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Market Share Regulation?*

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Abstract

In the 1950s and 60s, Japanese and US antitrust authorities occasionally used the degree of concentration to regulate industries. Does regulating firms based on their market shares make theoretical sense? We set up a simple duopoly model with stochastic R&D activities to evaluate market share regulation policy. On the one hand, market share regulation discourages the larger company's R&D investment and causes economic inefficiency. On the other hand, it facilitates the smaller company's survival, and prevents the larger company from monopolizing the market. We show that consumers tend to benefit from market share regulation. However, the social welfare including firms' profits would be hurt if both firms are equally good at R&D innovation. Nonetheless, if the smaller firm can make innovations more efficiently, then protecting smaller firms through market share regulation can improve the social welfare. We relate our analysis to a case study of Asahi Brewery's introducing Asahi Super Dry to become the top market share company in the industry.

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1 Introduction

Traditionally, antitrust authorities have monitored the degree of concentration (or the market shares of firms) of an industry as an important measure of the market's competitiveness. In the US, the Department of Justice and the Federal Trade Commission monitored the degree of concentration of each industry to protect consumers against firms' colluding in more concentrated industries. This view, that a high degree of concentration leads to collusion, is based on the old industrial organization theory (the "Harvard School" or "structuralists") that proposes a framework to analyze industries — the Structure-Conduct-Performance Paradigm (the SCPP: see Bain 1959 for details; Viscusi, Harrington, and Vernon 2005, pages 62-69, for a summary). The SCPP emphasizes the role of market structure (the degree of concentration, the condition for entry to the market, etc.), market conduct (pricing strategies, investment decision, etc.), which in turn determines market performance (efficiency, fairness, etc.). Thus, the theory presumes that the market structure of an industry determines the performance of a market. Bain (1959) provided a series of empirical evidence showing that in highly concentrated markets the profit ratios are high, and concluded that if the market structure is highly concentrated, collusions tend to occur, hurting the market's performance. The structuralists suggested that the antitrust authority should use structural regulation, that is, divide dominant firms in an industry if the market structure of the industry satisfies a certain set of conditions.¹ In contrast, the Chicago School, especially Demsetz (1973), argued that the high profit ratios in highly concentrated markets may be caused by the cost efficiency of firms in the industry, and that having many smaller firms in the industry may result in inefficiency.² Demsetz also cautioned that regulations based on the degree of concentration may cause

¹The Neal report (1968) to President Lyndon Johnson is based on S-C-P paradigm. The proposed legislation was designed to reduce concentration in any industry in which any four or fewer firms had an aggregate market share of 70% or more. However, in the transition to the next Nixon administration, the policies suggested in the Neal report were ignored (see Foer, 2003).

²To measure concentration, the most widely used measure is still the concentration ratio, which is simply the share of total industry sales accounted for by the m largest firms. However, clearly, there is fundamental problem with this measure, since this measure does not distinguish the market in which all largest firms have equal shares and the one in which the top firm is really a dominant firm in comparison with other large firms. The Herfindahl=Hirshman Index (HHI) fixes this problem and has a nice theoretical support if applied to a Cournot market (Viscusi et al., 2005). However, as Viscusi et al. precisely point out, it is not clear what policy implications can be drawn from HHI. Demsetz's criticism applies to HHI as well.

efficiency damages in the market by discouraging firms' R&D investments.³ Following the Neal report, in late 1960s and early 1970s, influenced by the structuralists' view, the US Department of Justice and the Federal Trade Commission sued corporate giants such as IBM, ATT, Xerox, and Kelloggs based on the fact that these firms had exceedingly high market shares in their industries. However, these court battles revealed that using market shares as a measure of competitiveness of industries is not accurate and not very useful. After these court battles, the Chicago School's view defeated the Harvard structuralists' view in practice, and the market shares of firms in industries per se are no longer regarded as an important measure in US antitrust policies.

However, in some countries the antitrust authorities still seem to be concerned with the market shares of firms. Pressure may be put on to the dominant firm by the antitrust authority's explicitly referring to the country's antitrust law, or by implicit threats from the general public to firms that wield monopoly power in the markets. For example in Turkey, the antitrust division still gives guidance to dominant firms, although they no longer announce direct market share limits since the EU accession process has started. It appears that if the antitrust authority observes a firm with over 50% of the market share, they regulate the dominant firm. If the dominant firm's market share is 55%, then it is not allowed to have a contract with a retailer such that it sells only the dominant firm's products. However, if its market share is 35%, it is allowed to make such an exclusive contract.⁴ The antitrust division of Turkey has given high priority to complaints against firms with more than 50%, and it is known that the fines are harsher for these firms. In addition, if a firm has a market share more than 50%, it must ask the antitrust division for permission when purchasing another firm. In the Turkish mobile phone industry, the dominant firm, Turkcell, was under heavy pressure from the antitrust division until recently when its share reduces to 50%.⁵

However, are these structural regulations by the antitrust authorities ever useful? If firms know that they can be punished if their market shares exceed some threshold level, then they would try to keep their market shares below that level. Such response by a firm would cause inefficiency in resource allocation as long as the dominant firms are

³After the release of the Neal report, a second commission, a group of University of Chicago academics led by George Stigler, wrote a report for the incoming Nixon administration (the "Stigler Report") denouncing the feasibility of attacking conglomerates using the existing antitrust laws (see Foer, 2003).

⁴Block Exemption Communiqué on Vertical Agreements, amended by the Competition Board of Turkey Communiqués No. 2003/3 and 2007/2; Communiqué No. 2002/2.

⁵Access to Mobile Network and Out-going Calls Market Analysis. (December 2009) Market Analysis Series, Information and Communication Technologies Authority of Turkey.

more cost efficient than other firms, as Demsetz (1973) pointed out.⁶ On the one hand, the dominant firms should be more cost-efficient than other firms, and forcing them to reduce their market shares by a market share regulation may cause resource misallocations. Moreover, even if a small firm exits the market, the resource that is used to pay the fixed operation cost could be saved.⁷ A market share regulation could do even more harm if we consider firms' R&D activities. A successful R&D investment may improve the quality of product, or may reduce production cost through improvements in production process. In either case, it will increase the market share of the firm. It can be particularly harmful for society if the most cost efficient firm is discouraged from engaging R&D investment for the society.⁸ On the other hand, however, there is also a good reason to fear that the dominant firm will exercise monopoly power after the smaller firms exit the market. These acts must harm consumers quite a bit, and the dominant firm indeed may attempt a "predation" exercise by improving its technology through R&D investment in order to totally monopolize the market, raising market price. This predation practice through R&D investment can be considered a "non-price monopolization practice" (Motta 2004, page 454), but it is hard for the anti-trust authority to prove the motivation of investment. If structural regulation provides a temporary relief to a small firm that can grow into a competitive rival of the dominant firm through their R&D activities, preventing this non-price monopolization practice, then the increased competition may improve resource allocation. In this paper, we will investigate this possibility. We employ a model of an oligopolistic market with stochastic R&D and fixed costs of operations to evaluate the welfare effects of regulation on R&D decisions.

Although the concentration measure of an industry is no longer considered significant in Japan's antitrust policies, at one time the structuralists' principle was more thoroughly applied there than in the US. In the post-war Japan, right after the World War II, under the rule of the US military, many *zaibatsu* conglomerates were divided into many pieces, and some dominant firms were also divided into smaller companies after being cited as the monopolists with very high market shares. In the next subsection, we will look in detail into episodes that the Japanese beer industry went through under a market share regulation policy conducted by the Japanese government. This case study appears to provide a best supporting case for a market share regulation policy and will highlight the

⁶Lahiri and Ono (1989) show that helping inefficient firms can reduce the social welfare by misallocation of resources.

⁷See, for example, Creane and Konishi (2009).

⁸For the literature on R&D investments, see surveys by Tirole (1988) and Reinganum (1989).

possible pros and cons of a structural regulation policy.

