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ORIGINAL ARTICLE

Inference on noncooperative entry deterrence

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Abstract

This study empirically investigates strategic entry-deterrence behavior under oligopolistic competition. I develop a structural econometric model describing incumbents' entry-deterrence behavior based on the framework of Gilbert and Vives. I show theoretically that incumbents' marginal costs are interval-identified under the assumption that incumbents deter entry in equilibrium. The structural model is estimated using data from the Japanese aluminum smelting industry. A Vuong-type model selection test utilizing an instrument demonstrates that the entry-deterrence model is more consistent with the data than an ordinary Cournot competition model without entry threats.

1 | INTRODUCTION

Strategic entry deterrence is one of the central research issues that continues to command attention in the field of industrial organization. It is essential to understand comprehensively the process by which firms deter entry and the consequences to devise an effective competition policy to enhance market performance. Therefore, researchers in the industrial organization field have examined theoretically whether various firms' strategies are effective for entry deterrence (Tirole, 1988; Vives, 1999). Antitrust policymakers and researchers have been interested not only in how entry is deterred in theory but also in whether firms undertake entry-detering strategies in the real world and how such behavior can be detected (Lieberman, 1987; Smiley, 1988). This study empirically investigates strategic entry-deterrence behavior under oligopolistic competition.

Compared with the significant advances in theoretical studies, there are relatively few empirical studies that provide evidence on strategic entry deterrence. One of the reasons why the number of empirical studies is small is that the literature largely focuses on industries in which researchers can clearly identify the emergence of new entry threats; for example, patent expiration in the pharmaceutical industry (see Ellison & Ellison, 2011), entry plans in the casino industry (Cookson, 2017), and Southwest's endpoint operation in the airline industry (Sweeting et al., 2020). Researchers provide empirical evidence by demonstrating the change of incumbents' strategies around the emergence of such new entry threats. However, the approach limits the examination of an industry where firms may have strategically undertaken entry deterrence, but researchers cannot identify the emergence of the entry threats that firms face.¹ In general, it is difficult for researchers to identify new threats.

Departing from the above approach, this study relies on conduct testing, which is used in the empirical industrial organization literature. Conduct testing is a statistical method for determining which model of firm conduct or competition is appropriate to describe the competition in a particular industry. In the conduct testing literature, researchers construct and estimate various competing models of firm conduct, compare the models, and determine which model has the best explanatory power.² More specifically, researchers utilize the Vuong-type model selection

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test developed by Vuong (1989) and extended by Rivers and Vuong (2002) to statistically compare two competing models of firm conduct.

To adopt the conduct testing approach, it is necessary to estimate a structural model of entry deterrence. I develop a structural model of entry deterrence based on the theoretical model of Gilbert and Vives (1986). In their model of entry deterrence, incumbents' commitment to production quantity is an entry-deterrence strategy. Using the equilibrium condition of their theoretical model, I show that incumbents' marginal costs can be identified from observable data, which enables me to estimate the structural model. Specifically, the marginal costs are not point-identified but interval-identified using the equilibrium condition. The upper bounds of the interval-identified marginal costs correspond to the level of costs at which the incumbents are indifferent between deterring or allowing entry, whereas the lower bounds correspond to those identified under the assumption of Cournot competition. Furthermore, I propose a method to numerically calculate the upper bounds of the identified marginal costs, as they may not have a closed-form representation, depending on the specification of the demand function.

The Japanese aluminum smelting industry in the post-World War II period provides a good case study to examine empirically strategic entry deterrence. The history of the industry indicates that its incumbent firms were threatened by the entry of potential rival firms and that the incumbents were likely to undertake entry-detering strategies. The simple characteristics of aluminum as a product prevent firms in the industry from using certain methods of entry deterrence, such as advertising or brand proliferation. Furthermore, the data on the capacity utilization rate suggest that the overcapacity strategy is not suitable to describe the industry. These features enable us to investigate the industry using the entry-deterrence model where incumbents' commitment to production quantity is a strategic variable.

The Japanese aluminum industry is suitable for a case study not only because of the suspicion or likelihood of entry-deterrence behavior but also because of data appropriateness. Recent studies in the conduct testing literature, Backus et al. (2021) and Duarte et al. (2020), propose using generalized method of moments (GMM) objective functions based on excluded instruments for marginal cost as a criterion function in the framework of Rivers and Vuong (2002). This is because Berry and Haile (2014) demonstrate that we can utilize a moment condition constructed from the excluded instruments to falsify a model of firm conduct. Various types of economic variables can be adopted as appropriate excluded instruments in a differentiated product industry, such as the product characteristics of other firms. However, there are limited appropriate excluded instrumental variables in a homogeneous product industry. The data on the Japanese aluminum industry include (rival) firms' cost-efficiency measures, which provide the basis for an appropriate instrument. Therefore I can perform the model selection test based on excluded instruments.

The results of these tests suggest that the entry-deterrence model is more consistent with the data than the Cournot or perfect competition models. Furthermore, because the data include a sample period in which the threat of entry has disappeared, I test firm conduct in this period to provide an insight into whether the threat of entry makes the aluminum industry a competitive environment. The results show that after the threat of entry has disappeared, the Cournot and perfect competition models are both consistent with the data to a similar degree, with the former being slightly more consistent.

1.1 | Related literature

This study is related to two strands of literature in the field of industrial organization. The first strand comprises studies that aim to provide empirical evidence of strategic entry deterrence. Commonly, studies adopt the approach of examining different investment strategies between firms in situations with and without entry threats. The seminal work by Lieberman (1987) investigates whether incumbent firms strategically maintain excess capacity in a rapidly growing chemical industry. If an incumbent has an incentive to deter the entry of potential rivals in a growing industry, the industry growth rate and the capacity utilization rate that are sufficient to elicit new capacity installation will be lower for incumbents than for entrants. However, Lieberman (1987) shows that entrants and incumbents exhibit similar investment strategies. Cookson (2017) examines whether capacity expansion strategies vary between incumbents facing or not facing entry threats. The casino entry plan data on which Cookson (2017) focuses enables him to identify clearly whether an incumbent is threatened by entry plans because the data include information on the planned site of a proposed entrant. By employing a difference-in-difference method, Cookson shows that incumbents expand their capacity with a motive to deter entry. Ellison and Ellison (2011) introduce a novel approach for empirically examining entry deterrence. They prove that there is a nonmonotonic relationship between market size (or attractiveness of entry) and

strategic investment under entry-deterrence motives and that the relationship is monotonic if firms do not invest for the purpose of entry deterrence. Therefore, they propose testing the monotonicity between market size and incumbents' investment to examine strategic entry-deterrence behavior. Sweeting et al. (2020) adopt Ellison and Ellison's (2011) approach to examine limit pricing. The present study contributes to this literature by presenting new empirical evidence in environments where the methods adopted in the existing literature are not applicable.

Several studies in this strand of literature rely on a structural econometric approach. To investigate the entry-deterrence impact of code-sharing, which is a form of strategic alliance in airline industries, Gayle and Xie (2018) estimate a dynamic structural model of entry and exit in the tradition of Ericson and Pakes (1995). They show that code-sharing influences potential entrants' market entry costs and thereby effectively functions as a means of entry deterrence. In addition, they demonstrate that entry costs vary according to the form of code-sharing and the identity of entrants. From the perspective of predation differing from entry deterrence, Snider (2009) and Williams (2012) show that incumbent firms in the US domestic airline industry had predatory incentives when they invested in capacity building and thereby induced entrants to exit the market.

The second strand of literature to which this study contributes is concerned with the issue of conduct testing and identifying markup and marginal cost based on model assumptions. Understanding firm conduct is not only of general interest for researchers but also a fundamental component of structural models used for policy evaluation. Therefore, researchers in the industrial organization field have developed and empirically tested various structural models describing firm conduct. Several studies use pairwise model selection tests for nonnested models originally developed by Vuong (1989) and extended by Rivers and Vuong (2002). The tests have been applied to various economic issues, including collusion (Doi & Ohashi, 2019; Gasmi et al., 1992), vertical relationships (Bonnet & Dubois, 2010; Sudhir, 2001), and common ownership (Backus et al., 2021).^{3,4}

In recent years, new insights have been developed within this strand of literature. Berry and Haile (2014) generalize Bresnahan's (1982) idea of "demand rotation" to identify the degree of competition and derive testable restrictions to falsify a model of firm conduct. The restriction is a moment condition constructed from an excluded instrument for marginal cost. Building on Berry and Haile's (2014) arguments, Backus et al. (2021) and Duarte et al. (2020) propose a test using a GMM objective function based on excluded instruments as a criterion in Rivers and Vuong's (2002) test framework. Furthermore, Backus et al. (2021) develop a method of constructing a scalar instrumental variable using the assumption of the mean independence of the marginal cost shock and the instrument rather than the no-correlation assumption.

Salvo (2010) is one of the studies most relevant to this one because it develops a structural econometric model where incumbents face a threat of imports and tests the model using Vuong's type model selection test. However, there are significant differences between the current study and Salvo (2010) because the way that the threat of entry is modeled is quite different between the two papers and because I employ the excluded instrument, that is, the rival firms' cost-efficiency measure, to test the model. Therefore, this study contributes to this literature by providing a new identification result for marginal costs under the assumption of an entry-deterrence model based on Gilbert and Vives (1986), and by testing the model utilizing the new insights for testing firm conduct.

The remainder of the paper is organized as follows. Section 2 introduces the model describing the entry-deterrence behavior of incumbent firms and presents the identification result for the incumbents' marginal cost. Section 3 provides an overview of the development of the Japanese aluminum smelting industry. Section 4 presents the specification employed for empirical analysis, elaborates on the data set used, and provides estimation and testing results. Section 5 concludes by summarizing the main results and identifying topics for future research.

2 | MODEL AND IDENTIFICATION OF MARGINAL COSTS

In this section, I first describe a theoretical model of entry deterrence based on Gilbert and Vives (1986) and then show that the marginal costs of the incumbents are interval-identified using the equilibrium condition of the model. The identified marginal cost is used to estimate the marginal cost function and the tests of firm conduct in Section 4.

2.1 | Settings

I consider a two-stage game with complete information. There are M incumbent firms and a potential entrant. Both the incumbents and the entrant produce a homogeneous product. Let i represent a generic incumbent and e represent the

entrant. In the first stage of the game, the incumbent firms independently make their respective production decisions. In the second stage, the potential entrant decides on whether to enter and, if it does enter, its level of production, given the incumbents' first-stage output. The entrant incurs a sunk entry cost if it enters. Given the total output, the market-clearing price is realized.

Incumbent firm i 's cost function is assumed to be $C_i(x) = c_i x$, where $c_i \geq 0$ is a positive constant that can differ between incumbents, and x represents a level of production. The entrant has a cost function of $C_e(x) = c_e x + F$ if $x > 0$, and zero otherwise, where $F \geq 0$ is a sunk entry cost and $c_e \geq 0$ is a constant marginal cost for the entrant.

Let $P(X)$ denote the inverse demand function, where X represents the total industry output. I assume that $P(X)$ is twice continuously differentiable, downward sloping, that is, $P' < 0$, and concave, that is, $P'' < 0$, whenever $P(X)$ is positive. In addition, I assume that the inverse demand and each firm's marginal cost functions intersect, that is, a value of ξ exists such that $P(\xi) = c_i$ for each firm.

Ignoring entry for a moment, let $r(Z, c)$ be the optimal level of output for an incumbent firm with marginal cost c when the other firms produce a total output of Z . In other words,⁵

$$r(Z, c) = \operatorname{argmax}_x P(x + Z)x - cx. \quad (1)$$

The convexity of the response function $r(Z, c)$ in Z is assumed.⁶

The potential entrant actually enters the market if the profit that it earns as a Stackelberg follower exceeds the sunk entry cost; otherwise, it does not enter. Because the profit that the entrant earns as a Stackelberg follower is decreasing in the first-stage total output, there exists a minimum level of first-stage total output that induces the entrant to give up entering the market. It is referred to as the critical limit output, Y , for the oligopoly, and satisfies the following equation:

$$\pi_e(r(Y, c_e), Y) = F,$$

where $\pi_e(r(Y, c_e), Y) = (P(r(Y, c_e) + Y) - c_e)r(Y, c_e)$ is the maximum profit that the entrant can earn as a Stackelberg follower.

2.2 | Best response function and entry-detering equilibrium

Consider incumbent i and let the other incumbents produce Z to analyze the incentive for entry deterrence and drive the best response function, $\phi_i(Z)$.

