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Product quality investment co-operation and sharing among downstream rivals: An application to mobile telecommunications

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Abstract: We analyze incentives for cooperation on product quality investments and sharing of quality improvements in a Hotelling duopoly. In the standard set up, an identical increase in quality by both firms does not affect demand, since demand elasticity is unaffected. If product quality investments makes demand more inelastic, firms' incentives for investments and sharing may be significantly altered. However, if the impact on demand elasticity is not too strong, a ban on cooperation on product quality investments as well as sharing is welfare improving. Our motivation is 5G investments within mobile telecommunications, where cooperation on investments as well as network sharing is an topical issue.

1 Introduction

Our motivation is from mobile telecommunications where product quality improvements currently takes place through 5G investments. The arena of competition within mobile telecommunications markets has changed remarkably the recent years, from voice to data. This development has significantly increased the importance of network infrastructure quality, while the cost of improving quality increase as higher spectrum bands are deployed. While market players argue that mergers increase product quality

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investment levels. Motta and Tarantino (2017) find no support for such claims as long as there is no significant merger-specific R&D efficiency gains.[1]

An alternative route for the industry is network sharing, where, ideally, one can exploit economies of scale at the upstream network level without sacrificing the intensity of price competition in the downstream market. Competition authorities and sector-specific regulators have taken a more friendly approach towards cooperation with respect to network sharing agreements than complete mergers. We therefore observe a market structure with a semi-collusive regime in several mobile markets.

We show how competing firms' incentives to invest into and to share product quality improvements change if "loyal" consumers benefit more from investments than less loyal consumers. The benchmark is the standard Hotelling duopoly model, where an identical increase in quality improvements by both firms does not affect demand, and all investment incentives erode under complete sharing of product quality improvements. In contrast, we show that if product quality investments increase a firm's market power over the "loyal" consumers more, such that demand becomes more inelastic, firms will invest into product quality improvements even with complete sharing of quality improvements. More specific, we show that under semi-collusion, where firms cooperate on investments and level of sharing, firms choose complete sharing. If firms non-cooperatively decide all variables, the level of sharing crucially depends on how product quality investments affects the demand elasticity. Semi-collusion (weakly) increases sharing and investments.

When comparing the market outcomes, where firms are free to decide on sharing of product improvements, total welfare are higher under semi-collusion compared to no collusion as long as product quality investments make demand more inelastic. However, a ban on both collusion in investments and sharing of product quality improvements increases welfare as long as investments does not increase firms' market power over loyal consumers too much.

In the policy debate on allowing rivals to cooperate on decisions on product quality investments and sharing, the this is rarely given attention. An explanation may be that it is almost impossible for policy makers to make ex ante predictions on how product quality investments affect demand elasticity. Nevertheless, we show that this may have crucial impact on firms' incentives, as well as welfare.

[1] Bourreau et. al. (2018) analyze the impact of mergers on incentives to undertake demand-enhancing investments, and they show that the outcome is ambiguous. See also Bourreau and Jullien (2018) and Jullien and Lefouili (2018).

Similar as Motta and Tarantino (2017), who also analyze investment incentives in mobile markets, we use elements from the strategic R&D literature (the seminal paper by d'Aspremont and Jacquemin, 1988, and subsequent papers). In contrast to us, Motta and Tarantino consider process innovation investments, that typically do not affect elasticity of demand. Waterman (1990) and Anderson, Foros and Kind (2017) allow for that investments make demand more inelastic in a Hotelling framework. Our model may be considered as a generalization of these models, since we allow for "slight" deviations from the standard formulation of Hotelling (1929).