1.1 A Case Study: History of the Japanese Beer Industry

After World War II, the Allied Powers General Headquarters (GHQ) demilitarized Japanese society, democratized the political process, and decentralized the wealth and power in the first phase of the military occupation of Japan between 1945 and 1947. In decentralizing wealth and power, the GHQ engaged in breaking up Japan's *zaibatsu* conglomerates, fostering the growth of labor unions and carrying out a rural land reform program. Subsequently, General MacArthur pressured the Japanese Congress to pass the Law for the Elimination of Excessive Concentrations of Economic Power, which authorized dismantling any company that so dominated a particular market that potential newcomers were unlikely to survive (McClain, 2002, Chapter 15). Enjoying 75% share of the market, the Dai-Nippon Brewery was divided into Asahi and Nippon (later Sapporo) Breweries in 1949. Due to dysfunctional organization and unnecessary rivalries between the two newly created companies, Asahi and Sapporo lost their market shares over the years to a third smaller company Kirin Brewery, and Kirin rapidly became the leading company. In 1973, when Congress proposed an amendment of the Antitrust law to give *Kousei Torihiki Inkai* (the Japan Fair Trade Commission) the power to divide monopolistic companies, Kirin Brewery had a very good reason to be afraid of being divided into smaller companies by observing Dai Nippon Brewery's fate and Kirin's own success.⁹ From then on, Kirin Brewery stopped advertising their products completely for a few years, and tried not to expand their market share.¹⁰ With this effort, Kirin's market share stayed around the low 60s for 15 years. In this period, beer companies started to provide a new variety of beers (Japanese beer was rather homogeneous for many years until then). In 1987, Asahi Brewery introduced Asahi Super Dry to the market, which was an instant huge success: the market share of Asahi Brewery steadily increased from 10% to 45% over the next decade, surpassing Kirin's market share in the beer industry.¹¹

⁹Although the amendment of the Antitrust law was passed in 1977, no specific number on the market share was listed in the guidelines.

¹⁰<http://www.kirinholdings.co.jp/company/history/group/07.html>

¹¹After 1994, the market for low-malt beer (Happoshu) expanded rapidly mainly because low-malt beer is cheaper than regular beer by enjoying a lower tax rate. The alcoholic beverage is popular among consumers for having a lower tax than beverages that the nation's law classifies as "beer."

	Asahi	Kirin	Sapporo	Suntory		Asahi	Kirin	Sapporo	Suntory
1949	36	25	38		1978	11.6	<i>62.3</i>	19.6	6.5
1950	34	29	37		1979	11.0	<i>63.3</i>	19.2	6.5
1951	34	30	36		1980	11.0	<i>62.4</i>	19.6	6.9
1952	32	33	34		1981	10.3	<i>62.9</i>	20.1	6.7
1953	33	33	33		1982	9.9	<i>62.4</i>	19.9	7.8
1954	32	37	31		1983	10.2	<i>61.4</i>	19.9	8.5
1955	32	37	31		1984	9.8	<i>61.7</i>	19.6	8.8
1956	31	42	27		1985	9.6	<i>61.4</i>	19.8	9.2
1957	31	42	26		1986	10.4	59.7	20.7	9.2
1958	31	40	28		1987	12.9	57.0	20.6	9.5
1959	29	42	26		1988	20.6	50.8	19.8	8.8
1960	27	45	26		1989	24.9	48.3	18.4	8.4
1961	28	42	28		1990	24.7	49.2	18.0	8.1
1962	26	45	26		1991	23.8	49.6	18.1	7.7
1963	24	46	26	1	1992	24.0	49.7	18.2	7.2
1964	25.1	46.3	25.4	1.2	1993	24.3	49.4	18.6	6.8
1965	23.2	47.5	25.4	1.9	1994	26.0	49.1	18.2	5.8
1966	22.1	50.9	23.8	1.7	1995	27.2	48.8	17.6	5.5
1967	21.9	49.5	25.0	3.2	1996	30.4	46.6	17.1	5.0
1968	19.9	51.6	24.4	4.1	1997	34.4	42.6	16.8	5.2
1969	18.9	53.3	23.3	4.5	1998	39.5	38.4	15.8	5.3
1970	17.2	55.6	23.0	4.3	1999	43.4	36.2	14.5	5.0
1971	14.8	59.1	22.1	4.0	2000	45.6	34.2	14.3	5.1
1972	14.1	<i>60.2</i>	21.3	4.5					
1973	13.7	<i>61.4</i>	20.3	4.6					
1974	13.0	<i>62.6</i>	19.6	4.7					
1975	13.5	<i>60.9</i>	20.2	5.4					
1976	12.0	<i>63.8</i>	18.5	5.7					
1977	12.1	<i>62.1</i>	19.6	6.3					

Table 2 (Beer companies' share trends: in Tadao Konishi, *Industrial policy*, Toyo Keizai Shimposha (2001).

On the one hand, for the Asahi Brewery, the implicit market share regulation gave them a chance to conduct R&D to develop its new products, and they were lucky enough to win the gamble. So, it may appear that the market share regulation helped to improve efficiency of the market. On the other hand, however, Kirin Brewery's investment was perhaps discouraged by this policy. If there were no market share regulation, then Kirin might have succeeded in innovation, and this success might have greatly improved efficiency. Of course, it also could have led to Kirin's monopolization of the Japanese beer industry, but the efficiency improvement from Kirin's low-cost production could surpass the loss from the monopoly pricing.

1.2 The Rest of the Paper

In the following, we present our simple duopoly model with heterogeneous marginal costs of production (a dominant low-cost firm and a small high-cost firm) and stochastic cost-reducing R&D.¹² In the presence of fixed cost in operation, we assume that the smaller firm might exit dependent on parameter values. With this model, we will try to explain the experience of the Japanese beer industry. When the small firm does not exit the market, we first show that the dominant firm has more incentive to invest in R&D than the small firm,¹³ and identify the set of parameter values in which only the dominant firm invest in R&D (Proposition 1). With the possibility of the small firm's exit, the incentive of R&D is further encouraged for the dominant firm, and is further discouraged for the small firm (Proposition 2). Then, we identify the set of parameter values in which (i) the dominant firm only invests without market share regulation, while (ii) the smaller firm only invests

¹²In Appendix A, we show that a type of quality-enhancing R&D model is equivalent to cost-reducing R&D model. Spence (1984) suggests that the Lancaster-type characteristic good model also has the same structure as cost-reducing R&D model. It would be ideal if we can use a product-developing R&D model since our motivating example is Asahi Super-Dry. However, the Hotelling type one-dimensional model is not rich enough to accommodate a new product meaningfully in a duopoly market, and the Dixit-Stiglitz model can only generate new products that are orthogonal to the existing products. A differentiated product model along the line of Anderson, de Palma, and Thisse (1992) may be useful, but it would be too complicated for the purpose of this paper. This is why we use cost-reducing (or quality-enhancing) R&D model in this analysis.

¹³This result is the same as one of the results in Ishida, Matsumura, and Matsushima (2011), but the setup of the model is very different. Their model assumes R&D to be deterministic, while we assume stochastic R&D. They assume that there are many high-cost firms and show that the low-cost firm's profit can increase when the number of high-cost firms increases. In contrast, we introduce fixed cost of operation for each firm, endogenize the high-cost firm's exit decision, and conduct welfare analysis.

with market share regulation (Proposition 3). We provide a numerical example that satisfies the parameter restrictions in Propositions 2 and 3 (Proposition 4 and Example 1). Then, we conduct welfare analysis: we evaluate market share regulation by consumer price and social welfare (total surplus). Although the expected consumer price is lower under market share regulation, (expected) social welfare, taking firms' fixed and production costs into considerations, is always harmed by adopting market share regulation, assuming that firms are symmetric in the technology of R&D innovation (Propositions 5 and 6). This is because it is more beneficial for society for the dominant firm to succeed in R&D than for the small firm to succeed in R&D, given symmetric R&D technology. That is, without market share regulation, Kirin Brewery may succeed in R&D resulting in Kirin's monopoly, but social welfare is improved more than it is with Asahi's success in R&D. This is partly because Asahi's fixed cost of operation is saved under Kirin's monopoly.

