［論文］

A Note on Vertically Integrated Firms' Incentives to Participate in the Wholesale Market : From the Viewpoint of Upstream Firms' Quadratic Cost Function

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I. INTRODUCTION

Vertically integrated firms have their own input-producing sector upstream, which enables them to produce enough goods to meet their internal demand. Nevertheless, in reality, they often buy inputs from the wholesale market, which is organized among vertically non-integrated firms. In addition, they often sell inputs to the market. Could this behavior of integrated firms have any theoretically beneficial reason, or is it only a passing whim? In order to understand the characteristics of vertical markets accurately, we have to answer a small, but profound question: Why do vertically integrated firms participate in the wholesale market?

Some previous studies tried to answer this artless question. Gaudet and Long (1996) and Schrader and Martin (1998) show that firms can purchase inputs in equilibrium. Inderst and Valletti (2009) explain that firms' optimal behaviors are changeable according to the differentiation degrees of their goods. Lin (2006) shows that firms can prefer partial vertical separation, and have incentives to participate in the wholesale market in such cases. These studies include very suggestive ideas compared to the traditional assumption as in Salinger (1988), who stated that firms have no incentives to participate in the market.

However, to our knowledge, these studies seem to have omitted an important viewpoint, namely, the firms' capacity constraints. In this paper, we intend to answer the above-mentioned question from this perspective. Now, the cost function of a firm, in some circumstances, may indicate capacity constraints. For instance, if the producing sector of a firm has a convex-shaped cost function, then the marginal costs become larger as the production quantities increase. That is, the firm is reluctant to increase production. Thus, a convex-shaped cost function often substitutes for the firm's capacity constraints or cost inefficiencies. Throughout the paper, we adopt this thought. If the cost function is convex in upstream producers, then we can consider the following scenario:

There exists an economy consisting of some symmetric vertically integrated firms and symmetric non-integrated upstream/downstream firms. The non-integrated firms form a wholesale market. The final goods supplied to consumers are perfectly homogeneous. The cost function of the upstream sectors or firms is strictly convex (typically quadratic), and has a common parameter indicating the degree of capacity constraints or production inefficiency, namely, a socially penetrated production technology.

In this case, how do integrated firms behave? When they maximize their own profit à la Cournot, they would like to produce as much input as possible, but cannot easily do so due to capacity constraints. Thus, they might decide to purchase inputs from the wholesale market. We could assume two cases.

First, if the capacity constraint is small, firms face constant marginal costs and can produce inputs without outside trade. The alternatives are between purchasing and not purchasing. Second, if the capacity constraint is large, it seems wise for integrated firms to purchase inputs from the market. However, since the cost function is common among firms, the other upstream firms also face high capacity constraints. That is, upstream firms cannot afford to produce extra inputs for integrated firms. At this point, the integrated firms might decide to sell inputs to the wholesale market to increase revenues.

In this paper, we show that in most cases, a vertically integrated firm tends to strategically select outside trade through the wholesale market in various ways. Our study offers three contributions to the literature.

First, we show that a vertically integrated firm has the option to purchase inputs, but it prefers selling through 'spin-off' in a constraint-free environment if the size of wholesale market is small. Although this result is consistent with Lin (2006), we also show that firms prefer not only selling inputs through spin-off but also purchasing through 'direct entry', if many upstream firms exist in the market.

Lin (2006) classifies vertical separation into 'Direct Entry' and 'Spin-Offs'. In the former strategy, an upstream sector acts as a total-profit-maximizer, whereas in the latter, the sector acts as a partial-profit-maximizer. Thus, intuitively, the former strategy dominates the latter in terms of the joint profit of the integrated firm. However, we find that an opposite phenomenon occurs under some circumstances, due to the existence of a wholesale market. This finding is our second contribution.

The third area relates to regulatory policy. In a high capacity-constrained environment, an integrated firm selects the strategy of selling inputs through Direct Entry, although we find that the Spin-Off strategy is optimal from the social welfare viewpoint. Thus, authorities should not automatically tolerate an integrated firm's strategy.

