Welfare effects of dominant retailers*

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Abstract

This paper analyzes three variants of a model to study the welfare effects of dominant retailers' presence in a competitive-goods market. We consider a competitive market with numerous consumers and producers who manufacture and retail. We assume that the dominant retailers are more cost-efficient in retailing than the producer and have market power both in upstream and downstream markets. In our model, entry of two dominant retailers always benefits the market if the producer stays in the retail market to generate competition pressure. However, if the dominant retailers replace the producer in retailing, there are trade-offs between cost-efficiency and competition.

Keywords: Dominant retailer, Market power, Retailing costs

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1 Introduction

In this paper, we analyze three vertical structures to compare market outcomes and social welfare. We are interested in the impacts of the presence of dominant retailers in a market which would be competitive if it was not for a dominant retailer. Even if retailers sell competitive-goods, they can have market power over consumers in various ways. The retailers could offer better retailing service or carry a wide variety of goods to attract one-stop shoppers. Once retailers have market power over consumers in a downstream(retail) market, they often have buyer power over producers in an upstream(wholesale) market. With growing prevalence of superstore retailers such as Wal-Mart and Carrefour, there are more and more competitive-goods sold via dominant retailers who have market power both in upstream and downstream markets. If a good portion of consumers buy the goods dealt by dominant retailers, there might not be enough competition to achieve a social optimum even in a market with many manufacturers conventionally counted as a competitive market. On the other hand, dominant retailers are often more cost-efficient than smaller retailers due to economies of scale and scope. This paper examines the effects of such retailers' presence on market outcomes and their welfare implications.

There is growing literature to study dominant retailers' behaviors and their impacts. While our focus is on the competitive-goods, a great portion of the literature aims to examine whether or not dominant retailers can reduce consumer prices by exercising buyer power against producers with market power. von Ungern-Sternberg (1996), Dobson and Waterson (1997), Chen (2003), and Erutku (2005) analyze the effects of dominant retailers' countervailing power against a single producer on consumer prices and social welfare in various settings. More recently, Iozzi and Valletti (2014) and Chen et al. (2016) study the effects of buyer power of dominant retailers. Johansen and Nilssen (2016) are more focused on incentives to form a big retail store rather than its impacts. Johansen and Nilssen (2016) analyze interactions between one-stop shopping and buyer power to find when there is an incentive to create big stores. Several papers study dominant retailers' impacts mainly within a retail industry. Chen and Rey

(2012) analyze theoretically the effect of loss-leading strategies employed by large retailers on their smaller, rival retailers' profits and consumer surplus. Hausman and Leibtag (2007), Volpe III and Lavoie (2008), and Jia (2008) study empirically the effects of Wal-Mart on other retailers or consumer surplus. Our approach is different from these studies because we analyze the dominant retailers' impact on the vertical market of the goods dealt by dominant retailers.

We set up a simple model that has three components: a producer, duopoly retailers, and consumers. We have one producer to make the model simple, but intend to analyze a market with numerous producers. The model is set up in such a way that the producer's quantity decision can be interpreted as the aggregation of many individual producers' decisions. The producer and the consumers behave as price-takers. The duopoly retailers can set neither retail price nor wholesale price directly, but they have market power in the sense that their decision on the quantity affects the wholesale and retail prices, which are decided along the producer's supply curve and the consumers' demand curve, respectively. The duopoly retailers have a cost advantage in retailing over the producer. We then consider three variants of the model. The first case is a benchmark, competitive market without dominant retailers. The producer manufactures the goods and sells directly to the consumers. In the next two cases, the duopoly retailers enter the market. In the second case, the producer stays out of the retail market upon the duopoly retailers' entry. The producer manufactures and sells all the goods to the duopoly retailers, who resell the goods to the consumers. In the third case, the producer keeps retailing even after the duopoly retailers enter the market. The producer manufactures the goods and sells them to the retailers in the wholesale market and to the consumers in the retail market. By comparing equilibrium outcomes across the three cases, we can analyze the impacts of the presence of the dominant retailers. Our results show that the third case yields the highest social welfare among the three cases, but does not achieve the social optimum. Comparison between the first and the second cases depends on market conditions such as production costs, retailing costs, and market demand. In our model, emergence of the duopoly retailers, who have market power and a cost advantage, always improves social welfare and consumer surplus as long as the producer stays in the retail market to generate competitive pressure. Moreover if the dominant retailers' cost advantage over the producer is large, the retailers' entry can benefit even the producer by enlarging the market.

This paper is distinct from the existing studies on dominant retailers whose focus is mostly on the impacts of buyer power against a monopolist. Our focus is on the impacts of the existence of dominant retailers in the competitive-goods market. Our approach is also different from much research on concentration in the retail industry. We analyze the impacts that dominant retailers bring in the market of competitive-goods dealt by dominant retailers rather than in the retail industry. The rest of the paper is organized as follows. The next section presents three variants of the model and computes the equilibrium for each case. We then compare the equilibrium outcomes and discuss policy implications in Section 3. Finally, we conclude in Section 4.

2 Model and Analysis

2.1 Basic environments

We consider two levels of markets with one producer (labeled 0) and two symmetric retailers (labeled 1 and 2). The producer manufactures the goods and sells them to the retailers at a wholesale price r in the upstream market and/or to the consumers at a retail price p in the downstream market. The retailers resell the goods to the consumer at a retail price p in the downstream market. The demand in the downstream market is given by

$$p = b - aQ, \tag{1}$$

where Q is the market quantity of goods.

We assume that the producer behaves as a price-taker both in the upstream and downstream markets. We consider a single producer instead of numerous individual producers for computational convenience. The aggregate profit and quantity obtained by each individual producer maximizing profit separately taking prices as given is the same as the profit and quantity that would be obtained if a single price-taking producer were to maximize profit (Mas-Colell et al. (1995), p.148). In other words, the producer's profit-maximizing solution for given prices in our model is the same as the solution of the aggregate profit-maximizing problem of numerous individual producers who take prices as given. Hence, throughout the paper, we interpret the producer's behavior in our model as the aggregate behavior of numerous individual producers.

In contrast, the retailers are not price-takers. When the retailers make a decision on their retailing quantities, they think forward how their quantity decisions would affect the wholesale and retail prices, knowing that the producer and the consumers take prices as given. Once the retailers choose their retailing quantities, the wholesale and the retail prices are decided respectively along the producer's supply curve and the consumers' demand curve.

