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ABSTRACT

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Using a general two-stage framework, this paper gives sufficient conditions for increasing competition to have negative or positive effects on R&D-investment, respectively. Both possibilities arise in plausible situations, even if one uses relatively narrow definitions of increasing competition. The paper also shows that competition is more likely to increase the investments of leaders than those of laggards. When R&D-spillovers are strong, competition is less likely to increase investments. The paper also identifies conditions under which low initial levels of competition make a positive effects of competition on investment more likely. Extending the basic framework, the paper shows that separation of ownership and control, endogenous entry and cumulative investments make positive effects of competition on investment more likely. Imperfect upstream competition weakens the effects of competition on investment.

JEL Classification: L13, L20 and L22
Keywords: competition, cost reduction and investment

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1 Introduction

Even though economists have been trying to understand the effects of the intensity of competition on R&D-investment for decades, the issue remains unsettled. While some authors argue that competitive pressure is essential to induce R&D-investments, others emphasize the Schumpeterian idea that some monopoly power is necessary for innovation. The theoretical analysis of the subject has been inconclusive. Depending on the definition of "competitive intensity" and the underlying oligopoly framework, investments can be increasing or decreasing functions of competition.[1]

Understanding the driving forces behind these different predictions is difficult, because the models differ with respect to small details. I will therefore provide a general framework that allows searching for robust predictions, because it captures several notions of increasing intensity of competition and different types of oligopolies. To reveal the intuition in the most transparent fashion, I opted for simplicity in other respects: The most basic version of the game has two stages, with cost-reducing investment followed by product market competition. This is not entirely innocuous, because it rules out situations where the investments are not observable by competitors and therefore have no strategic effect in the product market.

I will mostly consider duopolies.[2] One firm (the *leader*) may be exogenously more efficient than the other one (the *laggard*), that is, it has lower marginal costs. The initial efficiency levels and the cost-reducing investments determine the efficiency Y_i in the product market stage. Together with a competition parameter θ, the efficiency levels determine the output $Q^i(Y_i, Y_j; \theta)$ and the profit margin $M^i(Y_i, Y_j; \theta)$ of each firm in the second-stage product market equilibrium, and hence the profit $\Pi^i = Q^i \cdot M^i$ (gross of investment costs). By assumption, and in line with many examples, higher own efficiency increases both components of a firm's profit: Lower marginal costs lead to higher outputs and profit margins.

[1] For elementary models on this topic, see Motta (2004, ch.2); Vives (2008) provides a more sophisticated analysis. Similar issues are discussed in a macroeconomic context (Aghion et. al. 1997, 2001)

[2] Generalizations of most results to more than two firms are possible at the cost of additional notation.

The framework covers many familiar cases. In particular, the competition parameter can be interpreted quite broadly. It does not necessarily refer to a competition *policy* parameter, but more generally to some parameter of the market environment capturing the intensity of competition. The framework applies to a Hotelling model where θ is the inverse of transportation costs; differentiated linear Cournot or Bertrand models where θ corresponds inversely to the extent of horizontal product differentiation, as captured for instance by the demand functions of Shubik and Levitan (1980) or Singh and Vives (1984). θ may also capture a shift from Cournot to Bertrand competition or an increase in the number of firms for an otherwise given environment. The parameter shift can also be interpreted as a change in cartel policy or intellectual property rights protection (see Schmutzler 2009).

Our defining assumptions on the competition parameter θ are inspired by two common properties of these examples (and many others). First, the profit margin M^i of each firm in the product market equilibrium decreases with θ; competition thus has a negative *margin effect*.[3] Second, the *output sensitivity effect* is non-negative: The positive effect of greater efficiency on equilibrium output ($Q_i^i \equiv \frac{\partial Q^i}{\partial Y_i}$) weakly increases with competition θ.

I give sufficient conditions for the effects of competition on investment to be positive or negative. Both possibilities arise naturally. Thus, searching for a general relation between competition and investment is in vain. I also provide conditions under which competition increases the investments of some firms (e.g., leaders) and decreases those of others (e.g., laggards).

The conditions derived help to uncover the circumstances under which competition is more likely to have a positive or negative effect on a firm's investment. Several testable predictions emerge from the basic model. First, competition is more likely to have a positive effect on the investments of leaders than on those of laggards, and the effect on strong laggards is robustly negative.[4] Second, when investments have higher spillovers, increasing com-

[3] Boone (2008) provides a reasonable example where this property of a competition parameter is *not* satisfied. The ideas of the following analysis could still be applied, but at the cost of having to distinguish more cases.

[4] This is related to, but not identical, to the concept of weak increasing dominance, which requires that leaders invest more than laggards (Cabral and Riordan 1994, Athey and Schmutzler 2001, Cabral 2002, 2008): I am arguing that increasing competition works

petition is more likely to reduce investments. Third, an inverse U-shaped relation between competition and investment is not necessarily more likely than a U-shaped relation.

The basic model is closely related to Vives (2008) who arrives at the more definite conclusion that competition quite generally has positive effects on investment. Several reasons explain these different findings. First, Vives does not consider initial asymmetries, so that the robust negative effect of competition on laggards does not show up. Second, Vives confines himself to product differentiation parameters.[5]

The basic model uses the following assumptions:

(i) There is no separation of ownership and control;

(ii) Investment decisions are one-shot;

(iii) The number of firms is exogenously fixed;

(iv) Firms provide R&D-inputs inhouse or from a competitive market.

Relaxing each of these restrictions has a clear-cut effect on the relation between competition and investment. The effects of competition on investment tend to be more positive with separation of ownership and control, with cumulative investments and with endogenously determined entry decisions. When firms buy R&D inputs from an upstream market, the effects of competition and investment tend to be reduced in absolute values, no matter whether they are positive or negative. I will also sketch how the approach can help to understand the effects of downstream competition on the innovation incentives of a vertically integrated upstream monopolist who supplies downstream competitors and his own downstream subsidiary.

Section 2 introduces the basic model. Section 3 provides comparative statics results. Section 4 applies these results to familiar examples. Section

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in favor of increasing dominance.

[5] Also, even when increasing competition refers to lower product differentiation, there is at least one example not considered by Vives where increasing competition has a negative effect on investment in non-degenerate parameter regions even for symmetric firms (see Sacco and Schmutzler 2010).

5 uses the general results and the examples to clarify under which circumstances a positive effect of competition is likely in the basic model. Section 6 moves beyond the basic model. Section 7 concludes.

2 Set-up

I shall consider the following class of two-stage games. In period 1, firms $i = 1, 2$ can carry out a cost-reducing investment. In period 2, they engage in product-market competition. Initially, firm i has constant marginal cost $c_i = \overline{c} - Y_i^0$ for some exogenous reference level $\overline{c}$ of marginal costs.[6] In the first stage, given (Y_1^0, Y_2^0), each firm chooses its investment y_i. In the second stage, firm i has marginal costs $c_i = \overline{c} - Y_i$, where $Y_i = Y_i^0 + y_i + \lambda y_j$ is the efficiency level after the investment stage and $\lambda \in [0, 1]$ is a spillover parameter. We introduce a parameter θ from some partially ordered set to capture the intensity of competition; the defining properties of which will be introduced below. The product-market game is assumed to have a unique Nash equilibrium for arbitrary θ and $\mathbf{Y} = (Y_1, Y_2)$, corresponding to prices $p^i (Y_i, Y_j; \theta)$.[7] The demand function for firm i is $q^i (p^i, p^j; \theta)$, where p^i and p^j are the prices of firm i and firm j, respectively. We allow for the case where competition does not enter demand directly, so that q^i is only a function of p^i and p^j. This will be reasonable when θ reflects stricter competition policy or a shift from Cournot to Bertrand competition, but not when θ stands for an increase in the degree of substitutability between goods.

The following notation will be used:

1. Equilibrium profit margins $M^i (Y_i, Y_j; \theta) \equiv p^i (Y_i, Y_j; \theta) - \overline{c} + Y_i$
2. Equilibrium outputs $Q^i (Y_i, Y_j; \theta) \equiv q^i (p^i (Y_i, Y_j; \theta), p^j (Y_i, Y_j; \theta); \theta)$
3. Gross equilibrium profits $\Pi^i (Y_i, Y_j; \theta) = M^i (Y_i, Y_j; \theta) \cdot Q^i (Y_i, Y_j; \theta)$

[6] The choice of $\overline{c}$ is arbitrary; to simplify calculations, I usually choose $\overline{c} = 0$ or $\overline{c} = a$, where a is the maximal willingness to pay for any unit of the good.

[7] For price competition, $p_i (Y_i, Y_j; \theta)$ is the equilibrium price; for quantity competition, it denotes the market clearing price for equilibrium outputs.

I will maintain the following assumptions throughout, all of which hold in the examples to be discussed in Section 3 below.

(A1) $q^i(p^i, p^j; \theta)$ is weakly decreasing in p^i and weakly increasing in p^j, $j \neq i$.

Thus, the firms produce (potentially imperfect) substitutes.

(A2) $p^i(Y_i, Y_j; \theta)$ is weakly decreasing in Y_i and Y_j, $j \neq i$.