2 The Basic Model

We assume that both the dominant and small firms can reduce the cost of production through their R&D efforts. If a firm is successful in its cost reduction efforts then its cost will decrease by a certain amount.

We consider a Cournot duopoly market. There is a commodity besides a numeraire good, and its (inverse) demand is a continuous function $P(Q)$ in $[0, \bar{Q}]$ that is twice continuously differentiable with $P'(Q) < 0$ for all $Q \in (0, \bar{Q})$ and $P(\bar{Q}) = 0$. There are two firms in the market with a fixed cost of production $F > 0$. This fixed cost must be paid as long as a firm stays in the market (if a firm exits the market then it does not need to pay F).

Firms 1 and 2 differ in their constant marginal costs c_1 and c_2 . Each firm i 's production level is denoted by q_i . Firm i 's profit function is written as

$$\pi_i(q_i, q_j) = (P(Q) - c_i) q_i,$$

where $i \neq j$ and $i, j \in \{1, 2\}$, and $Q = q_1 + q_2$. The first-order condition for profit maximization (assuming an interior solution) is

$$P'(Q)q_i + P(Q) - c_i = 0. \tag{1}$$

This implies

$$q_i = \frac{(P(Q) - c_i)}{-P'(Q)},$$

and firm i 's profit is written as

$$\pi_i(q_i, q_{-i}) = \frac{(P(Q) - c_i)^2}{-P'(Q)}.$$

We assume the **strategic substitutability** condition throughout the paper: for all $i = 1, 2$, for all $Q \geq q_i \geq 0$,

$$P''(Q)q_i + P'(Q) < 0.$$

Note that the second-order condition for profit maximization ($P''(Q)q_i + 2P'(Q) < 0$) is guaranteed by strategic substitutability. We say that the demand is **weakly convex** if $P''(Q) \geq 0$ holds for all $Q \in (0, \bar{Q})$ and $q_i \in (0, Q)$.¹⁴ In proving some of our main results, we need the weak convexity of demand. The strategic substitutability condition guarantees the uniqueness of equilibrium, as is seen below. Summing up the first order conditions, we have

$$P'(Q)(q_1 + q_2) + 2P(Q) - (c_1 + c_2) = 0,$$

or

$$P'(Q)Q + 2P(Q) = C, \tag{2}$$

where $C = c_1 + c_2$ denotes the aggregate marginal cost. Differentiating the LHS of equation (2) with Q , we obtain

$$\begin{aligned} \frac{d(LHS)}{dQ} &= P''(Q)Q + 3P'(Q) \\ &= P''(Q)q_1 + P'(Q) + P''(Q)q_2 + P'(Q) + P'(Q) \\ &< 0. \end{aligned}$$

The inequality holds by the strategic substitutability conditions. This implies that the LHS is strictly decreasing in Q . Thus, equation (2) has a unique solution when the strategic substitutability condition is imposed. Totally differentiating equation (2), we obtain

$$(P''(Q)Q + 3P'(Q))dQ = dC,$$

thus, $\frac{dQ}{dC} = \frac{1}{P''(Q)Q + 3P'(Q)} < 0$ holds. Moreover, $\frac{dP}{dC} = P'(Q) \times \frac{dQ}{dC} > 0$ holds. Summarizing them, we have the following lemma.

Lemma 1. Under the strategic substitutability condition, the equilibrium is unique. Moreover, equilibrium market price P and equilibrium quantity Q is functions of aggregate

¹⁴Weak convexity is satisfied for linear demand.

marginal cost C only. Moreover, P are strictly increasing in C , and Q is strictly decreasing in C .

Initially, firm 1 has a cost advantage over firm 2: that is, firms' marginal costs satisfy $0 < \bar{c}_1 < \bar{c}_2 < 1$, where \bar{c}_1 and \bar{c}_2 are the original marginal costs of firms 1 and 2, respectively. Firms 1 and 2 have options of conducting R&D investment by spending a fixed amount $\Theta > 0$. If R&D investment succeeds, then the marginal cost will be reduced by $\Delta \in (0, \bar{c}_1)$, but the success of R&D investment is assumed to be uncertain. That is, if firm i succeeds in R&D then its marginal cost becomes $c_i = \bar{c}_i - \Delta$, and $c_i = \bar{c}_i$ otherwise. Thus, $\bar{c}_1 - \Delta > 0$. We assume that even after innovation occurs, firms produce positive outputs if they stay in business. That is, even if only firm 1 succeeds in R&D, firm 2 still produces a positive amount (if it stays in the market),

$$P(Q(\bar{c}_1 - \Delta + \bar{c}_2)) - \bar{c}_2 > 0.$$

Denote the success probabilities of firms 1 and 2 by r_1 and r_2 , respectively — we allow probabilities of success to differ across firms. We assume that the two firms' probabilities of success are statistically independent. Assuming that both firms invest, there are four possible realizations. Each realization occurs according to the following table.

		Firm 2	
		Succeed	Fail
Firm 1	Succeed	$r_1 r_2$	$r_1(1 - r_2)$
	Fail	$(1 - r_1)r_2$	$(1 - r_1)(1 - r_2)$

Once the R&D outcomes for both firms are realized, they compete in the Cournot duopoly market. The following lemma shows the relationship between equilibrium outcomes of a duopoly market when all firms stay in the market. Superscripts ss , sf , fs , and ff represent the R&D outcomes by firms 1 and 2 in order: i.e., sf represents the case where firm 1 succeeds and firm 2 fails.

Lemma 2. Suppose that the strategic substitutability is satisfied and that both firms operate after the R&D outcome is realized. Then, we have the following results:

1. $P^{ss} < P^{sf} = P^{fs} < P^{ff}$ and
 $Q^{ss} > Q^{sf} = Q^{fs} > Q^{ff}$
2. $P^{fs} > P^{ff} - \frac{\Delta}{2}$, $P^{ss} > P^{fs} - \frac{\Delta}{2}$,
 $P^{ss} > P^{ff} - \Delta$

3. $q_1^{sf} > q_1^{ss} > q_1^{ff} > q_1^{fs}$,
 $q_2^{fs} > q_2^{ss} > q_2^{ff} > q_2^{sf}$,
 $q_1^{ff} > q_2^{ff}$, $q_1^{ss} > q_2^{ss}$, and $q_1^{sf} > q_2^{fs}$
4. $\pi_1^{sf} > \pi_1^{ff}$, $\pi_1^{sf} > \pi_1^{ss}$,
 $\pi_2^{fs} > \pi_2^{ff}$, $\pi_2^{fs} > \pi_2^{ss}$,
 $\pi_1^{ff} > \pi_2^{ff}$, and $\pi_1^{ss} > \pi_2^{ss}$

Each firm must pay a fixed cost $F > 0$ if it continues to operate. Thus, if a firm's rival gets a strong cost advantage, then it goes out of business and the rival can enjoy monopolist status.¹⁵

With these preliminary results, we will investigate under what conditions firm 1 only invest in R&D and firm 2 exits if firm 1 succeeds in R&D without market share regulation (Proposition 2), and under what conditions firm 2 only invests in R&D under market share regulation (Proposition 3).

2.1 Payoffs of Firms Under No Market Share Regulation and No Firm Exit

We first consider the basic case of no market share regulation with no firm exiting. That is, fixed cost of operation F is ignored in this subsection (F will be introduced in the next subsection). Firms 1 and 2 choose whether to conduct R&D investment, then Nature plays and the outcome of investment is realized.

When both firms invest, firm $i = 1, 2$ the following expected payoffs (recall Θ denotes R&D investment cost):

$$E\pi_i(I, I) = r_1 r_2 \pi_i^{ss} + r_1 (1 - r_2) \pi_i^{sf} + (1 - r_1) r_2 \pi_i^{fs} + (1 - r_1) (1 - r_2) \pi_i^{ff} - F - \Theta.$$

When firm 1 does not invest while firm 2 invests, then the firms' expected profits are

$$E\pi_1(N, I) = r_2 \pi_1^{fs} + (1 - r_2) \pi_1^{ff} - F,$$

and

$$E\pi_2(N, I) = r_2 \pi_2^{fs} + (1 - r_2) \pi_2^{ff} - F - \Theta.$$

¹⁵We can assume that both Δ s and F s are firm-specific, and it might be more reasonable to assume that they are heterogeneous. However, such a generalization makes calculations messy and unclear, so we pin down these two parameter values common to both firms.

