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COST-SAVING PRODCTION TECHNOLOGIES AND STRATEGIC DELEGATION

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Abstract

This work analyzes a managerial delegation model in which firms that produce a differentiated good can choose between two production technologies: a low marginal cost technology and a high marginal cost technology. For the former to be adopted more investment is needed than for the later. By giving managers of firms an incentive scheme based on a linear combination of profit and sales revenue, we find that Bertrand competition provides a stronger incentive to adopt the cost-saving technology than the strict profit maximization case. However, the results may be reversed under Cournot competition. We show that if the degree of product substitutability is sufficiently low (high), the incentive to adopt the cost-saving technology is larger under strict profit maximization (strategic delegation).

JEL Classification: O31, L13

Key words: Cost-saving production technologies, strategic delegation, duopoly

1 Introduction

This work examines the incentives to acquire cost-saving production technologies in a managerial delegation model. We find this analysis quite relevant since, although it is generally argued that a study of a firm's objective function should take into account the owner-manager relationship, most works on oligopolistic interaction take up the question of technology choice by treating firms as economic agents with the sole objective of profit maximization (see Bester and Petrakis (1993), Röller and Tombak (1990)).[1]

In this work we analyze an oligopolistic industry consisting of two firms that produce a differentiated good under both Bertrand and Cournot competition. The type of production technology choice we describe in this work can be illustrated by using the British steam generating industry as an example (see Wield (1985)). Given the large decline in the home market, in an attempt to make the firm internationally competitive Babcock Power Ltd designed a cost-reduction program in 1980 to cut costs by 25 per cent. The implementation of this program needed a £20 million investment: £8 million on plant, £8 million on a new building and £4 million on other facilities. We set our model in this context. We assume that firms invest in the modernization of machinery, manufacturing and assembly facilities (i.e. firms invest in the setting up of a new production plant) which reduce their manufacturing unit costs. Since we do not consider the licensing of production technologies, the investment needed to implement a new technology is assumed to be exogenous.

The literature on strategic delegation, which started with Vickers (1985), Fershtman and Judd (1987) and Sklivas (1987), examines the incentive contracts that owners of competing firms give their managers and how these incentive contracts can affect the oligopoly outcome. These works show that profit-maximizing owners will turn their managers away from strict profit maximization for strategic reasons. In this work we study how strategic delegation contracts affect firms' technology choices in a differentiated industry. Like Fershtman and Judd (1987), we assume that firms' managers will be given an incentive to maximize an objective function consisting of a linear combination of profits and sales revenue.

Bester and Petrakis (1993) analyze firms' technology choices in a differentiated industry when firms' objective is to maximize strict profits. They focus on the choice between two types of production technology: a low marginal cost technology and a high marginal cost technology. For the former to be adopted more investment is needed than for the later. In this framework, the gains from a low-marginal-cost technology over a high-marginal-cost technology depend on how the following variables are affected: (I) the difference between price and unit cost of production (i.e. the net price), (II) the output level and (III) the investment needed to adopt the cost-saving technology relative to the high marginal cost technology (denoted by F). Under both price and quantity com-

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[1] Nett (1994) moves away from strict profit maximization. He studies the reasons for different production costs between public and private firms in the context of a mixed duopoly.

petition, the cost-saving technology leads to higher prices and output. Thus, for both price and quantity competitions we find two opposing forces. On the one hand, (I) and (II) lead to a positive incentive to adopt the low marginal cost technology. On the other hand, (III) leads to a negative incentive. Thus, if F is sufficiently low, (I) and (II) together dominate (III) and, as a result, both firms find the adoption of the cost-saving technology profitable. For intermediate values of F, the net price increase and the quantity increase induced by both firms' adoption of the low marginal cost technology are not large enough for (I) and (II) to offset the investment amount. However, the adoption of this technology by a single firm induces both a larger net price and a larger market share for the firm that adopts the cost-saving technology large enough for (I) and (II) to offset (III) in that firm. Finally, if F is sufficiently high, (III) dominates (I) and (II) together and, as a result, neither firm finds the adoption of the low marginal cost technology profitable.

