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Abstract

We study third degree price discrimination in intermediate good markets, in which costs of production for the downstream firms are determined by their investment choices. We focus on the effect of the sequence of firm actions and analyze two models with different timing of investments, before or after the upstream monopolist sets the input prices. When investments are determined after the prices are set, an indirect effect of input prices on the derived demand from downstream firms must be taken into account, due to the change of investment incentives. This causes the upstream firm to possibly charge the more efficient downstream firm a lower price, a result contrasting previous findings. Using linear demand and quadratic investment costs, we show that not only the downstream firms but also the upstream monopolist prefers the sequence of play in the latter model, i.e., it benefits from committing to prices before investments are undertaken. A change of timing from the first model to the second constitutes a strict Pareto improvement.

JEL Classification: D2, D4, L1

Key Words: price discrimination, intermediate good, investments, timing

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I. Introduction

Price discrimination in intermediate good markets is prevalent especially in countries where such practices are not prohibited or in international markets where national antitrust laws do not apply. Perhaps counter-intuitively, models of third degree price discrimination have generally shown that a less efficient firm receives a discount from the monopolistic upstream firm relative to a more efficient firm. In these models, however, the importance of the timing of firm actions has been largely neglected. Different sequences of play affect the strategic interactions between firms and can lead to different market outcomes. In this paper, we consider that downstream firms make complementary investments that lower production cost and then explore the consequence of timing of these investments in relation to price setting by upstream monopolist.

We study two models of vertical structure with different timing of investments made by the downstream firms. By saying investments, we mean the general costly activities that can be used to lower a firm's production cost. They may include, but are not limited to, R&D expenditures, managerial effort, and the purchase of fixed capital, etc. We show that if investment levels are chosen after the monopolist sets the prices of the intermediate good, a more efficient firm may end up paying a lower price than a less efficient firm. The timing of investments plays an important role: an indirect effect of input price on quantity demanded, through the change of downstream firms' investment incentives, must also be taken into account when the monopolist sets the prices before the downstream firms invest. Interestingly, we show that a change of sequence from one model (the upstream firm commits to input prices first) to the other (the upstream firm sets input prices after investments are made) benefits all parties including the upstream

monopolist, the downstream firms and the consumers. Thus allowing the downstream firms to react to the price set by the upstream firm forces the upstream firm to internalize the effect of higher prices on reduced investment and leads to a Pareto improvement. This suggests firms have a strong incentive to structure a vertical relationship to achieve this, and makes the latter model an appealing choice for future research.

While the Anti-Price Discrimination Act of 1936 (often referred to as the Robinson-Patman Act) in the United States concerned primarily intermediate goods markets, most economic studies have been on price discrimination in the final goods markets. One of the main findings in this literature is that the monopolist should charge more in markets with lower elasticity of demand, an optimal pricing rule under third degree discrimination. (See, e.g., Tirole (1988).) In a seminal paper, DeGraba (1990) employed a model with a monopoly supplier and two downstream producers who engage in Cournot competition in the final market. He showed that the supplier charges the lower cost producer a higher price than the higher-cost firm under price discrimination, partially offsetting the cost advantage. This was confirmed in Yoshida (2000) in an extension to n downstream firms with different α-β-efficiency (to produce one unit of the final good, one firm needs more of the input and also incurs a higher marginal cost). These theoretical findings are actually consistent with the results in final good markets that low elasticity is penalized. Demand for inputs from the lower cost firm is less elastic and thus it should be charged a higher price by the profit-maximizing upstream firm. What's different in a vertical structure, that faced by the upstream firm is *derived* demand based on a downstream firm's choice of output to supply in the final market.

Though theoretically intuitive, it contradicts many people's expectation that, being a larger buyer, a more efficient firm should be able to get a better deal. Katz (1987) first argued that a large downstream firm has higher ability to vertically integrate backward and consequently should be charged a lower price by the input provider. Following a similar spirit, Inderst and Valletti (2009) showed that if there is threat of demand-side substitution the more efficient buyer receives a discount. Because the transaction cost for finding another supplier of the same inputs can be spread over a larger volume, this lower cost buyer is more likely to switch. The additional participation constraint leads to a lower price charged to it. Allowing the use of two-part tariff contracts, Inderst and Shaffer (2009) also showed that a more efficient firm obtains a lower wholesale price. By extracting all profits, the monopolist's interest is in line with the downstream firms and the wholesale prices are set to maximize industry profits. In this paper, we study price discrimination under linear pricing, without altering the upstream firm's monopolistic status.