When Z is sufficiently large, firm i has no incentive to deter entry; rather, entry is blockaded. This is because the total output of the first stage exceeds the limit output when firm i merely produces according to its Cournot best response function, that is, $r(Z, c_i) + Z \geq Y$ holds. Let $\bar{Z}(Y, c_i)$ satisfy the following equation:

$$Z + r(Z, c_i) = Y. \quad (2)$$

The solution represents the minimum output level of Z with which firm i can block entry by merely producing the Cournot optimal output.⁷

When firm i cannot block entry, that is, $Z < \bar{Z}(Y, c_i)$, firm i may or may not have an incentive to deter entry. In this case, firm i has two options: deterring or allowing entry. On the one hand, when firm i attempts to deter entry, it will produce $Y - Z$ to make up the difference between Y and Z , and will earn

$$\bar{\pi}^{NE}(Z, Y, c_i) = (P(Y) - c_i)(Y - Z). \quad (3)$$

Here, $\bar{\pi}^{NE}(Z, Y, c_i)$ represents the value (or maximal profit) of the incumbent arising from deterring entry. On the other hand, when firm i allows entry, it behaves as if it were a Stackelberg leader and earns:

$$\pi^E(Z, c_i, c_e) = (P(s(Z, c_i, c_e) + Z + r(s(Z, c_i, c_e) + Z, c_e)) - c_i)s(Z, c_i, c_e), \quad (4)$$

where $\pi^E(Z, c_i, c_e)$ represents the value of the firm arising from allowing entry and $s(Z, c_i, c_e)$ is the optimal output of firm i when the potential entrant enters the market and produces optimally given the first-stage total output.

Firm i compares the two values of (3) and (4) and the optimal strategy becomes one involving a threshold. When $Z = \bar{Z}(Y, c_i)$, firm i will deter entry because $Y - Z$ corresponds to the Cournot best response and the value of deterring entry is necessarily larger than that of allowing entry. When $Z < \bar{Z}(Y, c_i)$, the incentive to deter entry gradually disappears as Z becomes smaller. The value of deterring entry in Equation (3) is a linear decreasing function in Z , whereas that of allowing entry in Equation (4) is strictly convex and decreasing in Z , as shown in Lemma 2 in Appendix A.1. On the basis of these two arguments, there is a unique threshold such that when Z exceeds this threshold, the value of deterring entry exceeds the value of allowing entry. The threshold, denoted by $\underline{Z}(Y, c_i, c_e)$, is the unique solution to the equation:

$$\pi^{NE}(Z, Y, c_i) = \pi^E(Z, c_i, c_e). \quad (5)$$

Therefore, if $Z > \underline{Z}(Y, c_i, c_e)$, firm i has an incentive to deter entry, but otherwise it allows entry.

The above arguments are summarized as the following best response function of firm i :

$$\phi_i(Z) = \begin{cases} r(Z, c_i) & \text{if } Z \geq \bar{Z}(Y, c_i), \\ Y - Z & \text{if } \underline{Z}(Y, c_i, c_e) \leq Z < \bar{Z}(Y, c_i), \\ s(Z, c_i, c_e) & \text{if } 0 \leq Z < \underline{Z}(Y, c_i, c_e). \end{cases} \quad (6)$$

The following proposition states the existence of entry-deterring equilibria. At any equilibria, the limit output Y is produced in the first stage, and each incumbent's output satisfies a certain condition. This condition is important for the identification of marginal costs.

Proposition 1. *Let X^C be the total output in the Cournot equilibrium between incumbents, let \bar{Y} be the largest Y such that the ϕ s intersect on the hyperplane $\sum_{i=1}^M x_i = Y$, and let X_{-i} be $\sum_{j \neq i} x_j$. If $X^C \leq Y \leq \bar{Y}$, then any $x = (x_i)_{i=1}^M$ in the set $\mathcal{E} = \left\{ x \in \mathbb{R}_+^M \mid \sum_{i=1}^M x_i = Y, r(X_{-i}, c_i) \leq x_i \leq Y - \underline{Z}(Y, c_i, c_e), \forall i \right\}$ and the potential entrant remaining out of the market is a subgame perfect equilibrium. Incumbents prevent entry by producing a total output of Y .*

Proof. See Appendix A.2. □

The model and the proposition introduce cost heterogeneity into those of Gilbert and Vives (1986). Because introducing cost heterogeneity does not change the incumbent's best response function, the proof is almost the same as theirs.

2.3 | Identification of marginal cost

To consider the identification problem concerning the incumbents' marginal cost $(c_i)_{i=1}^M$, it is first necessary to define the observables for a researcher. A researcher can observe the market price P and the firm-level output $(x_i)_{i=1}^M$. The researcher need not observe entry cost F , but it is assumed that the marginal cost of a potential entrant c_e is observable. Although the assumption that c_e is known is strong, it is realistic that a researcher has prior knowledge of the range of possible values for a parameter. That is, a researcher knows that c_e falls into a known interval of $[\underline{c}_e, \bar{c}_e]$. In this case, to construct a conservative identification region for the incumbents' marginal cost, let c_e be \underline{c}_e .⁸

To identify the incumbents' marginal cost, the following proposition is useful. The proposition shows that firms with higher marginal costs are less willing to deter entry if other firms do not produce a sufficient amount.

Proposition 2. *When $\underline{Z}(Y, c_i, c_e) > 0$, $\underline{Z}(Y, c_i, c_e)$ is strictly increasing in c_i .*

Proof. See Appendix A.2. □



Assume that an entry-deterring equilibrium is realized in the data, that is, $(x_i)_{i=1}^M \in \mathcal{E}$. Therefore, the quantity that a researcher observes satisfies:

$$r(X_{-i}, c_i) \leq x_i \leq Y - \underline{Z}(Y, c_i, c_e), \quad \forall i. \quad (7)$$

Because $\underline{Z}(Y, c_i, c_e)$ is strictly increasing in c_i and $r(X_{-i}, c_i)$ is strictly decreasing in c_i , given the other arguments, both functions have their inverse functions, denoted by $\underline{Z}^{-1}(Y, \cdot, c_e)$ and $r^{-1}(X_{-i}, \cdot)$, respectively. Therefore, Equation (7) can be rearranged as

$$r^{-1}(X_{-i}, x_i) \leq c_i \leq \underline{Z}^{-1}(Y, Y - x_i, c_e), \quad \forall i. \quad (8)$$

Note that the limit output Y is observable because it corresponds to the incumbents' total output $X = \sum_i x_i$ in any entry-deterring equilibrium. Therefore, both sides of Equation (8) are identified from the data.

To apply the data to Equation (8), it is necessary to be able to compute the function on both sides. Because the function on the left-hand side is the inverse of the Cournot best response, it can be calculated from the first-order condition of the optimization problem (1), as in previous studies. Conversely, it may not be possible to solve the function $\underline{Z}^{-1}(Y, Y - x_i, c_e)$ analytically, depending on the shape of the demand function. Appendix A.3 provides a method to calculate the value of the right-hand side of Equation (8) numerically.

3 | THE JAPANESE ALUMINUM SMELTING INDUSTRY POST-WORLD WAR II

In this section, I describe the post-World War II development of the Japanese aluminum smelting industry. There are several reasons why the postwar industry data are appropriate for empirical research on entry deterrence. First, incumbent firms operating in the industry evidently faced the threat of entry and, hence, were likely to undertake entry-deterring strategies. Second, because the properties of aluminum are simple, making it difficult to produce differentiated products, firms operating in the industry could not use various methods of entry deterrence, such as brand proliferation or advertisements. Furthermore, during the sample period on which I focus, it is unlikely that overcapacity was employed as an entry barrier. Over the sample period, the average industry operating ratio, defined as the ratio of annual production over annual capacity, was 0.89. Third, because the 1973 oil crisis changed the market environment and profitability of the industry, it is possible to compare firm conduct with and without entry threats by dividing the whole sample into two subsamples, before and after 1973. This section describes the development of the industry and aluminum production to guide the empirical specification in Section 4.⁹

The Japanese aluminum smelting industry experienced both a remarkable rise and decline during the period of analysis. Postwar aluminum smelting in Japan began with three incumbent firms, Nippon Light Metal, Sumitomo Chemical, and Showa Denko. With the rapid growth in demand, these incumbent firms expanded their smelting facilities, and new companies, Mitsubishi Chemical, Mitsui Aluminum, and Sumikei Aluminum, entered the industry. As a result, the total annual capacity grew from about 65,000 tons in 1955 to 1,640,000 tons in 1978. However, the two oil crises of 1973 and 1979 sharply increased the cost of aluminum smelting and deprived the industry of its global competitiveness and prosperity. As a result, by 1987, all except one plant had closed, and almost all domestic aluminum demand since has been satisfied by imports. The focus of this study is on this period of dramatic change.

The postwar Japanese aluminum industry is characterized by a three-level vertical supply chain consisting of (i) aluminum smelting; (ii) processing, including rolling, extrusion, and die casting; and (iii) production of final consumer products. At the first level in the supply chain, firms produce aluminum ingots from raw materials, such as imported bauxite. At the second level, aluminum undergoes processing, for example, rolling and heat treatment to harden it. After processing, aluminum has the properties required to make a final product at the third level of the supply chain. Each level of the supply chain comprises vertically separated companies. The focus of this study is on the first level of the supply chain.

There are two types of aluminum used in the second and third levels of the supply chain: primary aluminum, which is made from bauxite, and secondary aluminum, which is made from aluminum products that have been discarded as waste. Primary and secondary aluminum differ in their levels of purity and uses. Our focus is on primary aluminum, which has purity levels of 99.0%–99.9%.^{10,11}

Although aluminum is used in a variety of applications, an increase in demand from the construction and transportation sectors supported the rapid growth of the industry. Table 1 shows the volume of product shipments in the second level of the supply chain classified by shipping destinations. The table shows that shipments to the transportation and construction sectors increased significantly in the 1960s and 1970s. The increase in shipments to the construction sector is particularly noteworthy, rising from 3% of total shipments in the 1950s to 33% in the 1970s. This was a result of the rapid increase in the popularity and the spread of aluminum window sashes. By contrast, during the 1980s, shipments to the construction sector did not grow as much as previously. Figure 1 shows the volume of demand for aluminum and a measure of construction activity, which is the total floor area of the buildings on which construction had commenced. Demand is represented by the sum of domestic production and imports of primary aluminum. The figure suggests that demand from the construction sector was the main driver of growth in the industry.

The demand for aluminum in postwar Japan continued to increase during the 1970s, but the domestic suppliers began to be replaced by overseas producers (imports). The oil crisis took a heavy toll on the Japanese aluminum smelters. Figure 1 shows that after the 1973 oil shock, domestic production fell, and imports rose. Although imports continued to rise after 1973, domestic production did not increase in the 1970s, and when the second oil shock occurred

TABLE 1 Shipments by destinations.

Year	Total shipment	Transport	Construction	Metal product	Packaging	Others
1950–1959	81 (100%)	10 (13%)	2 (3%)	16 (20%)	1 (3%)	51 (63%)
1960–1969	497 (100%)	106 (21%)	78 (16%)	83 (17%)	6 (1%)	225 (45%)
1970–1979	1729 (100%)	366 (21%)	571 (33%)	240 (14%)	67 (4%)	485 (28%)
1980–1989	2625 (100%)	761 (29%)	747 (28%)	376 (14%)	173 (7%)	568 (22%)

Note: Secondary-stage annual shipments by shipping destinations in thousands of tons, averaged over 10 years, are listed. The values in the parentheses are the ratios of shipments to the destination over the total shipments. As the raw materials used in the second stage include not only primary aluminum but also secondary aluminum, the total shipment in the table is larger than the value of primary aluminum demand in Figure 1.