The producer's (total) cost in manufacturing goods is $C = (1/2)cQ^2$ with $c > 0$. The goods manufactured by the producer can be supplied to the consumer directly by the producer and/or indirectly through the retailers. Let q_0 be the amount of goods that the producer supplies to the consumer directly. Let q_i with $i = 1,2$ be the amount of goods that retailer i buys from the producer and resells to the consumers. Note that $Q = q_0 + q_1 + q_2$ holds in any equilibrium. If the producer sells the goods to the consumers directly, it has to pay retailing costs in addition to the production costs. The retailing costs of the producer are given by $RC_0 = (1/2)\beta_h q_0^2$. If retailer i sells the goods to the consumers, it has to pay retailing costs $RC_i = (1/2)\beta_l q_i^2$ where q_i is the amount of goods that retailer i sells to the consumers. We assume that

$$0 < \beta_l < \beta_h < c \tag{2}$$

This means that the retailing costs are smaller than the production costs. In addition, the retailers have a cost advantage over the producer in retailing.

Given the retail price and the wholesale price, the producer's profit is

$$\Pi_0 = pq_0 + r(q_1 + q_2) - \frac{1}{2}c(q_0 + q_1 + q_2)^2 - \frac{1}{2}\beta_h q_0^2, \tag{3}$$

and the retailer i's profit is

$$\Pi_i = pq_i - rq_i - \frac{1}{2}\beta_l q_i^2. \tag{4}$$

In the wholesale market, the supply curve for the goods is obtained from the producer's profit maximization problem as follows:

$$r = c(q_0 + Q^w) \text{ for given } q_0 \tag{5}$$

where r is the wholesale price, and Q^w is the wholesale quantity. In equilibrium, $Q^w = q_1 + q_2$ holds.

Below, we compute consumer surplus and social welfare for welfare analysis. Given that the market demand is linear as in (1), the consumer surplus is

$$CS = \frac{1}{2}aQ^2. \tag{6}$$

Then, we can define the social welfare as

$$SW = CS + \Pi_0 + \Pi_1 + \Pi_2. \tag{7}$$

Since the monetary transfers in the retail and the wholesale markets do not affect the social welfare, the social welfare depends only on the amount of goods (q_o, q_1, q_2) that the producer and the retailers retail. A straightforward calculation shows that the social welfare is maximized at

$$q_0^* = \frac{\beta_l}{(a+c)(2\beta_h + \beta_l) + \beta_h\beta_l} b \tag{8}$$

$$q_1^* = q_2^* = \frac{\beta_h}{(a+c)(2\beta_h + \beta_l) + \beta_h\beta_l} b. \tag{9}$$

At the social optimum, both the producer and the retailers supply goods to the consumers. Note that, at the social optimum, the producer's marginal costs of retailing are equalized to each retailer's marginal costs of retailing (i.e., $\beta_h q_0^o = \beta_l q_i^o$); thus the retailers, who are more efficient in retailing, supply more goods to the consumers than does the producer. When the social welfare is maximized, the market supply is

$$Q^* = q_0^* + q_1^* + q_2^* = \frac{2\beta_h + \beta_l}{(a+c)(2\beta_h + \beta_l) + \beta_h\beta_l} b. \tag{10}$$

The maximized social welfare is

$$\mathrm{SW}^* = \frac{2\beta_h + \beta_l}{2((a+c)(2\beta_h + \beta_l) + \beta_h\beta_l)} b^2. \tag{11}$$

Below, we present three different cases of vertical structures to compare equilibrium outcomes. In the first case, there is no retailer; thus, the producer sells its goods to the consumers directly. The producer and the consumers are price-takers, thus the market quantity and price are determined as a competitive equilibrium. In the second case, the producer manufactures the goods but does not retail. Instead, the producer sells the goods to the retailers in the wholesale market and the duopoly retailers compete with each other by choosing a quantity q_i. In the last case, the producer sells to the consumers directly as well as through the retailers. The retailers are market leaders and the producer is a follower in the retail market. This means that the retailers decide their quantities q_1 and q_2 simultaneously, and then the producer decides its quantity q_0.

Case 1: Supply only by the producer

We first consider the case in which there are no retailers and the producer sells the goods to the consumers directly. In this case, there does not exist a wholesale market. Since the producer and the consumers behave as price-takers, the retail price and the market quantity are determined at a competitive equilibrium. Maximizing the producer's profits in (3) given p with $q_0 = Q$ and $q_1 = q_2 = 0$, we obtain a market supply of $p = (c + \beta_h)Q$. From the market demand and supply, we obtain the retail price and the market quantity at equilibrium as follows:

$$p^{(1)} = \frac{c + \beta_h}{a + c + \beta_h} b \tag{12}$$

$$Q^{(1)} = q_0^{(1)} = \frac{1}{a + c + \beta_h} b. \tag{13}$$

Case 2: Supply only by the retailers

We next consider the case in which the producer manufactures the goods and supplies them to the consumers only through the retailers. In other words, $q_0 = 0$. Two retailers choose q_1 and q_2 simultaneously. Since the consumers and the producer behave as price-takers, the retail price is set on the consumers' demand (1), and the wholesale price is set on the producer's supply (5) in the wholesale market. As a result, $p = b - a(q_1 + q_2)$ and $r = c(q_1 + q_2)$ in equilibrium. Given that $p = b - a(q_1 + q_2)$ and $r = c(q_1 + q_2)$, each retailer i chooses q_i to maximize its profits in (4). Hence, we obtain

$$q_1^{(2)} = q_2^{(2)} = \frac{1}{3a + 3c + \beta_l} b \tag{14}$$

as a Nash equilibrium. The market quantity is as follows:

$$Q^{(2)} = q_1^{(2)} + q_2^{(2)} = \frac{2}{3a + 3c + \beta_l} b. \tag{15}$$

In the equilibrium, the retail price and the wholesale price are determined as:

$$p^{(2)} = b - a(q_1^{(2)} + q_2^{(2)}) = \frac{a + 3c + \beta_l}{3a + 3c + \beta_l} b \tag{16}$$

$$r^{(2)} = c(q_1^{(2)} + q_2^{(2)}) = \frac{2c}{3a + 3c + \beta_l} b. \tag{17}$$

Case 3: Supply by the producer and the retailers

In the last case, the producer and the retailers supply the goods to the consumers. In the retail market, the retailers and the producer compete in quantities as market leaders and a follower. The competition proceeds in two stages. At stage 1, each retailer i chooses q_i simultaneously. At stage 2, the producer chooses q_0 after observing q_1 and q_2. We find an equilibrium by backward induction.