When firm 1 invests while firm 2 does not, then the firms' expected profits are

$$E\pi_1(I, N) = r_1\pi_1^{sf} + (1 - r_1)\pi_1^{ff} - F - \Theta,$$

and

$$E\pi_2(I, N) = r_1\pi_2^{sf} + (1 - r_1)\pi_2^{ff} - F$$

Clearly, if neither firm invests, for $i = 1, 2$, we obtain

$$E\pi_i(N, N) = \pi_i^{ff} - F.$$

It is easy to see that as long as firm 2 does not exit when firm 1 succeeds while firm 2 does not, firm 2 always operates in the market:

$$\pi_2^{sf} > F.$$

Now, let us analyze an equilibrium of this two-stage duopoly game. To find a Nash equilibrium, we need to investigate best responses. Under strategic substitutability and weakly convex demand, we have the following result.

Proposition 1. Suppose that $\pi_2^{sf} > F$ (no firm exits in any outcome). Then, under strategic substitutability and weakly convex demand, there is a range of Θ such that only firm 1 invests in unique subgame perfect Nash equilibrium. Specifically, the condition is expressed as

$$r_2 \left[r_1(\pi_2^{ss} - \pi_2^{sf}) + (1 - r_1)(\pi_2^{fs} - \pi_2^{ff}) \right] < \Theta < r_1 \left[r_2(\pi_1^{ss} - \pi_1^{fs}) + (1 - r_2)(\pi_1^{sf} - \pi_1^{ff}) \right].$$

Investing in R&D is a dominant strategy for firm 1 if and only if the second inequality is satisfied. Firm 2 does not invest in R&D when firm 1 invests, if and only if the first inequality is satisfied.

2.2 No Market Share Regulation with Possible Exit

Here, we will introduce F , which may force one of the firms to exit the market. We will concentrate on the case where only firm 2 can exit.¹⁶ The only case where this happens is when firm 1 succeeds and firm 2 fails in R&D. Firm 1 does not exit even if firm 2 succeeds and firm 1 fails in R&D. So, we have the following condition.

$$\pi_2^{sf} < F < \min \left\{ \pi_1^{fs}, \pi_2^{ff} \right\}.$$

¹⁶For the case of entry deterrence, see Dixit (1980).

By Lemma 2, there is a value for F that satisfies the above condition. Under this condition, if sf is the outcome, firm 1 would enjoy monopoly profit if firm 2 exits. In this case, firm 1 earns Π_1^s , where uppercase Π represents monopoly profit. Clearly, firms' payoffs will be affected by this possible exit, and we will denote their payoffs by $\tilde{\pi}_i$. Their payoffs are modified in the following two cases:

1. When both firms invest, firm $i = 1, 2$ the following expected payoffs:

$$E\tilde{\pi}_1(I, I) = r_1 r_2 \pi_1^{ss} + r_1 (1 - r_2) \Pi_1^s + (1 - r_1) r_2 \pi_1^{fs} + (1 - r_1) (1 - r_2) \pi_1^{ff} - F - \Theta,$$

and

$$E\tilde{\pi}_2(I, I) = r_1 r_2 \pi_2^{ss} + (1 - r_1) r_2 \pi_2^{fs} + (1 - r_1) (1 - r_2) \pi_2^{ff} - (1 - r_1 + r_1 r_2) F - \Theta.$$

2. When firm 1 invests, while firm 2 does not, then the firms' expected profits are

$$E\tilde{\pi}_1(I, N) = r_1 \Pi_1^s + (1 - r_1) \pi_1^{ff} - F - \Theta,$$

and

$$E\tilde{\pi}_2(I, N) = (1 - r_1) \pi_2^{ff} - (1 - r_1) F$$

Note that when firm 2 exits, it does not need to pay fixed cost F anymore. Since $\pi_2^{sf} < F$ and $\pi_1^{sf} < \Pi_1^s$, we obviously have the following relationship:

$$\begin{aligned} E\tilde{\pi}_1(I, I) &> E\pi_1(I, I) \\ E\tilde{\pi}_1(I, N) &> E\pi_1(I, N) \\ E\tilde{\pi}_1(N, I) &= E\pi_1(N, I) \\ E\tilde{\pi}_1(N, N) &= E\pi_1(N, N) \end{aligned}$$

Thus, if $\pi_2^{sf} < F$ holds instead of $\pi_2^{sf} > F$, then we have

$$\begin{aligned} E\tilde{\pi}_1(I, I) - E\tilde{\pi}_1(N, I) &> E\pi_1(I, I) - E\pi_1(N, I) \\ E\tilde{\pi}_1(I, N) - E\tilde{\pi}_1(N, N) &> E\pi_1(I, N) - E\pi_1(N, N), \end{aligned}$$

i.e., firm 1 has a stronger incentive to invest in R&D. In contrast, for firm 2, we have

$$\begin{aligned} E\tilde{\pi}_2(I, I) - E\tilde{\pi}_2(I, N) &= r_1 r_2 \pi_2^{ss} + (1 - r_1) r_2 \pi_2^{fs} + (1 - r_1) (1 - r_2) \pi_2^{ff} - (1 - r_1 + r_1 r_2) F - \Theta \\ &\quad - \left[(1 - r_1) \pi_2^{ff} - (1 - r_1) F \right] \\ &= r_2 \left[r_1 (\pi_2^{ss} - F) + (1 - r_1) (\pi_2^{fs} - \pi_2^{ff}) \right] - \Theta \\ &< r_2 \left[r_1 (\pi_2^{ss} - \pi_2^{sf}) + (1 - r_1) (\pi_2^{fs} - \pi_2^{ff}) \right] - \Theta \\ &= E\pi_2(I, I) - E\pi_2(I, N), \end{aligned}$$

i.e., firm 2 has a weaker incentive to invest in R&D. Clearly, firm 1's investment incentive is strengthened, so in the range of Θ that is specified in Proposition 1, investing is still the dominant strategy for firm 1. Firm 2 has less incentive to invest in R&D when firm 1 invests. Thus, there is a wider range of Θ in which firm 1 invests while firm 2 does not. Summarizing this, we have the following proposition.¹⁷

Proposition 2. Suppose that $\pi_2^{sf} < F < \pi_2^{ff}$ (firm 2 exits when firm 1 succeeds in R&D). Then, under strategic substitutability and weakly convex demand, there is a range of Θ such that only firm 1 invests in unique subgame perfect Nash equilibrium. Specifically, this range of Θ is:

$$r_2 \left[r_1(\pi_2^{ss} - F) + (1 - r_1)(\pi_2^{fs} - \pi_2^{ff}) \right] < \Theta < r_1 \left[r_2(\pi_1^{ss} - \pi_1^{fs}) + (1 - r_2)(\Pi_1^s - \pi_1^{ff}) \right]$$

When firm 2 can exit the market, investing in R&D is a dominant strategy for firm 1 if and only if the second inequality is satisfied. Firm 2 does not invest in R&D when firm 1 invests, if and only if the first inequality is satisfied.

2.3 Market Share Regulation

Now, we will consider market share regulation. We assume that market share regulation imposes on firm 1 not to increase its original market share, as was imposed on Kirin Brewery. The original market share for firm 1 is calculated as

$$\bar{s}_1 = \frac{q_1^{ff}}{Q^{ff}} = \frac{(P^{ff} - \bar{c}_1)}{(P^{ff} - \bar{c}_1) + (P^{ff} - \bar{c}_2)}.$$

Basically, market share regulation is imposed on firm 1: firm 1's market share s_1 must satisfy $s_1 \leq \bar{s}_1$. In contrast, there is no share regulation for firm 2. We will consider two cases that will be affected by the market share regulation before we study firms' R&D incentives.