Our model takes into account the fact that delegation of production decisions has strategic effects. We consider an oligopolistic industry consisting of two firms that produce a differentiated good in which owners have to choose the incentive contracts that are offered to managers. We analyze the implications of incentive contracts within Bester and Petrakis's (1993) context. Let us briefly explain how incentive parameters affect firms' technology choice decisions.

It is well known that under price competition, strategic delegation leads to higher prices than strict profit maximization (see, for example, Fershtman and Judd (1987)). As a result, positive effect (I) is reinforced. We also show that positive effect (II) is, in general, weakened. This result is reversed under quantity competition. We find that under price competition, the incentive to adopt the low marginal cost technology is at least as large when firms' owners delegate price decisions than in the strict profit maximization case. That is, the reinforcement of effect (I) offsets the weakening of effect (II), whereas effect (III) is equal in both cases. However, under quantity competition results depend on market parameter values. If the degree of product substitutability is sufficiently low, we find that the incentive to adopt the cost-saving technology is larger under strict profit maximization than under strategic delegation. In this case, the weakening of effect (I) provoked by owners' incentives to managers is at least as powerful as the reinforcement of effect (II). By contrast, when products are perceived by consumers as being close substitutes, the incentive to adopt the cost-saving technology is larger under strategic delegation. In this case, the weakening of effect (I) provoked by owners' incentives to managers is less powerful than the reinforcement of effect (II). We explain this result by the fact that the larger the degree of product substitutability is, the higher the market competition is. This effect is reinforced under strategic delegation since when firms compete by setting quantities, their owners make their managers more aggressive than under strict profit maximization, which in turn leads to greater market competition. Hence the larger incentive to acquire a cost-saving technology under strategic delegation.

Since we assume that firms are considering whether to set up a new production plant, our approach considers the investment level as exogenously de-

termined. By contrast, Saracho (2002) assumes that there is an innovator who sets the price of the innovation. She analyzes the adoption of cost-reducing innovations in a context of strategic delegation by considering n firms that produce a homogeneous good and compete in quantities. Other works study the influence of the way in which workers are organized to bargain wages on firms' decisions about technology choice (see Tauman and Weiss (1987), Calabuig and Gonzalez-Maestre (2002)). Bárcena-Ruiz and Olaizola (2004) analyze a managerial delegation model in which firms can choose between flexible and dedicated production technologies.

There are works related with our paper which combine the technology choice literature with the literature on strategic delegation. Lambertini and Primavera (2001) analyze a model of strategic delegation with cost-reducing R&D. However, they analize a different question that our paper: the relative profitability of delegation versus process innovation. On the other hand, Zhang and Zhang (1997) develop a model of strategic delegation with cost-reducing R&D with the possibility of spillovers across firms. They assume that the decisions on R&D correspond to firms' managers. They show that if spillovers between firms are small (great) enough, then managerial firms have higher (lower) R&D than the firms managed by owners. These works analyze the incentives to acquire cost-saving production technologies under Cournot behavior with homogeneous goods. However, we show in our paper that the results we obtain depend on the degree in which goods are substitutes. Besides, we consider that the owners arewho decide whether to adopt the cost-saving technology since we assume that firms invest in the setting up of a new production plant.

The rest of the paper is organized as follows. Section 2 describes the general features of a differentiated duopoly model under strategic delegation. Section 3 analyzes the gains from cost-saving technologies under price competition and shows how strategic delegation affects firms' decisions compared to the strict profit maximization case. Section 4 takes up the case of quantity competition. Finally, Section 5 contains some conclusions.

2   The model

We consider a single industry consisting of two firms that produce a differentiated good. Before the market opens firms can choose between two different production technologies: Technology-l (low-marginal-cost technology), which has constant marginal cost c_l and fixed cost F_l and Technology-h (high-marginal-cost technology), which has constant marginal cost c_h and fixed cost F_h, with $c_l < c_h$ and $F_l > F_h$. For the sake of simplicity we normalize F_h to zero and denote $F_l = F$.