(A2) holds in most oligopoly models. Because the product market game has a unique equilibrium, the investment game reduces to a one stage game with payoff functions

$$\pi^i(y_i, y_j; \theta) = \Pi^i\left(Y_i^0 + y_i + \lambda y_j, Y_j^0 + y_j + \lambda y_i; \theta\right) - K(y_i). \tag{1}$$

(A3) $Q^i(Y_i, Y_j; \theta)$ is weakly increasing in Y_i and weakly decreasing in Y_j, $j \neq i$.

This assumption is related to (A1) and (A2). To see this, define

$$\begin{aligned}
\eta^o &\equiv \frac{\partial q^i}{\partial p^i}\left(p^i(Y_i, Y_j; \theta), p^j(Y_i, Y_j; \theta)\right) \cdot \frac{\partial p^i}{\partial Y_i}(Y_i, Y_j; \theta); \\
\eta^c &\equiv \frac{\partial q^i}{\partial p^j}\left(p^i(Y_i, Y_j; \theta), p^j(Y_i, Y_j; \theta)\right) \cdot \frac{\partial p^j}{\partial Y_i}(Y_i, Y_j; \theta).
\end{aligned}$$

η^o reflects the *own-price effect* of efficiency on output: By (A2), lower costs of firm i reduce its equilibrium price p^i which, by (A1) works towards higher equilibrium output Q^i. η^c reflects the *competitor-price effect*: As c_i falls, the competitor's price falls by (A2), which reduces firm i's output Q^i. As $Q_i^i \equiv \frac{\partial Q^i}{\partial Y_i} = \eta^o + \eta^c$, (A3) says that the own price effect dominates over the competitor price effect. Indeed, this is true in all our examples. The next assumption is slightly more problematic.

(A4) $M^i(Y_i, Y_j; \theta)$ is weakly increasing in Y_i and weakly decreasing in Y_j, $j \neq i$.

As $M^i(Y_i, Y_j; \theta) = p^i(Y_i, Y_j; \theta) - \overline{c} + Y_i$ and $\frac{\partial M^i}{\partial Y_i} = \frac{\partial p^i}{\partial Y_i} + 1$, the first part of the assumption states that the cost reductions are larger than the induced price reductions. This holds in many, but not all, oligopoly models.[8] Finally, I introduce two defining properties of the competition parameter.

(C1) $M^i(Y_i, Y_j; \theta)$ is weakly decreasing in θ.

The notion that competition reduces margins (and prices) is standard. The relation between θ and output is less clear. To see why, assume that M^i and Q^i are differentiable in the competition parameter.[9] Then

$$\frac{dQ^i}{d\theta} = \frac{\partial q^i}{\partial p^i}\frac{\partial p^i}{\partial \theta} + \frac{\partial q^i}{\partial p^j}\frac{\partial p^j}{\partial \theta} + \frac{\partial q^i}{\partial \theta}. \tag{2}$$

If the own price effect dominates over the competitor price effect, the sum of the first two terms are positive. However, the direct effect $q^i_\theta \equiv \frac{\partial q^i}{\partial \theta}$ can be negative, potentially compensating the price-induced effects. Thus, equilibrium output may rise or fall as competition increases. Moreover, as we will see below, competition may have differential impacts on the output of leaders and laggards.

The second defining assumption of competition is as follows:

(C2) $Q^i_{i\theta} \geqslant 0$.

To understand (C2), consider the effects of competition on $Q^i_i \equiv (\eta^o + \eta^c)$. Intuitively, $|\eta^c|$, the output effect of higher own efficiency resulting from the induced lower competitor prices, is small for soft competition. Indeed, the examples below confirm this. However, η^o is more likely to increase in θ: Part of the effect of higher efficiency on own output that is induced by lower own prices comes from a business-stealing effect that is absent with weak competition. In all examples where a change in θ refers to an increase in the intensity of competition for a given number of firms, the own price effect dominates over the competitor price effect.

Definition 1 *θ is a* ***competition parameter*** *if (C1) and (C2) hold.*

[8] For instance, it does not hold globally in a Cournot duopoly with demand generated from CES utility functions.

[9] We shall maintain this assumption in the rest of the paper, even though nothing of substance depends on it.

We shall illustrate the definition with specific examples in Section 4.

For some results, it is useful to invoke additional properties.

(C3) $\frac{\partial \Pi^i}{\partial Y_j}$ is weakly decreasing in θ.

Thus, as competition increases, the adverse effect of a more efficient competitor on own profits implied by (A3) and (A4) becomes larger in absolute value. This is plausible at least when one moves from no competition to some competition.[10]

(C4) $\frac{\partial y_i}{\partial y_j}$ is weakly decreasing in θ.

To understand this property, note that, in a large class of investment games without strong spillovers, actions are strategic substitutes (see Bagwell and Staiger 1994, Athey and Schmutzler 2001). To understand why, note that

$$\Pi^i_{ij} = Q^i_i \cdot M^i_j + M^i_i \cdot Q^i_j + M^i \cdot Q^i_{ij} + Q^i \cdot M^i_{ij}.$$

In linear examples, the last two terms disappear. The first two terms are typically negative because of (A3): If competitors invest a lot, own margins and outputs fall. This reduces the benefits from increasing own outputs and markups by becoming more efficient. (C4) thus corresponds to the following intuitive notion: If (plausibly) the negative effect of the competitor's investments on own output and margin is more pronounced when competition is intense, then the reason to reduce own investments as a response becomes more pronounced.

Finally, most standard notions of competition have the effect that they reduce gross profits:

(C5) Π^i is weakly decreasing in θ.

(C3)-(C5) will be invoked when we move beyond the basic model.

[10]See the cautionary remarks in Section 5.2, however.

3 General comparative statics results

I will now provide some general results that are well-known from other contexts. (A1)-(A4) and (C1)-(C5) are not necessary to derive the results. I will suppose for simplicity that investments are chosen from some compact subset of the reals, and $\Pi^i (Y_i, Y_j; \theta)$ and $\pi^i (y_i, y_j; \theta)$ are twice continuously differentiable, even though much of the following easily generalizes to discrete choice sets and more general objective functions. Also, I assume existence and uniqueness of the equilibrium in the investment game. The following result shows that the properties of $\pi^i_{i\theta} \equiv \frac{\partial^2 \pi^i}{\partial y_i \partial \theta}$ are essential for comparative statics. When $\pi^i_{i\theta} > 0$, θ shifts out player i's reaction curve.[11] This does not guarantee that competition increases player i's investment, but there are several sets of additional conditions that lead to this outcome.

Proposition 1 *$y_i(\theta)$ is weakly increasing in θ for $i = 1, 2$ if, for $i = 1, 2$ and $j \neq i$, one of the following conditions (i)-(iii) holds:*
(i) $\pi^i_{i\theta} \geq 0$ and $\pi^i_{ij} \equiv \frac{\partial^2 \pi^i}{\partial y_i \partial y_j} \geq 0$.
(ii) $\pi^i_{i\theta} \geq 0$, $\pi^i (y_i, y_j; \theta)$ is symmetric and concave in y_i; $y_i(\theta) = y_j(\theta)$ for all θ considered, and the Hahn stability condition $\pi^i_{ii} \pi^j_{jj} \geq \pi^i_{ij} \pi^j_{ji}$ holds.
(iii) $\pi^i (y_i, y_j; \theta)$ is concave in y_i. Near the equilibrium, $\pi^i_{i\theta} \geq \frac{\pi^i_{ij}}{\pi^j_{jj}} \pi^j_{j\theta}$, and the Hahn-stability condition holds.

Proof. See Appendix 1. ■

By switching the signs in $\pi^i_{i\theta} \geq 0$ and $\pi^i_{i\theta} \geq \frac{\pi^i_{ij}}{\pi^j_{jj}} \pi^j_{j\theta}$ in (i) - (iii), one arrives at sufficient conditions for *negative* effects of competition on investment. Also, without spillovers ($\lambda = 0$), $\pi^i_{i\theta} = \Pi^i_{i\theta} \equiv \frac{\partial^2 \Pi^i}{\partial Y_i \partial \theta}$, whereas, with positive spillovers $\pi^i_{i\theta} = \Pi^i_{i\theta} + \lambda \Pi^i_{j\theta}$. Either way, the conditions of the theorem reflect properties of the gross profit function Π^i that are independent of the precise form of the investment cost functions, because, by assumption, these functions do not depend on θ.[12]

To understand (i), consider Figure 1. $\theta = L$ (H) refers to the situation

[11] This follows from a well-known comparative statics result of Topkis (1978) for the maximizer of a supermodular function, as positivity of the relevant mixed partials for differentiable functions guarantees supermodularity.

[12] In Section 6.2 I will give reasons why costs may sometimes depend on competition, and I will discuss the implications.