We assume an industry in which the upstream firms or sectors produce homogeneous goods and have common technologies or inefficiencies, and that a wholesale market exists. Inevitably, we consider public services or infrastructure industries like electricity, gas, and so on. We especially assume the electricity industry throughout the paper. However, although we are aware of the importance of the network sector in the electricity industry, we exclude this sector to observe the pure relations between the generators and retailers. Our model may be similar to the structure of Brunekreeft (2002). Nevertheless, we intend to provide policymakers with further theoretical support.

The rest of the paper is organized as follows. In Section II, we present the basic model for No Entry (NE), Direct Entry (DE), and Spin-Off (SO), following Lin (2006). Note that we further classify DE into 'selling DE' and 'purchasing DE.' We subsequently compare solutions. In Section III, we extend the model to confirm whether an integrated firm prefers another strategy to those illustrated in the basic model. The last section concludes.

II. BASIC MODEL

We assume an economy in which there is only one vertically integrated firm (firm 0), two upstream firms (firm $u1$ and $u2$), and two downstream firms (firm $d1$ and $d2$).[1] We suppose a linear inverse demand function[2] $p = 1 - Q$ and a quadratic power generation cost function [3]

$$C(y) = \frac{c}{2}y^2, \tag{1}$$

where p, Q, y indicates the retail price, total output, and generation quantity, respectively. We interpret parameter $c \in [0, \infty)$ as the level of capacity constraints, power generating technologies, or efficiency.[4] In the initial setting, non-integrated firms ui and dj form the wholesale market and the wholesale price w is determined as the market is cleared.

The game is as follows. In the stage 1, upstream firms (generators) compete in quantity. In the stage 2, downstream firms (retailers) compete in quantity. [5]

II.1 No Entry

First, we establish the basic case (No Entry; NE) in which firm 0 never participates in the wholesale market.

This assumption follows Salinger (1988, §II), and this case corresponds to vertical integration. The profit functions are as follows.

$$\pi_0 = (1 - Q)q_0 - \frac{c}{2}q_0^2 \text{ where } Q \equiv q_0 + q_1 + q_2,$$
$$\pi_j^d = (1 - Q - w)q_j, \ \ j = 1,2$$
$$\pi_i^u = wx_i - \frac{c}{2}x_i^2, \ \ i = 1,2 \tag{2}$$

Here, q_0 and q_j indicate output supplied in the retail market and x_i input supplied to the wholesale market by the non-integrated power generating firms. The retail sector of firm 0 is capable of giving load-dispatch instructions to the generating sector, and it must bear the cost $(c/2)q_0^2$ when its

1) This restrictive assumption is for simplicity, though we assume that other inefficient firms have already exited the industry.
2) We ignore any incidental goods, such as after-sales services. Therefore, this industry is assumed to be producing homogeneous goods.
3) One can of course model using a more formal function, $C(y)=c_0y^2+c_1y+c_2$. In such a setting, if c_0 is quite small, the marginal cost appears to be constant, and if c_0 is large the marginal cost is increasing, just as in (1).
4) We assume that there is no gap in power generating technologies or efficiency between firms u1, u2, and 0 because generation technology instantly spreads socially.
5) Since we assume that downstream firms are wholesale-price takers, the number of downstream firms might have to be large enough. We however adopt a specific number to express some threshold values in real numbers.

own customers demand q_0. We solve the game by backward induction.