Different from the extant literature which exogenously assumes downstream firms' marginal production costs, with one firm's cost being higher than another, we make costs of production endogenous by allowing firms to choose the level of complementary investment. One firm is more efficient than another if a lower cost of investment is incurred to reduce marginal cost to a same level. We distinguish two types of vertical structures which differ in the timing of downstream firms' investment choice. In a supplier-manufacturer type of vertical relationship, as we name it primarily for convenience, the marginal cost of a downstream firm is determined by its production technology which usually entails large scale investment and long time horizon, and thus

is assumed to be done before the upstream supplier sets input prices. For a wholesaler-retailer type of vertical relationship, a downstream firm's marginal cost in selling products in the final market may be highly variable and easily controllable due to choice of complementary inputs such as managerial effort, shelf space, etc. In this case, the downstream firms' choices of investment are more likely made after the input price is set and the profitability of this product is fully understood. It is worth noting that both DeGraba (1990) and Inderst and Valletti (2009) have studied downstream firms' technology choices under price discrimination. The timing in their models would be analogous to our first model. What's different, they derived the pricing rule by assuming different production technologies and then studied firms' technological choices without making a difference about their investment expenses. Here, we directly assume different investment costs at the very beginning and use an "integrated" three stage model. Our second model is new to the literature.

We focus on the case of downstream firms that operate in separate markets. This can be due to geographical or technological barriers. For instance, in many countries, one mobile service provider is the exclusive contractor with Apple Inc. to provide mobile services bundling iPhone products. Because of differences in language and telecommunication standards, cross-border shopping is rare and each service provider can be seen as a monopolist in its own country.[1] The assumption of separate markets can also be appropriate when the downstream firms pursue monopolistic competition in the final good market. A unique branding, distinctive packaging or different after-sale services can all grant a firm substantial market power in the short run. Independence among final markets greatly reduces the analytical challenges in these three stage models. Also, it

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[1] Inderst and Valletti (2009) argue that geographic market segmentation is particularly relevant for Europe.

enables us to focus on the important but overlooked difference between intermediate and final good markets: demand for an intermediate good is determined not only by consumer preferences but also by a downstream firm's production technology.

The rest of the paper is organized as follows. In Section II, we introduce the two three-stage models with different timing of the downstream firms' investment choices to study the upstream firm's pricing strategy and obtain some general results. In section III, we assume a linear demand function and a quadratic cost function to illustrate the results and compare market outcomes under different timing. The last section discusses these two models and concludes the paper.

II. The Models

Consider a monopolistic upstream firm which sells an intermediate good to n downstream firms. To produce each unit of the final good, each downstream firm uses one unit of the intermediate good as input. Also, downstream firm i, $i = 1, 2, \ldots, n$, incurs a constant marginal cost to transform the intermediate good into the final good. The initial level of marginal cost is c_0, which can be lowered to $(c_0 - x_i)$ by investing into the complementary production technology, $i = 1, 2, \ldots, n$. We will call $x = (x_1, x_2, \ldots, x_n)$ the firms' cost reduction levels, which is in one-to-one correspondence with their chosen investments with the following assumptions. The cost of investments is $R(x_i, \theta_i)$, with $\frac{\partial R(\cdot)}{\partial x_i} > 0, \frac{\partial^2 R(\cdot)}{\partial x_i^2} > 0$, and $\frac{\partial^2 R(\cdot)}{\partial x_i \partial \theta_i} > 0$. Manufacturer i's cost efficiency is measured by θ_i. Note that a lower value of θ represents higher efficiency: if $\theta_i < \theta_j$, lowering marginal production cost to any same level would cost

firm j more than firm i, so firm i is more efficient. The last inequality, $\frac{\partial^2 R(\cdot)}{\partial x_i \partial \theta_i} > 0$, is

referred to as the single-crossing condition in the contract theory literature. Here, it

simply says that the marginal cost of investment rises with θ. We do not consider the

trivial case that only fixed cost of investment is different for these firms, since in that

case their incentives for investment will be the same as long as cost reduction is

profitable. The upstream firm's cost of supplying the intermediate good is normalized to

zero.

As has been discussed in the introduction, we focus on the circumstance when

downstream firms operate in n separate markets and each serve as a monopolist in its

own market. In market i, consumer demand for the final good is represented by $p_i = P(q_i)$, with $P'(q_i) < 0$. Also, we assume the demand function and investment cost

function are well behaved such that the optimization problems have their second order

conditions satisfied and a unique interior solution exists.