At stage 2, given that the retailers choose q_1 and q_2, the producer as a price-taker chooses q_0 maximizing its profit in (3). Simple algebra yields

$$q_0 = \frac{1}{c+\beta_h} p - \frac{c}{c+\beta_h}(q_1+q_2). \tag{18}$$

In addition, by noting that the retail price p is set on the consumers demand curve, $p = b - aQ$, and $Q = q_0 + q_1 + q_2$ in equilibrium, we obtain:

$$p = b - a(q_0 + q_1 + q_2) \tag{19}$$

By plugging p in (19) into (18) and rearranging terms, we obtain q_0, the quantity of the goods that the producer sells to the consumers as follows:

$$q_0 = \frac{b-(a+c)(q_1+q_2)}{a+c+\beta_h}. \tag{20}$$

On the other hand, the wholesale price r is set on the producer's supply curve $r = c(q_0 + Q^w)$ and $Q^w = q_1 + q_2$ in equilibrium. By applying (20), we obtain the wholesale price given q_1 and q_2 at equilibrium as follows:

$$r = c(q_0+q_1+q_2) = \frac{c(b+(q_1+q_2)\beta_h)}{a+c+\beta_h}. \tag{21}$$

At stage 1, two retailers decide their retailing quantities knowing what would happen at stage 2. By plugging (18) into (19) and solving with respect to p, we have

$$p = \frac{b(c+\beta_h) - a(q_1+q_2)\beta_h}{a+c+\beta_h}. \tag{22}$$

Given p in (22) and r in (21), retailer i's profit is

$$\Pi_i = \left(\frac{b(c+\beta_h) - a(q_i+q_j)\beta_h}{a+c+\beta_h}\right) q_i - \left(\frac{c(b+(q_i+q_j)\beta_h)}{a+c+\beta_h}\right) q_i - \frac{1}{2}\beta_l q_i^2. \tag{23}$$

Maximizing (23) with respect to q_i, the first order necessary condition implies that

$$2a\beta_h q_i - b\beta_h + a\beta_h q_j + a\beta_l q_i + 2c\beta_h q_i + c\beta_h q_j + c\beta_l q_i + \beta_h\beta_l q_i = 0. \tag{24}$$

By solving (24) for $i = 1,2$, we have

$$q_1^{(3)} = q_2^{(3)} = \frac{\beta_h}{(a+c)(3\beta_h + \beta_l) + \beta_h\beta_l} b. \tag{25}$$

By plugging (25) into (18), we have

$$q_0^{(3)} = \frac{(a+c)(\beta_h + \beta_l) + \beta_h\beta_l}{(a+c+\beta_h)((a+c)(3\beta_h + \beta_l) + \beta_h\beta_l)} b. \tag{26}$$

The market quantity is then

$$Q^{(3)} = q_0^{(3)} + q_1^{(3)} + q_2^{(3)} = \frac{(a+c)(3\beta_h + \beta_l) + \beta_h\beta_l + 2\beta_h^2}{(a+c+\beta_h)((a+c)(3\beta_h + \beta_l) + \beta_h\beta_l)} b. \tag{27}$$

By plugging q_i in (25) into (20) and (21), we obtain the retail price and the wholesale price as follows:

$$p^{(3)} = \frac{(c+\beta_h)((a+c)(3\beta_h + \beta_l) + \beta_h\beta_l) - 2a\beta_h^2}{(a+c+\beta_h)((a+c)(3\beta_h + \beta_l) + \beta_h\beta_l)} b \tag{28}$$

$$r^{(3)} = \frac{(a+c)(3\beta_h + \beta_l) + \beta_h\beta_l + 2\beta_h^2}{(a+c+\beta_h)((a+c)(3\beta_h + \beta_l) + \beta_h\beta_l)} bc. \tag{29}$$

3 Comparison of equilibria

In this section, we compare equilibrium outcomes among the three cases analyzed in the previous section. Proposition 1 compares the retail quantity, retail price, and wholesale price at equilibrium. Propositions 2-5 compare the consumer surplus, producer's profits, retailer's profits, and social welfare, respectively.

Proposition 1 *Given β_h and β_l, $Q^{(2)} > Q^{(1)}$ and $p^{(2)} < p^{(1)}$ hold if and only if*

$$2\beta_h - \beta_l > a + c. \tag{30}$$

For any β_h and β_l, the following inequalities hold:

$$Q^{(1)} < Q^{(3)};\ Q^{(2)} < Q^{(3)};\ p^{(1)} > p^{(3)};\ p^{(2)} > p^{(3)};\ and\ r^{(2)} < r^{(3)}. \tag{31}$$

Proof. Note that

$$Q^{(2)} - Q^{(1)} = \frac{(2\beta_h - \beta_l - (a + c))}{(3a + 3c + \beta_l)(a + c + \beta_h)} b, \tag{32}$$

and $p^{(2)} - p^{(1)} = -a(Q^{(2)} - Q^{(1)})$. Hence the first part of the proposition follows immediately. The second part of the proposition is straightforward from the prices and quantities derived in the previous section. ■

The first part of Proposition 1 compares the retail price and quantity between Case 1 and Case 2. The larger is the difference between the retailer's and the producer's retailing costs, the larger is the value of the left-hand side of the inequality (30). Thus, the first part of Proposition 1 can be interpreted as follows: if the retailers' cost advantage over the producer in retailing is large, the retailing quantity is larger and the retail price is lower in Case 2 than in Case 1.[1]

The second part of Proposition 1 shows that the retailing quantity is larger and the retail price is lower in Case 3 than in Case 1 or in Case 2. Interestingly, this result holds regardless of the size of retailers' cost advantage over the producer. When we compare Case 1 and Case 3, it is tempting to think that entry of retailers who have market power over the consumers and the producer would alleviate competition in the retail

[1] In Case 2, we consider a retail market in which two retailers compete with each other to supply the goods to the consumers. Instead, we may consider a retail market in which the goods are supplied to the goods through one monopolistic retailer. Then, one can show that, regardless of the dominant retailer's cost advantage, the price is always higher and the market quantity is always smaller in the monopolistic retail market than in the market without retailers. In other words, we cannot find the trade-off between the dominant retailer's cost advantage and its effect of making the market less competitive.

market to cause a rise of the retail price. However, even if the retailers have market power, they are new, lower-cost competitors against the producer in the retail market; thus, their entry actually increases competitive pressure. As long as the producer keeps retailing, unlike Case 2, retailers' entry does not hurt competitiveness in the retail market. The second part of Proposition 1 says that the wholesale price is higher in Case 3 than in Case 2. This is intuitively clear, because allowing the producer to sell the goods to the consumers means that the producer has an option other than selling the goods to the retailers. This means that market circumstances in Case 3 favor the producer in determining the wholesale price.