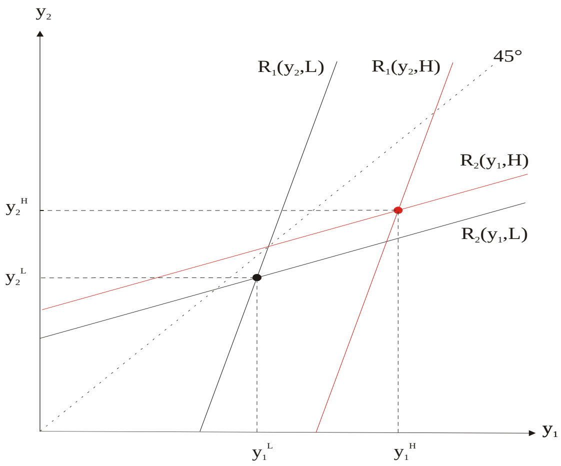

Figure 1: Strategic Complements

before (after) a parameter increase. Because $\pi^i_{i\theta} \geq 0$, reaction functions shift out as θ increases. The supermodularity condition in (i), $\pi^i_{ij} = \Pi^i_{ij} \geq 0$, implies increasing reaction functions, so that the indirect effects of competition reinforce the direct effects. Thus, competition increases both players' investments.

However, as argued at the end of Section 2, unless spillovers are sufficiently large, investments are typically strategic substitutes, so that the direct and indirect effects have opposite signs. Even then, part (ii) shows that, if $\pi^i_{i\theta} \geq 0$ for both firms (so that both reaction functions are shifted outwards) competition increases both players' investments if the functions π^i are symmetric (see Figure 2).

The case of asymmetric firms is more complex with strategic substitutes. Figure 3 shows that it is possible that only one firm increases its investments, even though both reaction functions are shifted outwards as competition increases. The intuition is straightforward. If the shift is more pronounced for firm 1 than for firm 2, and the reaction function of firm 2 is sufficiently steep, then the direct positive effect of competition on investment for firm 2 (outward shift of own reaction functions) is outweighed by the negative effect that firm 1 increases investments, to which firm 2 reacts by reducing investments. However, even in the asymmetric case with strategic substitutes, an

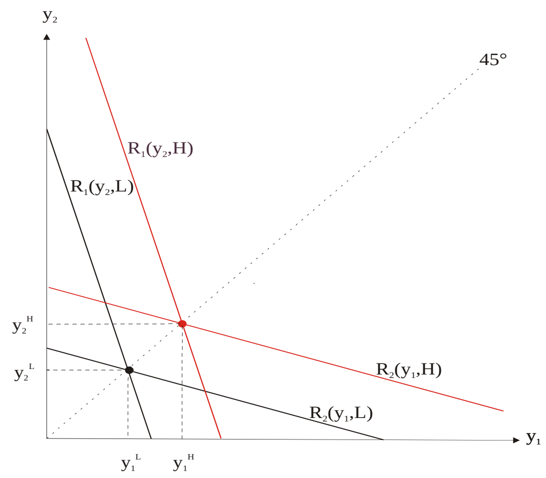

Figure 2: Strategic Substitutes (Symmetric Case)

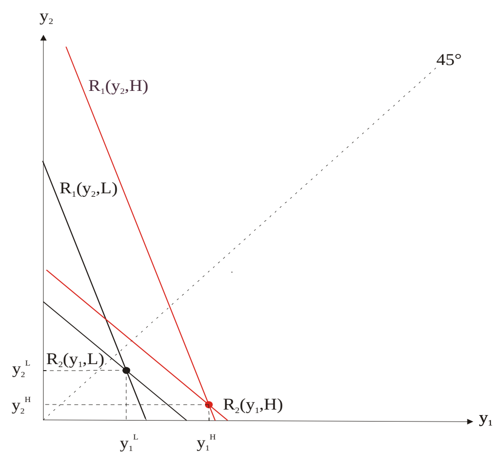

Figure 3: Strategic Substitutes: Counterexample

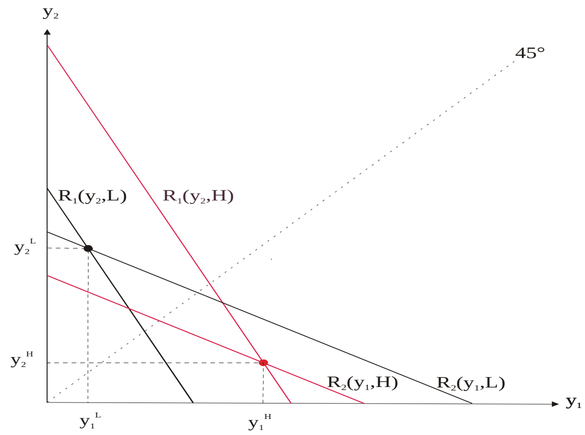

Figure 4: Asymmetric Effects on Investment Incentives

outward shift of both reaction functions guarantees a positive effect on both equilibrium investments as long as reactions to changes in the other player's investment are not too strong. This requirement is captured by the condition in (iii): $\frac{\pi^1_{12}}{\pi^2_{22}}$ is the slope of the reaction function of firm 2.

The next proposition is useful to identify situations where competition increases the investments of one firm and decreases those of the other one, which happens when one firm is the leader and the other firm is the laggard.

Proposition 2 *Suppose for some $i \in \{1,2\}$ and $j \neq i$, the following conditions hold: (a) $\pi^i_{i\theta} \geq 0$; (b) $\pi^j_{j\theta} \leq 0$; (c) $\pi^i_{ij} \leq 0$ and (d) $\pi^j_{ji} \leq 0$. Then y_i is weakly increasing in θ and y_j is weakly decreasing.*

Proof. Conditions (a)-(d) imply $\pi^i_{i\theta} \geq 0$; $\pi^j_{j\theta} \leq 0$; $\pi^i_{ij} \leq 0$ and $\pi^j_{ji} \leq 0$. The result therefore follows from Theorem 5 in Milgrom and Roberts (1990) by reversing the order on the strategy space of one firm. ■

The intuition is captured in Figure 4: By (a) and (b), θ shifts out firm i's reaction curve and shifts firm j's reaction curve inwards. By (c) and (d), these direct effects are mutually reinforcing: As both reaction functions are decreasing, an increase of firm i's investment reduces firm j's investment incentives and vice versa.

As $\Pi^i = Q^i \cdot M^i$, Proposition 1 implies the following loosely stated result:

Corollary 1 *Suppose for $i = 1, ..., I$,*

$$\Pi^i_{i\theta} = Q^i_i \cdot M^i_\theta + M^i_i \cdot Q^i_\theta + Q^i \cdot M^i_{i\theta} + M^i \cdot Q^i_{i\theta} \tag{3}$$

is sufficiently large (small). Then $y_i(\theta)$ is weakly increasing (weakly decreasing) in θ for $i = 1, ..., I$.

Here, "sufficiently large" reduces to "positive" for symmetric firms and for games with strategic complementarities (Parts (i) and (ii)). For other games, "sufficiently large" means that expression (3) must be greater than $\frac{\pi^i_{ij}}{\pi^j_{jj}}\pi^j_{j\theta}$, which is positive (Part (iii)).

Expression (3) captures the total effect of competition on investment incentives, $\Pi^i_{i\theta}$. Each of the four terms corresponds to one intuitive transmission channel by which competition affects investment incentives. The first term in (3), $Q^i_i \cdot M^i_\theta$, is the *margin effect* of competition: By (A3), investment has a positive effect on output ($Q^i_i > 0$). By (C1), M^i_θ is negative. As competition increases, margins decrease, so that the positive effect of expanding output on profits becomes smaller. The second term, $M^i_i \cdot Q^i_\theta$, is the *output effect* of competition: By (C1), investment increases margins, M^i_i. If $Q^i_\theta > 0$ the output effect of competition on marginal investment incentives is positive; if $Q^i_\theta < 0$, it is negative. The third term, $Q^i \cdot M^i_{i\theta}$, is the *cost-pass-through effect* of competition. Because $M^i_{i\theta} = p^i_{i\theta}$, the sign of the cost-pass-through effect is positive if and only if $p^i_{i\theta} \equiv \frac{\partial}{\partial\theta}\left(\frac{\partial p^i}{\partial Y_i}\right) \geq 0$, that is, competition reduces the sensitivity of equilibrium prices to costs. The examples below will show that the cost-pass-through effect is ambiguous.[13] The fourth term, $M^i \cdot Q^i_{i\theta}$, the *output-sensitivity effect* of competition, is positive under (C2): As θ increases, output reacts more strongly to efficiency, which enhances the incentive to invest.

Summing up, the analysis in this section shows why more intense competition does not have clear-cut effects on investment. The effect of competition on investment incentives, $\Pi^i_{i\theta}$, consists of the four transmission channels just discussed. The margin effect is negative, whereas the output-sensitivity ef-

[13] For instance, when competition corresponds to increasing substitutability, the sign depends on whether firms compete à la Bertrand or à la Cournot.

fect is positive. The output effect and the cost-pass-through effect can be positive or negative.

4 Examples

The following examples show how (3) helps to understand under which circumstances competition has positive effects on investments. Whenever I calculate equilibrium investment levels explicitly, the investment cost function is $K(y_i) = y_i^2$; however, the comparative statics also hold for more general cost functions.