Two models with different sequence of firm actions are analyzed. In the first

model, the downstream firms choose investment before the upstream monopolist sets the

price of intermediate goods. This may best characterize a supplier-manufacturers type of

vertical structure where downstream firms' production technology usually involves large

investment and a long time horizon and thus must be done before this vertical

relationship is built. In the second model, downstream firms' investment decisions are

made after the price of intermediate goods is set. This may better represent a wholesaler-

retailers type of vertical structure where costs involved in the selling procedure are easily

variable in the short run. We call the first model the supplier-manufacturers model (S-M)

and the second model the wholesaler-retailers model (W-R). These names are mainly for convenience and the timing of the game is what is essential.

□ **The Supplier-Manufacturers model**

Consider a vertical structure in which a monopolistic upstream firm sells an input to n downstream firms. As we have noted, in this model, investment levels are chosen before the upstream firm sets the input prices. The timing of the game is then: at stage 1, downstream firms choose an investment level that lowers their marginal cost of production; at stage 2, observing the downstream firms' costs of production, the upstream firm sets input prices, $w = (w_1, w_2, \dots, w_n)$, where w_i is the unit price charged to firm i; at stage 3, downstream firms purchase the intermediate goods, produce final products and sell them in the final markets.

Using backward induction, we start with the downstream firms' choices of quantities, which also determine their demands for inputs in the intermediate good market. In stage 3, given w_i, the input price charged by the upstream firm, and $c_0 - x_i$, the cost of production it has chosen in stage 1, downstream firm i's optimal production level is given by:

(1) $P'(q_i)q_i + P(q_i) - c_0 - (w_i - x_i) = 0$.

And the second order condition ensuring a unique interior solution is:

(2) $P''(q_i)q_i + 2P'(q_i) < 0$.

Write $q_i = q(w_i - x_i)$, we have $q'(\cdot) = \frac{1}{P''q + 2P'} < 0$, which means a downstream firm's demand for input decreases in the price charged by the upstream firm and increases in the cost reduction level it has chosen in the first stage.

Then in stage 2, given the cost reduction levels of the downstream firms, x, the upstream supplier then sets input prices w to solve:

$$\max_{w} \sum_{i=1}^{n} q(w_i - x_i)w_i$$

The first order condition determines the input prices charged to each manufacturer:

(3) $\quad q(w_i - x_i) + q'(w_i - x_i)w_i = 0.$

The second order condition ensuring a unique interior solution is: $2q'(\cdot) + w_i q''(\cdot) < 0.$

Plugging in $q'(\cdot)$ and $q''(\cdot)$, it can be written as:

(4) $\quad 4P'(\cdot) + 5P''(\cdot)q(\cdot) + P'''(\cdot)q^2(\cdot) < 0.$

Write $w_i = w(x_i)$, we have the following result: (All proofs are in the Appendix.)

Lemma 1: $\frac{\partial w(\cdot)}{\partial x_i} < 1; \frac{\partial w(\cdot)}{\partial x_i} > 0$ if and only if

(5) $\quad 2P'(\cdot) + 4P''(\cdot)q(\cdot) + P'''(\cdot)q^2(\cdot) < 0.$

Condition (5) is stronger than the second order condition (4). Together with (2), it implies (4). It is valid for a number of demand functions including linear demand which we will use to derive a closed form solution. Other functions satisfying this condition include $p = a - bq^c$ for $c > 0$, $p = a + \frac{b}{q^c}$ for $c > 1$ and $p = a - be^q$.[2] Under this condition, a downstream firm's benefit from cost reducing investments will be partially offset by a higher input price charged the upstream firm. Intuitively, investment lowers the production cost and raises the downstream firm's profit margin for each unit of

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[2] One exception we could think of is $p = a - b \ln q$, which satisfies (4) but violates (5). In this case, $\frac{\partial w(\cdot)}{\partial x_i} = 0$ and the monopolist charges a uniform price.

production. Accordingly, the value of the input has increased and the upstream firm can ask for a higher price.

From Lemma 1, when condition (5) is satisfied, the downstream firm which has a lower marginal cost (determined by its chosen investment level in the first stage) will be charged a higher input price by the upstream firm. However, since the handicapping is only partial, $\frac{\partial w(\cdot)}{\partial x_i} < 1$, there is still incentive for the more efficient firm to select a lower cost technology, and consequently receive a higher price for each unit of the intermediate good.

Proposition 1: In the supplier-manufacturers model, the upstream monopolist charges a higher price of the intermediate good to the more efficient downstream firm than to a less efficient firm if and only if condition (5) is satisfied.

This result is by and large consistent with previous finding that a less efficient firm receives a discount under third degree price discrimination, but only when the demand function satisfies (5). The downstream firms are only partially handicapped by the upstream monopolist, and as a result, there is still incentive for the more efficient firm to choose a lower cost technology given its lower cost of investment. The upstream firm, after observing their chosen costs, charges the downstream firm with lower elasticity of derived demand (the lower production cost firm) a higher input price. Adding the investment stage does not alter the general pricing rule since investments are sunk at the time when the upstream firm prices.