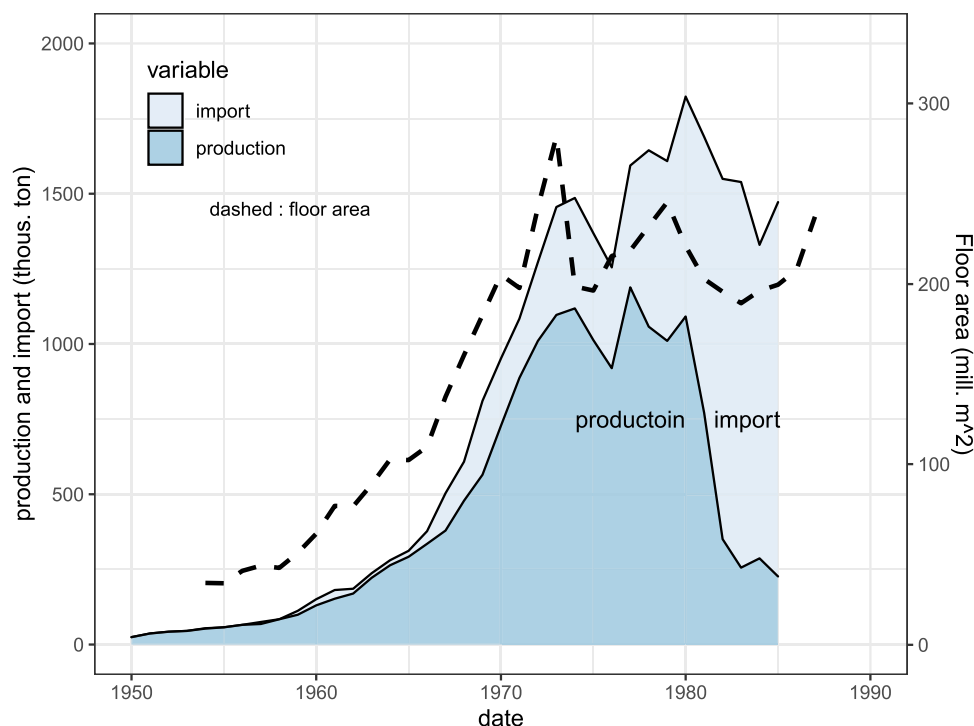


FIGURE 1 Demand and construction activity.

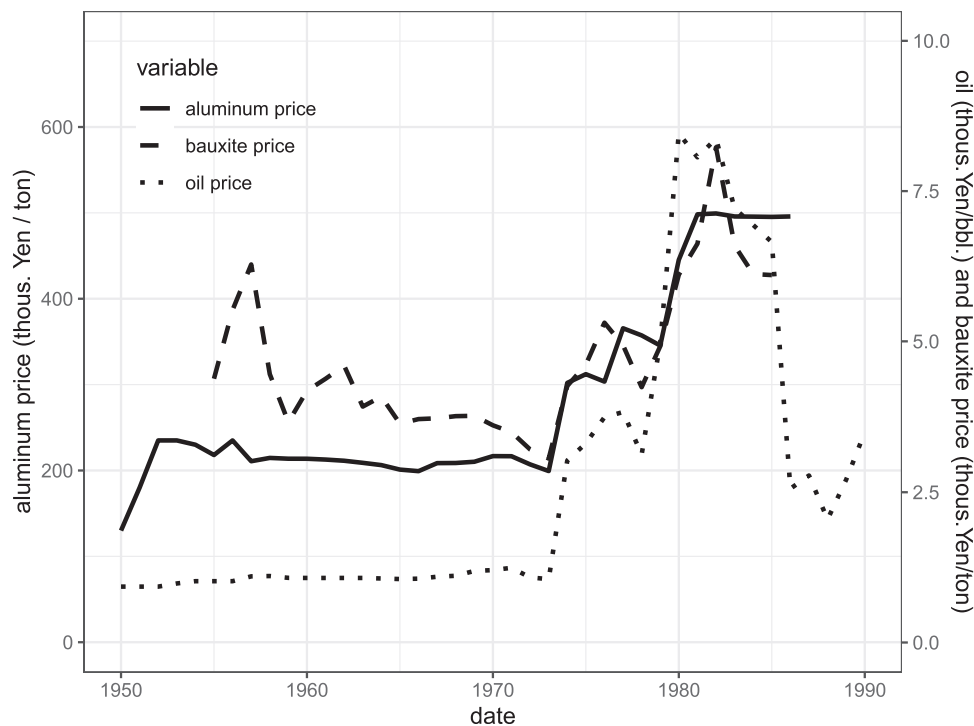


FIGURE 2 Aluminum, oil, and bauxite prices.

in 1979, domestic production fell sharply. The reason why the oil crisis hit the domestic smelters so hard relates to the main raw material for aluminum and how it was sourced by domestic smelters.

Although the main raw material for aluminum is bauxite, the production of aluminum is highly electricity-intensive. Aluminum is produced by electrolyzing the intermediate product alumina (or aluminum oxide), employing the Hall–Héroult process, after the alumina is extracted from bauxite by the Bayer process. The electrolyzing process requires a large amount of electricity. Specifically, approximately 15,000 kWh of electricity is consumed in the Hall–Héroult process to produce a unit ton of aluminum¹² and the electricity costs accounted for about 25% of total costs even before the oil crisis (Miwa, 2016).

In addition, Japanese smelters relied mainly on oil-fired thermal power generation to meet their electric power needs, whereas overseas smelters used low-cost electricity generated by hydropower (Peck, 1988). Therefore, the oil crisis increased the electricity costs of aluminum smelting for Japanese firms in particular. Figure 2 shows crude oil, imported bauxite, and aluminum prices. The 1973 oil shock raised the price of oil threefold, and the 1979 shock further increased it to more than seven times the level before the oil crisis. These increased oil prices led to a decline in the share of domestic firms' production shown in Figure 1.

3.1 | The presence and disappearance of entry threats

Before the oil crisis, the aluminum industry achieved substantial profits, making it attractive to potential new entrants. In October 1960, the first entry plan to the industry since the end of the war was reported in a newspaper. Nisso Steel, an open-hearth furnace steel manufacturer and a group company of an integrated steel manufacturer, Yahata Steel Corporation, planned to commercialize aluminum smelting. Yahata Steel had shown interest in aluminum production before the report and it took a leading role in the commercialization of aluminum, expanding and revising Nisso's plan to include aluminum processing as well as smelting. There was fierce opposition from the three existing companies to Yahata's plan to enter the aluminum smelting and processing industry.

In response to this opposition, the Ministry of International Trade and Industry (MITI) postponed approval of the entry. Ultimately, entry into the smelting sector was abandoned, and a new company, Sky Aluminum, which engaged only in the processing business, was established and began operating in 1967.¹³



The threat of entry remained for the three existing firms even after Nisso (and Yahata) withdrew their plans to enter the smelting industry. Mitsubishi Chemical announced its intention to enter the industry in December 1960, about the same time as Nisso's entry plan announcement. A joint venture of the Mitsui group companies, Mitsui Aluminum, was established as an aluminum smelting business in January 1968. As in the case of Nisso, the incumbent companies opposed the entry plans of these companies. In these cases, despite their opposition, the entry did occur.¹⁴ Mitsubishi commenced operations in May 1963 at Naoetsu City in Nigata Prefecture, and Mitsui Aluminum began to operate in January 1971 at Miike in Fukuoka Prefecture.

The 1973 oil crisis significantly altered Japan's aluminum smelting industry, which relied on oil-fired thermal power generation to produce aluminum. After the oil shock, smelting was no longer a lucrative industry. Electricity costs accounted for about 25% of the industry's total costs before the oil crisis, but with the oil crisis, they rose to over 40% in 1975 (Miwa, 2016). This cost increase was such that the production cost per ton of aluminum exceeded the selling price.¹⁵ Indeed, two companies (Kobe Steel and Furukawa Aluminum) had planned to enter the industry, but both abandoned these plans immediately after the oil shock. Thus, after the oil shock, it appears that the industry was no longer subject to significant entry threats.

The change in the competitive environment might have led to a change in firm conduct in the industry. Figure 2 shows that smelting firms were unable to pass through the rising prices of raw materials to aluminum prices after the oil crisis. As a cost pass-through rate of less than 100% is the nature of imperfect competition,¹⁶ this observation suggests a change in firm conduct from a competitive one to an uncompetitive one.

On the basis of the above overview of the industry, I model its structure, including demand and costs, select the variables used in the analysis, and split the whole sample into two subsamples, before and after the 1973 oil shock. Finally, it is noteworthy that several industrial policies were implemented by MITI after the oil shocks, particularly in the late 1970s and early 1980s, that are not explicitly modeled in the empirical analysis. The objective of the industrial policies was not to aid and sustain the industry,¹⁷ but to promote the reduction of excess capacity, which had been brought about by the increased electricity costs. Specifically, from 1978, existing companies could receive an annual sum equivalent to approximately 6% (the annual interest rate) of the book value of their "frozen" capacity.¹⁸ Because the industrial policies would have affected the dynamic incentives of firms in relation to their capacity choices, but would not have influenced static competition, I exclude analysis of the policies from the scope of this study.

4 | EMPIRICAL ANALYSIS

By comparing alternative economic models that describe the competition in the Japanese aluminum industry, it is possible to test whether the incumbent firms attempted to deter entry by committing to excessive production output. The three models of competition tested are (i) Cournot, (ii) entry deterrence, and (iii) perfect competition. Because marginal costs are interval-identified under the assumptions of the entry-deterrence model, I use the upper bounds on marginal costs for the entry-deterrence model.

Employing the upper bounds has the following two implications.¹⁹ First, employing those assumes that a specific equilibrium arises in the data. Although there are multiple equilibria in which entry is deterred, firms taking an entry-detering strategy produce more than they would produce if no entry threat existed. Because the total output in a Cournot equilibrium is decreasing in firms' marginal costs, the difference between the counterfactual Cournot total output of incumbents with marginal costs equal to the upper bounds and the observed limit output becomes as large as possible. In other words, this approach means that the equilibrium arises where the firms' output is maximally affected and increased in response to the threat of entry.

Second, a test using specific values of partially identified parameters, such as in this study, may have implications for the result of a formal test where two partially identified models are compared when the formal test is infeasible. A formal Vuong-type model selection test where two moment inequality models are compared is developed by Shi (2015). The test is structured to select the model that includes a distribution closer to the true distribution.²⁰ In other words, the test is structured to compare the best distributions of each of the two models. Given the test structure, when the specific values of partially identified parameters are used and favored over the point-identified model, this may mean that the partially identified model will be favored in a formal model selection test developed for partially identified models. However, this is intuition and not a mathematical result.²¹

4.1 | Demand and cost specification and testing method for firm conduct

4.1.1 | Demand function

To test firm conduct, it is necessary to estimate a demand function. A log-linear demand function²² for aluminum demand is specified as follows:

$$\log Q_t = \alpha_0 + \alpha_1 \log P_t + \alpha_2 \log X_t + \epsilon_t^D, \quad (9)$$

where Q_t is the sum of domestic production and imports, P_t is the aluminum ingot price, X_t denotes demand shifters, and ϵ_t^D represents an unobserved demand shock. The shifter X_t includes the total floor areas of buildings on which construction had commenced in a period, a linear time trend, and month fixed effects. Because there appear to be delays in the effect of the total floor area on aluminum demand, as seen in Figure 1, the 12-month moving averages are used in the demand analysis. I assume a constant price elasticity for aluminum demand. As Figure 1 shows, there are large differences in demand between the beginning and the end of the sample. Among the several specifications employed in the literature, I select constant price elasticity because the price effect on demand will be well captured in this form. For example, if I fitted a linear demand function to the data, the estimated linear demand would over (under) estimate the price effect on demand at the beginning (end) of the sample.

The parameters of the demand function are estimated by two-stage least squares (2SLS) using the imported bauxite price, the oil price, and the average electricity intensity as instrumental variables for the aluminum price P_t .²³ The electricity intensity, which is often used as a measure of inefficiency in the industry, can be calculated as the ratio of the consumption of electricity to production output.²⁴ Because the unobserved demand shock ϵ_t^D may involve serial correlation, the standard errors of estimates are adjusted following Newey and West (1987).²⁵

4.1.2 | Cost function

To proceed with the test, the cost function for a firm engaging in aluminum smelting needs to be estimated. A linear marginal cost function for aluminum smelting is specified as

$$MC_{jt} = \beta_0 W_t + \beta_1 W_{jt} + \gamma_j + \epsilon_{jt}, \quad (10)$$

where MC_{jt} is the constant marginal cost for firm j at time t , W_t and W_{jt} are exogenous cost shifters, γ_j is a firm fixed effect, and ϵ_{jt} is an unobserved cost shock. The cost shifter W_t , which is common between firms, includes the bauxite price, a time trend, and month fixed effects, whereas the shifter W_{jt} , which varies between firms, includes the product of the crude oil price and firm-level electricity intensity (rather than just electricity intensity), $W_{jt} = \text{oil price}_t \times \text{electricity intensity}_{jt}$.

In the cost analysis, I use the 12-month moving average for the oil price. This is because not all smelters had their own thermal power generation equipment. In other words, several firms met their power needs by buying electricity. Because the price set by electricity companies does not immediately reflect the rise in oil prices, I assume that oil prices have a delayed effect on firms' marginal costs.²⁶ I expect the firm fixed effects in the cost function (10) to capture the differences among firms in terms of how they sourced their power needs.