4.1 Substitutability (Shubik-Levitan)

In a market with differentiated goods, let inverse demands be

$$p^i(q_i, q_j) = 1 - q_i - bq_j, \tag{4}$$

where $0 \leq b \leq 1$ (Shubik and Levitan 1980). The corresponding demand functions $q^i(p^i, p^j)$ satisfy $\frac{\partial q^i}{\partial p^j} > 0$ for $b > 0$; thus the goods are substitutes. For $b = 0$, firms are monopolists; $b = 1$ corresponds to homogeneous goods. Higher b corresponds to better substitutability. Thus, define $\theta = b$.

The middle line in Figure 5 plots investments as a function of θ for $c_1^0 = c_2^0 = 0.5$, assuming $\theta \in [0, 1)$. Investments decrease with competition for symmetric firms and laggards, but for the leader they increase as competition becomes very intense.

Competition has a strictly negative effect except for strong leaders, for whom the relation is U-shaped. The result reflects countervailing underlying effects. To see this, note that that $Q_i^i > 0$; $M_i^i > 0$; $M_\theta^i < 0$; $Q_{i\theta}^i > 0$; $M_{i\theta}^i < 0$. Further, under symmetry $Q_\theta^i > 0$ if $\theta > 0.5$ (see Appendix 2). Thus, while the margin effect and the cost-pass-through effect are both negative, the output-sensitivity effect is always positive and the output effect is positive for intense competition ($\theta > 0.5$). The U-shaped rather than decreasing investment function for leaders reflects the fact that the output effect is more likely to be positive for leaders.

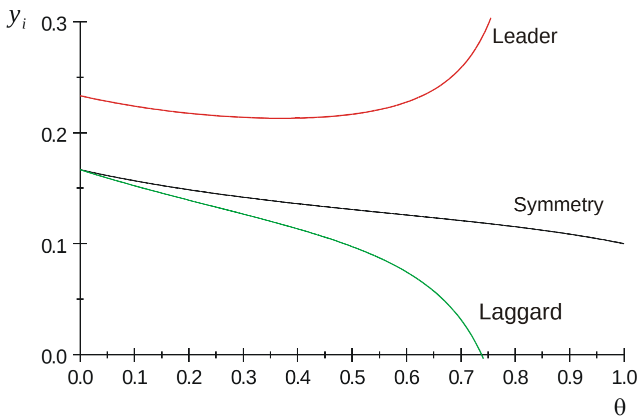

Figure 5: Differentiated Bertrand Competition

Sacco and Schmutzler (2010) show that, with Cournot competition, the effect is U-shaped for leaders and for symmetric firms, and it is negative for strong laggards. Intuitively, for Cournot competition, higher efficiency induces an output reduction of the competitor. Compared to the case of strong differentiation, this output reduction dampens the price-reducing effect $|p_i^i|$, so that the cost-pass-through effect should be positive. Under price competition, however, greater efficiency induces lower prices of both firms, enhancing the price-reducing effect of greater efficiency. Thus, compared to the case with little product differentiation where such considerations play no role, cost reductions induce more substantial price reductions, so that $|p_i^i|$ should increase. Hence, the cost-pass-through effect works towards a positive relation between competition and investment under Cournot competition, and conversely under Bertrand competition.

4.2 Substitutability (Singh-Vives)

In Section 4.1, an increase in $\theta = b$ not only increases substitutability; it also shifts both demand functions inwards. An inverse demand function without this property was analyzed by Singh and Vives (1984), namely

$$p^i\left(q_i, q_j; \theta\right) = 1 - \frac{1}{1+\theta} q_i - \frac{\theta}{1+\theta} q_j. \tag{5}$$

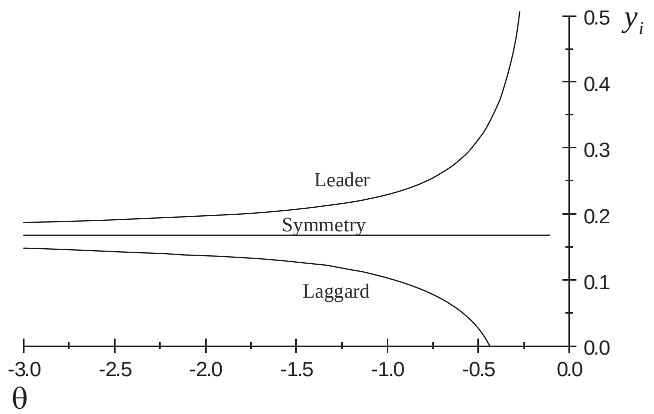

Figure 6: The effects of increasing transportation costs

It can be shown that, in both the Bertrand and the Cournot case, investment depends positively on the substitution parameter θ for this demand function, except for firms that are lagging far behind; for which the relation is negative.[14] The main reason behind this more positive effect of competition on investment than in the Shubik-Levitan case is that the output effect is now unambiguously positive (See Appendix 2).

4.3 Transportation costs

Next, consider a Hotelling duopoly. Consumers buy at most one unit of a homogeneous good, and are uniformly distributed on $[0, 1]$. Firms are located at $q_1 = 0$ and $q_2 = 1$. Consumers incur transportation costs t per unit distance in addition to the price p^i. Competition affects the leader's investments positively and the laggard's negatively, as depicted in Figure 6.[15] This figure is drawn for $c_1^0 = c_2^0 = 0.5$ (symmetric case), $c_1^0 = 0.3$ (leader) and $c_2^0 = 0.7$ (laggard).

Simple calculations show that $M_\theta^i < 0$; $Q_i^i > 0$; $M_i^i > 0$; $Q_{i\theta}^i > 0$; $M_{i\theta}^i = 0$ (See Appendix 2). Crucially, $Q_\theta^i > 0$ if and only if i is a leader; hence the

[14] Again, in the Bertrand case, a restriction on b ($b < 0.85$) is necessary for symmetric investment equilibria to exist.

[15] We assume that transportation costs are in an intermediate range where second-order conditions hold, both firms are active and all consumers buy one unit.

same is true of the output effect.[16] As a result, the sign of $\Pi^i_{i\theta}$ is determined by whether a firm is leader or laggard. Also, it is straightforward to show that $\Pi^i_{ij} < 0$, so that Proposition 2 can explain the differential impact of competition on the investments of the two firms: Intuitively, because competition has a positive output effect for leaders and a negative output effect for laggards, increasing θ has the direct effect that it raises the leader's investment incentives and reduces those of the laggard. As investments are strategic substitutes, both effects are mutually reinforcing.

4.4 Cournot vs. Bertrand

Our framework can be adapted to understand how switching from Cournot competition to Bertrand competition affects investments. To this end, reconsider the differentiated goods examples of Section 4.1. Let $\theta \in \{0, 1\}$, where $\theta = 0$ for Cournot and $\theta = 1$ for Bertrand. Even though θ does not affect demand functions $q^i\left(p^i, p^j\right)$, it affects equilibrium outputs, margins and profits. Therefore the terms $Q^i\left(Y_i, Y_j; \theta\right)$, $M^i\left(Y_i, Y_j; \theta\right)$, $\Pi^i\left(Y_i, Y_j; \theta\right)$ still make sense. Figure 7 displays the investments for the Cournot case (Sacco and Schmutzler 2010) and those for the Bertrand case (Figure 5) in one diagram for $c^0_1 = c^0_2 = 0.5$. Investments are thus always higher for soft (Cournot) competition, though the difference approaches zero as b does.[17]

What lies behind this clear negative effect of competitive intensity (in the sense of moving from Cournot to Bertrand competition) on investments? We compare the four components of $\Pi^i_i = Q^i M^i_i + M^i Q^i_i$ for $\theta = 0$ and $\theta = 1$. In Figure 8, the middle line describes equilibrium output and margin as a function of b in the Cournot case. The upper line describes equilibrium output in the Bertrand case.[18] The lower line describes the equilibrium margin in the Bertrand case. The figure thus shows that the margin effect is negative, that is, M^i is greater for $\theta = 0$ than for $\theta = 1$, and the output

[16] The remaining two non-zero effects, the positive demand-sensitivity effect and the negative markup effect, happen to sum up to a positive effect for leaders, a negative effect for laggards, and they cancel out in the symmetric case.

[17] For the Bertrand case, the figure is drawn for the parameter region where the second-order condition holds ($b < 0.933$).

[18] Recall that a symmetric equilibrium only exists for $b < 0.923$.

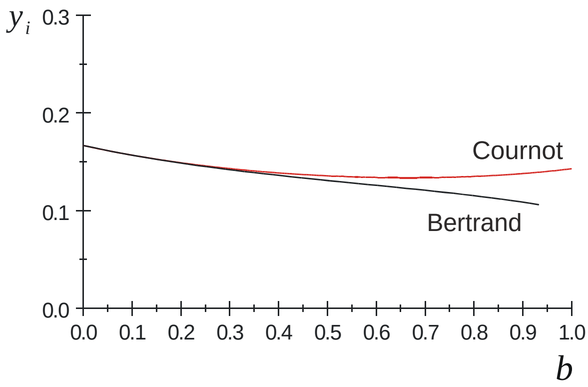

Figure 7: Cournot vs. Bertrand competition

effect is positive, that is, Q^i is smaller for $\theta = 0$ than for $\theta = 1$. Similarly, the cost-pass-through (output-sensitivity) effects can be obtained by comparing M_i^i (Q_i^i) in the Bertrand and the Cournot case.