□ **The Wholesaler-Retailers Model**

We now turn to another model which differs in the timing of firm actions from the one discussed earlier. It may better characterize a wholesaler-retailers type of vertical structure in which the monopolistic upstream firm is a manufacturer of a consumer product under its unique brand name or an exclusive distributor of this manufacturer. Final goods sold to consumers may be very close, in a physical sense,[3] to intermediate goods provided by the upstream wholesaler. The downstream firms are mainly in charge of selling them to consumers in the final good market. Few, if any, further production process is needed. However, the selling procedure may entail some costs which are easily variable and heavily impacted by managerial effort. For example, costs involved in organizing products on shelves, managing inventory, providing follow-up services, etc. How much investment to spend on these procedures is more likely determined after prices of the intermediate goods have been set by the upstream firm so that a full costbenefit analysis can be conducted. As a result, we make a different assumption on the timing of the game that investments to lower production cost are chosen after the upstream firm sets the input prices.

The game is played in the following sequence: in stage 1, the upstream firm sets input prices, w, charged to the downstream firms; in stage 2, downstream firms choose an investment level that lowers marginal cost of production; and in stage 3, downstream firms produce final goods and sell them in the final markets.

The third stage is the same as before. The optimal quantity is defined by (1) and we have the same first and second derivatives for $q_i = q(w_i - x_i)$. In stage 2, given the

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[3] Before consumers make a purchase from a retailer, extra packaging may be needed at the sales stage. Also, after-sale services might be bundled with the physical part of the product.

input price, w_i, which was set by the upstream monopolist in the first stage, downstream

firm i's objective function is then: [4]

$$\max_{x_i} \ (P(q(w_i - x_i)) - c_0 + x_i - w_i)q(w_i - x_i) - R(x_i, \theta_i)$$

By plugging the optimal condition for quantity choice in the last stage (1) into the first

order condition, we have the optimal level of cost reduction as defined by:

(6) $\quad q(w_i - x_i) - \frac{\partial R(\cdot)}{\partial x_i} = 0.$

Write $x_i = x(w_i, \theta_i)$. With the second order condition being satisfied, we can prove the

following comparative statics:

Lemma 2: $\frac{\partial x(\cdot)}{\partial \theta_i} < 0$, and $\frac{\partial x(\cdot)}{\partial w_i} < 0$.

The first comparative static in Lemma 2 says that with higher cost of investments,

a downstream firm chooses a lower cost reduction level (or equivalently, lower

investments), holding everything else constant. The second comparative static says that

being charged a higher input price, the downstream firm chooses a lower cost reduction

level. This is a very important result since it tells us that the upstream firm's pricing

strategy in the first stage would affect a downstream firm's investment incentives, which

in turn affect the quantity of inputs demanded from this downstream firm. In determining

an input price charged to a downstream firm, the monopolist need consider both a direct

effect and an indirect effect of this price on the derived quantities demanded as defined

by (1). From what we have had in the third stage, $q_i = q(w_i - x_i)$, w_i affects q_i directly,

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[4] Since the choices of q_i and x_i are made by the same firm, they are effectively simultaneous here. Of course, the analytical results are not changed whether we solve them simultaneously or sequentially

but also indirectly through its effect on x_i, another determinant of q_i. Suppose that the monopolist increases the price charged on firm i, w_i, the direct effect will cause the downstream firm to decrease its demand of inputs since $q'(\cdot) < 0$. But also, this will cause the firm to decrease its investment in the cost reduction technology, which again causes q_i to decrease. This additional effect, as compared with that in the supplier-manufacturers model, will indeed affect the upstream firm's pricing strategy.

In the first stage, the upstream monopolist's problem is to solve:

$$\max_{w} \sum_{i=1}^{n} q(w_i - x(w_i, \theta_i)) w_i.$$

The first order condition is:

(7) $q'(\cdot)\left(1 - \frac{\partial x(\cdot)}{\partial w_i}\right) w_i + q(w_i - x(w_i, \theta_i)) = 0.$

Again, assume the second order conditions are satisfied in all ranges we consider ($\widehat{S.O.C.} < 0$). Then, by differentiating (6) with respect to θ_i, we find how the optimal input prices vary with respect to the downstream firms' cost parameters:

(8) $\frac{\partial w_i}{\partial \theta_i} = -\frac{\Delta}{\widehat{S.O.C.}}$, where $\Delta = -\left(q'(\cdot) - \frac{q''(\cdot)q}{q'(\cdot)}\right)\frac{\partial x(\cdot)}{\partial \theta_i} - q'(\cdot)w_i \frac{\partial^2 x(\cdot)}{\partial w_i \partial \theta_i}.$

With the denominator being negative, the sign of the partial derivative of the input price charged to firm i with respect to its efficiency coefficient is the same as the sign of Δ, which is in general ambiguous. Thus we prove the following result:

Proposition 2: In the wholesaler-retailers model, the upstream monopolist charges a lower price of the intermediate good to the more efficient downstream firm than to a less efficient firm if $\Delta > 0$, a higher price if $\Delta < 0$, and an equal price if $\Delta = 0$.

Thus by alternating the sequence of the upstream firm setting input prices and downstream firms making investments, we have obtained a result different from that in the previous model. The more efficient firm may receive a lower price under third degree price discrimination. The first term in Δ (when divided by $\widehat{S.O.C.}$) accounts for the direct effect of the input price on the downstream firm's derived demand. Under condition (5), $q'(\cdot) - \frac{q''(\cdot)q}{q'(\cdot)} = \frac{2P'+4P''q+P'''q^2}{(P''q+2P')^2} < 0$. As a result, this term is negative since $\frac{\partial x(\cdot)}{\partial \theta_i} < 0$. That means, considering this effect only, the monopolist should charge a more efficient retailer a higher wholesale price. Following our analysis of the supplier-manufacturers model, this is quite intuitive and consistent with the literature on third degree price discrimination that the monopolist should charge more in markets with lower elasticity of demand. Since a more efficient firm will choose a lower cost technology and thus become less flexible with respect to its derived demand for the intermediate good, a higher input price can be charged.

However, there is a second term which (when divided by $\widehat{S.O.C.}$) accounts for the indirect effect of the wholesale price on the retailer's derived demand. With $q'(\cdot) < 0$, the sign of it depends on the sign of the cross partial derivative, $\frac{\partial^2 x(\cdot)}{\partial w_i \partial \theta_i}$, which measures how a downstream firm's investment responsiveness with respect to the input prices varies for different cost parameters. Since $\frac{\partial x(\cdot)}{\partial \theta_i} < 0$, if this cross partial derivative is positive, that means a less efficient firm (with higher θ) is less responsive to an input price change. Then this indirect effect alone leads the monopolist to charge a higher price to this firm and a lower price to the more efficient firm. Again, lower elasticity is penalized under third degree price discrimination. Together with our earlier discussion,

the sign of $\frac{\partial w_i}{\partial \theta_i}$ would depend on which effect has a larger magnitude. If $\frac{\partial^2 x_i(\cdot)}{\partial w_i \partial \theta_i} \leq 0$, then

we have $\frac{\partial w_i}{\partial \theta_i} < 0$ and the upstream monopolist should again charge the more efficient

downstream firm a higher price for the intermediate good.

Unfortunately, the sign of this cross partial derivative is generally ambiguous

without additional restrictions placed on the demand function and the cost functions.

However, under some common assumptions in the literature, when the final market has

linear demand and the cost of investment can be expressed as the form $R(\cdot) = \theta_i f(\cdot) +$

$g(\cdot)$, we do have $\frac{\partial^2 x_i(\cdot)}{\partial w_i \partial \theta_i} > 0$ and a positive second term in Δ.[5] Having obtained these

general intuitions, in the next section we will assume some specific functional forms of

market demand and costs of investment to conduct further analyses on these three-stage

models.

III. Timing of Investments

With the additional choice of investments, we find the timing of firm actions

plays an important role. Under different sequences of play, the strategic interaction

between firms is affected and the monopolist's pricing strategy changes. In the

wholesaler-retailers model, the monopolist may charge a more efficient downstream firm

a lower price, which contrasts with some established results from the literature. To

further our analysis of the timing issue, we assume specific functional forms for the final

market demand and the downstream firms' costs of investment.

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[5] This can be seen by differentiating (6) first by w_i and then by θ_i.

Linear demand and quadratic investment costs have been widely used in the literature of price discrimination and R&D (e.g., D'Aspremont and Jacquemin, 1988; DeGraba, 1990). To our understanding, this is the only option that can lead to a closed form solution. In the following, we assume the inverse demand function in market i is:

(9) $p_i = a - bq_i$.

We normalize b equal to one by the appropriate adjustment of output units and define $A \equiv a - c_0$ to simplify notation.

Also, assume the costs of investment for downstream firm i is given by:

(10) $R_i(x_i) = \gamma_i x_i^2 + \beta_i x_i + \alpha_i$.