Another feature that makes the Hotelling model appealing, in the case at hand, is that the mobile market is matured when it comes to the number potential customers; everyone has a mobile subscription. When networks upgrade to 5G, the motivation is rarely to increase the total number of consumers, but to increase the willingness to pay from consumers already connected to a mobile network, and steal consumers from the rival.[2]

2 The model

2.1 Some preliminaries

We start out with a generalization of the quality dimension in Hotelling (1929), and we do not allow for sharing of investments until further noticed. First, some standard elements of the Hotelling model. Two firms, $i \neq j \in \{0, 1\}$, compete in the downstream market, and they are are located at opposite ends of the unit Hotelling line (firm 0 at $x_0 = 0$ and firm 1 at $x_1 = 1$). A mass one of consumers is uniformly distributed. The utility derived by a consumer located at point x from buying from firm i decreases with the "distance" $td_i(x)$, where $d_i(x) = |x - x_i|$. The transportation cost, $t > 0$, is assumed to be large enough to ensure that both firms are active in equilibrium.

Each firm may invest k_i. The cost of investing k_i is $C(k_i)$, where C is strictly convex. For the sake of exposition, we assume $C(k_i) = \frac{\sigma k_i^2}{2}$ (with $\sigma > 0$ sufficiently large). Without loss of generality, we assume that $k_i \in [0, 1]$.[3] The (net) utility u_i

[2]The Hotelling model is used in the majority of papers analyzing mobile competition for voice calls; where the interplay between price competition in the downstream market and mobile termination rates has been the main topic (Laffont, Rey, Tirole, 1998a,1998b; and many subsequent papers).

[3]To ensure that $k_i \leq 1$, it is enough to assume that $C'(1)$ is high enough.

derived by a consumer located at x and buying from firm i at price p_i is given by:

$$v + k_i + t\left[\lambda\left(1 - k_i\right) d_i\left(x\right)\right] - t d_i\left(x\right) - p_i, \tag{1}$$

where we assume that v is high enough to ensure market coverage in equilibrium even without investments. The new element is in square bracket; the expected utility from product quality investment, k_i, interacts with the distanced-based disutility. We assume $\lambda \in [0,1]$, where the standard Hotelling setup corresponds to $\lambda = 0$. By contrast, if $\lambda > 0$, consumers who have a strong preference for firm i (i.e., located close to x_i) benefit more from an increase in k_i than consumers located further away from firm i. Hence, λ may be considered as a "loyalty" parameter. As will become clear later, this generalization of the standard Hotelling setup provides firms with generic incentives to share their investments while still competing for consumers.

We introduce the following additional notation and condition, defining $T = \lambda t$, where $T < \frac{4}{5}$. The parameter restriction ensures that second order conditions are satisfied in the investment game. Furthermore, it is sufficient to ensure that even the most distant consumer will find that an investment yields higher utility. Equation (1) may then be rewritten as $u_i\left(x\right) = v + k_i - \left(t - T\left(1 - k_i\right)\right) d_i\left(x\right) - p_i$. Deriving the demand functions (assuming full market coverage) then yields, for any vectors of prices $\mathbf{p} = \left(p_0, p_1\right)$ and qualities $\mathbf{k} = \left(k_0, k_1\right)$:

$$Q_i\left(\mathbf{p}, \mathbf{k}\right) = \frac{1}{2} - \frac{p_i - p_j}{\Omega\left(K\right)} + \frac{\left(2 - T\right)\left(k_i - k_j\right)}{2\Omega\left(K\right)},$$

where $\Omega\left(K\right) \equiv 2\left(t - T\right) + TK$ and $K \equiv k_0 + k_1$. We then have

Proposition 1 *Demand $Q_i\left(\mathbf{p}, K\right)$ becomes more inelastic when $\Omega\left(K\right)$ increases. If $T > 0$, demand becomes more inelastic under an identical increase of k_0 and k_1.*

These effects are crucial for the analysis below. In standard Hotelling ($T = 0$) an identical increase in quality by both firms does not affect demand. Under an identical increase in k_0 and k_1, the incremental quality is canceled out when comparing the demand of the two products. When allowing for $T > 0$, the willingness to pay increases more for closer consumers. An identical increase in investments increases a firm's market power over the "loyal" (captive) consumers, such that demand becomes more inelastic when both k_0 and k_1 increase by the same amount.[4]