2.3.1 Firm 1 succeeds and firm 2 fails

With the market share restriction, firm 1 cannot force firm 2 out of the market, even if it succeeds and firm 2 fails in R&D. Since firm 2's best response function is still the same

¹⁷Under weak convexity of demand, it is straightforward to show that $\pi_2^{sf} < \pi_2^{ss}$ holds.

(its marginal cost is still \bar{c}_2), firm 1 must maintain the same output level as before. Since the profit margin increases by Δ , firm 1's profit in this particular realization is

$$\bar{\pi}_1^{sf} = \frac{(P^{ff} - \bar{c}_1 + \Delta)(P^{ff} - \bar{c}_1)}{-P'(Q^{ff})} = \pi_1^{ff} \times \frac{P^{ff} - \bar{c}_1 + \Delta}{P^{ff} - \bar{c}_1} < \Pi_1^s.$$

The inequality holds, since Π_1^s is firm 1's monopoly profit when firm 1 succeeds in R&D. Thus even if the R&D investment is successful, firm 1's benefit is greatly reduced.

2.3.2 Both firms succeed

In this case, both firms reduces their marginal costs by Δ . Thus, after innovation, the new market share without restriction would be

$$s_1 = \frac{q_1^{ss}}{Q^{ss}} = \frac{(P^{ss} - \bar{c}_1 + \Delta)}{(P^{ss} - \bar{c}_1 + \Delta) + (P^{ss} - \bar{c}_2 + \Delta)} = \frac{1}{1 + \frac{P^{ss} - \bar{c}_2 + \Delta}{P^{ss} - \bar{c}_1 + \Delta}}.$$

Clearly, we have

$$\frac{P^{ss} + \Delta - \bar{c}_2}{P^{ss} + \Delta - \bar{c}_1} > \frac{P^{ff} - \bar{c}_2}{P^{ff} - \bar{c}_1},$$

and by Lemma 2.2, we have $P^{ss} + \Delta > P^{ff}$. Thus, $s_1 < \bar{s}_1$ holds, and the market share constraint is not binding in this case.

2.3.3 Incentives for R&D

Now, we are ready to study firms' R&D incentives under the market share regulation. First, let us analyze firm 1's R&D investment incentive. If firm 2 invests, firm 1's incentive to invest is described by the following comparison:¹⁸

$$\begin{aligned} & E\bar{\pi}_1(I, I) - E\pi_1(N, I) \\ &= \left[r_1 r_2 \pi_1^{ss} + (1 - r_1) r_2 \pi_1^{fs} + r_1 (1 - r_2) \bar{\pi}_1^{sf} + (1 - r_1) (1 - r_2) \pi_1^{ff} - r_2 \pi_1^{fs} - (1 - r_2) \pi_1^{ff} \right] - \Theta \\ &= r_1 \left[r_2 \left(\pi_1^{ss} - \pi_1^{fs} \right) + (1 - r_2) \left(\bar{\pi}_1^{sf} - \pi_1^{ff} \right) \right] - \Theta \\ &= r_1 \left[r_2 \left(\pi_1^{ss} - \pi_1^{fs} \right) + (1 - r_2) \Delta \times q_1^{ff} \right] - \Theta. \end{aligned}$$

If firm 2 does not invest, firm 1's incentive to invest is simply $r_1 \Delta \times q_1^{ff} - \Theta$. Thus, together, we can say that not investing in R&D is a dominant strategy for firm 1 if the

¹⁸In the last modification, we use

$$\bar{\pi}_1^{sf} - \pi_1^{ff} = \pi_1^{ff} \times \frac{P^{ff} - \bar{c}_1 + \Delta}{P^{ff} - \bar{c}_1} - \pi_1^{ff} = \pi_1^{ff} \times \left(\frac{P^{ff} - \bar{c}_1 + \Delta}{P^{ff} - \bar{c}_1} - 1 \right) = \Delta \times q_1^{ff}.$$

following conditions are satisfied:

$$\max \left\{ r_1 \left[r_2 \left(\pi_1^{ss} - \pi_1^{fs} \right) + (1 - r_2) \Delta \times q_1^{ff} \right], r_1 \Delta \times q_1^{ff} \right\} < \Theta$$

Now, move on to firm 2. Supposing that firm 1 does not invest; then firm 2's investment incentive is

$$\begin{aligned} & E\pi_2(N, I) - E\pi_2(N, N) \\ &= \left\{ r_2 \pi_2^{fs} + (1 - r_2) \pi_2^{ff} - \pi_2^{ff} \right\} - \Theta \\ &= r_2 \left(\pi_2^{fs} - \pi_2^{ff} \right) - \Theta. \end{aligned}$$

Thus, market share regulation increases firm 2's incentive to invest in R&D, while it reduces firm 1's incentive to invest.

The final question is if there is a range of Θ in which only firm 2 invests. For this, we need: $r_2 \left(\pi_2^{fs} - \pi_2^{ff} \right) > \max \left\{ r_1 \left[r_2 \left(\pi_1^{ss} - \pi_1^{fs} \right) + (1 - r_2) \Delta \times q_1^{ff} \right], r_1 \Delta \times q_1^{ff} \right\}$. Then, if Θ lies between these two values, only firm 2 invests in R&D.

Proposition 3. Suppose that market share regulation is binding for firm 1. Then, only firm 2 has an incentive to invest in R&D if the following condition is satisfied:

$$\max \left\{ r_1 \left[r_2 \left(\pi_1^{ss} - \pi_1^{fs} \right) + (1 - r_2) \Delta \times q_1^{ff} \right], r_1 \Delta \times q_1^{ff} \right\} < \Theta < r_2 \left(\pi_2^{fs} - \pi_2^{ff} \right).$$

Not investing in R&D is a dominant strategy for firm 1 if and only if the first inequality is satisfied. Firm 2 invests in R&D when firm 1 does not, if and only if the second inequality is satisfied.

2.4 Interesting Parameter Range: An Example

From Proposition 2, as long as fixed operation costs, R&D investment costs, and R&D success probabilities are symmetric between firms, then firm 1 should invest in R&D if only one firm invests in equilibrium. Proposition 3 shows that with market share regulation, it could only be firm 2 that invests in R&D. Combining these two propositions, we obtain the following proposition.

Proposition 4. Suppose that operational fixed cost F and R&D investment cost Θ satisfy the following three conditions:

1. $\pi_2^{sf} < F < \pi_2^{ff}$

2. $r_2 \left[r_1(\pi_2^{ss} - F) + (1 - r_1)(\pi_2^{fs} - \pi_2^{ff}) \right] < \Theta < r_1 \left[r_2(\pi_1^{ss} - \pi_1^{fs}) + (1 - r_2)(\pi_1^{ss} - \pi_1^{ff}) \right]$
3. $\max \left\{ r_1 \left[r_2(\pi_1^{ss} - \pi_1^{fs}) + (1 - r_2)\Delta \times q_1^{ff} \right], r_1\Delta \times q_1^{ff} \right\} < \Theta < r_2(\pi_2^{fs} - \pi_2^{ff})$.

Then, only firm 1 invests in R&D without market share regulation that prohibits firm 1's share expansion from the initial level, while only firm 2 invests in R&D with market share regulation.

Now, the question is whether there is a set of parameter ranges of F and Θ that satisfy these three conditions simultaneously. To find out how likely (or unlikely) it is that all the three conditions are satisfied, we will consider a linear demand example: $P(Q) = 1 - Q$. In this case, for marginal cost profile (c_1, c_2) there exists a unique equilibrium, which is characterized by

$$\begin{aligned}
p &= \frac{1 + c_1 + c_2}{3} \\
q_i &= \frac{1 + c_1 + c_2}{3} - c_i = \frac{1 + c_j - 2c_i}{3} \\
\pi_i &= \left(\frac{1 + c_1 + c_2}{3} - c_i \right)^2 = \left(\frac{1 + c_j - 2c_i}{3} \right)^2
\end{aligned}$$

for $i = 1, 2$. We show by the following example that the conditions in Proposition 4 can be met even if $r_1 = r_2$.