The FOCs of the stage 2 are $\partial\pi_0/\partial q_0 = 0$ and $\partial\pi_j^d/\partial q_j = 0\ \forall j$, which yield the reaction functions of the downstream firms. Imposing symmetry, we obtain each of the equilibrium outputs as a function of the wholesale price,

$$q_0 = \frac{1+2w}{3c+4},$$

$$q_j = \frac{1+c-(2+c)w}{3c+4}. \qquad (3)$$

We now turn to the stage 1. We can express the wholesale price as a function of total input. The market-clearing condition, $\Sigma_{i=1}^{2} x_i = \Sigma_{j=1}^{2} q_j$, yields the derived demand function,

$$w = \frac{2c+2-(3c+4)\sum_{i=1}^{2} x_i}{2c+4}. \qquad (4)$$

Therefore, the FOCs, $\partial\pi_i^u/\partial x_i = 0\ \forall i$, gives us the equilibrium input,

$$x^{\mathrm{NE}} = \frac{2c+2}{2c^2+13c+12}. \qquad (5)$$

Substituting (5) into each function above, we obtain the following main equilibrium values:

$$w^{\mathrm{NE}} = \frac{(c+1)(2c^2+7c+4)}{(c+2)(2c^2+13c+12)},$$

$$q_0^{\mathrm{NE}} = \frac{2c^2+9c+8}{(c+2)(2c^2+13c+12)},$$

$$q_j^{\mathrm{NE}} = \frac{2(c+1)}{2c^2+13c+12},$$

$$Q^{\mathrm{NE}} = \frac{6c^2+21c+16}{(c+2)(2c^2+13c+12)},$$

$$\pi_0^{\mathrm{NE}} = \frac{(2c^2+9c+8)^2}{2(c+2)(2c^2+13c+12)^2},$$

$$\pi^{d\,\mathrm{NE}} = \frac{4(c+1)^2}{(2c^2+13c+12)^2},$$

$$\pi^{u\,\mathrm{NE}} = \frac{2(c+4)(c+1)^3}{(c+2)(2c^2+13c+12)^2}. \qquad (6)$$

II.2 The profit function in partial vertical separation

So far, we focus on the hypothesis, à la Salinger (1988), that firm 0 never sells to or purchases input from the wholesale market. We now consider the case in which firm 0 might participate in the wholesale market. In a nutshell, the upstream sector can work as a profit maximizer. In this case, the profit function for firm 0 is

$$\pi_0 = \left[w x_0 - \frac{c}{2}x_0|x_0|\right] + \left[(1-Q)q_0 - \frac{c}{2}q_0^2\right]. \qquad (7)$$

The former [·] indicates the profit function for the upstream sector, π_0^u, and the latter indicates that of the retail sector, π_0^d.[6)] The first function follows Schrader and Martin (1998), who deal with the linear cost function. Similarly, the input x_0 can be positive or negative, that is, $x_0>0$ indicates selling and $x_0<0$ indicates purchasing. If the firm chooses to purchase, the revenue term $(c/2)x_0^2$ implies that firm 0 keeps its supply in house by x_0 units.

II.3 Selling Direct Entry

Lin (2006) and Schrader and Martin (1998) model the Direct Entry (DE) case, in which firm 0 maximizes its joint profit in the stage 1.

First, we consider the case in which firm 0 commits to selling inputs to the wholesale market.

We derive the solutions for the stage 2 as in the NE case after completing stage 1. Substitute (4) into (3), and then substitute these functions of w into (7). Maximizing this with respect to x_0, we obtain the reaction function for firm 0. We obtain the reaction function for ui using $\partial\pi_i^u/\partial x_i = 0\ \forall i$. These functions yield

$$x_0^{\mathrm{DE}} = \frac{2c^3+7c^2+2c-4}{2c^4+23c^3+74c^2+81c+28},$$

$$x_i^{\mathrm{DE}} = \frac{2c^3+9c^2+12c+6}{2c^4+23c^3+74c^2+81c+28}. \qquad (8)$$

6) Since we adopt the quadratic form function, namely, even function, we must use the absolute value representation in (7). Therefore, we must check for solutions based on the classification of firm 0's commitment of $x_0>0$ and $x_0<0$.