2.2 Model set up

Let us now allow firms to share their product quality investments. Denoting by $\theta \in [0,1]$ the degree of sharing of investments, the (net) utility $\hat{u}_i$ derived by a consumer located at x and buying from firm i at price p_i is given by:

$$\hat{u}_i(x) = v + \hat{k}_i - \left(t - T\left(1 - \hat{k}_i\right)\right) d_i(x) - p_i,$$

where $\hat{k}_i = k_i + \theta k_j$. The firms and the consumers all observe θ, k_i and k_j. Deriving the demand functions (assuming full market coverage) then yields, for any θ, $\mathbf{p} = (p_0, p_1)$ and $\mathbf{k} = (k_0, k_1)$:

$$Q_i(\mathbf{p}, \mathbf{k}, \theta) = \frac{1}{2} - \frac{p_i - p_j}{\Omega(K,\theta)} + \frac{(2-T)(1-\theta)(k_i - k_j)}{2\Omega(K,\theta)}$$

where $\Omega(K,\theta) = 2(t-T) + TK(1+\theta)$. As stated in Proposition 1, demand becomes more inelastic when $\Omega(K,\theta)$ increases. In what follows, we look for the subgame perfect Nash-equilibrium of the following sequential game: On stage 1, firms decide on the degree of the two-way sharing $\theta \in [0,1]$. On stage 2, firms set k_i and k_j. On stage 3 firms non-cooperatively set p_i and p_j.

We investigate two alternative decision processes on stage 1 and 2. In the semi-collusion regime (sc), firms jointly decide on θ, k_i and k_j so as to maximize their joint-profit. In the no collusion regime (nc), firm i proposes θ_i on stage 1, and the realized degree of sharing is the lowest of the two values, $\theta = \min[\theta_i, \theta_j]$). On stage 2, firms simultaneous decide k_i and k_j.

2.3 Price Competition (Stage 3)

Taking θ and $\mathbf{k} = (k_i, k_j)$ as given, we now consider the pricing equilibrium. Firm i sets its price p_i so as to maximize its profit $p_i Q_i(\mathbf{p}, \mathbf{k}, \theta)$. By solving the first-order conditions, we find the equilibrium price and operating profit:

$$p_i^e(\mathbf{k},\theta) = \frac{3\Omega(K,\theta) + (2-T)(1-\theta)(k_i - k_j)}{6}, \pi_i^e(\mathbf{k},\theta) = \frac{[p_i^e(\mathbf{k},\theta)]^2}{\Omega(K,\theta)}.$$

[4]Waterman (1990) and Anderson, Foros and Kind (2017) (implicitely) restrict attention to the extreme case where $\lambda = 1$. Our formulation is then a generalization that allow for $\lambda > 0$.

2.4 Semi-collusion (stage 1 and 2)

The joint-profit maximization program writes as:[5]

$$\max_{(\mathbf{k},\theta)} \left(\pi_0^e(\mathbf{k},\theta) + \pi_1^e(\mathbf{k},\theta) - C(k_0) - C(k_1)\right)$$

Investment decision: Rather than choosing k_i and k_j, it turns out to be convenient to let firms choose the total level, K, and the degree of asymmetry $\Delta = k_i - k_j$ with $\Delta \in [-K, K]$. By using the notation $\tau(\theta) = \frac{(2-T)(1-\theta)}{3}$, we have

$$p_i^e(\mathbf{k},\theta) = \frac{\Omega(K,\theta) + \tau\Delta}{2} \quad \text{and} \quad p_j^e(\mathbf{k},\theta) = \frac{\Omega(K,\theta) - \tau\Delta}{2}.$$

The firms' joint-profit maximization program can thus be rewritten:

$$\max_{(K,\Delta,\theta)} \Pi(K,\Delta,\theta) = \frac{\Omega(K,\theta)}{2} + \frac{\tau(\theta)^2\Delta^2}{2\Omega(K,\theta)} - C\left(\frac{K+\Delta}{2}\right) - C\left(\frac{K-\Delta}{2}\right).$$