We next compare the consumer surplus (CS). In the first case where the producer directly sells the goods to the consumers, the consumer surplus is

$$CS^{(1)} = \frac{a}{2}(Q^{(1)})^2 = \frac{a}{2(a+c+\beta_h)^2}b^2. \tag{33}$$

In the second case where only the retailers supply the goods to the consumers, the consumer surplus is

$$CS^{(2)} = \frac{a}{2}(Q^{(2)})^2 = \frac{2a}{(3a+3c+\beta_l)^2}b^2. \tag{34}$$

In the last case where both the producer and the retailers supply the goods to the consumers, the consumer surplus is

$$CS^{(3)} = \frac{a}{2}(Q^{(3)})^2 = \frac{1}{2}\frac{a((a+c)(3\beta_h+\beta_l)+\beta_h\beta_l+2\beta_h^2)^2}{(a+c+\beta_h)^2((a+c)(3\beta_h+\beta_l)+\beta_h\beta_l)^2}b^2. \tag{35}$$

Proposition 2 *Given β_h and β_l, $CS^{(1)} < CS^{(2)}$ holds if and only if (30) holds. In addition, for any β_h and β_l, $CS^{(1)} < CS^{(3)}$ and $CS^{(2)} < CS^{(3)}$ hold.*

Proof. Since $CS = (1/2)aQ^2$, the results are immediate from Proposition 1. ■

The first part of Proposition 2 compares the consumer surplus between Case 1 and Case 2. If the dominant retailers replace the producer's retailing, it can have a negative effect on the consumer surplus because the dominant retailers have market power over consumers and a positive effect because the dominant retailers' smaller retailing costs would lead to a drop of the retail price. Thus, if the dominant retailers' cost advantage over the producer is large, the positive effect dominates the negative effect on the consumer surplus and so the consumer surplus is improved when the dominant retailers replace the producer in retailing. The second part of Proposition 2 shows that Case 3 yields the highest consumer surplus. As mentioned earlier, there are more competition pressures in the retail market when both the producer and the retailers sell the goods to the consumers than when only the producer or the retailers sell the goods to the consumers. The consumers are better off in the market more competitive in the supply side.[2]

From (3) and (4), we can directly calculate the producer's and the retailer's profits for each case. In the first case, the producer's profit is

$$\Pi_0^{(1)} = p^{(1)}Q^{(1)} - \frac{1}{2}c(Q^{(1)})^2 - \frac{1}{2}\beta_h(Q^{(1)})^2 = \frac{c+\beta_h}{2(a+c+\beta_h)^2}b^2. \tag{36}$$

In the second case, the producer's profit is

$$\Pi_0^{(2)} = r^{(2)}Q^{(2)} - \frac{1}{2}c(Q^{(2)})^2 = \frac{2c}{(3a+3c+\beta_l)^2}b^2, \tag{37}$$

and retailer i's profit is

$$\Pi_i^{(2)} = p^{(2)}q_i^{(2)} - r^{(2)}q_i^{(2)} - \frac{1}{2}\beta_l(q_i^{(2)})^2 = \frac{2a+2c+\beta_l}{2(3a+3c+\beta_l)^2}b^2. \tag{38}$$

In the last case, the producer's profit is

$$\begin{aligned}\Pi_0^{(3)} &= p^{(3)}q_0^{(3)} + r^{(3)}(q_1^{(3)} + q_2^{(3)}) - \frac{1}{2}c(q_0^{(3)} + q_1^{(3)} + q_2^{(3)})^2 - \frac{1}{2}\beta_h(q_0^{(3)})^2 \\ &= \frac{\begin{pmatrix}(c+\beta_h)((a+c)(\beta_h+\beta_l)+\beta_h\beta_l)^2 \\ +4c\beta_h(a+c+\beta_h)((a+c)(2\beta_h+\beta_l)+(\beta_h+\beta_l)\beta_h)\end{pmatrix}}{2(a+c+\beta_h)^2((a+c)(3\beta_h+\beta_l)+\beta_h\beta_l)^2}b^2\end{aligned} \tag{39}$$

[2] Chen (2003) also presents a model where the presence of fringe competition is crucial for consumer welfare in a market with a dominant retailer. Chen (2003) examines the countervailing power of a dominant retailer against its supplier, a monopolist with original market power. He shows that the presence of fringe competition in the retail market is crucial for countervailing power to benefit consumers.

and retailer i's profit is

$$\Pi_i^{(3)} = p^{(3)} q_i^{(3)} - r^{(3)} q_i^{(3)} - \frac{1}{2}\beta_l (q_i^{(3)})^2 = \frac{((a+c)(2\beta_h + \beta_l) + \beta_h\beta_l)\beta_h^2}{2(a+c+\beta_h)((a+c)(3\beta_h+\beta_l)+\beta_h\beta_l)^2} b^2. \quad (40)$$

In the next two propositions, we compare the producer's and the retailers' profits for each case. The producer's profit is compared in Proposition 3.

Proposition 3 *For any* β_h *and* β_l, $\Pi_0^{(2)} < \Pi_0^{(1)}$ *and* $\Pi_0^{(2)} < \Pi_0^{(3)}$ *hold. There exist* γ_1, γ_2, γ_3, *and* γ_4 *with* $0 < \gamma_1 < \gamma_2 < \gamma_3 < \gamma_4$ *for which the following hold:*

(i) *if* $\gamma_4 < a/c$, *then for any* β_h *and* β_l, $\Pi_0^{(1)} > \Pi_0^{(3)}$ *holds;*

(ii) *if* $\gamma_3 < \mathrm{a/c} < \gamma_4$, *then there exists* $\hat{\beta}_h \in (0, c)$ *such that* $\beta_h < \hat{\beta}_h$ *implies* $\Pi_0^{(1)} > \Pi_0^{(3)}$; $\beta_h > \hat{\beta}_h$ *implies the existence of* $\hat{\beta}_l \in (0, \beta_h)$ *such that* $\Pi_0^{(1)} < \Pi_0^{(3)}$ *for* $\beta_l < \hat{\beta}_l$ *and* $\Pi_0^{(1)} > \Pi_0^{(3)}$ *for* $\beta_l > \hat{\beta}_l$;