Since $x_0^{DE}>0$, c must be in $(0.588,\infty)$[7]. We calculate the main equilibrium values as follows:

$$w^{DE}=\frac{2c^3+9c^2+12c+6}{2(c+1)(c+2)(c+7)},$$

$$q_0^{DE}=\frac{c^2+5c+5}{(c+1)(c+2)(c+7)},$$

$$q_j^{DE}=\frac{3c+2}{2(c+1)(c+7)},$$

$$Q^{DE}=\frac{4c+9}{(c+2)(c+7)},$$

$$\pi_0^{DE}=\frac{\begin{pmatrix}8c^8+124c^7+794c^6+2737c^5+5545c^4\\+6752c^3+4821c^2+1856c+304\end{pmatrix}}{2(c+2)(c+1)^2(c+7)^2(2c^2+7c+4)^2},$$

$$\pi^{d\,DE}=\frac{(3c+2)^2}{4(c+1)^2(c+7)^2},$$

$$\pi^{u\,DE}=\frac{(c+4)(2c^3+9c^2+12c+6)^2}{2(c+1)(c+2)(c+7)^2(2c^2+7c+4)^2}. \tag{9}$$

II.4 Purchasing Direct Entry

Next, we consider the case in which firm 0 commits to purchasing inputs from the wholesale market (DE′). We derive solutions for the stage 2 as for the NE and DE cases. In the stage 1, firm 0 commits to $x_0<0$ and solves the following objective function:

$$\pi_0=wx_0+\frac{c}{2}x_0^2+(1-Q)q_0-\frac{c}{2}q_0^2. \tag{10}$$

Substituting the solutions from the stage 2 into (10), the coefficient of x_0^2 is c^2-c-3. Assuming a concave-shaped profit, c must be in $[0,2.302)$. The FOCs with respect to x_0 and x_i yield reaction functions, leading to the following solutions.

$$x_0^{DE'}=\frac{-2c^3-7c^2-2c+4}{2c^4+11c^3+2c^2-33c-28},$$

$$x_i^{DE'}=\frac{(2c+3)(c^2-2)}{2c^4+11c^3+2c^2-33c-28},$$

$$X^{DE'}=\frac{2c^3-c^2-10c-8}{2c^4+11c^3+2c^2-33c-28}. \tag{11}$$

Note: $X\equiv\sum_{t=0}^{2}x_t$. If $c\in[0,2.302)$, then we can confirm by plotting that the numerator of $X^{DE'}$ is negative. Thus, taking $X>0$ into account, the denominator must be negative. Since firm 0 committed to $x_0<0$, the numerator of $x_0^{DE'}$ must be positive. Hence, c must be in $[0,0.588)$.

The above fact suggests a threshold at which firm 0 sells or purchases inputs. This finding differs from Schrader and Martin's (1998) result, which concludes that vertically integrated firms always choose to purchase. The main equilibrium values are

$$w^{DE'}=\frac{(2c+3)(c^2-2)(2c^2+7c+4)}{2(c+2)(2c^4+11c^3+2c^2-33c-28)},$$

$$q_0^{DE'}=\frac{2c^4+9c^3+3c^2-23c-20}{(c+2)(2c^4+11c^3+2c^2-33c-28)},$$

$$q_j^{DE'}=\frac{2c^3-c^2-10c-8}{2(2c^4+11c^3+2c^2-33c-28)},$$

$$Q^{DE'}=\frac{(2c+3)(2c^3+3c^2-9c-12)}{(c+2)(2c^4+11c^3+2c^2-33c-28)},$$

$$\pi_0^{DE'}=\frac{4c^7+16c^6-27c^5-163c^4-24c^3+565c^2+768c+304}{2(c+2)(2c^4+11c^3+2c^2-33c-28)^2},$$

$$\pi^{d\,DE'}=\frac{(2c^3-c^2-10c-8)^2}{4(2c^4+11c^3+2c^2-33c-28)^2},$$

$$\pi^{u\,DE'}=\frac{(c+1)(c+4)(2c+3)^2(c^2-2)^2}{2(c+2)(2c^4+11c^3+2c^2-33c-28)^2}. \tag{12}$$

II.5 Spin-Off

We consider Spin-Offs (SOs) as the final vertical separation case, which is treated by Lin (2006) as a 'Partial Spin-Off' (PSO); note that 'SO' in Lin (2006) corresponds to (perfectly) vertical separation. In this case, firm 0 maximizes the profit of the upstream sector in the upstream stage and behaves as a non-integrated upstream firm.