Given that the demand function has already been estimated, it is possible to identify marginal costs under different assumptions for competition. If the Cournot model is assumed to describe the competition in the industry, marginal costs can be identified using the first-order condition and estimated as follows:

$$\widehat{MC}_{jt}^C = P_t \left(1 + \frac{q_{jt}}{Q_t} \frac{1}{\hat{\alpha}_1} \right). \quad (11)$$

where q_{jt} is each firm's production quantity and $\hat{\alpha}_1$ is the estimated price elasticity of demand. If the entry-deterrence model is assumed to represent industry competition, the upper bounds of the interval-identified marginal costs are estimated as

$$\widehat{MC}_{jt}^{ED} = \underline{Z}^{-1}(Q_t, Q_t - q_{jt}, c_{et}). \quad (12)$$

In the case of entry deterrence, the marginal cost of potential entrant c_{et} must be known in advance to identify the incumbents' marginal costs. Let the entrant's marginal cost be

$$c_{et} = P_t \times 0.9. \quad (13)$$

On the basis of accounting data, the net profit margins of Nippon Light Metal²⁷ in the 1960s ranged from 4% to 6%. As noted in Section 2, to obtain a conservative (or wide) estimate of the identification region, it is necessary to set low marginal costs for the entrant. Therefore, the marginal cost of a potential entrant is set lower than the level analogous to the incumbents' accounting unit cost.²⁸

Depending on the form of the demand function specified, the function for estimating the upper bounds, $\underline{Z}^{-1}(\cdot)$, cannot be calculated explicitly. Therefore, in this study, the marginal costs are calculated numerically using the method described in Appendix A.3. Finally, when the aluminum industry is assumed to be characterized by perfect competition, marginal costs can be identified and estimated as

$$\widehat{MC}_{jt}^P = P_t. \quad (14)$$

4.1.3 | Testing method

Using the different marginal costs estimated by Equations (11), (12), and (14), the assumptions of firm conduct can be tested. Pairwise model selection tests for nonnested models originally developed by Vuong (1989), and further extended by Rivers and Vuong (2002), are beneficial for this exercise. The tests are designed to determine which of the two models being pairwise compared is appropriate in explaining the data. A distinctive feature of the test is that both pairwise compared models can be misspecified. Furthermore, whereas Vuong (1989) formalized model selection tests based on the criterion of the likelihood of a model, Rivers and Vuong (2002) enable a test based on a broad class of criterion functions, including the residual sum of squares or moment-based objective functions.

There are several approaches to the test, depending on the criterion function used in the test. Conduct testing literature using the Vuong-type model selection tests rely mainly on a criterion function such as a likelihood, or the residual sum of squares of an estimated marginal cost function (Bonnet & Dubois, 2010; Doi & Ohashi, 2019; Gasmi et al., 1992). The idea underlying the tests based on these criterion functions is to detect which estimated marginal costs are best correlated to variables that are likely to affect firms' marginal costs (Bonnet & Dubois, 2010). Conversely, Berry and Haile (2014) derive restrictions to empirically distinguish firm conduct. They show that models describing oligopolistic competition are testable using an appropriate instrumental variable. Specifically, if the competition model employed to identify marginal costs is correct, identified cost shocks are independent of the instrument; however, this is not the case when the model is incorrect. Backus et al. (2021) propose using a moment-based criterion function to conduct testing based on Rivers and Vuong's (2002) framework. Here, the latter approach, which relies on instruments, is employed.

The criterion function that I employ here is represented for model h as

$$\begin{aligned} Q_n^h &= \hat{g}_h' \hat{W} \hat{g}_h, \\ \hat{g}_h &= \frac{1}{n} \sum \hat{\epsilon}_{jt}^h \hat{z}_{jt}, \\ \hat{W} &= \left(\frac{1}{n} \sum \hat{z}_{jt} \hat{z}_{jt}' \right)^{-1}, \end{aligned}$$

where $\hat{\epsilon}_{jt}^h$ is the residual of the estimation of the cost function (10) and \hat{z}_{jt} is the residual of the linear projection of instrument Z_{jt} on independent variables of the cost function (10). The criterion function corresponds to the GMM objective function with the moment condition of $E[\epsilon_{jt}^h Z_{jt}] = 0$.

Taking any two models h and h' , the null hypothesis that the two models equally satisfy the moment condition can be tested. The Rivers and Vuong's (2002) test statistic is given by

$$T = \frac{\sqrt{n}(Q_n^h - Q_n^{h'})}{\hat{\sigma}_n^{hh'}}, \quad (15)$$

where $\hat{\sigma}_n^{hh'2}$ is the estimator of the asymptotic variance of the difference in the criterion functions.²⁹ Because the specifications of our econometric models are nonnested, the test statistic has a standard normal distribution under the null hypothesis. Therefore, it is possible to select a better model by comparing the value of the statistic with critical values of the standard normal distribution. Because the criterion function (15) is a lack-of-fit criterion, the null is rejected in favor of model h rather than h' if the test statistic T is smaller than -1.96 in the test with $\alpha = 0.05$.

4.2 | Data

Most of the data for this study are sourced from the *Yearbook of Aluminum Smelting*,³⁰ which was issued annually from 1948 to 1985, and distributed only to divisions in MITI and organizations associated with the light metal business.

The yearbook provides useful monthly plant-level information on production, shipments, and raw material consumption, including electricity use. Because the yearbook includes industry-level total shipment values and volume information, the average aluminum shipment price data can be calculated by dividing the total shipment values by the total shipment volumes. The import data on bauxite and primary aluminum are drawn from *Trade Statistics of Japan* from the Ministry of Finance. The oil price used in the analysis is the West Texas Intermediate crude oil price, which is converted into yen using monthly average yen-dollar rates. The total floor area of buildings on which construction had commenced is sourced from the *Survey of Building Construction Work Started*. All price variables are deflated by an industry deflator (the Corporate Goods Price Index in nonferrous metal products) in constant 1970 Japanese yen.

Month-level data from January 1955 to December 1980 (312 months) were used for the empirical analysis, although the yearbook provides data from 1950 to 1985. I confine the sample period for the empirical analysis to the selected dates for several reasons. First, I use data from 1955 onward because this was the year in which aluminum production in Japan recovered to its prewar level. This also excludes the Korean War (1950–1953) from the analysis, which significantly and unusually affected Japanese aluminum demand. Second, I end the period of analysis in 1980 owing to concerns regarding price data credibility after 1980. The yearbook provides price information other than the shipment price, which is used in the empirical analysis. Prices surveyed by several institutions are listed in the yearbook on a monthly basis. Although the surveyed price data moves in the same way as shipping price data until 1980, the surveyed price data show a downward trend despite the shipment price remaining high after 1980. Therefore, I only used data up to 1980 for the analysis. Table 2 provides descriptive statistics on each variable.

4.3 | Results

4.3.1 | Demand estimation

Table 3 shows the estimation results of the demand function (9). The demand equation is estimated using ordinary least squares (OLS) and 2SLS. The first and second columns in the table show the estimation results for 2SLS and OLS, respectively. The third column presents the results of the first-stage regression of the 2SLS estimation. The estimated price coefficients have the expected signs and statistical significance in the 2SLS estimation. The results of the 2SLS estimation suggest that the price elasticity of aluminum demand is low ($\hat{\alpha} = -0.338$ in column 1). The estimate of the elasticity is similar to that of a previous study; Boyd et al. (1995) estimate that elasticity averaged -0.21 during the period 1965–1988 for the US aluminum industry. The estimate of the coefficient for the demand shifter, the total floor

TABLE 2 Summary statistics.

Variables	Unit	<i>n</i>	Mean	sd	Minimum	Maximum
production	Thousand tons	312	46.42	34.65	3.81	104.24
import	Thousand tons	312	16.35	18.99	0.00	89.15
floor	Million m ²	312	12.07	6.60	2.13	26.34
eunit	MWh/ton	312	17.46	1.55	14.89	21.50
price	Thousand JPY/ton	312	268.75	39.65	186.53	332.50
oil price	Thousand JPY/barrel	312	1.87	0.95	0.90	5.62
bauxite price	Thousand JPY/ton	312	4.83	1.50	2.11	10.71
prodF	Thousand tons	1313	11.03	7.31	0.21	28.31
eunitF	MWh/ton	1313	17.16	2.23	12.63	61.11

Note: The variables “floor” and “eunit” denote the “total floor area of buildings on which construction had commenced” and the “electricity intensity,” respectively. The variables “prodF” and “eunitF” represent the firm-level production quantity and electricity intensity, respectively.

Abbreviation: JPY, Japanese yen.

TABLE 3 Demand estimates.

	IV (1)	OLS (2)	F. S. (3)
price	−0.338** (0.139)	−0.079 (0.086)	
floor (M.A.)	1.020*** (0.089)	1.138** (0.078)	0.131 (0.085)
eunit			0.588** (0.243)
oil price (M.A.)			0.364*** (0.063)
bauxite price			0.235*** (0.045)
Observations	312	312	312
<i>R</i> ²	0.989	0.990	0.756
Adjusted <i>R</i> ²	0.989	0.989	0.743
Residual S.E.	0.123	0.119	0.077

Note: The dependent variable is demand, which is calculated as the sum of domestic production and imports in columns (1) and (2), whereas the dependent variable is the aluminum price in column (3), as the column shows the first-stage regression of the two-stage least squares estimation. All three specifications include a linear time trend and month fixed effects; their estimated coefficients are not included in the table. For the floor variable, because there appear to be delays in the effect of floor area under construction on aluminum demand, as seen in Figure 1, the 12-month moving averages are used. Because the effect of oil prices on smelters' production cost is potentially delayed, the oil prices are transformed into 12-month moving averages. All dependent and independent variables except the time trend and the month fixed effects are transformed into logarithmic forms. Heteroskedasticity and serial correlation robust Newey–West standard errors are shown in parentheses. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Abbreviations: F.S., first stage; IV, independent variable; M.A., moving averages; OLS, ordinary least squares; S.E., standard errors.

area of buildings on which construction had commenced, also shows the expected sign and statistical significance. The results of the first-stage regression suggest that the coefficients of the three cost shifters (average electricity intensity, oil price, and bauxite price) have the expected signs. The 2SLS estimation results are employed for the following cost function estimation and tests of firm conduct.

4.3.2 | Cost and cost function estimation

Using the estimation results of the demand function, each firm's marginal costs under the different assumptions of firm conduct are estimated.³¹ Figure 3 shows the estimated marginal costs until 1974. The dashed, solid, and dotted lines

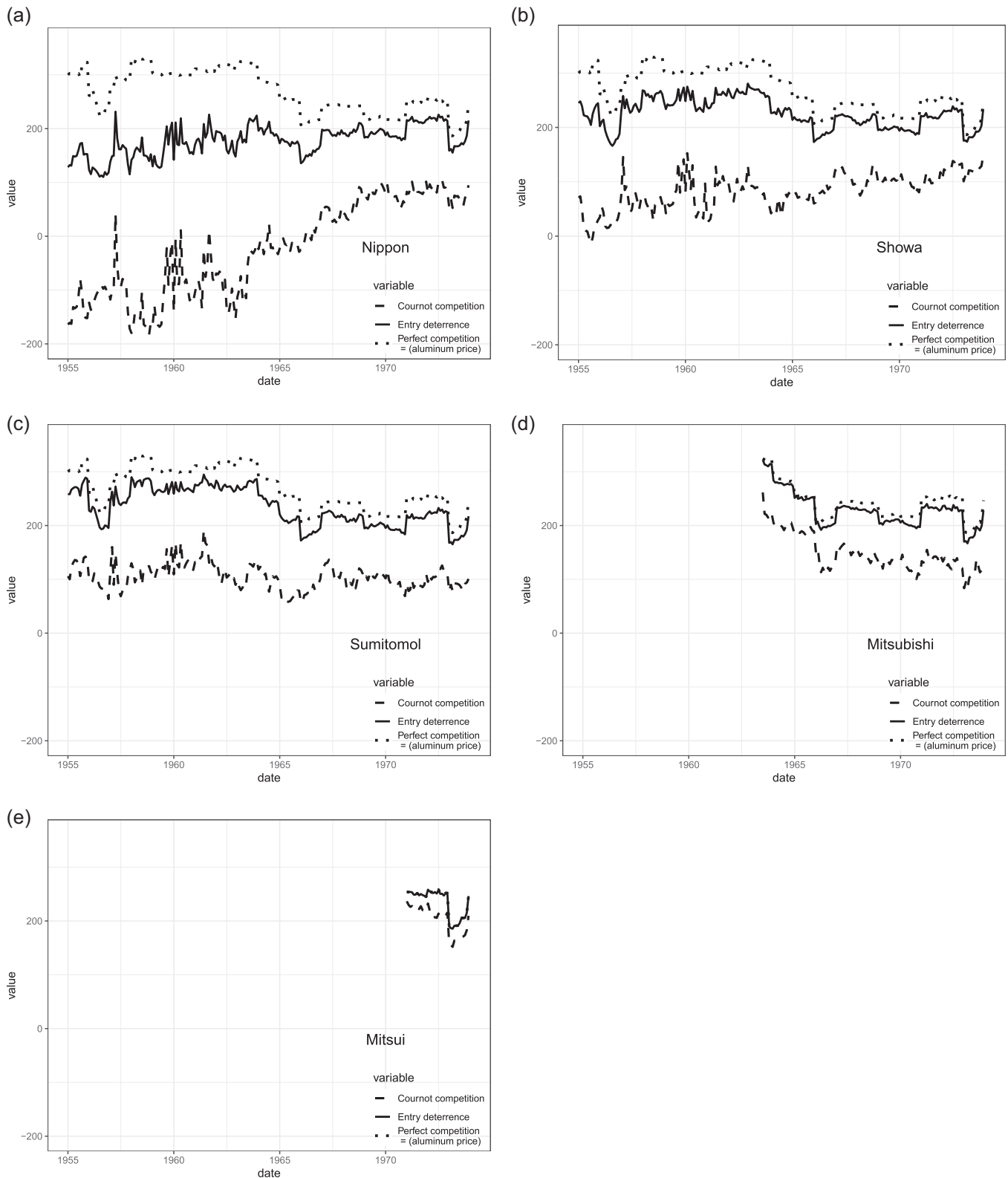


FIGURE 3 Identified marginal costs under three competing models. (a) Nippon Light Metal, (b) Showa Denko, (c) Sumitomo Chemical, (d) Mitsubishi Chemical, and (e) Mitsui Aluminum.