(iii) *if* $\gamma_2 < a/c < \gamma_3$, *then for any* $\beta_h \in (0, c)$, *there exists* $\hat{\beta}_l \in (0, \beta_h)$ *such that* $\Pi_0^{(1)} < \Pi_0^{(3)}$ *for* $\beta_l < \hat{\beta}_l$ *and* $\Pi_0^{(1)} > \Pi_0^{(3)}$ *for* $\beta_l > \hat{\beta}_l$;

(iv) *if* $\gamma_1 < a/c < \gamma_2$, *then there exists* $\hat{\beta}_h \in (0, c)$ *such that* $\beta_h < \hat{\beta}_h$ *implies the existence of* $\hat{\beta}_l \in (0, \beta_h)$ *such that* $\Pi_0^{(1)} > \Pi_0^{(3)}$ *for* $\beta_l < \hat{\beta}_l$ *and* $\Pi_0^{(1)} > \Pi_0^{(3)}$ *for* $\beta_l > \hat{\beta}_l$; $\beta_h > \hat{\beta}_h$ *implies* $\Pi_0^{(1)} < \Pi_0^{(3)}$ *for all* $\beta_l \in (0, \beta_h)$.

(v) *if* $a/c < \gamma_1$, *then for any* β_h *and* β_l, $\Pi_0^{(1)} < \Pi_0^{(3)}$ *holds.*

Proof. The proof is quite long and tedious, so we leave it in the Appendix. ■

Proposition 3 shows that the dominant retailers' entry does not always have to harm the producer's profits; it depends on market conditions. As Proposition 1 shows, the retailers' entry can increase the retailing quantity at equilibrium; this has a positive effect on the producer's profits because the producer can enjoy a gain from manufacturing and selling more goods. However, the retailers' entry also has a negative effect on the producer's profits because the producer has to sell all or part of its goods to the retailers who have market power to extract the producer's surplus in the wholesale market instead of price-taking consumers and has to compete with the retailers in the retail market. The first part of Proposition 3 implies that the negative effect of the retailers' entry on the producer's profits always dominates the positive effect, if the producer does not retail. Hence, the producer is worst off in Case 2 where the producer does not retail. If the producer retails, the positive effect can actually dominate the negative effect depending on market conditions especially when the retailers' cost advantage is large; in this case the retailers' entry benefits the producer. The second part of Proposition 3 shows complete comparison of the producer's profits between Case 1 and Case 3 over the market conditions.[3]

Proposition 4 compares each retailer's profits.

Proposition 4 For any β_h and β_l, $\Pi_{\mathrm{i}}^{(2)} > \Pi_{\mathrm{i}}^{(3)}$ where i=1,2 holds.

Proof. Note that

$$\Pi_i^{(3)} - \Pi_i^{(2)} = -\frac{b^2}{2(3(a+c)+\beta_l)^2(a+c+\beta_h)((a+c)(3\beta_h+\beta_l)+\beta_h\beta_l)^2} \times \mathrm{A}, \tag{41}$$

where

[3] In should be noted that the producer in the model is a representative producer who represents a mass of infinitesimal producers who behave as a price-taker. Thus, the producer in the model does not have a bargaining power over the retailers and decides only the quantity of goods given the market prices. One might think that the producer may be able to choose not to supply the goods to the retailers in the case with $\Pi_0^{(1)} > \Pi_0^{(3)}$. But, this possibility does not coincide with the assumption that the producer is a price taker and does not have a bargaining power over the retailers.

$$\begin{aligned}A = {} & 18a^3\beta_h^2 + 12a^3\beta_h\beta_l + 2a^3\beta_l^2 + 54a^2c\beta_h^2 + 36a^2c\beta_h\beta_l + 6a^2c\beta_l^2 \\ & +24a^2\beta_h^2\beta_l + 12a^2\beta_h\beta_l^2 + a^2\beta_l^3 + 54ac^2\beta_h^2 + 36ac^2\beta_h\beta_l + 6ac^2\beta_l^2 \\ & +48ac\beta_h^2\beta_l + 24ac\beta_h\beta_l^2 + 2ac\beta_l^3 + 12a\beta_h^2\beta_l^2 + 3a\beta_h\beta_l^3 + 18c^3\beta_h^2 \\ & +12c^3\beta_h\beta_l + 2c^3\beta_l^2 + 24c^2\beta_h^2\beta_l + 12c^2\beta_h\beta_l^2 + c^2\beta_l^3 + 12c\beta_h^2\beta_l^2 \\ & +3c\beta_h\beta_l^3 + 2\beta_h^2\beta_l^3.\end{aligned} \tag{42}$$

It is trivial to show that $A > 0$ and so $\Pi_i^{(3)} < \Pi_i^{(2)}$ holds. ■

Proposition 4 says that the retailers are always better off in Case 2 where the producer cannot sell the goods to the consumers directly and has to sell the goods via the retailers than in Case 3 where the producer can retail as well. This is intuitively clear. If the producer cannot retail, the retailers come to have more market power in both wholesale and retail markets; this implies that the market environments are more favorable to the retailers.

We finally compare the social welfare. In the first case, the social welfare is

$$SW^{(1)} = \Pi_0^{(1)} + CS^{(1)} = \frac{1}{2(a + c + \beta_h)} b^2. \tag{43}$$

In the second case, the social welfare is

$$SW^{(2)} = \Pi_0^{(2)} + \Pi_1^{(2)} + \Pi_2^{(2)} + CS^{(2)} = \frac{4a + 4c + \beta_l}{(3a + 3c + \beta_l)^2} b^2. \tag{44}$$

In the last case, the social welfare is

$$\begin{aligned}SW^{(3)} &= \Pi_0^{(3)} + \Pi_1^{(3)} + \Pi_2^{(3)} + CS^{(3)} \\ &= \frac{\begin{pmatrix} ((a + c)(5\beta_h + \beta_l) + 2\beta_h^2 + \beta_h\beta_l)((a + c)(\beta_h + \beta_l) + \beta_h\beta_l) \\ +2(a + c)(2(a + c) + 3\beta_h)\beta_h^2 \end{pmatrix}}{2(a + c + \beta_h)((a + c)(3\beta_h + \beta_l) + \beta_h\beta_l)^2} b^2.\end{aligned} \tag{45}$$

The next proposition compares the social welfare in each case.