The process for the stage 2 follows that for the DE case, and firm 0 maximizes its upstream profit in the stage 1, i.e.,

$$\pi_0^u=wx_0-\frac{c}{2}x_0^2, \tag{13}$$

7) Throughout the paper, we represent the solution of a high-order equation as a decimal approximation.

and the FOCs yield

$$x_0^{SO} = x_i^{SO} = \frac{c+1}{c^2+8c+8}. \tag{14}$$

The main solutions are

$$w^{SO} = \frac{(c+1)(2c^2+7c+4)}{2(c+2)(c^2+8c+8)},$$
$$q_0^{SO} = \frac{c^2+5c+5}{(c+2)(c^2+8c+8)},$$
$$q_j^{SO} = \frac{3(c+1)}{2(c^2+8c+8)},$$
$$Q^{SO} = \frac{4c^2+14c+11}{(c+2)(c^2+8c+8)},$$
$$\pi_0^{SO} = \frac{2c^4+17c^3+50c^2+63c+29}{2(c+2)(c^2+8c+8)^2},$$
$$\pi^{d\,SO} = \frac{9(c+1)^2}{4(c^2+8c+8)^2},$$
$$\pi^{u\,SO} = \frac{(c+4)(c+1)^3}{2(c+2)(c^2+8c+8)^2}. \tag{15}$$

II.6 Comparison

Figure 1 illustrates the comparative results. In the figure, the notations N, D, D′, and S indicate NE, DE, DE′, and SO, respectively. We calculate social welfare, W, defining $Q^2/2+\sum\pi$.

II.6.1 Spin-off firm's profit

First, we find $\pi_0^{SO} > \pi_0^{NE}$ on all intervals, implying that the upstream sector of firm 0 can profit from selling inputs to rivals, and thus, firm 0 itself succeeds in absorbing profits from rivals through the wholesale market.

II.6.2 Social welfare

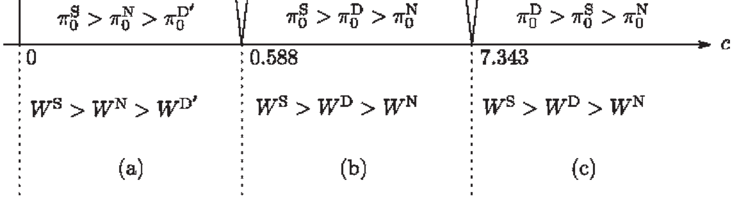
Regarding social welfare, Figure 1 indicates that

$$W^{SO} > W^{DE} > W^{NE} > W^{DE'} \tag{16}$$

for all $c \in \mathbb{R}_+$. There is an intuitive explanation for this result.[8)] Since consumer surplus (CS) dominates producer surplus (PS) in the present model, the magnitude of the correlation of social welfare is consistent with that of CS. Thus, retail price p, or wholesale price w, controls the above results.[9)]

Let S^{NE}, the supply curve under NE in the wholesale market, be a benchmark. In that case, note that $X=x_1+x_2$. If DE′ is chosen, the total input changes to $X=x_0+x_1+x_2$, where $x_0<0$. Thus $S^{DE'}$ could be located to the left. Similarly, S^{DE} could exist to the right of S^{NE} since $x_0>0$. In the SO case, under which the upstream sector of firm 0 is a non-integrated upstream firm, S^{SO} could be located to the right of S^{DE}.

Figure 1. Spin-off firm's profit and social welfare



8) This ranking does not always hold. See the next section.