Generating asymmetry between the two firms has conflicting effects on joint-profits. On the one hand, it increases total revenue by generating some price discrimination effect. On the other hand, it increase investment costs. Under a relatively mild condition, we can guarantee that Π is a strictly concave function of Δ. We have indeed:

$$\frac{\partial^2\Pi}{\partial\Delta^2} = \frac{\tau(\theta)^2}{\Omega(K,\theta)} - 2\sigma.$$

Therefore, if the cost function is sufficiently convex, the profit function is concave in Δ. We can easily check that it is then optimal for the firms to minimize the cost and firms are symmetric with respect to investments. We have:

$$\frac{\partial\Pi}{\partial\Delta} = \frac{\tau(\theta)^2\Delta}{\Omega(K,\theta)} - \frac{1}{2}C\left(\frac{K+\Delta}{2}\right) + \frac{1}{2}C\left(\frac{K-\Delta}{2}\right),$$

and this partial derivative is thus equal to 0 for $\Delta = 0$. The firms' joint-profit function

[5] We assume that the firms operate two "plants" also in the semi-collusion regime; the aggregate cost function is given by $C(k_0) + C(k_1)$. This is analogous to the conventional assumption made in the strategic R&D literature (d'Aspremont and Jacquemin, 1988). This approach is also used by Motta and Tarantino (2017).

then simplifies to:

$$\Pi\left(K,\theta\right)=\Pi\left(K,0,\theta\right)=\frac{\Omega\left(K,\theta\right)}{2}-2C\left(\frac{K}{2}\right).$$

Given that Ω is linear and strictly increasing in K, Π is strictly concave in K and, given the sharing decision, θ, the optimal total level of investment is:

$$\frac{\partial\Pi\left(K,\theta\right)}{\partial K}=0\Leftrightarrow K\left(\theta\right)=\frac{T\left(1+\theta\right)}{\sigma}.$$

Each firm's investment level is then given by:

$$k^{sc}(\theta)=\frac{K\left(\theta\right)}{2}=\frac{T\left(1+\theta\right)}{2\sigma} \tag{2}$$

The optimal level of investment is thus an increasing function of sharing (θ).

Sharing decision: Given the optimal investment level, we can rewrite joint-profit as a function of the sharing decision only:

$$\Pi\left(K\left(\theta\right),\theta\right)=t-T+\frac{T^2\left(1+\theta\right)^2}{4\sigma} \tag{3}$$

From (2) and (3) we then have:

Proposition 2 *Semi-collusion: Firms fully share their investments, $\theta^{sc}=1$, and each firm's level of investment is $k^{sc}(1)=\frac{T}{\sigma}$.*

2.5 No collusion (stage 1 and 2)

Investment decision: Let θ be the selected level of sharing, that is $\theta=\min\left[\theta_0,\theta_1\right]$. We first look at investment decisions for a given level of sharing (θ). Firm i thus chooses k_i so as to maximize its own profit:

$$\max_{k_i}\left(\frac{\left[p_i^e\left(\mathbf{k},\theta\right)\right]^2}{\Omega\left(K,\theta\right)}-C\left(k_i\right)\right).$$

Because $p_i^e\left(\mathbf{k},\theta\right)$ and $\Omega\left(K,\theta\right)$ are both linear functions of k_i, nothing guarantees that the profit function is strictly concave in k_i. However, this is always the case under a mild condition on σ when $T=0$. In this case, Ω does not depend on investment levels and the profit function is thus quadratic in k_i. To guarantee that it is strictly concave, we thus only need to have:

$$\sigma > \frac{2}{\Omega\left(K,\theta\right)}\left(\frac{\partial p_i^e}{\partial k_i}\right)^2 \Leftrightarrow \sigma > \frac{\left(1-\theta\right)^2}{9t}.$$

A sufficient condition is thus to have $\sigma > \frac{1}{9t}$. As long as T is not too large and the cost function is sufficiently convex, the profit function will still be strictly concave in k_i and the optimal solution is given by the first-order condition. We can then show that the investment subgame has a unique symmetric equilibrium:

$$k_i = k_j = k^{nc}\left(\theta\right) = \frac{4+T-\left(4-5T\right)\theta}{12\sigma}. \quad (4)$$