Proposition 5 There exist β^{o} and β^{oo} with $0 < \beta^{o} < \beta^{oo}$ for which the following are true:

(i) *If* $\beta_h < \beta^{o}$, *then* $SW^{(1)} > SW^{(2)}$ *holds;*

(ii) *If* $\beta_h > \beta^{oo}$, *then* $SW^{(1)} < SW^{(2)}$ *holds;*

(iii) *If* $\beta^{o} < \beta_h < \beta^{oo}$, *then there exists* $\bar{\beta} \in (0, \beta_h)$ *such that* $SW^{(1)} < SW^{(2)}$ *for* $\beta_l < \bar{\beta}$ *and* $SW^{(1)} > SW^{(2)}$ *for* $\beta_l > \bar{\beta}$.

In addition, for any β_h *and* β_l, $SW^{(1)} < SW^{(3)}$ *and* $SW^{(2)} < SW^{(3)}$ *hold.*

Proof. The proof is quite long and tedious, so we leave it in the Appendix. ■

The first part of Proposition 5 compares the social welfare between Case 1 and Case 2. If the retailers' cost advantage over the producer is large, the social welfare increases in the second case where the producer has to supply the goods to the consumers through the retailers compared with the first case where the producer sells the goods to the consumers directly . Notice that the retailers' replacement of the producer in retailing has a negative effect on social welfare by making the market less competitive and a positive effect on social welfare by reducing the retailing cost. The latter dominates the former when the cost advantage of the retailers is large enough.

In addition, the second part of Proposition 5 shows that the social welfare is the highest in Case 3 where the producer can supply the goods to the consumers directly as well as indirectly through the retailers. As mentioned earlier, although the retailers have market power, they are new, lower-cost competitors against the producer in the retail market. Hence, the market in which both the producer and the retailers supply the goods to the consumers is more competitive than the market in which only the producer or only the retailers supply the goods to the consumers. This implies that the market in the third case is more efficient than the markets in the other cases in terms of social welfare.

It has to be noted that our results share the insight with the famous Williamson tradeoff. Williamson (1968) is interested in the welfare effect of horizontal merger of firms and claims that there is a trade-off associated with horizontal mergers between gains from reducing production costs and the losses associated with monopolistic prices. The welfare effect of the merger depends on the relative size of the gains from cost reduction and the losses from anti-competitive price settings. Such a trade-off is found in our model. In particular, by comparing Cases 1 and 2, we show that there is such a trade-off associated with the replacement of the competitive producer with the dominant retailers with lower costs in the retail market. We also show that, if the producer survives in the retail market after the dominant retailers enter the market, entry of the dominant retailers always improves the social welfare. In this case, the entry of dominant retailers increases the competitive pressure in the retail market, and so does not yield losses from anti-competitive price settings; as a result, the Williamson trade-off is not observed.

This paper provides insights on policy regarding dominant retailers. Our results imply that it is important to have competition in the retail market in order that the dominant retailers' cost reduction translates into increase in social welfare. Hence a policy for maintaining competition pressure may be needed in a retail market with dominant retailers. We can consider, for instance, a policy to encourage or facilitate direct-retailing. Today the prevalence of online platform markets makes it easier for the producer to retail themselves, whereas small, local retailers have been driven out a lot by large retailers.

Our model illustrates a market with dominant retailers where there are price-taking producers and consumers but the social optimum is not attained if dominant retailers' cost reduction is considered. In our model, the third case yields the highest social welfare, but it does not achieve the social optimum SW^* in (11). With prevalence of superstore retailers and one-stop shoppers, many consumers often choose among only the goods in the store they visit. Hence there may not be enough competition in the markets of the goods which have little effect on consumers' choice of retailers, regardless of how many competitive producers and consumers are in the market; this is the case for many grocery and daily consumer goods today. Our results suggest that there is room to improve social welfare by enhancing competition in a competitive-goods market with dominant retailers.

4 Concluding Remarks

In this paper, we set up a model to study the impacts of dominant retailers' presence in a competitive-goods market. The dominant retailers can improve cost-efficiency in retailing but cause loss in social welfare by exercising market power. We consider these trade-offs between cost-efficiency and competition in our model. We compare market outcomes and social welfare among three different vertical structures: (i) only the price-taking producer retails; (ii) two dominant retailers retail; (iii) two dominant retailers and the price-taking producer retail. The dominant retailers have lower retailing costs than the producer. In our model, the third case always leads to the highest equilibrium quantity, consumer surplus, and social welfare, while comparison between the first and second cases depends on market conditions. If the dominant retailers' cost advantage is large, the third case yields the highest profits for the producer as well. Hence, it is crucial to social welfare whether or not the producers continue retailing to generate competition pressure when the dominant retailers exercise market power.

Appendix

Proof of Proposition 3. Note that

$$\Pi_0^{(2)} - \Pi_0^{(1)} = -\frac{1}{2}\frac{H_1(\beta_h,\beta_l)}{(3a+3c+\beta_l)^2(a+c+\beta_h)^2}b^2, \tag{46}$$

where

$$\begin{aligned} H_1(\beta_h,\beta_l) = 4c\beta_h^2 - \left(\beta_l^2 + 6(a+c)\beta_l + (9a+c)(a+c)\right)\beta_h \\ -(\beta_l^2 + 6(a+c)\beta_l + 5(a+c)^2)c. \end{aligned} \tag{47}$$

Given β_l, $H_1(\beta_h,\beta_l)$ is convex in $\beta_h \in [0,c]$ and so is maximized at $\beta_h = 0$ or $\beta_h = c$. Note that

$$H_1(0,\beta_l) = -(\beta_l^2 + 6(a+c)\beta_l + 5(a+c)^2)c < 0 \tag{48}$$

$$H_1(c,\beta_l) = -2c(\beta_l^2 + 6(a+c)\beta_l + 10ac + 7a^2 + c^2) < 0. \tag{49}$$

Thus, $H_1(\beta_h,\beta_l) < 0$ for all β_h satisfying $0 < \beta_h < c$. This proves that $\Pi_0^{(2)} < \Pi_0^{(1)}$ holds.