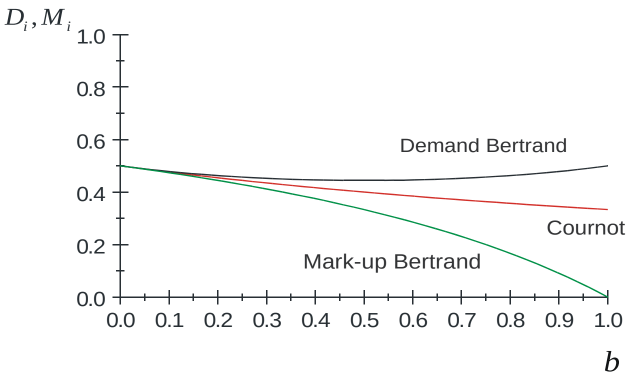

Figure 8: Cournot vs. Bertrand: Absolute demand and markup effects

Figure 9 shows that the output-sensitivity effect is positive, whereas the cost-pass-through effect is negative.

Increasing competition by moving from Cournot to Bertrand competition thus has a negative effect on investments for two reasons. First, it reduces the margin, which reduces the incentive to increase output. Second, it reduces the positive reaction of margins to reducing own marginal costs. However, under

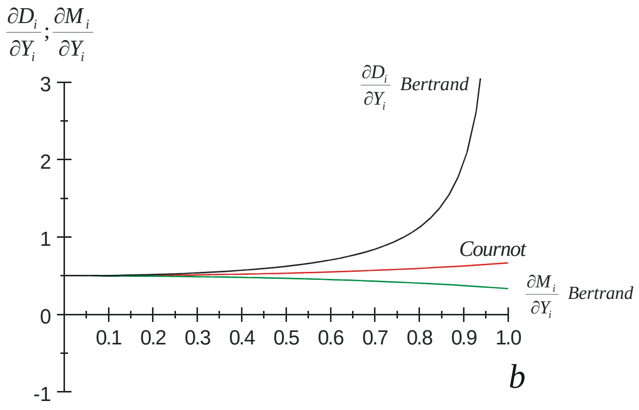

Figure 9: Cournot vs. Bertrand: Cost-pass-through and demand-sensitivity

Bertrand competition, equilibrium output is higher, making margin increases through investments more attractive. Also, the sensitivity of equilibrium output to efficiency is higher. Nevertheless, the negative effects dominate.

4.5 Summary

Table 10 summarizes the examples.[19]

	Absolute Demand	Absolute Markup	Demand Sensitivity	Cost-Pass-Through	Total Effect
Linear Cournot	-	-	0	0	-
Differentiated Cournot (3)	-	-	+	+	∪
Differentiated Bertrand (3)	+	-	+	-	-
Differentiated Cournot (4)	+	-	+	+	+
Differentiated Bertrand (4)	+	-	+	-	+
Hotelling	0	-	+	0	0
Bertrand vs. Cournot	+	-	+	-	-

Figure 10: Summary of examples (Symmetric Case)

[19] In the differentiated Bertrand and Cournot examples the number in brackets refers to the number of the underlying demand function.

For simplicity, it only contains the symmetric cases. In line with (C1) and (C2), the margin effect is always non-positive, and the output sensitivity effect is always non-negative. The output effect and the cost-pass through effect are ambiguous, which complicates matters further.

5 When does competition raise investments?

I now use the general approach of Section 3 and the examples to identify which factors work towards a positive effect of competition.

5.1 Leaders vs. laggards

In the Hotelling case, competition increases the investments of leaders and decreases those of laggards. In the Bertrand example with differentiated goods (Shubik-Levitan 1980), the effect of competition on investment is U-shaped for strong leaders; it is negative for all other firms. In the Cournot case, competition has a negative effect on strong laggards, but a U-shaped effect for leaders, symmetric firms and firms that are not lagging behind too far. With Singh-Vives demand, the effects are positive except for strong laggards. Based on the examples, we therefore obtain the following results:

Observation 1: *Investment tends to have a more positive effect for leaders than for laggards; and they are robustly negative for laggards.*

There are two reasons why increasing competition has a more positive investment effect for leaders than for laggards. First, the positive output sensitivity effect $M^i Q^i_{i\theta}$ implied by (C2) is substantial only when margins are large – but when firms are lagging far behind, their margins are low. Second, because of (C2), Q^i_θ and hence the output effect $M^i_i Q^i_\theta$ is more likely to be positive when a firm is efficient.

5.2 Spillovers

Spillovers ($\lambda > 0$) tend to make a negative effect of competition on investments more likely.

Proposition 3 *Suppose (C3) holds and (i)* $\frac{\partial^3 \Pi^i}{\partial Y_i \partial Y_j \partial \theta} = \frac{\partial^3 \Pi^i}{(\partial Y_i)^2 \partial \theta} = \frac{\partial^3 \Pi^i}{(\partial Y_j)^2 \partial \theta} = 0$ *for* $i = 1.2$, $j \neq i$ *or (ii) investment costs are sufficiently large. As spillovers* (λ) *increase,* $\pi^i_{i\theta}$ *falls.*

Proof. See Appendix 1. ■

To repeat, condition (C3) that $\frac{\partial^2 \Pi^i}{\partial Y_j \partial \theta} < 0$ appears plausible. At least for a move from no competition (two monopolists) to some degree of competition, the adverse effect of a more efficient competitor on own profits becomes larger: Without competition $\frac{\partial \Pi^i}{\partial Y_j} = 0$, whereas with competition typically $\frac{\partial \Pi^i}{\partial Y_j} < 0$. However, closer scrutiny suggests that moving from intermediate to higher levels of competition does not necessarily lead to a decline in $\frac{\partial \Pi^i}{\partial Y_j}$. Proceeding as in (3),

$$\Pi^i_{j\theta} = Q^i_j \cdot M^i_\theta + M^i \cdot Q^i_{j\theta} + Q^i \cdot M^i_{j\theta} + M^i_j \cdot Q^i_\theta.$$

For instance, the first term, $Q^i_j \cdot M^i_\theta$, is positive: As competition reduces margins, it reduces the negative effect of the output reduction following a competitor's increase in efficiency. A similar statement holds for the last term.[20] In all our examples, at least for sufficently symmetric firms, the remaining effects dominate, so that $\Pi^i_{j\theta} < 0$. We are left with a slightly tentative conclusion.

Observation 2: *If investments have higher spillovers, marginal investment incentives are more likely to be negatively affected by competition.*

5.3 The effects of pre-existing competition

It seems intuitive that, while some competition is good for investments, "excessive competition" may have negative effects, suggesting an inverted-U relation between competiton and investment. Thus, low initial levels of competition would appear to make it more likely that further increases of competition increase investments. The examples have already shown that such a general statement cannot be supported in our partial equilibrium frame-

[20] The second term introduces an effect that cannot be strictly positive, because $Q_j = 0$ for $\theta = 0$, whereas $Q_j < 0$ for $\theta > 0$.

work.[21] The only non-monotone examples feature a U-shape. Even so, (C2) gives two reasons why increasing competition may have positive effects only when the initial level of competition is low. First, with low competition, margins and hence the output sensitivity effect ($M_i Q^i_{i\theta}$) should be high. Second, by (C2), Q^i_i is higher when competition is intense, suggesting that the negative margin effect $Q^i_i M^i_\theta$ is more pronounced when competition is intense.

The fact that the effect of competition on investment can be U-shaped even so comes from a simple source: While M^i_θ has a negative effect on margins, this effect is typically convex: When competition has already reduced margins substantially, further competition does not reduce them much more.[22] We summarize the discussion as follows:

Observation 3: *It is not necessarily more likely that competition has a positive effect on investment incentives when the initial level of competition is low than when it is high.*

5.4 The effects of the number of firms

Rather than changes in the intensity of competition for a given number of firms, consider now increases in the number of firms for an otherwise unchanged environment. First, I shall provide an analogous result to Proposition 1 that gives conditions under which the sign of the effect of the change of the number of firms on investment is given exactly by the sign of the effect on marginal investment incentives.

Suppose there are $n \geq 2$ firms. Replace the parameter θ by n and write

$$\Pi^i \left(Y_i, \mathbf{Y}_{-i}; n\right) = M^i \left(Y_i, \mathbf{Y}_{-i}; n\right) \cdot Q^i \left(Y_i, \mathbf{Y}_{-i}; n\right).$$

Otherwise, proceed as in Section 2. Write net profits as $\pi^i \left(y^i, \mathbf{y}_{-i}; n\right)$. For any investment level y, let $\mathbf{y}_n$ be the $n-1$-dimensional vector consisting of identical entries y. Finally, introduce a weak strategic substitutes condition.

[21] Aghion et al. (1997, 2001) derive an inverse U-shape from general equilibrium considerations.

[22] In the differentiated Cournot example of Sacco and Schmutzler (2010), this effect dominates, resulting in the U-shaped relation observed there.

Definition 2 *The investment game satisfies* ***strategic substitutes at the diagonal*** *(SSD) if* $\frac{\partial \pi^i}{\partial y_i}(y_i, \mathbf{y}_n; n)$ *is weakly decreasing in* $\mathbf{y}_n$ *for all* y_i *and* y.