represent marginal costs estimated by the models assuming Cournot competition, entry deterrence, and perfect competition, respectively. Under Cournot competition, the more firms produce, the lower the identified marginal cost becomes. The figure shows that this is also the case under the entry-deterrence model; Nippon Light Metal held a high market share in the 1950s and 1960s, and its marginal costs are estimated to be lower than those of the other firms in the Cournot and entry-deterrence models.

To test the models, the marginal cost functions represented by Equation (10) are estimated using two different samples. One sample includes data for the period before the 1973 oil crisis (i.e., from January 1955 to December 1973), whereas the other includes data after the shock (i.e., from January 1974 to December 1980). As seen in Section 3, in the first period, the incumbent firms were likely to be exposed to entry threats and, hence, might have attempted to deter entry. Conversely, after the 1973 oil shock, entry threats disappeared as a result of the reduced profitability of the industry.

Table 4 shows the cost function estimation results. Columns (1)–(3) are estimated employing the pre-oil-shock data and using the marginal costs estimated under the assumptions of Cournot, entry deterrence, and perfect competition, respectively. Columns (4) and (5) are estimated employing the post-oil-shock data and using the marginal costs estimated under the assumptions of Cournot and perfect competition, respectively.

To interpret the estimated coefficients, it is useful to introduce engineering and chemical formulas that convert the raw materials, crude oil, and bauxite, into the product, aluminum. The estimated cost function includes the bauxite price and the product of the oil price and electricity intensity as explanatory variables. First, β_0 , the coefficient of the bauxite price, identifies how much bauxite is used to produce 1 ton of aluminum. Because about 4 tons of bauxite are consumed to produce 1 ton of aluminum, β_0 is expected to be close to 4. Second, β_1 , the coefficient on the product term, identifies how much crude oil is needed to produce 1 MWh of electricity. To understand the interpretation of the coefficient, recall that electricity is needed to smelt aluminum and that crude oil is burned to generate electricity. Because $\beta_1 W_{jt}$ is equal to the marginal and unit cost of oil to produce 1 ton of aluminum, the following decomposition reveals why β_1 identifies the oil intensity for the generation of 1 MWh of electricity.

$$\begin{aligned}\beta_1 W_{jt} &= \text{unit cost of oil (thousand yen/ton)} \\ &= \text{oil intensity (barrels/ton)} \\ &\quad \times \text{oil price (thousand yen/barrel)} \\ &= \text{oil intensity for electricity (barrels/MWh)} \times \text{electricity intensity (MWh/ton)} \\ &\quad \times \text{oil price (thousand yen/barrel),}\end{aligned}$$

TABLE 4 Cost function estimates.

	Dependent variable				
	\widehat{MC}^C (1)	\widehat{MC}^{ED} (2)	\widehat{MC}^P (3)	\widehat{MC}^C (4)	\widehat{MC}^P (5)
bauxite price	1.961 (1.247)	7.734*** (1.521)	9.426*** (1.608)	11.419*** (3.488)	29.557*** (1.400)
eunitF	1.440 (1.504)	4.452*** (0.520)	5.521*** (0.619)	0.344* (0.208)	0.267*** (0.080)
Observations	846	846	846	467	467
R^2	0.714	0.645	0.829	0.805	0.590
Adjusted R^2	0.708	0.637	0.825	0.797	0.573
Residual S.E.	45.458	23.328	16.834	23.542	23.735
Sample	Before			After	

Note: The dependent variables are the marginal costs identified under the different identification assumptions of competition. All specifications include a linear time trend, month fixed effects, and firm fixed effects as explanatory variables, although the estimated coefficients are omitted from the table. Because the effect of the oil price on smelting production cost potentially involves delays, the oil prices are transformed into 12-month moving averages. Columns (1)–(3) are estimated using the sample period before the 1973 oil crisis, whereas columns (4) and (5) use the period after the 1973 oil crisis. Standard errors are clustered by firm and shown in parentheses. The symbols *, **, and *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Abbreviations: M.A., moving averages; S.E., standard errors.

where the oil intensity for electricity represents how much crude oil is used to produce 1 unit of electricity. According to several energy-related statistics, about 1.5 barrels of crude oil enables the generation of 1 MWh of electricity. Therefore, we expect β_1 to be 1.5.³²

Both β_0 and β_1 are estimated with the economically correct signs in Table 4, and the estimated values vary depending on the assumption regarding firm conduct and the sample period. If model selection was based on the values of the estimated coefficients, a model with a $\hat{\beta}_0$ close to four and a $\hat{\beta}_1$ close to 1.5 would be selected. Therefore, the Cournot and entry-deterrence models may be selected in the pre-oil-shock period and the Cournot model may be selected in the post-oil-shock period.

When the cost function is estimated using the post-oil-shock period sample, the coefficients are significantly different from our expectations. This may be because modeling static competition as Cournot or perfect competition is too simple to capture the aluminum industry. Although the nature of the industrial policy introduced suggests it would not affect static competition, it may have had some impact. Although the cost function is not accurately estimated, Vuong's test allows for misspecification and at least selects the model that is closer to the true model among the two options.

4.3.3 | Model selection test

Employing the residuals of the cost function estimation and the instruments, I perform the model selection test. Two types of instruments are utilized. First, I use a demand shifter, namely, the total floor areas of buildings on which construction had commenced in a period. The use of demand variables for the inference of firm conduct originates with the conduct parameter estimation, including Bresnahan (1982). The other type of instrument is the rival firms' cost shifter, electricity intensity. The electricity intensity only reflects the technological aspects of the firm and is not expected to correlate with the own firm's or the rival firms' cost shocks. More specifically, I employ the difference between the average of the rival firms' cost shifter and the firm's own cost shifters, which is represented as follows:

$$Z_{jt} = \text{electricity intensity}_{jt} - \frac{1}{\# \text{ rivals}} \sum_{r \neq j} \text{electricity intensity}_{rt}. \quad (16)$$

Even if an instrument satisfies the moment condition, the instrument may be weak and cause inferential problems.³³ Duarte et al. (2020) show that the weakness of an instrument causes two problems, namely, size distortion³⁴ and loss of power.³⁵ They develop an F statistic test that can diagnose whether the instruments used in a test are weak. Depending on whether the Vuong test is rejected, the inferential issues of concern are different. When a Vuong test rejects its null hypothesis, size distortion is the main concern. Conversely, when a Vuong test confirms the null hypothesis, the loss of power is of greater concern. Duarte et al. (2020) calculate critical values for the F statistics that determine whether the instruments are weak and ensure that each inferential problem is not serious. These critical values vary depending on the number of instruments used for the test and each inferential problem.

Table 5 presents Vuong's test results and corresponding F statistics in parentheses. The upper half of the table, panel (a), presents the result when the demand shifter is used as an instrument, and the lower half, panel (b), presents the result when the rival firms' cost shifters are employed. The first and second columns display the results employing the sample before the 1973 oil crisis and the third column reports the test employing the sample after the 1973 oil crisis. Because the GMM criterion is a lack-of-fit criterion function, negative values of the test statistics mean that the model in the row displays a better fit than the model in the column.

For the pre-oil-shock period, the Vuong test statistics using the rival firms' cost shifter shows that the entry-deterrence model is most favored and the other two models are rejected in the test.³⁶ For example, the Vuong test statistic is 4.01 when the entry-deterrence model and the Cournot model are compared. This means that the entry-deterrence model is statistically more favored than the Cournot model. If the Vuong test rejects the null hypothesis, size distortion owing to weak instruments is a concern. The value of the F statistic is 97.51, which means that no large-size distortions are caused. More specifically, the value of the F statistic ensures that the asymptotic size of the test does not become a value greater than 0.075.^{37,38}

When employing the demand shifter as an instrument, no inferences can be made about the aluminum firms' conduct. The Vuong test statistics in panel (a) show that the three models are not statistically different for the pre-oil-shock period. However, this result does not necessarily mean that the three models are equivalent. The values of

TABLE 5 Testing results.

Model h/h'		Sample		
		Before		After
		(i) Entry deterrence	(ii) Perfect competition	(iii) Perfect competition
<i>Panel (a) IV: Demand shifter</i>				
(i)	Cournot competition	0.99 (1.51)	0.90 (1.28)	−0.06 (1.57)
(ii)	Entry deterrence	–	0.28 (2.80)	–
<i>Panel (b) IV: Rivals' cost shifter</i>				
(i)	Cournot competition	4.01 (97.51)	2.31 (61.09)	−0.48 (35.26)
(ii)	Entry deterrence	–	−4.45 (96.54)	–

Note: Panel (a) lists the values of the model selection test statistics using the demand shifter as an instrument, whereas panel (b) relies on the rival firms' cost shifter as an instrument. The corresponding F test statistics are provided in parentheses. As the generalized method of moment criterion function is a lack-of-fit criterion, a negative value suggests that the model in the row is better fitted than the models in the column. Because I do not estimate the marginal cost function under the assumption of the entry-deterrence model after the 1973 oil crisis, I only conduct the test that compares the Cournot and perfect competition models for the post-oil-shock period. I treat the recovered marginal cost as if it were data even though it is estimated, that is, I ignore the effect of uncertainty in the demand estimation on the test statistic. If the demand uncertainty were appropriately taken into account, the result would be conservative. Duarte et al. (2020) provide a way to adjust the calculation of $\hat{\sigma}_n^{hh'}$, the denominator of the Vuong test statistics, considering the uncertainty, in a differentiated product demand model setting where demand and cost are estimated using the same sample.

the corresponding F statistics are small, which means that the demand shifter has weak power. Therefore, I do not make any inference about firm conduct using the demand shifter.

For the post-oil-shock period, the Vuong test presents results that are slightly different from those expected. I suggest that the industry may have become relatively uncompetitive because of the disappearance of the entry threats confirmed in Section 3. It has also been confirmed that the cost pass-through was incomplete in the post-oil-shock period, as shown in Figure 2. However, the result from the Vuong test concludes that the data cannot distinguish perfect competition and Cournot competition. When I use the rivals' cost variable as an instrument, the Vuong test result is −0.48 and the corresponding F statistic is 35.26. The F statistic is sufficiently high to conclude that the instrument has strong power. Therefore, these results show that I cannot distinguish between the two models. When the demand shifter is an instrument, the F statistic is very small. Therefore, the demand shifter has no power to distinguish the firm conduct.

In summary, the Vuong tests support the hypothesis that the aluminum smelting industry in the pre-oil-shock period was an environment in which the threat of entry prevailed and incumbents attempted to deter entry. On the basis of the moment conditions constructed using a strong instrument, the entry-deterrence model was more consistent with the data than the other two models. Following the oil shock, it is possible that the industry transitioned to a less competitive environment. However, it is impossible to determine whether the industry is best described by perfect competition or Cournot competition from the firm conduct test.³⁹

5 | CONCLUSION

In this study, I propose a structural model of noncooperative entry deterrence. I show that the marginal costs of incumbents are interval-identified given the marginal cost of an entrant. Furthermore, using the upper bounds on the interval-identified marginal costs, I conduct a model selection test and show that the entry-deterrence model better explains the data for the Japanese aluminum industry facing entry threats than does the Cournot model with no entry

threats. In addition, I point out a caveat of using the upper bound, which is that it assumes that the equilibrium arises where the incumbents are most affected by the entry threat.