9) The equations in (3) yield $p=(1+c)(1+2w)/(4+3c)$, so $dp/dw>0$.

III. EXTENDED MODEL

III.1 Extending the number of upstream firms

Figure 1 in the previous section indicates that firm 0 prefers selling inputs to purchasing them regardless of the value of c. However, that may not be always the case. If the number of upstream firms in the wholesale market increases, in line with elementary microeconomic theory, the demand scale expands along the demand curve, and the wholesale price in equilibrium will thus fall. Then, firm 0 may purchase cheap inputs through DE' to supply outputs with as many consumers as possible. In this section, we show that there are cases in which firm 0 prefers DE′ and confirm whether DE′ optimizes social welfare.

Generalizing the number of upstream firms to n and solving the models as in the previous section, we obtain the main solutions as follows:

$$\pi_0^{\mathrm{NE}}=\frac{[(c+2)n+2c^2+7c+4]^2}{2(c+2)[(3c+4)n+2c^2+7c+4]^2},$$

$$\pi_0^{\mathrm{DE}}=\frac{\begin{bmatrix}(c+2)^2(4c^4+28c^3+61c^2+48c+16)n^2\\+4(c+2)^2(2c+1)(c^2+5c+3)(2c^2+7c+4)n\\+4(c+1)(2c+3)(c^2+5c+3)(2c^2+7c+4)^2\end{bmatrix}}{2(c+2)(2c^2+7c+4)^2[(3c+4)n+2c^2+10c+6]^2},$$

$$\pi_0^{\mathrm{DE}'}=\frac{\begin{bmatrix}(c+2)^2(4c^4+4c^3-11c^2+16)n^2\\+4(c+2)^2(2c-1)(c^2-c-3)(2c^2+7c+4)n\\-4(c+3)(c^2-c-3)(2c^2+7c+4)^2\end{bmatrix}}{2(c+2)\begin{bmatrix}(3c+4)(2c^2+c-4)n\\+2(c^2-c-3)(2c^2+7c+4)\end{bmatrix}^2},$$

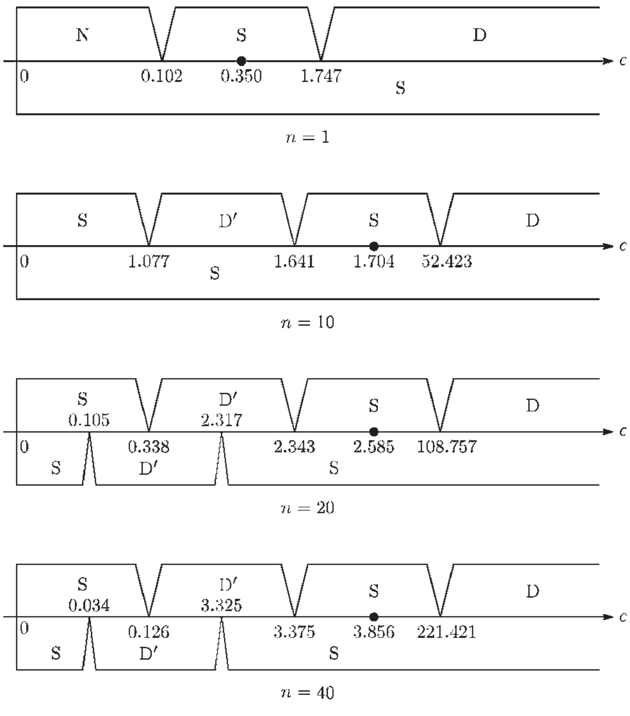
$$\pi_0^{\mathrm{SO}}=\frac{\begin{bmatrix}(c+2)^2n^2+4(c+1)(c+2)(c+3)n\\+4(c+1)^2(2c^2+11c+13)\end{bmatrix}}{2(c+2)[(3c+4)n+2(c+1)(c+4)]^2}. \tag{17}$$

We calculate social welfare W as in the previous section. We show the results in Figure 2 using dispersive n.