Thus, (SSD) requires player i's investment incentives to fall as the other players' investments increase symmetrically along the diagonal. The condition is motivated by the observation that strategic substitutes typically hold in duopoly investment games without spillovers.[23] The following result holds.

Proposition 4 *Consider a symmetric investment game such that* $\pi^i(y_i, \mathbf{y}_{-i}; n)$ *are concave in* y_i *and satisfy (SSD). Suppose for* $n^L < n^H$ *the game has symmetric equilibria* $\mathbf{y}_L \equiv \mathbf{y}(n^L) = (y_L, ..., y_L)$ *and* $\mathbf{y}_H \equiv \mathbf{y}(n^H) = (y_H, ..., y_H)$. *Suppose for all* $i \in \{1, 2, ..., n\}$ *and* $n^L < n^H$,

$$\frac{\partial \pi^i}{\partial y_i}\left(y, \mathbf{y}_L; n^L\right) > \frac{\partial \pi^i}{\partial y_i}\left(y, \mathbf{y}_H; n^H\right). \tag{6}$$

Then $\mathbf{y}_L > \mathbf{y}_H$.

Proof. See Appendix 1. ■

Proposition 4 states that, if an increase in the number of firms reduces marginal investment incentives of each firm, as required by (6), it also reduces investments in the symmetric equilibrium. Similar to (3), we obtain

$$\Pi^i_{in} = Q^i_i \cdot M^i_n + M^i_i \cdot Q^i_n + Q^i \cdot M^i_{in} + M^i \cdot Q^i_{in}. \tag{7}$$

As in Section 3, there are four transmission channels by which the number of firms affects marginal incentives. However, a higher number of firms quite robustly reduces both margins and output, so that both the margin effect $Q^i_i \cdot M^i_n$ and the output effect $M^i_i \cdot Q^i_n$ are negative. This suggests a clearer negative effect of increasing competition on investments, unless M^i_{in} and Q^i_{in} are positive and very large. However, most examples confirm the following:

Observation 4: *For symmetric firms, an increase in the number of firms tends to reduce investments per firm.*

To illustrate the asymmetric case, one can compare the investments in a homogeneous linear Cournot duopoly with those of a monopolist in an otherwise identical market. It is straightforward to show that, while introducing

[23] See the discussion in Section 2.

competition by a second firm always reduces investments of the former monopolist when the entrant is at least as efficient as the incumbent, entry of a less efficient firm can increase the incumbent's investments.[24] This is a variant of the theme that competition tends to have more positive effects on the investments of relatively efficent firms than on those of relatively inefficent firms (Section 5.1).

6 Beyond the basic model

The previous analysis has exposed several countervailing channels by which competition affects investment, so that there is no hope of expecting a robust and non-ambiguous relationship. It also identified some factors that are conducive to positive effects of competition on the investments of a firm. To make further progress in this direction, I will extend the framework in several directions.

6.1 Cumulative Investments

Suppose the game is played twice (periods $t = 1, 2$). Let Y^i_{t-1} be the efficiency level of the firm at the beginning of period t. Similarly, y^i_t is the investment in period t. Then we obtain the following result.

Proposition 5 *Suppose conditions (C3) and (C4) hold. If competition has a non-negative effect on investment incentives in the static game, then it also has a non-negative effect in each period of the two-period game.*

Proof. See Appendix 1. ■

The intuition is clearest when investments are strategic substitutes. Then investments in the two-period game have the additional benefit of lowering future investments of the competitor. By (C3), competition increases the negative effect of own investments on the future investments of the competitor. Furthermore, by (C4), competition makes the negative effect of first-period investments on the future investments of the competitor more desirable.

[24] Details available on request.

Observation 5: *If the effects of competition on investment are positive in the static game, they are also positive in the game with cumulative investments.*

6.2 Competition-dependent investment costs

So far, innovation costs were assumed to be independent of the competition parameter. Though this may appear to be innocuous at first sight, there are at least two natural reasons why competition might affect (marginal) investment costs.

6.2.1 Imperfect upstream competition

So far, we have summarized the R&D process in the cost function without specifying the source of the costs. We now assume that R&D requires inputs from an upstream supplier. Suppose further that there is an industry-specific component to R&D. Even without an explicit model of the interaction between the supplier and the downstream firms, it is plausible that the intensity of downstream competition has an impact on investment costs. According to our previous considerations, competition affects the willingness of downstream firms to pay for cost reductions. Whenever competition would increase investment incentives with marginal investment costs that are independent of θ, then increasing competition drives up the demand for the upstream input. With this in mind, marginal investment costs should be increasing in competition in this case, and conversely when competition would decrease marginal investment costs. These upstream cost effects should therefore dampen the original effects of competition and investment: When R&D inputs are bought from an imperfectly competitive upstream supplier, the effects of competition are less pronounced than when the inputs are supplied competitively (or inhouse).

Observation 6: *Imperfect upstream competition tends to reduce the strength of the relation between competition and investment.*

6.2.2 Agency models

When firms are controlled by managers rather than owners, competition can have the effect of decreasing the marginal costs of investment. To see this, I adjust the model of Schmidt (1996) to the present oligopolistic framework.[25]

Suppose that, in both firms, marginal costs can take values L or $H > L$. Suppose further, that each firm employs a risk-neutral agent who can affect the probability of low marginal costs by exerting effort costs $G(p^i)$, where G is increasing, convex and differentiable. For effort choices of p^i and p^j, we obtain expected profits

$$\begin{aligned}&\widetilde{\Pi}^i\left(p_i, p_j; \theta\right) = \\ &\quad p^i\left(1-p^j\right)\Pi^i\left(Y_i(L), Y_j(H); \theta\right) + p^i p^j \Pi^i\left(Y_i(L), Y_j(L); \theta\right) + \\ &\quad \left(1-p^i\right)\left(1-p^j\right)\Pi^i\left(Y_i(H), Y_j(H); \theta\right) + \left(1-p^i\right)p^j\Pi^i\left(Y_i(H), Y_j(L); \theta\right)\end{aligned}$$

Suppose there is a probability $l(p^i, p^j; \theta)$ that the agent loses his job, where l is differentiable, $\frac{\partial l}{\partial p^i} \leq 0$, $\frac{\partial l}{\partial p^j} \geq 0$, $\frac{\partial^2 l}{\partial p^i \partial \theta} \leq \theta$ and $\frac{\partial l^2}{(\partial p^i)^2} = 0$.[26] Intuitively, own effort reduces the risk of losing the job, and this becomes more pronounced as competition increases. Assume that losing the job involves private costs of $\lambda > 0$.

In Schmidt (1996), the principal in firm i chooses wages $\left(w_i^L, w_i^H\right)$ so as to maximize expected profits subject to the incentive, participation and wealth constraints of the agent. For simplicity, I confine myself to incentive constraints, assuming that the optimal contract involves $w_i^H = 0$ in line with wealth constraints. The incentive constraint

$$\max_{p^i} w_i^L p^i - G\left(p^i\right) - l(p^i, p^j; \theta)\lambda$$

leads to the first-order condition $w_i^L = G'\left(p^i\right) + \frac{\partial l}{\partial p^i}\lambda$. The agent must be

[25] Consistent with (C5), Schmidt (1996) assumes that competition corresponds to a parameter change that reduces a firm's profits for given effort levels. He does not model a competitor explicitly.

[26] A simple specification with this property is $l(p^i, p^j; \theta) = \theta\left(1-p^i\right)p^j$ with $\theta \in [0, 1]$: Layoffs can only arise in the worst state that an unsuccessful firm is facing a successful competitor, and the intensity of competition determines the fractions of cases in which this happens.

compensated for the net cost of effort, which consists of the effort cost minus the expected gain from reducing the lay-off probability. Thus, the principal maximizes $\widetilde{\Pi}^i\left(p_i, p_j; \theta\right) - C\left(p, \theta\right)$, where

$$C\left(p, \theta\right) = p^i \left(G'\left(p^i\right) + \frac{\partial l}{\partial p^i}\lambda \right).$$

The incentive to induce marginally higher effort is thus

$$\begin{aligned} &\left(1 - p^j\right)\left(\Pi^i\left(Y_i(L), Y_j(H); \theta\right) - \Pi^i\left(Y_i(H), Y_j(H); \theta\right)\right) \\ &+ p^j\left(\Pi^i\left(Y_i(L), Y_j(L); \theta\right) - \Pi^i\left(Y_i(H), Y_j(L); \theta\right)\right) \\ &- G'\left(p^i\right) - p^i G''\left(p^i\right) - \frac{\partial l}{\partial p^i}\lambda. \end{aligned}$$

The first two rows summarize the positive effects of investment on (expected) gross profits, and the effect of competition on these terms is as before. The third row describes the marginal cost effect. Competition reduces marginal costs: By increasing $\frac{\partial l}{\partial p^i}$, it increases the agent's own interest in exerting effort to avoid layoff. Because competition reduces the marginal costs of investment ($\frac{\partial^2 l}{\partial p^i \partial \theta} \leq \theta$ and hence $\frac{\partial^2 C^i}{\partial p^i \partial \theta} \leq 0$), there is an additional force in firms with separation of ownership and control that works towards a positive effect of competition on investment.