Finally, I note two limitations of this study. First, the entry-deterrence model essentially involves a static two-stage game. In the model, the incumbents and a potential entrant only take into account their current profit and, therefore, the incumbents attempt to deter a potential entrant's "hit and run" entry. However, in the real world, both incumbents and the entrant take into account not only their current profit but also their future profit when determining their strategic decisions. Therefore, a dynamic model would be more appropriate to describe the industry. However, the model in this paper is a static one without dynamic aspects.

Industry dynamics might also play an important role. Sweeting et al. (2020) extend a two-stage limit pricing entry-deterrence model to allow for any finite number of periods larger than two. They show that because the incentive to deter entry becomes larger than that in the two-stage game, their extended limit pricing model can explain a larger price decline to deter entry. The result of Sweeting et al. (2020) may suggest a consequence of introducing dynamics into the Gilbert and Vives (1986) model. If, following their results, the introduction of dynamics increased the incentive to deter entry, an entry-detering equilibrium would occur even at high marginal costs and then higher upper bounds on marginal costs might be identified.

Second, marginal cost is interval-identified. There are two reasons for this: (i) the difficulty of identifying where the limit output Y specifically lies within the interval $[X^C, \bar{Y}]$, and (ii) the existence of multiple equilibria. Because the data do not indicate where the limit output Y is in $[X^C, \bar{Y}]$, the upper bounds on marginal costs correspond to the marginal costs identified under the equilibrium where all firms are barely deterring entry. Furthermore, because there are multiple equilibria in the game, the knowledge of where Y is in between X^C and \bar{Y} is not sufficient for the point-identification. To introduce uncertainty in entry costs and cross sections of markets with observables that affect the uncertainty may assist with the point-identification of marginal costs. Waldman (1987) introduces uncertainty on the limit output Y in the model of Gilbert and Vives (1986). In his model, the first-order condition for the incumbents' profit maximization is used to characterize the entry-detering equilibrium. Therefore, if the variables that affect the uncertainty associated with the entry cost are observable, the first-order condition may point-identify the marginal cost. Furthermore, introducing cost uncertainty would be appropriate to describe real-world environments. Examination of the empirical validity of these approaches is an important subject that I reserve for future study.

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DATA AVAILABILITY STATEMENT

Data will be made available on request.

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NOTES

- ¹ Another reason why the body of empirical studies is relatively small is that "it is inherently difficult to distinguish strategic deterrence motives from other investment rationales" (Cookson, 2017).
- ² Although researchers previously used the conduct parameter method to understand the nature of competition in a market, for example, Bresnahan (1982) and Porter (1983), the difficulties in estimating the conduct parameter are now recognized (Corts, 1999; Puller, 2009).
- ³ Identification results for firms' marginal costs are presented in the literature for various purposes, not only for the model selection test. Examples include dynamic learning models (Irwin & Klenow, 1994; Ohashi, 2005), investment decision models (Pesendorfer, 2003), and price discrimination models (D'Haultfœuille et al., 2019; Miller & Osborne, 2014).
- ⁴ The usefulness of the Vuong-type model selection test is not limited to the testing of firm conduct. For example, Gayle and Luo (2015) provide a simulation study that shows the test has the power in distinguishing between alternate order-of-entry assumptions in an entry game.
- ⁵ Thus, $r(Z, c)$ is the Cournot best response.

- ⁶ The convexity is assumed in Gilbert and Vives (1986) because it simplifies the analysis of the incumbents' optimal production decision as a Stackelberg leader.
- ⁷ The solution is unique because the Cournot best response functions have a slope between -1 and 0 , as shown in Lemma 1 in Appendix A.1, and thus the left-hand side is increasing in Z . When the solution is negative, we set $Z(Y, c_i) = 0$.
- ⁸ I clarify why this is sufficient to conservatively construct the identification region for marginal costs in Appendix A.3.
- ⁹ Goto (1988) provides a good overview of the development of the industry and a description of public policy concerning the industry after the oil crisis.
- ¹⁰ Suslow's (1986) empirical analysis shows that the price of secondary aluminum does not influence the demand for primary aluminum.
- ¹¹ Although there is a possibility that aluminum products from different plants may be regarded as differentiated because of transportation costs, I ignore this possibility and model the industry as a nondifferentiated product industry. Some industries can be considered differentiated goods markets, or as composed of geographically different markets because of transportation costs, such as the ready-mixed concrete market. Ready-mixed concrete needs to be delivered to a construction site within a given time (one and a half hours in Japan) after it is ready-mixed at a plant. Therefore, the market is divided due to the high transportation costs, resulting in different prices in different regions. The aluminum industry, at least, does not have the high transportation costs created by such time constraints. In addition, I did not find any region-specific price data.
- ¹² Because of successive innovations in the smelting process, the electricity intensity declined in the sample period.
- ¹³ The model described in Section 2 and the model estimated and tested in Section 4 do not include any lobbying of MITI by incumbent firms. This means that I estimate an entry-deterrence model in which firms must produce more output in response to the threat of entry despite lobbying. If the lobbying was effective, then the incumbent smelting firms would not need to increase production volume and the Cournot model would be selected in the test. The result that the entry-deterrence model is favored in the test means that although the lobbying might have some effect, smelting firms must still increase output to deter entry, and the threat of entry made the environment more competitive for incumbents.
- ¹⁴ The model presented in Section 2 cannot explain the realized entry of Mitsubishi in 1970, Mitsui in 1973, and then Sumikei Aluminum in 1975. If there is uncertainty about the fixed costs of entry, then entry will occur with a positive probability even if the incumbent firms increase production to deter entry. Waldman (1987) develops such a model and shows that even if uncertainty is incorporated into the model of Gilbert and Vives, the incentives of the incumbents remain unchanged. Therefore, it is reasonable to use the Gilbert and Vives model to describe firm behavior, although the model cannot explain the realized entry itself.
- ¹⁵ It should be noted that the total cost estimate includes interest payments and depreciation costs.
- ¹⁶ See Ritz (2018) for the relationship between the cost pass-through rate and firm conduct.
- ¹⁷ The existing businesses requested that the government offer exceptionally low electricity rates as an industrial policy, but their request went unheeded.
- ¹⁸ Smelting equipment that became technically unusable after a certain period was referred to as "frozen."
- ¹⁹ It is common to employ a specific value for partially identified parameters in the industrial organization literature to enable the analysis to proceed. For example, Wollmann (2018) uses the midpoints of bounds on partially identified parameters for sunk costs to perform a counterfactual analysis.
- ²⁰ The moment inequality conditions yield a set of distributions that are consistent with those conditions.
- ²¹ The test structure of Shi (2015) is not appropriate for this study because the determination of firm conduct should be based on a criterion formed from excluded instruments (Berry & Haile, 2014), whereas the test developed by Shi (2015) prohibits this treatment. To my knowledge, a formal model selection test that enables the treatment has not been developed.
- ²² Although I assume a concave demand function in Section 2 following Gilbert and Vives (1986), the constant-elasticity demand in Equation (9) is not concave. As shown by Lemma 1 and its proof in Appendix A.1, the concavity assumption is employed to derive the Cournot best response function with a slope between -1 and 0 for all regions in Z . Afterward, this property concerning the slope is utilized to prove another Lemma and proposition. Therefore, the concavity is sufficient but not necessary. With the estimated log-linear demand function, I can confirm that the response function meets the slope condition when it is downward sloping.
- ²³ I use 2SLS instead of the efficient GMMs estimator. 2SLS allows for the estimation and interpretation of the first-stage regressions. Furthermore, while efficient GMM and 2SLS are identical under the assumption of homoskedasticity of the error terms, the latter is simpler to implement.
- ²⁴ Although the electricity intensity is calculated using production quantities, which are endogenous, it is not an endogenous variable because the value does not depend on the utilization rate and only reflects a technological aspect.
- ²⁵ Boyd et al. (1995) assume that the unobserved demand shock follows an autoregressive AR(1) process in the case of US primary aluminum demand.
- ²⁶ For the same reason, the oil price used as an instrumental variable in the demand estimation is converted to a 12-month moving average.

- ²⁷ Nippon Light Metal was the only firm specializing in aluminum in the 1960s.
- ²⁸ An alternative approach is to refer to engineering costs, which are calculated by building up the cost of raw materials. Tanaka (1969) estimates that the unit cost of aluminum production in 1969 (when the aluminum price was 205,000 yen) was 173,000 yen. Therefore, the cost represented by Equation (13) is an intermediate cost falling between the costs inferred from the accounting and engineering data. Several specifications are examined, including (i) $c_{et} = 0.95 \times P_t$, (ii) $c_{et} = 0.85 \times P_t$, and (iii) linear decreases in c_{et} over time from 240 to 180. The third specification reflects the lowering of costs in response to improvements in electricity intensity, which are observed in the data. In all cases, the qualitative results concerning the test of firm conduct are the same as in the case in which Equation (13) is assumed.
- ²⁹ There are two ways to estimate the asymptotic variance $\sigma_n^{hh'2}$, namely, the bootstrapping and delta methods. See Backus et al. (2021) for the bootstrapping method and Duarte et al. (2020) for the delta method. I obtain similar results from trying both methods, and report the result using the delta method.
- ³⁰ In Japanese, the title of the yearbook is “Aluminum Seiren Kogyo Tokei Nenpo.” The Japanese Aluminum Association provided me with copies of it.
- ³¹ Although I use month-level data to estimate marginal costs, the values are very similar if I aggregate the month-level data into quarterly-level data.
- ³² The conversion formula is based on modern technology, and there are two assumptions behind the formula. Burning fuel such as crude oil or gas releases thermal energy. How much energy the burned fuel produces depends on the composition of the imported crude oil. The Agency for Natural Resources and Energy, a division in the Ministry of Economy, Trade, and Industry, has established standard gross calorific values for various energy sources to be used in energy-related statistics. It estimates that 1 L of crude oil enables the generation of 38.26 MJ of thermal energy (Agency for Natural Resources and Energy, 2020). The standard values are revised every few years; however, the values for crude oil remain almost the same. Furthermore, not all of the thermal energy generated is converted into electricity. The formula assumes that 9370 J of thermal energy are required to use 1 Wh of electricity (Agency for Natural Resources and Energy, 2020). This means that 38.4% of the generated thermal energy is consumed as electricity because 1 Wh equals 3600 J if the loss is zero. How much thermal energy is transferred as electricity at the point of consumption is affected by several factors, including the efficiency of generating and transmitting electricity. Thermal efficiency, a measure of the performance of a generator, has improved from about 30% in the 1960s to about 40% today in Japan (The Federation of Electric Power Companies of Japan, each year). However, the improvement has not been sufficient to distort the interpretation of the coefficients.
- ³³ For example, suppose that one of the two models of firm conduct tested is correct and the other is incorrect. A computer-generated normal random variable would satisfy the moment condition as an instrument, but firm conduct should not be revealed by this variable and the true model will not be favored in the test.
- ³⁴ When the null hypothesis H_0 is correct, the probability of rejecting the null becomes higher than the prespecified significance level.
- ³⁵ Assume that the alternative hypothesis is correct. When the sample size is increased, the null hypothesis cannot be rejected with a probability approaching 1.
- ³⁶ I do not consider a collusion model as a competing model in the test. However, using the conjectural variation model or conduct parameter approach, I can construct a model of collusion. The marginal cost is identified and estimated as $\hat{MC}^{\text{collusion}} = P_t \times (1 + \frac{\theta}{\epsilon_t} \frac{q_{it}}{Q_{it}})$, where θ is a conduct parameter and ϵ_t is the demand elasticity. The value of θ equal to 1 corresponds to a model of collusion. This model is rejected by the models adopted as competing models in Table 5. Although the model is a type of collusion model, it cannot approximate a model that describes the cartel mechanism using a repeated game theory (Corts, 1999).
- ³⁷ The critical value is 31.4.
- ³⁸ As a robustness check, I use the average of the rival firms' electricity intensity rather than the difference and obtain a qualitatively similar result for Vuong's test. However, the F test statistics do not exceed the critical values.
- ³⁹ Although I use only the Vuong test result to infer firm conduct, I can construct a model confidence set, which is a concept proposed by Hansen et al. (2011). A model confidence set is a set of models constructed such that it will contain the best model with a given level of confidence, and is similar to a confidence interval for an estimated parameter. Duarte et al. (2020) propose a procedure to construct an MCS when several criteria (i.e., several kinds of instruments) are available. Following their procedure, the MCS is {Entry Deterrence} for the pre-oil-shock period, and {Perfect Competition, Cournot Competition} for the post-oil-shock period. Constructing the MCS requires computing additional test statistics. The full results are available on request.
- ⁴⁰ Although Gilbert and Vives (1986) provide a proof under cost homogeneity, it is possible to provide a proof under cost heterogeneity in exactly the same way. Gilbert and Vives (1986) do not present the comparative statics on the incumbents' marginal costs, which would be most relevant for the empirical analysis in this study, because they assume that marginal costs are zero for all firms.
- ⁴¹ The property that $Y > s(Z, c_i, c_e) + Z$ at $Z = \underline{Z}(Y, c_i, c_e)$ can be proved by contradiction. Assume that $Y \leq s(Z, c_i, c_e) + Z$ at $Z = \underline{Z}(Y, c_i, c_e)$. The assumption induces that $P(Y) > P(X^E) = P(s + Z + r_e(s + Z))$ at $Z = \underline{Z}$ because the values of deterring and allowing entry are equal at $Z = \underline{Z}$. When $Z > \underline{Z}$, the value of deterring entry exceeds that of allowing entry. Therefore,

$\partial \pi^{NE} / \partial Z > \partial \pi^E / \partial Z$ at $Z = \underline{Z}$. This induces $\partial \pi^{NE} / \partial Z > \partial \pi^E / \partial Z \Leftrightarrow -(P(Y) - c_i) > -(P(X^E) - c_i) \Leftrightarrow P(Y) < P(X^E)$. This contradicts the property above and therefore $s(Z) < Y - Z$ when $Z = \underline{Z}(Y, c_i, c_e)$.