Each firm's owner delegates quantity or price decisions to a manager in order to improve his strategic position in the market. As in Fershtman and Judd (1987), we assume that owners offer 'take it or leave it' linear incentive schemes to risk-neutral managers. The manager of firm i $(i = 1, 2)$ receives a payoff: $\beta_i + B_i O_i$, where β_i and B_i are constant, $B_i > 0$, and O_i is a linear combination

of profits and sales revenue. The owner selects β_i and B_i so that the manager only gets his opportunity cost, which is normalized to zero. Formally, firm i's manager will be given an incentive to maximize:

$$O_i = \alpha_i \Pi_i + (1 - \alpha_i) S_i, \tag{1}$$

where

$$\Pi_i = (p_i - c_i) q_i - F_i \text{ and } S_i = p_i q_i, \tag{2}$$

represent firm i's profit and sales revenue, respectively and α_i is the incentive parameter chosen by firm i's owner. We make no restrictions on α_i. From (1) and (2) we obtain:

$$O_i = (p_i - c_i \alpha_i) q_i - \alpha_i F_i; \ i, j = 1, 2; \ i \neq j. \tag{3}$$

As (3) shows, firm i's manager considers $\alpha_i c_i$ as the marginal cost of production when taking price or quantity decisions. In this way, firm i's owner can make his manager more (less) aggressive, i.e. he can make his manager to produce a higher (lower) output level than a profit maximizer firm by choosing an incentive parameter such that the marginal cost of production considered by the manager is lower (higher) than that considered by a profit maximizer firm.

In order to study firms' technology choice when there is strategic delegation, we consider a three stage game. In the first stage, firms' owners simultaneously choose the production technology. In the second stage, firms' owners simultaneously determine the incentive structure for their managers. Finally, in the third stage, managers play an oligopoly game, with each firm's manager knowing his incentive contract, the incentive contract of the competing manager and the nature of demand and costs. We assume the timing of the above decisions based on the fact that the production technology choice is a more long-term decision than the setting of managers' incentives.

The state of the game in the first stage is summarized in Figure 1. We solve the game by backward induction from the last stage of the game to obtain a subgame-perfect Nash equilibrium.

Firm 2

		l	h
Firm 1	l	$\Pi(ll)$, $\Pi(ll)$	$\Pi(lh)$, $\Pi(hl)$
	h	$\Pi(hl)$, $\Pi(lh)$	$\Pi(hh)$, $\Pi(hh)$

Figure 1. Summary of the game

In Figure 1, $\Pi(ll)$ denotes the profit of a firm that adopts Technology-l when both firms adopt this technology. $\Pi(hh)$ denotes the profit of a firm that adopts Technology-h when both firms adopt this technology. When only one firm adopts the cost-saving technology, $\Pi(lh)$ denotes the profit of the firm that adopts Technology-l and $\Pi(hl)$ denotes the profit of the firm that adopts Technology-h. If a firm is indifferent between the two technologies, we assume that it chooses the cost-saving technology.

To determine whether the results are robust to changes in the type of competition in which firms are involved, we determine the equilibria in different contexts.

3 Bertrand competition

We first study the Bertrand equilibrium in which firms compete by setting prices. The demand functions of both goods are assumed to be linear:

$$q_i = a - p_i + bp_j; \ a > \underline{a}; \ 0 < b < 1; \ i,j = 1,2; \ i \neq j,$$

where p_i and q_i are the price and the quantity of good i produced by firm i, respectively.[2]

To show how strategic delegation affects firms' decisions, we consider first the simple profit maximization case.

3.1 Benchmark case: Profit-maximizer firms

In this case we have a two stage game. In the first stage, firms' owners simultaneously choose the production technology. And, in the second stage, owners set prices.

In stage two, firm i's owner chooses p_i to maximize Π_i taking the competitor's price, p_j, as fixed. This problem leads to the following solution:

$$\widehat{p}_i = \frac{a\,(2+b) + 2c_i + bc_j}{4 - b^2}; \ i,j = 1,2; \ i \neq j. \tag{4}$$

In the first stage, firms' owners simultaneously choose the production technology. Firms' profits and prices are given by Table 1.[3]

It can easily be seen from (4) that $\widehat{p}_i$ decreases with both firm i's and firm j's marginal cost reduction. Therefore, the marginal cost reduction on both firms induces firm i to behave more aggressively (i.e. to set a lower price). As a result, we have $p\,(hh) > p\,(hl) > p\,(lh) > p\,(ll)$. That is, when both firms adopt Technology-l the equilibrium price is lowest, $p\,(ll)$, while if both firms adopt Technology-h the equilibrium price is highest, $p\,(hh)$. We obtain intermediate prices when only one firm adopts the cost-saving technology, with the firm with the lowest marginal cost being the one that chooses the lowest price, $p\,(hl) > p\,(lh)$. This effect is strategically disadvantageous for firm i.