Firm i is more efficient than firm j if $\gamma_i \leq \gamma_j$, $\beta_i \leq \beta_j$ and $\alpha_i \leq \alpha_j$ with at least one of the first two inequalities being strict.[6] To ensure that the firms' objective functions are well defined and a unique interior solution exists, we assume the following restrictions on the parameters are satisfied:

(A1) $\gamma_i > 1/4$;

(A2) $\beta_i < A/8$.

The coefficient on the linear term (β_i) can be positive or negative. But if β_i is negative, we only consider the range where $R_i(x_i)$ rises. That is, $x_i \in [-\frac{\beta_i}{2\gamma_i}, \infty)$ if $\beta < 0$. Also, we assume the constant term α_i is not too big such that a zero investment solution is avoided. Using backward induction same as in the previous section, we can solve the equilibrium prices and cost reduction levels.

In the supplier-manufacturers model, the downstream firms choose:

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[6] As discussed earlier, the case that only the fixed cost differs would not affect the firms' incentives of investment as long as zero investment is ruled out.

(11) $x_i{}^{S-M} = \frac{A-8\beta_i}{16\gamma_i-1}.$

And the upstream monopolist sets the input prices as:

(12) $w_i{}^{S-M} = \frac{A}{2} + \frac{A-8\beta_i}{32\gamma_i-2},$

which decreses both in γ_i and in β_i. As a result, consistent with the conclusion in

Propositio 1, a less efficient firm is charged a lower price by the upstream monopolist.

In the wholesaler-retailers model, the downstream firms choose:

(13) $x_i{}^{W-R} = \frac{A-w_i-2\beta_i}{4\gamma_i-1} = \frac{\frac{A}{2}+\frac{\beta}{4\gamma_i}-2\beta_i}{4\gamma_i-1},$

and the upstream firm sets the following input prices:

(14) $w_i{}^{W-R} = \frac{A}{2} - \frac{\beta_i}{4\gamma_i}.$

Since $\gamma_i > 0$, which downstream firm receives a lower input price simply depends on the

magnitude of $\frac{\beta_i}{\gamma_i}$. This yields the following result:

Proposition 3: With linear final market demand and quadratic investment costs, in the

supplier-manufacturers model, the more efficient downstream firm is charged a higher

input price than the less efficient firm. In the wholesaler-retailers model, the more

efficient downstream firm (firm i) is charged a lower input price than the less efficient

firm (firm j) if $\frac{\beta_i}{\gamma_i} > \frac{\beta_j}{\gamma_j}$, a higher input price if $\frac{\beta_i}{\gamma_i} < \frac{\beta_j}{\gamma_j}$, and an equal input price if $\frac{\beta_i}{\gamma_i} = \frac{\beta_j}{\gamma_j}$.

These results illustrate the general conclusion found in the previous section. Since

a linear demand function satisfies condition (5), the more efficient downstream firm is

charged a higher input price than the less efficient firm in the supplier-manufacturers

model. Also, the result is generally ambiguous in the wholesaler-retailers model. Under the assumed functional forms, whether the upstream firm charges a higher or lower price to the more efficient firm depends on the ratio of the coefficients on the quadratic term and the linear term. Suppose firm i is more efficient with $\gamma_i = 2$ and $\beta_i = 1$. If the less efficient firm j has $\gamma_i = 3$ and $\beta_i = 2$, then firm i will be charged a higher price than firm j, since $\frac{1}{2} < \frac{2}{3}$. Instead, if firm j has $\gamma_i = 5$ and $\beta_i = 2$, then firm i will be charged a higher price than firm j, since $\frac{1}{2} > \frac{2}{5}$. And if firm j has $\gamma_i = 4$ and $\beta_i = 2$, the upstream firm should charge these firms the same price for the intermediate good.

Thus we find a circumstance under which a more efficient firm receives a discount, unlike what has been established in the literature. The timing of investments taken by the downstream firms plays a critical role: when the upstream firm sets the input prices before they choose the investment levels, an indirect effect of the prices on the downstream firms' quantity demanded, through the change of their cost reduction incentives, must be taken into consideration in addition to the direct effect. With final market demand being linear and the costs of investment being quadratic, this indirect effect impacts how the upstream firm sets input prices in an opposite direction and may dominate the direct effect, causing the upstream firm to charge a lower price to the more efficient firm and a higher price to the less efficient firm.

An important question that follows is, if a downstream firm can choose the timing of its investment, then should it commit to a production technology before the monopolist sets the price for the intermediate good or to retain flexibility and choose the investment level until the upstream firm has sets the price? This may have rich implications in real world situations.