REFERENCES

- Agency for Natural Resources and Energy. (2020). *Standard gross calorific value and carbon emission factors by energy sources (Enerugigenbestsu Hyojun Hatsunetsuryo/Tanso Haisyutsu Keisu)* (in Japanese). https://www.enecho.meti.go.jp/statistics/total_energy/xls/stte_039.xlsx
- Backus, M., Conlon, C., & Sinkinson, M. (2021). *Common ownership and competition in the ready-to-eat cereal industry* [Working Paper]. National Bureau of Economic Research.
- Berry, S. T., & Haile, P. A. (2014). Identification in differentiated products markets using market level data. *Econometrica*, 82(5), 1749–1797.
- Bonnet, C., & Dubois, P. (2010). Inference on vertical contracts between manufacturers and retailers allowing for nonlinear pricing and resale price maintenance. *The RAND Journal of Economics*, 41(1), 139–164.
- Boyd, R. G., Jung, C., & Seldon, B. J. (1995). The market structure of the US aluminum industry. *Journal of Economics and Business*, 47(3), 293–301.
- Bresnahan, T. F. (1982). The oligopoly solution concept is identified. *Economics Letters*, 10(1), 87–92.
- Cookson, J. A. (2017). Anticipated entry and entry deterrence: Evidence from the American Casino Industry. *Management Science*, 64(5), 2325–2344.
- Corts, K. S. (1999). Conduct parameters and the measurement of market power. *Journal of Econometrics*, 88(2), 227–250.
- D'Haultfoeulle, X., Durrmeyer, I., & Février, P. (2019). Automobile prices in market equilibrium with unobserved price discrimination. *The Review of Economic Studies*, 86(5), 1973–1998.
- Doi, N., & Ohashi, H. (2019). Market structure and product quality: A study of the 2002 Japanese airline merger. *International Journal of Industrial Organization*, 62, 158–193.
- Duarte, M., Magnolfi, L., & Sullivan, C. (2020). *Testing firm conduct* [Working Paper].
- Ellison, G., & Ellison, S. F. (2011). Strategic entry deterrence and the behavior of pharmaceutical incumbents prior to patent expiration. *American Economic Journal: Microeconomics*, 3(1), 1–36.
- Ericson, R., & Pakes, A. (1995). Markov-perfect industry dynamics: A framework for empirical work. *The Review of Economic Studies*, 62(1), 53–82.
- Gasmi, F., Laffont, J., & Vuong, Q. H. (1992). Econometric analysis of collusive behavior in a soft-drink market. *Journal of Economics & Management Strategy*, 1(2), 277–311.
- Gayle, P. G., & Luo, Z. (2015). Choosing between order-of-entry assumptions in empirical entry models: Evidence from competition between burger king and McDonald's restaurant outlets. *The Journal of Industrial Economics*, 63(1), 129–151.
- Gayle, P. G., & Xie, X. (2018). Entry deterrence and strategic alliances. *Economic Inquiry*, 56(3), 1898–1924.
- Gilbert, R., & Vives, X. (1986). Entry deterrence and the free rider problem. *The Review of Economic Studies*, 53(1), 71–83.
- Goto, A. (1988). Japan: A sunset industry. In M. J. Peck (Ed.), *The world aluminum industry in a changing energy era* (pp. 90–120). Resources for the Future.
- Hansen, P. R., Lunde, A., & Nason, J. M. (2011). The model confidence set. *Econometrica*, 79(2), 453–497.
- Irwin, D. A., & Klenow, P. J. (1994). Learning-by-doing spillovers in the semiconductor industry. *Journal of Political Economy*, 102(6), 1200–1227.
- Lieberman, M. B. (1987). Excess capacity as a barrier to entry: An empirical appraisal. *The Journal of Industrial Economics*, 35(4), 607–627.
- Miller, N. H., & Osborne, M. (2014). Spatial differentiation and price discrimination in the cement industry: Evidence from a structural model. *The RAND Journal of Economics*, 45(2), 221–247.
- Miwa, H. (2016). *Aluminum industry of Japan: The rise and decline in aluminum smelting industry (Aruminium Seiren Gyo No Koryu to Suitai)*. Mie University Press (Mie Daigaku Syuppan Kai) (in Japanese).
- Newey, W. K., & West, K. D. (1987). A simple, positive semi-definite, heteroskedasticity and autocorrelation consistent covariance matrix. *Econometrica*, 55(3), 703–708.
- Ohashi, H. (2005). Learning by doing, export subsidies, and industry growth: Japanese steel in the 1950s and 1960s. *Journal of International Economics*, 66(2), 297–323.
- Peck, M. J. (Ed.). (1988). *The world aluminum industry in a changing energy era*. Routledge.
- Pesendorfer, M. (2003). Horizontal mergers in the paper industry. *The RAND Journal of Economics*, 34(3), 495–515.
- Porter, R. H. (1983). A study of cartel stability: The joint executive committee, 1880–1886. *The Bell Journal of Economics*, 14(2), 301.
- Puller, S. L. (2009). Estimation of competitive conduct when firms are efficiently colluding: Addressing the Corts critique. *Applied Economics Letters*, 16(15), 1497–1500.
- Ritz, R. A. (2018). Oligopolistic competition and welfare. In L. C. Corchón, & M. A. Marini (Eds.), *Handbook of game theory and industrial organization* (Vol. 1, pp. 181–200). Edward Elgar.
- Rivers, D., & Vuong, Q. H. (2002). Model selection tests for nonlinear dynamic models. *The Econometrics Journal*, 5(1), 1–39.
- Salvo, A. (2010). Inferring market power under the threat of entry: The case of the Brazilian cement industry. *The RAND Journal of Economics*, 41(2), 326–350.
- Shi, X. (2015). Model selection tests for moment inequality models. *Journal of Econometrics*, 187(1), 1–17.
- Smiley, R. (1988). Empirical evidence on strategic entry deterrence. *International Journal of Industrial Organization*, 6(2), 167–180.

- Snider, C. (2009). *Predatory incentives and predation policy: The American Airlines case* [Working Paper]. University of California at Los Angeles.
- Sudhir, K. (2001). Structural analysis of manufacturer pricing in the presence of a strategic retailer. *Marketing Science*, 20(3), 244–264.
- Suslow, V. Y. (1986). Estimating monopoly behavior with competitive recycling: An application to Alcoa. *The RAND Journal of Economics*, 17(3), 389–403.
- Sweeting, A., Roberts, J. W., & Gedge, C. (2020). A model of dynamic limit pricing with an application to the airline industry. *Journal of Political Economy*, 128(3), 1148–1193.
- Tanaka, H. (1969). Current status and issues in the aluminum industry (Aruminiumu Kogyo No Genjo to Kadai). Japan Light Metal Association (Keikinzoku Kyokai) (in Japanese).
- The Federation of Electric Power Companies of Japan. (each year). *Electricity statistics* (Denryoku Tokei Jouhou) (in Japanese). https://pdb.fepec.or.jp/pdb/%E3%83%87%E3%83%BC%E3%82%BF%E3%83%99%E3%83%BC%E3%82%B9%E4%B8%80%E8%A6%A7_%E9%9B%BB%E5%8A%9B%E7%B5%B1%E8%A8%88%E6%83%85%E5%A0%B1
- Tirole, J. (1988). *The theory of industrial organization*. MIT Press.
- Vives, X. (1999). *Oligopoly pricing: Old ideas and new tools*. MIT Press.
- Vuong, Q. H. (1989). Likelihood ratio tests for model selection and non-nested hypotheses. *Econometrica*, 57(2), 307–333.
- Waldman, M. (1987). Noncooperative entry deterrence, uncertainty, and the free rider problem. *The Review of Economic Studies*, 54(2), 301–310.
- Williams, J. W. (2012). *Capacity investments, exclusionary behavior, and welfare: A dynamic model of competition in the airline industry* [Working paper].
- Wollmann, T. G. (2018). Trucks without bailouts: Equilibrium product characteristics for commercial vehicles. *American Economic Review*, 108(6), 1364–1406.

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APPENDIX A

This appendix provides two lemmas, the proofs of propositions in Section 2, and a method for numerical calculation of the upper bounds of the incumbents' marginal cost.

A.1 | Lemmas

The first lemma establishes properties related to the response functions $r(Z, c_i)$ and $s(Z, c_i, c_e)$ and the second lemma is for the value functions in Equations (3) and (4).

Lemma 1. *The response functions $r(Z, c_i)$ and $s(Z, c_i, c_e)$ are decreasing in Z and have a slope between -1 and 0 .*

Proof. The proof is almost the same as that in Gilbert and Vives (1986).⁴⁰ When $r(Z, c_i)$ is positive, it solves the first-order condition for profit optimization. From the implicit function theorem, I have

$$\frac{\partial r(Z, c_i)}{\partial Z} = -\frac{P' + P''x}{2P' + P''x}.$$

Because the inverse demand function is assumed to be concave, $P'' < 0$, the Cournot best response has a slope between -1 and 0 . In the same manner, when $s(Z, c_i, c_e)$ is positive, it solves the first-order condition:

$$P(x + Z + r_e(x + Z)) - c_i + P'(x + Z + r_e(x + Z))(1 + r'_e)x = 0, \quad (\text{A1})$$

where $r_e(\cdot)$ is the abbreviation of $r(\cdot, c_e)$. The implicit function theorem produces

$$\begin{aligned} \frac{\partial s(Z, c_i, c_e)}{\partial Z} &= -\frac{P'(1 + r'_e) + P''(1 + r'_e)(1 + r'_e)x + P'r''_ex}{P'(1 + r'_e) + P''(1 + r'_e)(1 + r'_e)x + P'(1 + r'_e + r''_ex)} \\ &= -\frac{(1 + r'_e)(P' + P''(1 + r'_e)x) + xP'r''_e}{(1 + r'_e)(P' + P''(1 + r'_e)x) + xP'r''_e + (1 + r'_e)P'}. \end{aligned}$$

Therefore, the response function $s(Z, c_i, c_e)$ has a slope between -1 and 0 by the assumption that the Cournot best response function $r(Z, c_i)$ is convex in Z , that is, $r''_e > 0$. \square

Lemma 2. *The two value functions $\pi^{NE}(Z, Y, c_i)$ and $\pi^E(Z, c_i, c_e)$ have partial derivatives as follows:*

$$\begin{aligned} \frac{\partial \pi^{NE}}{\partial c_i} &= -(Y - Z), & \frac{\partial \pi^E}{\partial c_i} &= -s, \\ \frac{\partial \pi^{NE}}{\partial Z} &= -(P(Y) - c_i), & \frac{\partial \pi^E}{\partial Z} &= sP'(1 + r'_e), \\ \frac{\partial \pi^{NE}}{\partial Y} &= P'(Y)(Y - Z) + P(Y) - c_i, & \frac{\partial \pi^E}{\partial Y} &= 0, \end{aligned}$$

where s and r_e are the abbreviations of $s(Z, c_i, c_e)$ and $r(s + Z, c_e)$, respectively, for notational ease. The value of allowing entry $\pi^E(Z, c_i, c_e)$ is strictly decreasing and convex in Z .