Observation 7: *If the effects of competition on investment are positive in a model with owner-managed firm, the same is true in a model with separation of ownership and control.*

This observation is also obtained in other models with agency conflicts, which rely on very different mechanisms. For instance, similar results obtain in the model of Hermalin (1992) where managers propose contracts to firms.

6.3 Endogenous market participation

So far, we have assumed that a change in the level of competition leaves the number of firms unaffected. Clearly, however, with fixed costs, the number of firms should depend negatively on the intensity of competition if (C5) holds. Taking into account that a lower number of firms increases investment incentives, ignoring the effects of competition on market participation biases the effects of competition on innovation downwards.[27]

For a simple formalization, suppose firms $i = 1, 2$ decide whether to enter the market at a fixed cost F, before the investment game is played. Denote the profits of a monopolist firm i as $\Pi^i (Y_i; \theta)$. Then the equilibrium structure is described as follows.

1. If $\Pi^i (Y_i; \theta) \leq F$, there exists an equilibrium such that no firm enters.
2. If $\Pi^i \left(Y_i^*, Y_j^*; \theta\right) \geq F$ for the SPE choices Y_i^* and Y_j^* of the investment game with two firms, there exists an equilibrium where both firms enter.
3. In all other cases, only one firm enters in SPE.

If an increase in competition reduces the number of firms, then Section 5.4 applies: A reduction in the number of firms is likely to increase investment incentives of the remaining firm(s).

A slightly different approach would have firms deciding on investments *before* entering the markets. This problem is more complex, because multiple equilibria will typically arise in the second stage rather than in the first stage, and investment decisions have to be made before the equilibrium is selected. Intuitively, however, this introduces another positive effect of competition on investment, an intimidation effect: By investing more, a firm should increase the chances that the competitor exits. As competition intensifies, inducing such exit becomes more desirable.

Observation 8: *If the effects of competition on investment are positive in a model with an exogenous number of firms, the same is true in a model with endogenous market participation.*

6.4 Upstream investments

Recent literature has dealt with the investment incentives in vertical structures, e.g. network industries.[28] I will briefly sketch how the above approach can be modified to take upstream investments into account.

[27] For similar ideas, see Vives (2008) and in Raith (2003).

[28] See Bühler and Schmutzler (2005, 2008) for downstream investments, Chen and Sappington (2009) for upstream investments.

Downstream competition is modeled as above, with duopoly profits

$$\Pi_D^i\left(Y_i, Y_j; \theta\right) = Q_D^i\left(Y_i, Y_j; \theta\right) \cdot M_D^i\left(Y_i, Y_j; \theta\right)$$

for each vector (Y_1, Y_2) of efficiency levels and a competition parameter θ. Downstream firms require the input of an upstream monopolist supplier U; suppose the technology is one-to one, so that one input unit is required for each output unit. The upstream firm has initial constant marginal costs of $\overline{u}$ and can carry out upstream cost-reductions u at costs $K(u)$. Suppose the upstream monopolist is integrated with the downstream firm $i = 1$, whereas it supplies the downstream firm 2 at an access price $a(u;\theta)$, with $\frac{\partial a}{\partial u} < 0$. The functional form of $a(u;\theta)$ could either result from optimization of the upstream firm, a negotiation process or from regulation. It is natural to assume that lower upstream costs not only translate into lower access prices, but also into lower costs of the integrated firm. Thus, we let $Y_1 = Y_1(u)$, $Y_2 = Y_2(a(u;\theta))$, where $Y_1'(u) > 0$, $Y_2'(a) < 0$, $\frac{dY_1}{du} = 1$ and $\frac{dY_2}{da} = -1$. In this setting, the effect of competition on investment is considerably more complex than before, but the ideas from the basic model are a helpful starting point.

The upstream monopolist obtains revenues from downstream activities of its own subsidiary (firm 1) and from access revenues from firm 2. Write downstream output of firm 2 as $\widetilde{Q}_D^2(u;\theta) \equiv Q_D^2\left(Y_2(a(u)), Y_1(u); \theta\right)$. Denote the upstream margin as $\widetilde{M_U^2}(u) \equiv a(u) - (\overline{u} - u)$. Total upstream profits are

$$\Pi^T(u\,;\theta) = \Pi^1\left(Y_1(u), Y_2(a(u)); \theta\right) + \widetilde{M_U^2}(u) \cdot \widetilde{Q}_D^2(u;\theta).$$

Incentives to invest are thus

$$\frac{\partial \Pi^T}{\partial u} = \frac{\partial \Pi^1}{\partial Y_1} - \frac{\partial \Pi^1}{\partial Y_2}\frac{\partial a}{\partial u} + \frac{\partial \widetilde{M_U^2}}{\partial u}\widetilde{Q}_D^2 + \frac{\partial \widetilde{Q}_D^2}{\partial u}\widetilde{M_U^2}. \tag{8}$$

The first two terms reflect the effects of upstream investments on the integrated firm's downstream profits: $\frac{\partial \Pi^1}{\partial Y_1}$ is the incentive to reduce own (downstream) costs, as in the model without vertical structure. The analysis of competition in a horizontal setting (Section 3) thus applies verbatim to this term: Competition affects investments via the four transmission channels identified there.

The second term, $-\frac{\partial \Pi^1}{\partial Y_2}\frac{\partial a}{\partial u}$, captures a disincentive to invest which is related to well-known effects in models with spillovers: Investment reduces access costs and hence production costs of the downstream competitor, which is undesirable because it reduces own profits. As argued in Section 5.2, this effect should be stronger with intense competition.

The remaining two terms in (8) introduce concerns for access revenues. The term $\frac{\partial \widetilde{M}_U^2}{\partial u}\widetilde{Q}_D^2 = \left(1 + \frac{\partial a}{\partial u}\right)\widetilde{Q}_D^2(u;\theta)$ reflects the effects of own investments on the profit margin from supplying the competitor: Both the costs and the price for each unit of access fall as upstream investments increase. As long as the direct cost reduction effect dominates over the induced price effect ($1+\frac{\partial a}{\partial u} > 0$), the term is positive. The sign of $\frac{\partial \widetilde{Q}_D^2}{\partial u}\widetilde{M}_U^2 = \frac{\partial \widetilde{Q}_D^2}{\partial u}\left(a(u) - (\overline{u} - u)\right)$ reflects the net effect of upsteam cost reductions on the output of the competitor who benefits from lower access costs, but suffers from lower costs of the integrated firm. $\frac{\partial \widetilde{Q}_D^2}{\partial u}$ and hence the entire term may well be negative: If $\left|\frac{\partial a}{\partial u}\right|$ is sufficiently small, the separated firm suffers from lower costs of the competitor, but does not have much lower costs itself.

In spite of the structural similarity between $\frac{\partial \Pi^i}{\partial Y^i}$ and

$$\frac{\partial \widetilde{\Pi}_D^2}{\partial u} = \frac{\partial \widetilde{M}_U^2}{\partial u}\widetilde{Q}_D^2 + \frac{\partial \widetilde{Q}_D^2}{\partial u}\widetilde{M}_U^2, \tag{9}$$

the interpretation differs in several ways. First, $\widetilde{M}_U^2$ is not the margin of the downstream competitors, but of the upstream firm supplying them. Second, investments of the integrated firm also reduce the costs of the competitor, which tends to increase access revenues.

We now sketch the effects of competition on each term in (9). First, the effect of competition on margins $\widetilde{M}_U^2$ may be positive. For instance, if $a(u,\theta)$ results from negotiations between downstream firms and U, greater competition may involve better outside options of the upstream firm, so that greater downstream competition should increase the upstream margin. Second, the effect of competition on downstream output $\widetilde{Q}_D^2$, is similar to the (ambiguous) output effect.[29] Third, to understand the effects of competition

[29] Note, however, the potential asymmetry between integrated and separated firms. The integrated firm is often an established incumbent, whereas the entrants may be less experi-

on $\frac{\partial \widetilde{Q}_D^2}{\partial u}$, first suppose the two firms are monopolists. Then $\frac{\partial \widetilde{Q}_D^2}{\partial u}$ must be positive, because the separated firm faces lower access costs, whereas the lower downstream costs of the integrated firm do not affect the output of the separated firm. As competition increases, there is an adverse effect. Thus, it appears plausible that the downstream output-sensitivity effect is negative. Fourth, consider the effect of competition on $\frac{\partial \widetilde{M}_U^2}{\partial u} = \frac{\partial a}{\partial u}$. Without specifying further details, the effect is unclear. If access prices are determined by regulation one could easily imagine that this regulation is insensitive to the details of downstream competition, so that there might well be no effect. To sum up, increasing competition leads to additional positive and negative effects on upstream investment incentives. Future research will explore under which circumstances the positive effects dominate over the negative ones.

7 Conclusion

The paper has identified several channels by which competition affects investment. By assumption and consistent with many examples, competition reduces margins, and increases the sensitivity of equilibrium output with respect to efficiency. Adding to these ambiguities, competition can have positive or negative effects on equilibrium output and on the sensitivity of prices with respect to marginal costs. Together, this explains why the effects of competition on investment are ambiguous.