Example 1. Suppose that $c_1 = 0.5$, $c_2 = 0.6$, $\Delta = 0.2$, and $r_1 = r_2 = r$. In this case, equilibrium allocations *without market share regulation and without exit* are summarized in the following table:

firm 1 firm 2	Succeed	Fail
Succeed	$q_1^{ss} = \frac{0.8}{3}$ $\pi_1^{ss} = \frac{0.64}{9}$ $q_2^{ss} = \frac{0.5}{3}$ $\pi_2^{ss} = \frac{0.25}{9}$	$q_1^{sf} = \frac{1}{3}$ $\pi_1^{sf} = \frac{1}{9}$ $q_2^{sf} = \frac{0.1}{3}$ $\pi_2^{sf} = \frac{0.01}{9}$
Fail	$q_1^{fs} = \frac{0.4}{3}$ $\pi_1^{fs} = \frac{0.16}{9}$ $q_2^{fs} = \frac{0.7}{3}$ $\pi_2^{fs} = \frac{0.49}{9}$	$q_1^{ff} = \frac{0.2}{3}$ $\pi_1^{ff} = \frac{0.04}{9}$ $q_2^{ff} = \frac{0.1}{3}$ $\pi_2^{ff} = \frac{0.01}{9}$

and $\Pi_1^s = 0.1225$. Note that here the original market share for firm 1 is 66.7% ($q_1^{ff}/(q_1^{ff} + q_2^{ff})$), so $\bar{s}_1 = 0.667$. Substituting the numbers into condition 3, we have

$$\max \left\{ r \frac{0.48}{9} + (1 - r) \frac{0.04}{3}, r \frac{0.04}{3} \right\} < \frac{\Theta}{r} < \frac{0.40}{9}.$$

This condition is satisfied if r is not too large: for example, if $r = \frac{1}{4}$ then there is a value of Θ that satisfies the condition. Note that this situation occurs when Δ is large so that conducting R&D is lucrative enough for firm 2 if the attempt is successful. Condition 2 is much easier to satisfy: all values of Θ and r that satisfy the above inequalities also satisfy Condition 3 for any value of F :

$$r \frac{0.25}{9} + (1-r) \frac{0.40}{9} - rF < \frac{\Theta}{r} < r \frac{0.48}{9} + (1-r) \times 0.1185.$$

Condition 1 is satisfied if F belongs to the following interval:

$$\frac{0.01}{9} < F < 0.01.$$

This example shows that as long as we can find a set of parameters that satisfy Condition 3 (only firm 2 invests under market share regulation), then the rest is easy to satisfy. \square

The features of this equilibrium resemble the case study for the Japanese beer industry. By successful R&D investment, Asahi expanded its market share tremendously and became the top company in the industry. Note that the above example assumed that the success probabilities and the costs of R&D investment are symmetric among the firms. It is quite obvious that the conditions in Proposition 4 can be satisfied more easily if $r_1 < r_2$. It is also obvious that we can obtain the desired equilibrium more easily if $\Theta_1 > \Theta_2$ holds.

3 Consumer Price and Social Welfare

In this section, we conduct welfare analysis of share regulation policies.

First, look at consumer welfare. Consumer welfare is measured by the resulting consumer price, the US regulators' main criterion for evaluating antitrust policies.

Proposition 5. Suppose that parameter values satisfy Proposition 4's conditions. Then, the expected consumer price is lower (thus consumer welfare is higher) under market share regulation, if one of the following two conditions are satisfied: (i) $r_1 \leq r_2$ (firm 2's success probability is not lower than firm 1's), and (ii) $P_{MNPL}^s > P^{ff}$ (firm 1's monopoly price in the case of successful predation by R&D cost reduction is higher than the status quo duopoly price).

What about social welfare? Here, we need to think about cost-saving effects of R&D. If both firms are equally good at R&D activities, then the lower-cost firm's cost-saving

effect is stronger than the higher-cost firm's, and regulating market share may hurt social welfare. The following proposition confirms this even under possible predation.

Proposition 6. Suppose that $r_1 = r_2$ and that the parameter values satisfy the conditions in Proposition 1. Then, market share regulation harms the social welfare.

Proposition 6 says that market share regulation can never improve the social welfare if two firms are symmetric in cost and benefit in R&D investment. This result clearly does not support market share regulation. However, it is important to note that Proposition 6 requires the two firms are equally good at R&D: i.e., $\Delta_1 = \Delta_2$, $r_1 = r_2$, and $\Theta_1 = \Theta_2$. By the proof of Proposition 6, it is obvious that if r_1 is much smaller than r_2 (which is not contradictory to Proposition 4's requirement), then it is easy to cook up an example where market share regulation is superior from the social welfare point of view. Similarly, $\Theta_1 > \Theta_2$ and $\Delta_1 < \Delta_2$ make it easier to make market share regulation more attractive. Moreover, if the antitrust authority's objective is to protect consumers (as in the US) rather than to maximize social welfare taking firms' profits into account (as in Canada), then the policy may be justifiable.

4 Concluding Remarks

In this paper, we tried to evaluate the performance of market share regulation policies. By looking at episodes in the Japanese beer industry, we found that such a policy might be beneficial by providing a chance to weaker firms to catch up with a dominant firm. To analyze this possibility, we developed a duopoly model with stochastic (cost-saving) R&D and possible exit from the market, in which one firm has a marginal cost advantage. We first show that market share regulation can be used to encourage a weaker firm to invest in R&D while it discourages the dominant firm from investing. With a simple numerical example, we are able to show that we can mimic the Japanese beer industry's experience with our model. However, we also show that as long as firms are symmetric in R&D technology and in likelihood of success, then the social welfare will be reduced by adopting market share regulation, although consumers are better off by market share regulation. This is because the more efficient firm should be the one to conduct R&D investment if only one firm is investing. This result says that even though Asahi Brewery succeeded with the development of Asahi Super Dry, it might have been even better if Kirin Brewery succeed in R&D from the social welfare point of view, since Kirin was initially more efficient than Asahi.

However, the above conclusion relies on the assumption that the two firms are symmetric in efficiency of R&D investment. If for some reason (say, by Kirin's X-inefficiency), Kirin's R&D investment is less efficient than Asahi's, then the result can easily be reversed, and market share regulation in that case might be justifiable. Having said that, if market share regulation is not the only possible way to achieve the same goal (consider, say, R&D investment subsidies), it might not be easy to support market share regulation as a preferable policy.¹⁹

In this paper, we assumed that R&D investment is a binary decision. It would be nice if we can endogenize the scale of investment, and type of investment. However, the probability of success would differ depending on scale and type of investment, so there is so much freedom in choosing R&D investment technologies. We chose the simplest possible assumption in order to focus on the relationship between firms' R&D incentives and market share regulation. Still, it would be very interesting if we can develop a model in which firms can choose between high-risk-high-return (H-H) and low-risk-low-return (L-L) R&D projects (with no investment option). In the presence of annual fixed operation cost (with possibility of exiting the market), a large firm may choose a L-L project to expand its market share to kick out smaller firms out of the market to enjoy monopoly. In contrast, smaller firms can survive in the long run only by succeeding in achieving a big-hit thus they choose H-H projects if they decide to invest in R&D. Market share regulation may encourage smaller firms to invest in H-H projects by providing temporary remedies.²⁰ If it were the case, market share regulation may be said to be more justifiable. But again, R&D subsidy policy might also encourage small firms' H-H R&D investment.

¹⁹Armstrong and Sappington (2006) show that even the simple choice between regulated monopoly and unregulated competition is not always easy in practice. The relevant technological and demand conditions, regulator's skills and resources, efficiency of tax systems and capital markets, and the strength of other institutions can affect the appropriate choice between these regimes. Connecting it with the liberalization literature they claim that although liberalization should lead to reduced regulatory oversight and control, more pronounced regulatory and antitrust oversight may be required during the term to make sure that regulatory policy is designed appropriately to the level of competition and that competition is protected.

²⁰It is also possible that market share regulation provides incentives for smaller firms to choose L-L projects instead of H-H projects. However, perhaps if there are many small firms, L-L projects would become less attractive since even one small firm succeeds in a H-H R&D project.