Proof. The result for the partial derivatives of the value of deterring entry is straightforwardly calculated from Equation (3). Applying the envelope theorem to the value of allowing entry gives

$$\begin{aligned}
\frac{\partial \pi^E}{\partial c_i} &= \frac{\partial \pi^E}{\partial c_i} \Big|_{x=s(Z, c_i, c_e)} \\
&= \frac{\partial}{\partial c_i} (P(Z + x + r_e(x + Z))x - c_i x) \Big|_{x=s(Z, c_i, c_e)} \\
&= -x \Big|_{x=s(Z, c_i, c_e)} \\
&= -s, \\
\frac{\partial \pi^E}{\partial Y} &= \frac{\partial \pi^E}{\partial Y} (x) \Big|_{x=s(Z, c_i, c_e)} \\
&= 0.
\end{aligned}$$

Finally, I show that the value of allowing entry $\bar{\pi}^E(Z, c_i, c_e)$ is decreasing and convex in Z . Let π^E be the profit when entry is realized, that is, $\pi^E = P(x + Z + r_e(x + Z))x - c_i x$. Because $\bar{\pi}^E(Z, c_i, c_e)$ is the value function of an incumbent as a Stackelberg leader, applying the envelope theorem gives

$$\begin{aligned}
\frac{\partial \bar{\pi}^E}{\partial Z} &= \frac{\partial \pi^E}{\partial Z} \Big|_{x=s(Z, c_i, c_e)} \\
&= P'(1 + r'_e)x \Big|_{x=s(Z, c_i, c_e)} \\
&= sP'(1 + r'_e) \\
&= -P(s + Z + r_e(s + Z)) + c_i.
\end{aligned}$$

The third and fourth lines show that the value function $\bar{\pi}^E$ is decreasing in Z . The fourth equality uses the first-order condition of (A1). Therefore, $\frac{\partial^2 \bar{\pi}^E}{\partial Z^2} = -P'(1 + s')(1 + r'_e)$. Because s' and r'_e are between -1 and 0 , the second-order derivative is positive and $\bar{\pi}^E$ is convex in Z . \square

A.2 | Proof of proposition

Proposition 1 (Repost). Let X^C be the total output in the Cournot equilibrium between incumbents, let \bar{Y} be the largest Y such that the ϕ s intersect on the hyperplane $\sum_{i=1}^M x_i = Y$, and let X_{-i} be $\sum_{j \neq i} x_j$. If $X^C \leq Y \leq \bar{Y}$, then any $x = (x_i)_{i=1}^M$ in the set $\mathcal{E} = \left\{ x \in \mathbb{R}_+^M \mid \sum_{i=1}^M x_i = Y, r(X_{-i}, c_i) \leq x_i \leq Y - Z(Y, c_i, c_e), \forall i \right\}$ and the potential entrant remaining out of the market is a subgame perfect equilibrium. Incumbents prevent entry by producing a total output of Y .

Proof. When $Y = \bar{Y}$, each firm's incentive to deter entry is barely satisfied, and $x_i = Y - Z(Y, c_i, c_e)$ should hold for all i . Adding up all these conditions for each firm, I obtain:

$$(M - 1) = \sum_{i=1}^M \frac{Z(Y, c_i, c_e)}{Y}. \quad (\text{A2})$$

The unique solution of this equation is \bar{Y} . To prove its existence, I investigate the slope of $Z(Y, c_i, c_e)$, the minimum level of other firms' output at which firm i has the incentive to deter entry. When Y is sufficiently small, $Z(Y, c_i, c_e)$ is equal to zero and $\frac{\partial Z(Y, c_i, c_e)}{\partial Y} = 0$. This is because firm i can block or deter entry by itself if the limit output is sufficiently small. Therefore, the threshold at which $Z(Y, c_i, c_e)$ switches between zero and positive values is the maximum of the limit output at which a monopolist with marginal cost c_i can deter entry. When Y is larger than the threshold, $Z(Y, c_i, c_e)$ is the solution of Equation (5) and takes a positive value less than $\bar{Z}(Y, c_i)$. In this case, $\frac{\partial Z(Y, c_i, c_e)}{\partial Y} > 1$, as shown in Gilbert and Vives (1986, p. 75). When Y is sufficiently large, $Z(Y, c_i, c_e) = Y$ and the partial derivative is clearly equal to 1. This case occurs when $P(Y) \leq c_i$. As firm i cannot produce, the minimum level of Z at which firm i can block entry by merely producing the Cournot optimal output becomes Y , that is, $\bar{Z}(Y, c_i) = Y$. At $Z = \bar{Z}(Y, c_i) = Y$, the value of deterring entry and the value of allowing entry are both zero, and therefore $Z(Y, c_i, c_e)$ also becomes Y . Note that whenever $P(Y) > c_i$, because

firm i can produce to block entry, $\underline{Z}(Y, c_i) < Y$ and $\underline{Z}(Y, c_i, c_e)$ is also smaller than Y . As $\underline{Z}(Y, c_i, c_e)$ is the solution of Equation (5) in the range of $Z < \bar{Z}(Y, c_i)$, its value becomes Y when the limit output is large enough to satisfy $P(Y) \leq c_i$. From the above discussion, $\underline{Z}(Y, c_i, c_e)$ is zero up to the limit output level at which a monopolist can deter entry and it has a slope larger than or equal to 1 when it is positive. Therefore, $\frac{\underline{Z}(Y, c_i, c_e)}{Y}$ is weakly increasing in Y and the unique solution of Equation (A2) exists.

Taking the incumbent's strategy $(x_i)_{i=1}^M$ in an equilibrium, consider whether incumbent i has an incentive to deviate from x_i . Because $r(X_{-i}, c_i) < x_i$ is satisfied, firm i has no incentive to increase its production level. Furthermore, $x_i \leq Y - \underline{Z}(Y, c_i, c_e)$ and $\sum_{i=1}^M x_i = Y$ mean that $X_{-i} \geq \underline{Z}(Y, c_i, c_e)$. Therefore, firm i has an incentive to deter rather than allow entry given X_{-i} . Moreover, the entrant has no incentive to enter the market because the limit output Y is produced in the first stage. \square

Proposition 2 (Repost). When $\underline{Z}(Y, c_i, c_e) > 0$, $\underline{Z}(Y, c_i, c_e)$ is increasing in c_i .

Proof. To guarantee that \underline{Z} solves Equation (5), take (Y, c_i, c_e) such that $\underline{Z} > 0$. Because \underline{Z} solves Equation (5), from the implicit function theorem, the following equation holds:

$$\begin{aligned} \frac{\partial \underline{Z}}{\partial c} &= - \frac{\frac{\partial \pi^{NE}}{\partial c_i} - \frac{\partial \pi^E}{\partial c_i}}{\frac{\partial \pi^{NE}}{\partial Z} - \frac{\partial \pi^E}{\partial Z}} \Big|_Z = \underline{Z} \\ &= - \frac{-(Y - Z) - (-s)}{-(P(Y) - c_i) - sP'(1 + r'_e)} \Big|_Z = \underline{Z} \\ &= \frac{Y - (s + Z)}{-(P(Y) - c_i) + P(s + Z + r(s + Z)) - c_i} \Big|_Z = \underline{Z} \\ &= \frac{Y - (s + Z)}{P(X^E) - P(Y)} \Big|_Z = \underline{Z} \\ &> 0, \end{aligned}$$

where X^E represents the total output when entry is allowed, that is, $X^E = s + Z + r_e(s + Z)$. The third equality uses the first-order condition of a Stackelberg leader represented by Equation (A1). When $Z = \underline{Z}(Y, c_i, c_e)$, $Y > s + Z$ holds.⁴¹ As $\pi^{NE} = (P(Y) - c_i) \times (Y - Z) = (P(X^E) - c_i) \times s = \pi^E$ at $Z = \underline{Z}$, $P(X^E) > P(Y)$ and the last inequality hold. \square

A.3 | A method to calculate numerically the upper bounds of incumbents' marginal costs; right-hand side of Equation (8)

To calculate the right-hand side of Equation (8), the function $\underline{Z}^{-1}(Y, Y - x_i, c_e)$ is required. However, the function may not be derived explicitly, depending on the shape of the demand function specified and estimated in an empirical analysis. If the function may not be derived explicitly or even when the analytical calculation is difficult, Equation (5) suggests an alternative approach for numerically calculating the upper bounds. Because incumbent i , which has the upper bound, is indifferent between deterring or allowing entry given the other firms' total output X_{-i} , the upper bound solves the following Equation (A3) for c_i :

$$\pi^E(X_{-i}, c_i, c_e) = \pi^{NE}(X_{-i}, X, c_i), \quad (\text{A3})$$

where X is the observable industry total output, which corresponds to Y . The left-hand side $\pi^E(X_{-i}, c_i, c_e)$ is the value of a Stackelberg leader as a function of c_i , given the other firms' output X_{-i} and the entrant's marginal cost c_e . This function is represented as

$$\pi^E(X_{-i}, c_i, c_e) = (P(s(X_{-i}, c_i, c_e) + X_{-i} + r_e(s(X_{-i}, c_i, c_e) + X_{-i})) - c_i) \times s(X_{-i}, c_i, c_e).$$

The value function $\bar{\pi}^E$, the response function $s(\cdot)$, and $r_e(\cdot)$ are computable because (X_{-i}, c_e) is observed and $P(\cdot)$ is estimated. Conversely, the right-hand side of Equation (A3) is the value of deterring entry as a function of c_i . This function is represented as

$$\begin{aligned}\bar{\pi}^{NE}(X_{-i}, X, c_i) &= (P(X) - c_i) \times (X - X_{-i}) \\ &= -x_i c_i + P x_i.\end{aligned}$$

This is also computable because (P, x_i) is observed. By computing the two value functions and calculating the intersection of the two, the upper bound of the marginal costs can be calculated.

Figure A1 shows an example of how to calculate the upper bound. The horizontal axis represents marginal costs, and the vertical axis represents profits (values). The downward-sloping straight line represents the value of deterring entry for different values of c_i , given the other firms' output $Z = X_{-i}$ and the limit output $Y = X$. The curved dotted line represents the value of allowing entry for different c_i s given the other firms' output $Z = X_{-i}$ and the entrant's marginal cost c_e . The intersection of the two functions is the upper bound on c_i .

In addition, the figure reveals that the entrant's marginal cost is set to the lowest value of a researcher's prior belief, that is, $c_e = \underline{c}_e$, to construct the identification region on c_i conservatively. Because the value of allowing entry $\bar{\pi}^E(X_{-i}, c_i, c_e)$ is increasing in c_e , a decrease in c_e shifts the curved dotted line downward and the intersection of the two functions moves to the right: that is, the upper bound on c_i increases.

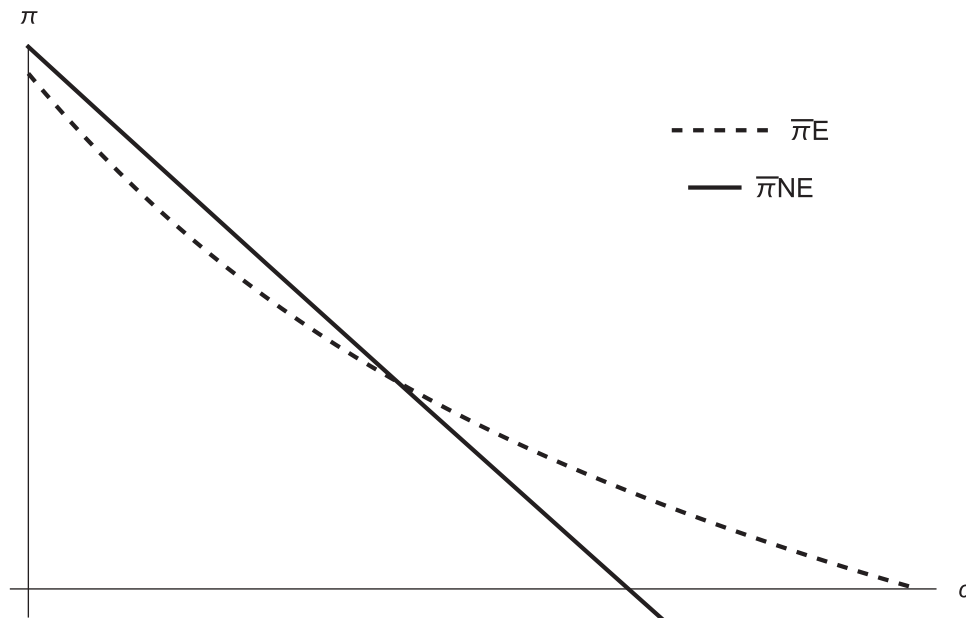


FIGURE A1 Upper bound on c_i .