Further, a positive effect of competition is more likely for leaders than for laggards, and it is less likely when spillovers are strong. Next, no general case can be made that an inverse relation between competition and investment is more likely than a U-shaped relation. With the alternative interpretation of increasing competition as an increase in the number of firms, however, competition has a clear negative effect.

Extensions of the basic model helped to identify various factors that influence the effects of competition on investment. A positive effect is likely

enced. Depending on the precise context, these differences may show up in cost differences, in which case the considerations from the leader-laggard model apply. Specifically, if the separated firm has cost disadvantages, the effect of greater competition on $\widetilde{Q}_D^2$ will tend to be negative.

to be fostered when investments are cumulative, when there is separation of ownership and control and when market participation is determined endogenously. Imperfect upstream markets reduce the effects of competition on investment, no matter whether they are positive or negative. The analysis also helps to obtain some intuition for the effects of downstream competition on upstream investments.

There are several limitations of the approach. First, I have not treated product innovations. A decomposition of investment incentives analogous to (3) along the lines sketched here would help to understand how the effects of competition on product innovation differ from those on process innovation.[30] Second, I have assumed that R&D investments are observable to competitors before they take their product market decisions. Taken literally, this is certainly a strong assumption.[31] Most of the arguments appear to rely, however, on the weaker notion that in the product-market stage firms are aware of their relative competitive position as determined by previous investments to some extent.

8 Appendix 1: Proofs

8.1 Proof of Proposition 1

(i) follows from Theorem 5 in Milgrom and Roberts (1990).[32]
(ii) By (i), it suffices to consider $\pi^i_{ij} < 0$. Total differentiation of the system of first order conditions shows that a negative effect of θ on investment would require $\pi^j_{j\theta}\pi^i_{ij} < \pi^i_{i\theta}\pi^j_{jj}$, and therefore, using symmetry $\pi^i_{ij} < \pi^j_{jj}$. For $\pi^i_{ij} < 0$ and symmetry, this condition is incompatible with stability.
(iii) follows from total differentiation of the system of first order conditions.

[30] One important difference is that, with product innovations, an innovating firm may want to continue to use the old product (Greenstein and Ramey 1998, Chen and Schwartz 2008). Gilbert (2006) summarizes some arguments pertaining to this discussion, see also Schmutzler (2009).

[31] Vives (2008) considers both observable and non-observable investments.

[32] This theorem is a comparative-statics result for supermodular games.

8.2 Proof of Proposition 3

First note that

$$\frac{\partial^2 \pi^i (y_i, y_j; \theta)}{\partial y_i \partial \theta} = \frac{\partial^2 \Pi^i \left(Y_i^0 + y_i + \lambda y_j, Y_j^0 + y_j + \lambda y_i; \theta\right)}{\partial Y_i \partial \theta} + \lambda \frac{\partial^2 \Pi^i \left(Y_i^0 + y_i + \lambda y_j, Y_j^0 + y_j + \lambda y_i; \theta\right)}{\partial Y_j \partial \theta}.$$

Therefore,

$$\frac{\partial^3 \pi^i (y_i, y_j; \theta)}{\partial y_i \partial \theta \partial \lambda} = \frac{\partial^2 \Pi^i}{\partial Y_j \partial \theta} + y_j \left(\frac{\partial^3 \Pi^i}{(\partial Y_i)^2 \partial \theta} + \frac{\partial^3 \Pi^i}{\partial Y_i \partial Y_j \partial \theta} \right) + y_i \left(\frac{\partial^3 \Pi^i}{\partial Y_i \partial Y_j \partial \theta} + \frac{\partial^3 \Pi^i}{(\partial Y_j)^2 \partial \theta} \right).$$

Thus, if either y_i and y_j or the terms in brackets are sufficently small, $\frac{\partial^3 \pi^i (y_i, y_j; \theta)}{\partial y_i \partial \theta \partial \lambda} < 0$. If (i) or (ii) holds, the statement thus holds.

8.3 Proof of Proposition 4

As $\frac{\partial \pi^i}{\partial y^i} \left(y^H, \mathbf{y}^H_{n^H}; n^H\right) = 0$, (6) implies $\frac{\partial \pi^i}{\partial y^i} \left(y^H, \mathbf{y}^H_{n^L}; n^L\right) > 0$. By concavity, $\frac{\partial \pi^i}{\partial y_i} \left(y_i, \mathbf{y}^H_{n^L}; n^L\right) > 0$ for any $y_i < y^H$. Finally, (SSD) implies $\frac{\partial \pi^i}{\partial y^i} \left(y_i, \mathbf{y}^i_{n^L}; n^L\right) > 0$. Therefore, $\mathbf{y}_L < \mathbf{y}_H$ is impossible.

8.4 Proof of Proposition 5

The game in period 2 corresponds to the static game. Hence, we only need to consider period 1. Denote the equilibrium investment of player i in the second stage game for each vector $\mathbf{Y}_1 = (Y_1^1, Y_1^2)$ of interim states as $y_2^i (\mathbf{Y}_1)$. Total payoffs can be written as functions of first-period investments:

$$\Pi_T^i \left(y_1^i, y_1^j; \theta\right) = \Pi^i \left(Y_0^i + y_1^i, Y_0^j + y_1^j; \theta\right) + \Pi^i \left(Y_0^i + y_1^i + y_2^i \left((\mathbf{Y}_0 + \mathbf{y}_1)\right), Y_0^j + y_1^j + y_2^j \left((\mathbf{Y}_0 + \mathbf{y}_1)\right); \theta\right) - K(y_1^i) - K(y_2^i (\mathbf{Y}_0 + \mathbf{y}_1)).$$

Because y_2^i will be chosen so as to satisfy $\frac{\partial \Pi^i}{\partial y_2^i} = \frac{\partial K^i}{\partial y_2^i}$, investment incentives in period 1 are $\frac{\partial \Pi_T^i}{\partial y_1^i} = 2\frac{\partial \Pi^i}{\partial Y_1^i} + \frac{\partial \Pi^i}{\partial Y_2^j}\frac{\partial y_2^j}{\partial y_1^i}$. Conditions (C3) and (C4) imply that $\frac{\partial \Pi^i}{\partial Y_2^j}\frac{\partial y_2^j}{\partial y_1^i}$ is increasing in θ.

9 Appendix 2: The Examples

9.1 Substitutability (Shubik-Levitan)

9.1.1 Quantity competition

Define $Y_i = 1 - c_i$, that is, $\overline{c} = 1$. For $2Y_i \geq \theta Y_j$; $2Y_j \geq \theta Y_i$,[33]

$$Q^i\left(Y_i, Y_j; \theta\right) = M^i\left(Y_i, Y_j; \theta\right) = \frac{2Y_i - \theta Y_j}{4 - \theta^2}.$$

9.1.2 Price competition

With price competition,

$$Q^i\left(Y_i, Y_j; \theta\right) = \frac{\left(2 - \theta^2\right) Y_i - \theta Y_j}{\left(4 - \theta^2\right)\left(1 - \theta^2\right)};\ M^i\left(Y_i, Y_j; \theta\right) = \frac{\left(2 - \theta^2\right) Y_i - \theta Y_j}{4 - \theta^2}.$$

9.2 Substitutability (Singh-Vives)

With quantity competition,

$$Q^i\left(Y_i, Y_j; \theta\right) = \frac{\left(1 + \theta\right)\left(2Y_i - \theta Y_j\right)}{\left(4 - \theta^2\right)};\ M^i\left(Y_i, Y_j; \theta\right) = \frac{2Y_i - \theta Y_j}{4 - \theta^2}.$$

With price competition,

$$Q^i\left(Y_i, Y_j; \theta\right) = \frac{\left(2 - \theta^2\right) Y_i - \theta Y_j}{\left(4 - \theta^2\right)\left(1 - \theta\right)};\ M^i\left(Y_i, Y_j; \theta\right) = \frac{\left(2 - \theta^2\right) Y_i - \theta Y_j}{4 - \theta^2}.$$

[33] The following results are taken from Sacco and Schmutzler (forthcoming).

9.3 Hotelling

In the Hotelling model, demand functions are given by

$$q^1(p^1, p^2; \theta) = \left(p^1 - p^2 + \theta\right)/2\theta \text{ and } q^2(p^2, p^1; \theta) = \left(p^2 - p^1 + \theta\right)/2\theta.$$

Defining $Y_i = -c_i$, it is straightforward to show that

$$Q^i\left(Y_i, Y_j; \theta\right) = \left(Y_j - Y_i + 3\theta\right)/6\theta;\ M^i\left(Y_i, Y_j; \theta\right) = \left(Y_i - Y_j - 3\theta\right)/3.$$

Thus,

$$Q^i_\theta = \left(Y_i - Y_j\right)/6\theta^2;\ M^i_\theta = -1;\ Q^i_i = -1/6\theta;\ M^i_i = 1/3;\ Q^i_{i\theta} = 1/6\theta^2;\ M^i_{i\theta} = 0$$

Simple but tedious calculations show that equilibrium investments are

$$y_i = \frac{1}{6} + \frac{Y^0_j - Y^0_i}{2(9\theta + 1)}.$$

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