Appendix A (quality-enhancing R&D)

In this appendix, we show that one type of quality-enhancing R&D model is equivalent to the cost-reducing R&D model that is used in this paper. Let $a_i \geq 0$ be the quality of the product of firm $i = 1, 2$, and let a representative consumer's utility function be:

$$U(q_1, q_2; a_1, a_2) = m + u(q_1 + q_2) + a_1 q_1 + a_2 q_2,$$

where m is the consumption of the numeraire good, and $u(Q)$ satisfies $u(0) = 0$, $u'(Q) > 0$, and $u''(Q) < 0$ for all $Q > 0$. If $a_1 = a_2 = 0$, then this utility function generates the standard demand function for homogeneous goods. However, if $a_1 \neq a_2$, then the representative consumer's demand for the two products are derived by the first order conditions:

$$p_i = u'(q_1 + q_2) + a_i,$$

where p_i is the price of commodity $i = 1, 2$. Noting that $u'(Q) = P(Q)$ is interpreted as inverse demand for basic good consumption (zero quality good), the firm i 's inverse demand is

$$p_i(q_i, q_j; a_i, a_j) = P(q_1 + q_2) + a_i.$$

Supposing that both firms have the same marginal cost of production $c > 0$, firm i 's profit function is

$$\begin{aligned} \pi_i(q_i, q_j; a_i, a_j) &= (p_i(q_i, q_j; a_i, a_j) - c) q_i \\ &= (P(q_i + q_j) + a_i - c) q_i \\ &= (P(q_i + q_j) - c_i) q_i, \end{aligned}$$

where $c_i = c - a_i$. Thus, cost-reducing R&D and quality-enhancing R&D have the same mathematical structures. It is easy to show that the consumer surplus would be the same in both cases.

Appendix B (proofs)

Proof of Lemma 2. By Lemma 1, 1 is straightforward. To show 2, we use the strategic substitutability condition. From equation (2), we know

$$P'(Q)Q + 2P(Q) = C$$

The strategic substitutability ($P''(Q)Q + P'(Q) < 0$) directly implies that $P'(Q)Q$ is decreasing in Q . Now, by the first-order conditions, we know

$$P'(Q^{ff})Q^{ff} + 2P(Q^{ff}) = \bar{c}_1 + \bar{c}_2$$

and

$$P'(Q^{fs})Q^{fs} + 2P(Q^{fs}) = \bar{c}_1 + \bar{c}_2 - \Delta.$$

Subtracting the former from the latter, we have

$$\begin{aligned} P^{fs} - P^{ff} &= P(Q^{fs}) - P(Q^{ff}) \\ &= \frac{1}{2} [P'(Q^{ff})Q^{ff} - P'(Q^{fs})Q^{fs} - \Delta] \\ &< -\frac{\Delta}{2}. \end{aligned}$$

Other inequalities in 2 are shown in the same way. 3 and 4 are straightforward from 1 and $\bar{c}_1 < \bar{c}_2$. \square

Proof of Proposition 1. We compare expected payoffs of investing and not investing.

Let's start with firm 1.

$$\begin{aligned} &E\pi_1(I, I) - E\pi_1(N, I) \\ &= r_1 r_2 \pi_1^{ss} + r_1 (1 - r_2) \pi_1^{sf} + (1 - r_1) r_2 \pi_1^{fs} + (1 - r_1) (1 - r_2) \pi_1^{ff} - \Theta - r_2 \pi_1^{fs} - (1 - r_2) \pi_1^{ff} \\ &= r_1 r_2 \pi_1^{ss} + r_1 (1 - r_2) \pi_1^{sf} - r_1 r_2 \pi_1^{fs} - r_1 (1 - r_2) \pi_1^{ff} - \Theta \\ &= r_1 \left[r_2 (\pi_1^{ss} - \pi_1^{fs}) + (1 - r_2) (\pi_1^{sf} - \pi_1^{ff}) \right] - \Theta, \end{aligned}$$

and

$$E\pi_1(I, N) - E\pi_1(N, N) = r_1 \pi_1^{sf} + (1 - r_1) \pi_1^{ff} - \Theta - \pi_1^{ff} = r_1 (\pi_1^{sf} - \pi_1^{ff}) - \Theta.$$

Clearly, if $\pi_1^{ss} - \pi_1^{fs} < \pi_1^{sf} - \pi_1^{ff}$ holds, then $E\pi_1(I, I) - E\pi_1(N, I) < E\pi_1(I, N) - E\pi_1(N, N)$ is satisfied.

$$\begin{aligned} &(\pi_1^{ss} - \pi_1^{fs}) - (\pi_1^{sf} - \pi_1^{ff}) \\ &= \left\{ \frac{(P^{ss} - \bar{c}_1 + \Delta)^2}{-P'(Q^{ss})} - \frac{(P^{fs} - \bar{c}_1)^2}{-P'(Q^{fs})} \right\} - \left\{ \frac{(P^{fs} - \bar{c}_1 + \Delta)^2}{-P'(Q^{fs})} - \frac{(P^{ff} - \bar{c}_1)^2}{-P'(Q^{ff})} \right\} \\ &= \left\{ \frac{(P^{ss} - \bar{c}_1 + \Delta)^2}{-P'(Q^{ss})} - \frac{(P^{fs} - \bar{c}_1 + \Delta)^2}{-P'(Q^{fs})} \right\} - \left\{ \frac{(P^{fs} - \bar{c}_1)^2}{-P'(Q^{fs})} - \frac{(P^{ff} - \bar{c}_1)^2}{-P'(Q^{ff})} \right\} \\ &< \left\{ \frac{(P^{ss} - \bar{c}_1 + \Delta)^2}{-P'(Q^{ss})} - \frac{(P^{fs} - \bar{c}_1 + \Delta)^2}{-P'(Q^{ss})} \right\} - \left\{ \frac{(P^{fs} - \bar{c}_1)^2}{-P'(Q^{fs})} - \frac{(P^{ff} - \bar{c}_1)^2}{-P'(Q^{fs})} \right\} \\ &< 0. \end{aligned}$$

We used weak convexity in the second to last inequality: $-P'(Q^{ff}) \geq -P'(Q^{fs}) \geq -P'(Q^{ss})$. This means that if $E\pi_1(I, I) - E\pi_1(N, I) > 0$ then $E\pi_1(I, N) - E\pi_1(N, N) > 0$ must hold, and investing becomes the dominant strategy for firm 1.

Now, let us turn to firm 2.

$$\begin{aligned}
& E\pi_2(I, I) - E\pi_2(I, N) \\
&= r_1 r_2 \pi_2^{ss} + r_1 (1 - r_2) \pi_2^{sf} + (1 - r_1) r_2 \pi_2^{fs} + (1 - r_1) (1 - r_2) \pi_2^{ff} - \Theta - r_1 \pi_2^{sf} - (1 - r_1) \pi_2^{ff} \\
&= r_1 r_2 \pi_2^{ss} - r_1 r_2 \pi_2^{sf} + (1 - r_1) r_2 \pi_2^{fs} - (1 - r_1) r_2 \pi_2^{ff} - \Theta \\
&= r_2 \left[r_1 (\pi_2^{ss} - \pi_2^{sf}) + (1 - r_1) (\pi_2^{fs} - \pi_2^{ff}) \right] - \Theta.
\end{aligned}$$

When $r_1 = r_2$, if $\pi_1^{ss} - \pi_1^{fs} > \pi_2^{ss} - \pi_2^{sf}$ and $\pi_1^{sf} - \pi_1^{ff} > \pi_2^{fs} - \pi_2^{ff}$, then we can conclude that there is some value Θ such that only firm 1 has an incentive to invest in R&D: i.e.,

$$r_2 \left[r_1 (\pi_2^{ss} - \pi_2^{sf}) + (1 - r_1) (\pi_2^{fs} - \pi_2^{ff}) \right] < \Theta < r_1 \left[r_2 (\pi_1^{ss} - \pi_1^{fs}) + (1 - r_2) (\pi_1^{sf} - \pi_1^{ff}) \right].$$