To compare $\Pi_0^{(2)}$ and $\Pi_0^{(3)}$, note that

$$\Pi_0^{(3)} - \Pi_0^{(2)} = \frac{b^2}{2(3(a+c)+\beta_l)^2(a+c+\beta_h)^2((a+c)(3\beta_h+\beta_l)+\beta_h\beta_l)^2} \times A_1, \tag{50}$$

where

$$\begin{aligned} A_1 = {} & 45a^4c\beta_h^2 + 30a^4c\beta_h\beta_l + 5a^4c\beta_l^2 + 9a^4\beta_h^3 + 18a^4\beta_h^2\beta_l + 9a^4\beta_h\beta_l^2 \\ & +180a^3c^2\beta_h^2 + 120a^3c^2\beta_h\beta_l + 20a^3c^2\beta_l^2 + 72a^3c\beta_h^3 + 144a^3c\beta_h^2\beta_l \\ & +74a^3c\beta_h\beta_l^2 + 6a^3c\beta_l^3 + 24a^3\beta_h^3\beta_l + 30a^3\beta_h^2\beta_l^2 + 6a^3\beta_h\beta_l^3 \\ & +270a^2c^3\beta_h^2 + 180a^2c^3\beta_h\beta_l + 30a^2c^3\beta_l^2 + 162a^2c^2\beta_h^3 + 324a^2c^2\beta_h^2\beta_l \\ & +168a^2c^2\beta_h\beta_l^2 + 18a^2c^2\beta_l^3 + 108a^2c\beta_h^3\beta_l + 144a^2c\beta_h^2\beta_l^2 + 36a^2c\beta_h\beta_l^3 \\ & +a^2c\beta_l^4 + 22a^2\beta_h^3\beta_l^2 + 14a^2\beta_h^2\beta_l^3 + a^2\beta_h\beta_l^4 + 180ac^4\beta_h^2 + 120ac^4\beta_h\beta_l \\ & +20ac^4\beta_l^2 + 144ac^3\beta_h^3 + \beta_h^3\beta_l^4 + 288ac^3\beta_h^2\beta_l + 150ac^3\beta_h\beta_l^2 + 18ac^3\beta_l^3 \end{aligned} \tag{51}$$

$+144ac^2\beta_h^3\beta_l + 198ac^2\beta_h^2\beta_l^2 + 54ac^2\beta_h\beta_l^3 + 2ac^2\beta_l^4 + 64ac\beta_h^3\beta_l^2$
$+44ac\beta_h^2\beta_l^3 + 4ac\beta_h\beta_l^4 + 8a\beta_h^3\beta_l^3 + 2a\beta_h^2\beta_l^4 + 45c^5\beta_h^2 + 30c^5\beta_h\beta_l$
$+5c^5\beta_l^2 + 45c^4\beta_h^3 + 90c^4\beta_h^2\beta_l + 47c^4\beta_h\beta_l^2 + 6c^4\beta_l^3 + 60c^3\beta_h^3\beta_l$
$+84c^3\beta_h^2\beta_l^2 + 24c^3\beta_h\beta_l^3 + c^3\beta_l^4 + 42c^2\beta_h^3\beta_l^2 + 30c^2\beta_h^2\beta_l^3 + 3c^2\beta_h\beta_l^4$
$+12c\beta_h^3\beta_l^3 + 3c\beta_h^2\beta_l^4.$

It is trivial to show that $A_1 > 0$ and so $\Pi_0^{(2)} < \Pi_0^{(3)}$ holds.
To compare $\Pi_0^{(1)}$ and $\Pi_0^{(3)}$, note that

$$\Pi_0^{(3)} - \Pi_0^{(1)} = \frac{2b^2\beta_h^2}{(a+c+\beta_h)^2((a+c)(3\beta_h+\beta_l)+\beta_h\beta_l)^2} H_2(\beta_h,\beta_l) \quad (52)$$

here

$$H_2(\beta_h,\beta_l) = c\beta_h^2 + c^2\beta_h - 2a^2\beta_h - ac\beta_h - a(a+c+\beta_h)\beta_l. \quad (53)$$

Notice that $H_2(\beta_h,\beta_l)$ is continuous and strictly decreasing in β_l. In addition, $\Pi_0^{(1)} > \Pi_0^{(3)}$ if and only if $H_2(\beta_h,\beta_l) < 0$ holds. Let $\gamma_1 = 1/3$, $\gamma_2 = (\sqrt{33}-3)/6$, $\gamma_3 = 1/2$, and $\gamma_4 = (\sqrt{17}-1)/4$. We consider five cases.

Case 1: Suppose that $\gamma_4 < a/c$ holds. In this case, we can show that, for all $\beta_h \in (0,c)$, $H_3(\beta_h,0) < 0$ holds. Let $\beta_h \in (0,c)$ be arbitrary. Since $H_2(\beta_h,\beta_l)$ is strictly decreasing in β_l, $H_2(\beta_h,\beta_l) < 0$ for all $\beta_l \in (0,\beta_h)$.

Case 2: Suppose that $\gamma_3 < a/c < \gamma_4$ holds. Then, we can see that

$$0 < \frac{(2a-c)(a+c)}{c} < c < \frac{(3a-c)(a+c)}{c-a}. \quad (54)$$

If $0 < \beta_h < (2a-c)(a+c)/c$, then $H_2(\beta_h,0) < 0$ holds, and so $H_2(\beta_h,\beta_l) < 0$ for all $\beta_l \in (0,\beta_h)$. If $(2a-c)(a+c)/c < \beta_h < c$, then $H_2(\beta_h,0) > 0$ and $H_2(\beta_h,\beta_h) < 0$. Since $H_2(\beta_h,\beta_l)$ is continuous and strictly decreasing in β_l, there exists $\hat{\beta}_l \in (0,\beta_h)$ such that, for all $\beta_l < \hat{\beta}_l$, $H_2(\beta_h,\beta_l) > 0$ and for all $\beta_l > \hat{\beta}_l$, $H_2(\beta_h,\beta_l) < 0$.

Case 3: Suppose that $\gamma_2 < a/c < \gamma_3$ holds. Then, we can see that

$$\frac{(2a-c)(a+c)}{c} < 0 < c < \frac{(3a-c)(a+c)}{c-a}. \quad (55)$$

For all β_h with $0 < \beta_h < c$, $H_2(\beta_h, 0) > 0$ and $H_2(\beta_h, \beta_h) < 0$ hold. Similarly as before, there exists $\hat{\beta}_l \in (0, \beta_h)$ such that, for all $\beta_l < \hat{\beta}_l$, $H_2(\beta_h, \beta_l) > 0$ and, for all $\beta_l > \hat{\beta}_l$, $H_2(\beta_h, \beta_l) < 0$.