Contrary to the semi-collusion regime, optimal levels of (individual) investments are now decreasing functions of the extent of sharing. Investments have two effects on price competition. On the one hand, it increases expected quality and thus allows the firm to charge a higher price. This effect is moreover exacerbated by sharing. On the other hand, it either increases the quality advantage relative to the rival firm, or reduces the quality disadvantage, and thus relaxes the competitive pressure on the investing firm. However, this effect is eliminated when investments are fully shared. Therefore, increasing the extent of sharing reduces the incentives to invest. In a sense, when firms fully share their investments, firms only care about the total level of investments (quality differences are eliminated through sharing) and thus have no longer additional incentives to increase their relative quality.

Sharing decision: Given that firms are then symmetric, the pricing equilibrium is also symmetric and we have

$$p_i^e = p_j^e = \frac{\Omega\left(K,\theta\right)}{2} \quad \Longrightarrow \quad \pi_i^e\left(K,\theta\right) = \frac{\Omega\left(K,\theta\right)}{4}.$$

The firm's individual profit function, $\Pi_i\left(\theta_i,\theta_j\right) = \pi_i^e\left(k\left(\theta\right),\theta\right) - C\left(k\left(\theta\right)\right)$, where $\theta = \min\left[\theta_0,\theta_1\right]$, is thus a quadratic function of θ and we have:

$$\Pi_i\left(\theta_i,\theta_j\right) = \Pi\left(\theta\right) \equiv \frac{1}{2}\left[t - T + T\left(1+\theta\right)k\left(\theta\right) - \sigma k\left(\theta\right)^2\right]. \quad (5)$$

For a given choice θ_j made by its rival, firm i actually selects θ rather than necessarily choosing a precise value for θ_i. Let θ^{nc} be the value of θ that firms would like to select, the value that maximizes $\Pi(\theta)$. Since $k(\theta)$ is a linear and decreasing function of θ, the profit $\Pi(\theta)$ is a strictly concave function of θ. This guarantees that there is a unique $\theta^{nc} \in [0,1]$. This implies that firm i's best-response to θ_j is given by:

$$\Theta_i(\theta_j) = \theta^{nc} \text{ if } \theta_j > \theta^{nc} \quad \text{and} \quad \Theta_i(\theta_j) \geq \theta_j \text{ if } \theta_j \leq \theta^{nc}.$$

Because of coordination failure, this game has multiple equilibria and any $\theta \leq \theta^{nc}$ can be sustained in equilibrium. However, only one equilibrium is trembling-hand perfect: suppose that there is an infinitesimal probability that firm j selects (by mistake) a value above θ^{nc} (for instance $\theta = 1$). In this case, firm i is no longer indifferent between all values above θ_j but strictly prefers θ^{nc} to all other values of θ. This thus guarantees uniqueness of the trembling-hand equilibrium (θ^{nc} is then a dominant strategy). This also means, that in the trembling-hand equilibrium, when firms independently select investment levels, the outcome is identical whether or not they coordinate on sharing. We show the following:

Proposition 3 *When firms decide non-cooperatively on the degree of sharing and on investments, there exists a trembling-hand perfect equilibrium where* $\theta^{nc} = \min\left\{1, \hat{\theta}\right\}$.

- *If* $T = 0$ *or* $T \in [\frac{4}{11}, \frac{4}{5})$, *firms fully share their investments,* $\theta^{nc} = 1$, *and invest* $k^{nc} = \frac{T}{2\sigma}$.
- *If* $T \in (0, \frac{4}{11})$, *firms partially share their investments and we have:*

$$\theta^{nc} = \hat{\theta} = \frac{16(1-T) + 31T^2}{(7T+4)(4-5T)} \quad \text{and} \quad k^{nc} = \frac{4 + T - (4-5T)\hat{\theta}}{12\sigma} = \frac{24T(2-T)}{12\sigma(4+7T)} \tag{6}$$