It is indeed the case, since we have

$$\begin{aligned}
& \left(\pi_1^{ss} - \pi_1^{fs} \right) - \left(\pi_2^{ss} - \pi_2^{sf} \right) \\
&= \left(\frac{(P^{ss} - \bar{c}_1 + \Delta)^2}{-P'(Q^{ss})} - \frac{(P^{fs} - \bar{c}_1)^2}{-P'(Q^{fs})} \right) - \left(\frac{(P^{ss} - \bar{c}_2 + \Delta)^2}{-P'(Q^{ss})} - \frac{(P^{fs} - \bar{c}_2)^2}{-P'(Q^{fs})} \right) \\
&= \left(\frac{(P^{ss} - \bar{c}_1 + \Delta)^2}{-P'(Q^{ss})} - \frac{(P^{ss} - \bar{c}_2 + \Delta)^2}{-P'(Q^{ss})} \right) - \left(\frac{(P^{fs} - \bar{c}_1)^2}{-P'(Q^{fs})} - \frac{(P^{fs} - \bar{c}_2)^2}{-P'(Q^{fs})} \right) \\
&= \frac{(\bar{c}_2 - \bar{c}_1) (2P^{ss} - \bar{c}_1 - \bar{c}_2 + 2\Delta)}{-P'(Q^{ss})} - \frac{(\bar{c}_2 - \bar{c}_1) (2P^{fs} - \bar{c}_1 - \bar{c}_2)}{-P'(Q^{fs})} \\
&> \frac{(\bar{c}_2 - \bar{c}_1) (2P^{ss} - \bar{c}_1 - \bar{c}_2 + 2\Delta)}{-P'(Q^{ss})} - \frac{(\bar{c}_2 - \bar{c}_1) (2P^{fs} - \bar{c}_1 - \bar{c}_2)}{-P'(Q^{ss})} \\
&= \frac{(\bar{c}_2 - \bar{c}_1) 2 (P^{ss} + \Delta - P^{fs})}{-P'(Q^{ss})} > 0.
\end{aligned}$$

The last inequality is shown by $P^{ss} + \frac{\Delta}{2} > P^{fs}$ (Lemma 2, 2). By exactly the same logic, we can prove $\pi_1^{sf} - \pi_1^{ff} > \pi_2^{fs} - \pi_2^{ff}$ as well. We have completed the proof. \square

Proof of Proposition 5. Since the conditions of Proposition 4 are satisfied, without market share regulation only firm 1 invests whereas with market share regulation, only firm 2 invests. The expected consumer price under *lassiez faire* is

$$r_1 P_{MNPL}^s + (1 - r_1) P^{ff},$$

and under market share regulation it is

$$r_2 P^{fs} + (1 - r_2) P^{ff},$$

where P_{MNPL}^s denotes the monopoly price by firm 1 when firm 1 succeeds in R&D. Let us start with (i). In this case, it suffices to show $P_{MNPL}^s > P^{fs}$. From the profit maximization condition, we know

$$P'(Q_{MNPL}^s)Q_{MNPL}^s + P(Q_{MNPL}^s) = \bar{c}_1 - \Delta$$

$$P'(Q^{fs})Q^{fs} + 2P(Q^{fs}) = \bar{c}_1 + \bar{c}_2 - \Delta.$$

We need to show that $Q_{MNPL}^s < Q^{fs}$ and $P(Q_{MNPL}^s) > P(Q^{fs})$. Suppose not. Then,

$$P'(Q^{fs})Q^{fs} + P(Q^{fs}) \geq P'(Q_{MNPL}^s)Q_{MNPL}^s + P(Q_{MNPL}^s) = \bar{c}_1 - \Delta$$

holds by strategic substitutability. Subtracting this from the second equation, we have

$$P(Q^{fs}) < \bar{c}_2.$$

This is a contradiction. Thus, condition (i) assures the desired result. Condition (ii) directly implies the result. \square

Proof of Proposition 6. We prove this proposition by two claims. First, we consider a hypothetical situation where firm 1 succeeds in R&D while firm 2 does not exit the market. We show that from the social welfare point of view this hypothetical situation is inferior to the case where firm 1 succeeds in R&D and firm 2 exits the market. Second, we show that from the social welfare point of view the hypothetical situation dominates the case where only firm 2 succeeds in R&D and both firms stay in the market.

Claim 1. Suppose that only firm 1 conducts R&D investment and succeeds in it. Then, the social welfare is higher if firm 2 exits from the market, if $\pi_2^{sf} < F$ holds.

Proof of Claim 1. The proof is by Figure 1 (see Figure 1). First note that under monopoly (firm 2 exits), the price and quantity are P_{MNPL}^s and Q_{MNPL}^s , and P^{sf} and Q^{sf} that under duopoly (firm 2 does not exit), respectively. Marginal costs of two firms are $\bar{c}_1 - \Delta$ and \bar{c}_2 , respectively.

Under monopoly, the social welfare is described by areas $A + B + D + E + G + H$ minus firm 1's fixed cost of operation and R&D expense, while under duopoly it is done by areas $A + B + C + D + E + F + G$ minus both firms' fixed costs and firm 1's R&D expense.

Thus, if areas $A + B + D + E + G + H$ are larger than areas $A + B + C + D + E + F + G$ minus firm 2's fixed cost, we are done. Note that areas $E + F$ are smaller than firm 2's fixed cost by assumption. Thus, it is sufficient to show that areas $A + B + D + E + G + H$ are larger than areas $A + B + C + D + G$, or areas $E + H$ are larger than C . The areas $E + H$ are described by

$$(P_{MNPL}^s - (\bar{c}_1 - \Delta)) \times q_2^{sf}$$

It is clear that area C is not larger than $(P_{MNPL}^s - P^{sf}) \times (Q^{sf} - Q_{MNPL}^s)$. Thus, we have

$$C < (P_{MNPL}^s - P^{sf}) \times (Q^{sf} - Q_{MNPL}^s) \leq (P_{MNPL}^s - P^{sf}) \times q_2^{sf} < (P_{MNPL}^s - (\bar{c}_1 - \Delta)) \times q_2^{sf} = E + H$$

Hence, the areas $E + H$ are larger than the area C . ■

Claim 2. Consider two cases: (i) only firm 1 invests in R&D and succeeds and both firms operate, and (ii) only firm 2 invests in R&D and succeeds. Then, case (i) dominates case (ii) from the social welfare point of view.

Proof of Claim 2. First recall $P^{sf} = P^{fs}$ since $\Delta_1 = \Delta_2 = \Delta$. Thus, the consumer surplus is the same between these two cases, and the only difference is total cost of production. The total cost of production in case (i) is

$$TC^{(i)} = (\bar{c}_1 - \Delta) \times q_1^{sf} + \bar{c}_2 \times q_2^{sf} = \bar{c}_1 \times q_1^{sf} + \bar{c}_2 \times q_2^{sf} - \Delta \times q_1^{sf},$$

and the total cost of production in case (ii) is

$$TC^{(ii)} = \bar{c}_1 \times q_1^{fs} + \bar{c}_2 \times q_2^{fs} - \Delta \times q_2^{fs}.$$

Since $q_1^{sf} > q_2^{fs}$ holds by $\bar{c}_1 < \bar{c}_2$, we conclude $TC^{(i)} < TC^{(ii)}$. Thus, the social welfare is higher in case (i). This proves Claim 2. ■

The above two claims show that *given that R&D is successful*, the situation where firm 1 conducts R&D (and firm 2 exits: *the laissez faire equilibrium*) is superior to that where firm 2 conducts R&D (*the market share regulation equilibrium*). Given this result, the rest is straightforward. Since $r_1 = r_2$, the success probabilities of R&D under the two equilibrium outcomes are the same. Noting that if R&D is not successful the two equilibrium outcomes are the same (the status quo equilibrium: both firms stay with marginal costs \bar{c}_1 and \bar{c}_2 , respectively), we conclude that market share regulation is less desirable than laissez faire from the social welfare point of view. □

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