However, this does not necessarily mean that the adoption of the cost-saving technology becomes less profitable. In fact, as (2) shows, the gains from a marginal cost reduction depend on how the following variables are affected: (I) the difference between price and marginal cost, i.e. the net price (denoted as p^*), (II) the output level and (III) the investment needed to acquire the cost-saving

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[2] The assumption $a > \underline{a}$, $\underline{a} = \frac{(2-b^2)c_h - bc_l}{2+b} < c_h$, is necessary to assure that each firm's output will be positive in equilibrium.

[3] All tables are relegated to the appendix.

technology. We can easily see that $p(lh)^* > p(ll)^* > p(hh)^* > p(hl)^*$ and $q(lh) > q(ll) > q(hh) > q(hl)$. Consequently, when analyzing the technology choice under price competition, we find two opposing forces: on the one hand, (I) and (II) lead to a positive incentive to adopt Technology-l, and on the other hand (III) leads to a negative incentive. Solving the first stage of the game we obtain the following result.[4] Let:

$$F_1^p = \frac{(2-b^2)(c_h-c_l)\left(2a(2+b)-(2-b^2)(c_h+c_l)+2bc_h\right)}{(4-b^2)^2},$$
$$F_2^p = \frac{(2-b^2)(c_h-c_l)\left(2a(2+b)-(2-b^2)(c_h+c_l)+2bc_l\right)}{(4-b^2)^2},$$

where F_1^p and F_2^p are the investment levels such that $\Pi(lh) = \Pi(hh)$ and $\Pi(hl) = \Pi(ll)$, respectively.

Lemma 1 *When firms owners do not delegate price decisions, in equilibrium:*
i) Both firms choose the low-marginal-cost technology if $F \leq F_2^p$.
ii) Both firms choose the high-marginal-cost technology if $F > F_1^p$.
iii) Only one firm chooses the low-marginal-cost technology if $F_2^p < F \leq F_1^p$.

If the adoption of Technology-l does not require any investment F, then $\Pi(lh) > \Pi(ll) > \Pi(hh) > \Pi(hl)$. This reflects the positive incentive to adopt Technology-l caused by both (I) and (II). This incentive is larger if the other firm does not adopt this technology. But since in our model the adoption of Technology-l requires an investment, different investment levels will produce different results in equilibrium. In fact, if F is sufficiently low ($F \leq F_2^p$), (I) and (II) together dominate (III) and, as a result, both firms find the adoption of Technology-l profitable. For intermediate values of F ($F_2^p < F < F_1^p$) only one firm adopts Technology-l. The net price increase and the quantity increase induced by both firms' adoption of Technology-l are not large enough for (I) and (II) to offset the investment amount. However, the adoption of Technology-l by a single firm induces a larger net price and a larger market share for the firm that adopts this technology, at the expense of the other firm's net price and market share, which is large enough for (I) and (II) to offset (III) in the firm that adopts Technology-l. Finally, if F is sufficiently high ($F \geq F_1^p$), (III) dominates (I) and (II) together and, as a result, neither firm finds the adoption of Technology-l profitable.

3.2 Equilibrium under strategic delegation

When firms' owners hire managers to take price decisions, we have a three stage game. In the first stage, owners simultaneously choose the production technology. In the second stage, owners simultaneously determine the incentive structure for their managers. Finally, in the third stage, managers take price decisions. The objective function of firm i's manager can be written as:

$$O_i = (p_i - c_i\alpha_i)(a - p_i + bp_j) - \alpha_i F_i; \quad i,j = 1,2; \quad i \neq j.$$

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[4] The same result is given by Proposition 1 in Bester and Petrakis (1993).