Proposition 4: With linear final market demand and quadratic investment costs, $x_i^{W-R} >$ x_i^{S-M}, $w_i^{W-R} < w_i^{S-M}$, and $\pi_i^{W-R} > \pi_i^{S-M}$.

That is, by remaining flexible and choosing its investment level after the price of the intermediate good is set, a downstream firm is charged a lower price, chooses a lower cost production technology and earns a higher profit than by committing an investment level before the price of the intermediate good is set. This is not surprising. From Lemma 2, we learned that a higher input price would lower the investment level taken by the downstream firms and consequently the quantity demanded, in addition to the direct effect. This is, apparently, in the favor of the downstream firm. Thus by remaining flexible and not committing to a production technology at that time, a downstream firm is better off by making the monopolist consider both effects when setting the input price.

What is more interesting, the upstream monopolist also prefers this sequence of play, that is, letting the downstream firms choose a production technology after it has set the input prices.

Proposition 5: With linear final market demand and quadratic investment costs, the upstream monopolist earns a higher profit in the wholesaler-retailers model than in the supplier-manufacturers model.

Considering that the upstream monopolist charges higher prices in the supplier-manufacturers model than in the wholesaler-retailers model, this is quite striking result.

Proposition 5 tells that its gain from selling a larger amount of the intermediate good outweighs the higher prices it charges for each unit it sells to the downstream firms. Since both parties are better off under this sequence of play, the wholesaler-retailers model is probably a more reasonable choice especially when at least one of the two parties is flexible in the timing of its strategies. Of course, the upstream firm has an incentive to renege on its set price and charge a higher price after observing the downstream firm's investment level. In real world settings, signing a contract can easily solve the problem.

The welfare implication of these comparisons is straightforward. Since all the firms gain under the wholesaler-retailers model, and a higher quantity is sold by the upstream firm which implies higher final outputs and higher consumer surplus, social welfare is improved in the wholesaler-retailers model when compared to that in the supplier-manufacturers model.

Proposition 6: With linear final market demand and quadratic investment costs, changing the sequence of play in the supplier-manufacturers model into that in the wholesaler-retailers model is a strict Pareto improvement.

Under the supplier-manufacturers model, choosing the lower cost technology by investments are partially penalized by a higher input prices set by the upstream firm. This causes lower investment levels, lower output level and lower social welfare. This is partly corrected when the investment choices are made after the input prices are set in the wholesaler-retailers model. An indirect effect will be taken into consideration and the

monopolistic power of the upstream firm is refrained from harming social welfare, at least to some extent.

IV. Conclusion

In this paper, we study two models of third degree price discrimination in intermediate good markets. Downstream firms' complementary production technologies are endogenously determined by their investments but the timing of investments can be either before or after the input prices are set by the upstream monopolist. When investments are chosen before the upstream monopolist sets the prices, under a fairly general condition, our result does not differ from previous findings that a less efficient downstream firm receives a discount instead of the more efficient one. However, when investments are determined after the input prices are set, the upstream monopolist may charge the more efficient firm a lower price than the less efficient firm. An indirect effect of input prices on the quantity demanded from the downstream firms must be taken into account, through the change of investment incentives. We illustrate these general results using linear demand and quadratic investment costs. Interestingly, both parties in the vertical structure prefer the sequence of play in the wholesaler-retailers model. Considering that consumer surplus also increases as output is higher, a change of timing from the supplier-manufacturers model to the wholesaler-retailers model constitutes a strict Pareto improvement.

The applicability of these models depends on the likely timing of investments, before or after prices of intermediate goods are set, and the ability of the upstream monopolist to commit to a price. In naming the two models, we argued that for a

supplier-manufacturers type of vertical relationship, production cost is mainly determined by technological innovations which must be done in a long horizon and thus may be before input prices are set. While in a wholesaler-retailer relationship, cost involved in the selling process is easily controllable by the downstream firms' managerial effort and may be done after input prices are set. However, this is only for conceptual convenience and does not apply to every setting. As was discussed later on, since both parties are better off under the sequence of play in the wholesaler-retailers model, it is probably more reasonable to choose this model especially when at least one of the two parties is flexible in its timing.

Admittedly, it is also very likely that some portion of the downstream firm's cost is determined before this vertical relationship builds, and the remaining portion is still variable after prices of the intermediate goods are set by the upstream firm. While the general ideas within this paper should still apply, the optimal pricing rule will be much more complicated as the number of stages expands to four. Also, the welfare effects of antitrust regulations (bans of price discriminations in some countries) in these three stage models are open for future researches.