The upper regions indicate firm 0's preferred strategies. For instance, if $n=1$ and $c\in[0,0.102)$, we can show $\pi_0^{\mathrm{NE}}>\pi_0^{\mathrm{SO}}>\pi_0^{\mathrm{DE}'}$, and thus firm 0 prefers NE to the other strategies. A dot on the horizontal axis indicates the division point of DE and DE′. On the other hand, the lower regions indicate socially optimal strategies. For instance, if n=1, we can show that $W^{\mathrm{SO}}>W^{\mathrm{NE}}>W^{\mathrm{DE}'}$ for $c\in[0,0.350)$ and $W^{SO}>W^{DE}>W^{NE}$ for $c\in(0.350,\infty)$, and thus SO is optimal for all $c\in\mathbb{R}_+$ from the social welfare viewpoint. Some of our findings are as follows:

- Firm 0 can select NE if and only if both n and c are quite small.
- Firm 0 can select DE′ and it is optimal for social welfare if n is large to some extent.
- Firm 0's preference does not always correspond with the socially optimal strategy (we show this in interval (c) in Figure 1).
- The range of DE′ preferred by firm 0 and by society tends to expand as n increases.

Figure 2. Extending the number of upstream firms



III.2 Discussion

As expected, an increase in the number of upstream firms reduces the wholesale price, which gives firm 0 the incentive to purchase inputs by means of DE′. This happens only if c is small, because only this situation (light capacity constraint) enables upstream firms to produce extra inputs for firm 0. If the number of downstream firms in the wholesale market increases, firm 0 will prefer to sell inputs by means of either SO or DE as long as the number of upstream firms is small.

IV. CONCLUDING REMARKS

This paper discussed the validity of a vertically integrated firm's sale or purchase of inputs through the wholesale market. We show in the basic model that the firm prefers to sell inputs over purchasing inputs by means of spin-offs or direct entry in a capacity-limited scenario. Our result is crucially distinct from those in Inderst and Valletti (2009), which shows that firm 0 selects to sell if the good is heterogeneous. Notably, we found that a spin-off might be socially optimal independent of capacity constraints, whereas the firm may select direct entry under tight capacity constraints.

However, in the extended model, we found that the firm might prefer to purchase inputs from the wholesale market over other strategies if its capacity constraints are relatively small and the number of upstream firms is large, and such a choice might be socially optimal. Regulators should monitor or regulate vertical integration appropriately, considering firms' degree of separation, capacity constraints, and the size of the wholesale market.

We now address the question raised in the introduction: our analysis shows that vertically integrated firms participate in the wholesale market because they can boost their profits by changing the degree of vertical separation skillfully while monitoring both the (common) capacity constraints and scale of the wholesale market. If the capacity constraint is tight, the upstream firms cannot afford to supply sufficient inputs to the downstream firms in the wholesale market. This gives the integrated firms a chance to sell inputs to the other downstream firms. Further, if many upstream firms exist in the wholesale market, the wholesale price falls, lowering the consumers' price subsequently. This expands the demand scale such that integrated firms are not able to compensate the demand by themselves. Then, if the capacity constraint is loose enough, the upstream firms can afford to produce extra inputs for the integrated firms. Therefore, fortunately, integrated firms can boost their profits by purchasing inputs from the wholesale market.

Future research should refine the analysis in this paper. There may be more than one integrated firms as analyzed in Lin (2006), and the degree of efficiency among firms may differ, as in Linnemer (2003). Secondly, policymakers may be interested in the case in which non-integrated upstream and downstream firms endogenously integrate. Toward this viewpoint, the analysis in Colangelo (1995) or Salant *et al.* (1983) might apply. In addition, Häckner (2003) presents the condition under which vertical integration between upstream and downstream firms improves (worsens) the social welfare. Finally, studies should also reconsider the role or mode of the wholesale market.

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