Proof. Replacing $k(\theta)$ in (5) by its value from (4) and solving for the unconstrained maximum of $\Pi(\theta)$ yields $\theta = \hat{\theta}$. It follows from (6) that $\hat{\theta}(T) > 0$ for $T \in [0, \frac{4}{5})$. Furthermore, $\hat{\theta} = 1$ for $T = 0$, $\hat{\theta} < 1$ for $0 < T < \frac{4}{11}$, and $\hat{\theta} \geq 1$ for $\frac{4}{11} \leq T < \frac{4}{5}$.We thus have $\theta^{nc} = \min\left\{1, \hat{\theta}\right\}$. ■

From above we have that for a given θ, $k^{sc}(\theta) \geq k^{nc}(\theta)$. As long as the part (i) in Proposition 3 holds, such that $\theta^{sc} = \theta^{nc} = 1$, we have $k^{sc}(1) = 2k^{nc}(1)$. If $T \in (0, \frac{4}{5})$, part (ii) of Proposition 3, we find $k^{sc}(1) - k^{nc}(\hat{\theta}) = 9\frac{T^2}{\sigma(7T+4)} > 0$. Consequently, we have the following corollary from Proposition 2 and Proposition 3:

Corollary 1 *Each network invests more into product quality with than without semi-collusion.*

3 Welfare

Given that the equilibrium is symmetric, total welfare writes as $W(\theta, k) = v + \widehat{k} - \frac{t-T(1-\widehat{k})}{4} - \sigma k^2$, where $\widehat{k} = k(1+\theta)$. When comparing the market outcomes in the two regimes we have:

Proposition 4 *Total welfare is higher under semi-collusion compared to no collusion as long as $T > 0$.*

Proof. $W(1, k^{sc}(1)) - W(1, k^{nc}(1)) = 2T\frac{1-T}{\sigma} > 0$ if $T \in [\frac{4}{11}, \frac{4}{5})$ and $W(1, k^{sc}(1)) - W\left(\hat{\theta}, k^{nc}(\hat{\theta})\right) = 9T^2\frac{16+8T-17T^2}{\sigma(7T+4)^2} > 0$ if $T \in (0, \frac{4}{11})$. ■

Let us finally consider a ban on sharing. In principle we may have four different regimes; semi-collusion (sharing allowed, sharing banned) and no collusion (sharing allowed, sharing banned). Above we considered the two regimes where sharing is allowed. In practice, semi-collusion with a ban on sharing has limited interest. Therefore, let us concentrate on a ban on sharing under the no collusion regime. Hence, we assume that the regulatory option is to set a ban $\theta^{ban} = 0$. We then show that:

Proposition 5 *Welfare is higher with no collusion and $\theta^{ban} = 0$ compared to semi-collusion and $\theta^{sc} = 1$ if $T \leq \overline{T}(\approx 0.12)$.*

Proof. $W(0, k^{nc}(0)) - W(1, k^{sc}(1)) = \frac{1}{36\sigma}(8 - 74T + 53T^2) \geq 0$ if $T \leq \overline{T} = \frac{37}{53} - \frac{3}{53}\sqrt{3}\sqrt{35} \approx 0.12$ ■

4 Concluding remarks

The effect of allowing competing firms to cooperate on product quality investments and sharing crucially depends on how such investments affect consumers' willingness to pay. If investments lead to an identical increase in all consumers' willingness to pay, or just slightly makes demand more inelastic, we show that a ban towards both cooperative investments and sharing is welfare improving compared to semi-collusion. In the latter case, firms may cooperate on investments as well as the degree of sharing of investments. For semi-collusion to be welfare improving, investments need to make demand significantly more inelastic.

For policymakers it is (almost) impossible to predict how investments will change demand elasticity. Nevertheless, this may be crucial for firms' incentive with respect to undertake investments and to share their investments, as well as welfare implications. Furthermore, there is concern from authorities that semi-collusion at the upstream level may be transferred into the downstream market, such that the outcome resembles a complete merger. We do not analyze the latter case.

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