 7.5 and 10. These welfare gains come largely from the increase in producer surplus: in both 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. This implies that 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 two regulation levels, the looser one, Regulation 10, yields higher social welfare than the tighter one, Regulation 7.5. 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 47 (the current number of MRIs per million people in Japan), which maximizes social welfare. Therefore, when designing regulation, the government must recognize such the trade-off between consumer and producer surplus and choose an optimal level of regulation.

Softening Competition in the Upstream Market Next, we study the impacts of changing the degree of upstream market competition. To illustrate the importance of the degree of competition in the upstream market, we consider three counterfactual scenarios. First, we merge three Japanese firms together (see JPN Merge, the fourth 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 fifth row of Table 5). When working as a cartel, given the current market share, firms proportionally reduce their production amount to maximize the industry profit, which is referred to as *Proportional Reduction* by Schmalensee (1987). The last scenario allows the merging all six firms to be a monopolist in the upstream market (see Monopoly, the sixth 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 the 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 would increase. The softer the competition in the upstream market, the more MRI manufacturers internalize the business-stealing effect 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 close to 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, which triggers an increase in high-tesla MRI production by foreign firms. 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 consumera who prefer low-tesla MRIs would 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 cases also confirms this 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. However, in the case where all manufacturers are merged, the merged MRI manufacturer would produce more high-tesla MRIs than low-tesla MRIs, further internalizing the business-stealing effect among medical institutions in the downstream market.

There are two important takeaways from these experiments. First, the Japanese data reveals the inefficiency that arises from the medical arms race. Second, we identify a new mechanism that counteracts the medical arms race – intervention in the upstream market, in addition to direct regulation of the downstream market, which is discussed in the existing literature. Our new approach may perform better as it further internalizes the business-stealing effect and allows production reallocation. However, in either case, in order to restore efficiency, we must understand the vertical structure of the industry.

Table 6: Changes in the Number of MRIs

	GE		Siemens		Philips		Shimazu		Toshiba		Hitachi		Total		
	L	H	L	H	L	H	L	H	L	H	L	H	L	H	Sum
Data	512	523	182	464	99	381	237	47	328	482	1,473	7	2,834	1,904	4,738
Model (Fit)	534	478	157	451	76	363	257	45	335	513	1,373	38	2,732	1,888	4,620
Regulation 7.5	97	115	30	106	14	85	44	10	60	116	273	8	518	440	958
Regulation 10	139	154	44	143	19	112	62	14	82	155	373	11	719	589	1,308
JPN Merge	454	611	159	567	91	454	(920, 511)						1,624	2,143	3,767
Cartel	124	122	41	115	18	87	50	10	70	122	314	8	617	464	1,081
Monopoly	(272, 356)												272	356	628

6 Conclusion

The recent increases in health care expenditures have led to the huge attention to 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 as free entry (no regulation of MRI adoption) of medical institutions and find that regulation 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 offers 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 1. $c_u(q) = Kq$ where K is a fixed constant.

Assumption 2. The equilibrium in the first stage is symmetric and we define q_u to be the equilibrium output per upstream firm.

Assumption MW1. $c_d(\cdot)$ is continuous, $c_d(0) = 0$, $c_d'(\cdot) \geq 0$, and $c_d''(\cdot) \geq 0$ for all $q \geq 0$.

Assumption MW2. The equilibrium in the third stage is symmetric and we define q_N to be the equilibrium output per downstream firm given that N firms have entered into the final good market.

Assumption MW3. $Nq_N > \hat{N}q_{\hat{N}}$ for all $N > \hat{N}$ and $\lim_{N\to\infty} Nq_N = M < \infty$ for some constant M.

Assumption MW4. $q_N < q_{\hat{N}}$ for all $N > \hat{N}$.

Assumption MW5. $P(Nq_N) - c_d'(q_N) \geq 0$ 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

$$\begin{aligned}
\frac{dW}{dN_u} &= \frac{d(N^e q_{N^e})}{dN_u} p(N^e q_{N^e}) - \frac{dN^e}{dN_u} c(q_{N^e}) - N^e \frac{dN^e}{dN_u} \frac{dq_{N^e}}{dN^e} c'(q_{N^e}) - \frac{dN^e}{dN_u} K \\
&= \frac{dN^e}{dN_u} q_{N^e} p(N^e q_{N^e}) + N^e \frac{dN^e}{dN_u} \frac{dq_{N^e}}{dN^e} p(N^e q_{N^e}) - \frac{dN^e}{dN_u} c(q_{N^e}) - N^e \frac{dN^e}{dN_u} \frac{dq_{N^e}}{dN^e} c'(q_{N^e}) - \frac{dN^e}{dN_u} K \\
&= \frac{dN^e}{dN_u} \left(p(N^e q_{N^e}) q_{N^e} - c(q_{N^e}) - p_u\right) + \frac{dN^e}{dN_u}(p_u - K) + \frac{dN^e}{dN_u} N^e \frac{dq_{N^e}}{dN^e}(p(N^e q_{N^e}) - c'(q_{N^e})) \\
&= \frac{dN^e}{dN_u} \left(-\frac{dp_u}{dN^e} q_u + N^e \frac{dq_{N^e}}{dN^e}(p(N^e q_{N^e}) - c'(q_{N^e}))\right) \\
&= \frac{dN^e}{dN_u} \left(-\frac{dp_u}{dN^e} q_u + N^e \frac{dq_{N^e}}{dN^e}(p(N^e q_{N^e}) - c'(q_{N^e}))\right) \\
&= \frac{dN^e}{dN_u} \left(-\frac{dq_{N^e}}{dN^e}(p(N^e q_{N^e}) - c'(q_{N^e}) \frac{N^e}{N_u} - \frac{dp(N^e q_{N^e})}{dN^e} q_{N^e} \frac{N^e}{N_u} + N^e \frac{dq_{N^e}}{dN^e}(p(N^e q_{N^e}) - c'(q_{N^e}))\right)
\end{aligned}$$

When $N_u = 1$, then

$$\frac{dW}{dN_u} = -\frac{dN^e}{dN_u} \frac{dp(N^e q_{N^e})}{dN^e} q_{N^e} \frac{N^e}{N_u} > 0.$$

Also, if $p_u = K$, then

$$\frac{dW}{dN_u} = \frac{dN^e}{dN_u} N^e \frac{dq_{N^e}}{dN^e}(p(N^e q_{N^e}) - c'(q_{N^e})) \leq 0,$$

with strict inequality if $p(N^e q_{N^e}) - c'(q_{N^e}) > 0$.

Appendix B Remaining Estimated Parameters

Table 7: 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	-5.56***	0.11
λ_2: Lower nest parameter	0.95***	0.001
mc_3: Small hospitals with low-tesla specific cost	3.84***	0.93
mc_4: Small hospitals with high-tesla specific cost	0.37***	0.01
mc_5: Large hospitals with low-tesla specific cost	-2.28***	0.59
mc_6: Large hospitals with high-tesla specific cost	0.41***	0.11
σ_ε^H: Variance for low-tesla MRI	0.63***	0.01
σ_ε^L: Variance for high-tesla MRI	0.94***	0.17
σ_ξ: Variance for market random effects	11.49***	0.76

Note 1: Significance levels are denoted by $*(< 0.1), **(< 0.05)$, and $***(< 0.01)$.

Note 2: 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.

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