In stage three, firm i's manager chooses p_i to maximize O_i taking the competitor's price, p_j, as fixed. The reaction functions derived from the above maximization problem are:

$$p_i = \frac{a + bp_j + c_i\alpha_i}{2}; \ i,j = 1,2; \ i \neq j.$$

Which can be solved for the equilibrium prices:

$$\widehat{p}_i = \frac{a(2+b) + 2c_i\alpha_i + bc_j\alpha_j}{4 - b^2}; \ i,j = 1,2; \ i \neq j. \tag{5}$$

In the second stage, firm i's owner chooses the incentive parameter of his manager, α_i, that maximizes his firm's profit, taking the competitor's incentive parameter, α_j, as fixed. Solving this problem we obtain the equilibrium incentive parameters:

$$\widehat{\alpha}_i = 1 + \frac{b^2\left(a\left(4+2b-b^2\right) - \left(4-3b^2\right)c_i + b\left(2-b^2\right)c_j\right)}{\left(16 - 12b^2 + b^4\right)c_i}; \ i,j = 1,2; \ i \neq j.$$

We can check that $\widehat{\alpha}_i$ decreases with c_i ($\partial\widehat{\alpha}_i/\partial c_i < 0$) and increases with c_j ($\partial\widehat{\alpha}_i/\partial c_j > 0$). Therefore, a marginal cost reduction in firm i (j) induces firm i to behave less (more) aggressively. Moreover, as $|\partial\widehat{\alpha}_i/\partial c_i| > |\partial\widehat{\alpha}_i/\partial c_j|$, a reduction in both firms' marginal cost makes firm i's manager less aggressive. Consequently, $\alpha(lh) > \alpha(ll) > \alpha(hh) > \alpha(hl)$. If only one firm adopts Technology-l the equilibrium incentive is greater, $\alpha(lh)$, for the firm that adopts Technology-l and smaller, $\alpha(hl)$, for the firm that adopts Technology-h. While we obtain intermediate values for the incentive parameter if both firms adopt Technology-h or neither firm adopts it, $\alpha(hh)$ and $\alpha(ll)$ respectively, with $\alpha(ll) > \alpha(hh)$. Note that $\widehat{\alpha}_i > 1$. Then, firm i's manager considers a higher marginal cost of production than that considered by a profit-maximizer firm. Therefore, firm i's owner makes his manager less aggressive (i.e. he makes his manager set a larger price) than a profit-maximizer firm.

It is straightforward from (5) that $\widehat{p}_i$ increases with both α_i and α_j. As a result, we have that $p(hh)_d > p(hl)_d > p(lh)_d > p(ll)_d$ and therefore there exists a negative strategic incentive to adopt Technology-l. Although strategic delegation leads to equilibrium prices which are higher than those corresponding to the strict profit maximization case: $p(hh)_d > p(hh)$, $p(hl)_d > p(hl)$, $p(lh)_d > p(lh)$ and $p(ll)_d > p(ll)$.

As (2) shows, the gains from a marginal cost reduction depend on how the following variables are affected: (I) the net price (denoted as p_d^*), (II) the output level and (III) the investment level. We can easily see that $p(lh)_d^* > p(ll)_d^* > p(hh)_d^* > p(hl)_d^*$ and $q(lh)_d > q(ll)_d > q(hh)_d > q(hl)_d$. Consequently, when analyzing the incentives for the adoption of cost-saving technologies, we find two opposing forces: on the one hand, (I) and (II) lead to a positive incentive to adopt Technology-l and, on the other hand, (III) leads to a negative incentive. To study which effect dominates, we solve the first stage of the game in which firms' owners simultaneously choose the production technology. Firms' profits,

prices and incentive parameters are given by Table 2. The first stage of the game leads to the following result. Let:

$$F_{1d}^{p} = \frac{2\left(2-b^2\right)\left(4-3b^2\right)(c_h-c_l)\left(2a\left(4+2b-b^2\right)-\left(4-3b^2\right)(c_h+c_l)+2b\left(2-b^2\right)c_h\right)}{\left(16-12b^2+b^4\right)^2},$$

$$F_{2d}^{p} = \frac{2\left(2-b^2\right)\left(4-3b^2\right)(c_h-c_l)\left(2a\left(4+2b-b^2\right)-\left(4-3b^2\right)(c_h+c_l)+2b\left(2-b^2\right)c_l\right)}{\left(16-12b^2+b^4\right)^2},$$

where F_{1d}^{p} and F_{2d}^{p} are the investment levels such that $\Pi\left(lh\right) = \Pi\left(hh\right)$ and $\Pi\left(hl\right) = \Pi\left(ll\right)$, respectively.