Appendix

Proof of Lemma 1:

From (3), we have $\frac{\partial w(\cdot)}{\partial x_i} = -\frac{-q'-w_iq''}{2q'+w_iq''} = 1 - \frac{q'}{2q'+w_iq''} < 1$. Also, $\frac{\partial w(\cdot)}{\partial x_i} =$

$\frac{q'+w_iq''}{2q'+w_iq''} = \frac{1}{2q'+w_iq''}\left(q' - \frac{qq''}{q'}\right) = \frac{1}{2q'+w_iq''}\left(\frac{1}{P''q+2P'} + \frac{3P''q+P'''q^2}{(P''q+2P')^2}\right)$ which is greater

than zero if and only if (5) is satisfied. ∎

Proof of Proposition 1:

In the first stage, downstream firm i's choice of investment (equivalently, choice

of cost reduction x_i) is determined by solving the following problem:

$$\max_{x_i} \left(P\big(q(w(x_i) - x_i)\big) - c_0 + x_i - w(x_i)\right)q(w(x_i) - x_i) - R(x_i, \gamma_i)$$

The first order condition implicitly defines the optimal level of investment:

$$(P(q_i) - c_0 + x_i - w(x_i))q'(\cdot)\left(\frac{\partial w(\cdot)}{\partial x_i} - 1\right)$$

$$+ \left(P'(\cdot)q'(\cdot)\left(\frac{\partial w(\cdot)}{\partial x_i} - 1\right) - \frac{\partial w_i}{\partial x_i} + 1\right)q(w_i - x_i) - \frac{\partial R(\cdot)}{\partial x_i} = 0.$$

With the second order condition being satisfied and $\frac{\partial^2 R(\cdot)}{\partial x_i \partial \theta_i} > 0$, differentiate the above

expression with respect to θ_i and we have $\frac{\partial x_i}{\partial \theta_i} < 0$, which means a more efficient

manufacturer chooses a lower cost technology. Together with Lemma 1, we prove the

proposition. ∎

Proof of Lemma 2:

From (6), we have $\frac{\partial x(\cdot)}{\partial \theta_i} = \frac{\frac{\partial^2 R(\cdot)}{\partial x_i \partial \theta_i}}{-q' - \frac{\partial^2 R(\cdot)}{\partial x_i^2}} < 0$, given that the denominator is negative

(the second order condition). Also, $\frac{\partial x(\cdot)}{\partial w_i} = -\frac{q'}{-q' - \frac{\partial^2 R(\cdot)}{\partial x_i^2}} < 0.$ ∎

Proof of Proposition 4:

Compare (11) to (13), (12) to (14), we have $x_i^{W-R} > x_i^{S-M}$ and $w_i^{W-R} < w_i^{S-M}$.

In the wholesaler-retailer model, if firm i were to choose $x_i = x_i^{S-M}$, its profit is

$\pi_i(x_i^{S-M}) = \left(\frac{A - w_i^{W-R} + x_i^{S-M}}{2}\right)^2 - R_i(x_i^{S-M})$ which is greater than $\pi_i^{S-M} =$

$\left(\frac{A - w_i^{S-M} + x_i^{S-M}}{2}\right)^2 - R_i(x_i^{S-M})$ since $w_i^{W-R} < w_i^{S-M}$. And $\pi_i^{W-R} > \pi_i(x_i^{S-M})$. ∎

Proof of Proposition 5:

In the supplier-manufacturers model, the upstream monopolist's profit from

market i is

$$\pi_{mi}^{S-M} = \frac{1}{2}(A - w_i^{S-M} + x_i^{S-M})w_i^{S-M} = 8\left(\frac{2A\gamma_i - \beta}{16\gamma_i - 1}\right)^2,$$

while in the wholesaler-retailers model, its profit is

$$\pi_{mi}^{W-R} = \frac{1}{2}(A - w_i^{W-R} + x_i^{W-R})w_i^{W-R} = \frac{(2A\gamma_i - \beta)^2}{8\gamma_i(4\gamma_i - 1)}.$$

We can easily verify that $\pi_{mi}^{S-M} < \pi_{mi}^{W-R}$ when $\gamma_i > 0$. ∎

Proof of Proposition 6:

Proposition 4 and Proposition 5 indicate that all firms earn a higher profit under the wholesaler-retailers model. Also by Proposition 4, final output in market i is $q_i^{W-R} = \frac{1}{2}(A - w_i^{W-R} + x_i^{W-R})$ in the wholesaler-retailers model, greater than the final output in the supplier-manufacturers model $q_i^{S-M} = \frac{1}{2}(A - w_i^{S-M} + x_i^{S-M})$. As a result, consumer surplus is also greater. ∎

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