Case 4: Suppose that $\gamma_1 < a/c < \gamma_2$ holds. Then, we can see that

$$\frac{(2a-c)(a+c)}{c} < 0 < \frac{(3a-c)(a+c)}{c-a} < c. \quad (56)$$

If $0 < \beta_h < (3a-c)(a+c)/(c-a)$, $H_2(\beta_h, 0) > 0$ and $H_2(\beta_h, \beta_h) < 0$ hold. Then, there exists $\hat{\beta}_l \in (0, \beta_h)$ such that, for all $\beta_l < \hat{\beta}_l$, $H_2(\beta_h, \beta_l) > 0$ and, for all $\beta_l > \hat{\beta}_l$, $H_2(\beta_h, \beta_l) < 0$. If $(3a-c)(a+c)/(c-a) < \beta_h < c$, then $H_2(\beta_h, \beta_h) > 0$ holds. Since $H_2(\beta_h, \beta_l)$ is strictly decreasing in β_l, $H_2(\beta_h, \beta_l) > 0$ for all $\beta_l \in (0, \beta_h)$.

Case 5: Suppose that $a/c < \gamma_1$ holds. Then, we can see that

$$\frac{(2a-c)(a+c)}{c} < \frac{(3a-c)(a+c)}{c-a} < 0. \quad (57)$$

For all β_h with $0 < \beta_h < c$, $H_2(\beta_h, \beta_h) > 0$ holds, and so $H_2(\beta_h, \beta_l) > 0$ for all $\beta_l \in (0, \beta_h)$. This proves the second assertion. ■

Proof of Proposition 5. From (43) and (44), we have

$$SW^{(2)} - SW^{(1)} = -\frac{H_3(\beta_h, \beta_l)}{2(3a+3c+\beta_l)^2(a+c+\beta_h)} b^2, \quad (58)$$

where

$$H_3(\beta_h, \beta_l) = \beta_l^2 + 2(2a+2c-\beta_h)\beta_l + (a+c)^2 - 8(a+c)\beta_h. \quad (59)$$

Note that $SW^{(2)} > SW^{(1)}$ if and only if $H_3(\beta_h, \beta_l) < 0$. Note that $H_3(\beta_h, \beta_l) < 0$ if and only if $\underline{\beta} < \beta_l < \bar{\beta}$, where

$$\underline{\beta} = -(2a + 2c - \beta_h) - \sqrt{(3a + 3c + \beta_h)(a + c + \beta_h)} \tag{60}$$

$$\bar{\beta} = -(2a + 2c - \beta_h) + \sqrt{(3a + 3c + \beta_h)(a + c + \beta_h)}. \tag{61}$$

If $\beta_h < (a + c)/8$, $\underline{\beta} < \bar{\beta} < 0$ holds. Thus, for all $\beta_l \in [0, \beta_h]$, $H_3(\beta_h, \beta_l) > 0$ is satisfied. If $(a + c)/8 < \beta_h < (\sqrt{5} - 2)(a + c)$, $\underline{\beta} < 0 < \bar{\beta} < \beta_h$ holds. This implies that, for all β_l with $0 < \beta_l < \bar{\beta}$, $H_3(\beta_h, \beta_l) < 0$ is satisfied and, for all β_l with $\bar{\beta} < \beta_l < \beta_h$, $H_3(\beta_h, \beta_l) > 0$ is satisfied. If $(\sqrt{5} - 2)(a + c) < \beta_h$, $\underline{\beta} < 0 < \beta_h < \bar{\beta}$ holds. Thus, for all $\beta_l \in [0, \beta_h]$, $H_3(\beta_h, \beta_l) < 0$ is satisfied. Letting $\beta^o = (a + c)/8$ and $\beta^{oo} = (\sqrt{5} - 2)(a + c)$, we complete the proof comparing $SW^{(1)}$ and $SW^{(2)}$.

In addition, we can see that

$$SW^{(3)} - SW^{(1)} = \frac{(a + c)(4\beta_h + \beta_l)\beta_h^2}{(a + c + \beta_h)((a + c)(3\beta_h + \beta_l) + \beta_h\beta_l)^2} b^2 > 0 \tag{62}$$

holds. In addition, note that

$$SW^{(3)} - SW^{(2)} = \frac{b^2}{2(3(a + c) + \beta_l)^2(a + c + \beta_h)((a + c)(3\beta_h + \beta_l) + \beta_h\beta_l)^2} \times A_2, \tag{63}$$

where

$$\begin{aligned} A_2 = {} & 9a^4\beta_h^2 + 6a^4\beta_h\beta_l + a^4\beta_l^2 + 36a^3c\beta_h^2 + 24a^3c\beta_h\beta_l + 4a^3c\beta_l^2 + 12a^3\beta_h^2\beta_l \\ & +18a^3\beta_h\beta_l^2 + 4a^3\beta_l^3 + 54a^2c^2\beta_h^2 + 36a^2c^2\beta_h\beta_l + 6a^2c^2\beta_l^2 + 36a^2c\beta_h^2\beta_l \\ & +54a^2c\beta_h\beta_l^2 + 12a^2c\beta_l^3 + 18a^2\beta_h^2\beta_l^2 + 12a^2\beta_h\beta_l^3 + a^2\beta_l^4 + 36ac^3\beta_h^2 \\ & +24ac^3\beta_h\beta_l + 4ac^3\beta_l^2 + 36ac^2\beta_h^2\beta_l + 54ac^2\beta_h\beta_l^2 + 12ac^2\beta_l^3 + 36ac\beta_h^2\beta_l^2 \\ & +24ac\beta_h\beta_l^3 + 2ac\beta_l^4 + 8a\beta_h^2\beta_l^3 + 2a\beta_h\beta_l^4 + 9c^4\beta_h^2 + 6c^4\beta_h\beta_l + c^4\beta_l^2 \\ & +12c^3\beta_h^2\beta_l + 18c^3\beta_h\beta_l^2 + 4c^3\beta_l^3 + 18c^2\beta_h^2\beta_l^2 + 12c^2\beta_h\beta_l^3 + c^2\beta_l^4 \\ & +8c\beta_h^2\beta_l^3 + 2c\beta_h\beta_l^4 + \beta_h^2\beta_l^4. \end{aligned} \tag{64}$$

It is trivial to show that $A_2 > 0$, so $SW^{(2)} < SW^{(3)}$ holds. ■

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