Lemma 2 *When firms' owners delegate price decisions, in equilibrium:*
i) Both firms choose the low-marginal-cost technology if $F \leq F_{2d}^{p}$.
ii) Both firms choose the high-marginal-cost technology if $F > F_{1d}^{p}$.
iii) Only one firm chooses the low-marginal-cost technology if $F_{2d}^{p} < F \leq F_{1d}^{p}$.

If the adoption of Technology-l does not require any investment F, then $\Pi\left(lh\right) > \Pi\left(ll\right) > \Pi\left(hh\right) > \Pi\left(hl\right)$. This reflects the positive incentive to adopt this technology caused by both (I) and (II). But since in our model the adoption of Technology-l requires an investment, different investment levels will produce different results in equilibrium. In fact, if F is sufficiently low $(F \leq F_{2d}^{p})$, (I) and (II) together dominate (III) and, as a result, both firms find the adoption of Technology-l profitable. The same argument used in Lemma 1 justifies the fact that for intermediate values of F $(F_{2d}^{p} < F < F_{1d}^{p})$ only one firm adopts Technology-l. Finally, if F is sufficiently high $(F \geq F_{1d}^{p})$, (III) dominates (I) and (II) together and, as a result, neither firm finds the adoption of Technology-l profitable.

3.3 Results

To show how strategic delegation affects firms' decisions about technology choice, we compare the results obtained under strict profit maximization and strategic delegation.

Let $\widetilde{a}$ be defined in Table 5 with $\widetilde{a}$ being the value of parameter a such that $F_1^{p} = F_{2d}^{p}$. Comparing Lemmas 1 and 2 we can see the following:

Lemma 3 *If $\widetilde{a} > c_h$, then $F_{1d}^{p} > F_{2d}^{p} \geq F_1^{p} > F_2^{p}$ whenever $a \geq \widetilde{a}$ and $F_{1d}^{p} > F_1^{p} > F_{2d}^{p} > F_2^{p}$ whenever $a < \widetilde{a}$. If $\widetilde{a} \leq c_h$, then $F_{1d}^{p} > F_{2d}^{p} \geq F_1^{p} > F_2^{p}$.*

Thus, from Lemmas 1 to 3 we obtain the following result.

Proposition 1 *Under price competition, the incentive to adopt the cost-saving technology is at least as great when firms' owners delegate price decisions as in the strict profit maximization case.*

The result obtained in Proposition 1 is illustrated in Figures 2a and 2b. More adoption of Technology-l is attained under strategic delegation than under strict profit maximization in the following cases: i) when $a > \widetilde{a}$, if $F_2^{p} < F < F_{1d}^{p}$ and ii) when $a < \widetilde{a}$, if $F_1^{p} < F < F_{1d}^{p}$ or $F_2^{p} < F < F_{2d}^{p}$. Note that if $a > \widetilde{a}$ and

$F_1^p < F < F_{2d}^p$, both firms adopt Technology-l under strategic delegation while neither firm adopts it under strict profit maximization. In all other cases, one firm adopts Technology-l under strategic delegation while neither firm adopts it under strict profit maximization.

[INSERT FIGURES 2a AND 2b AROUND HERE]

The maximum investment level for which both firms adopt Technology-l is higher under strategic delegation than under strict profit maximization, i.e. $F_{2d}^p > F_2^p$. And the larger the market size, a, the larger the difference between F_{2d}^p and F_2^p. As a result, the range of values of parameter F for which (ll) is an equilibrium is larger under strategic delegation than under strict profit maximization. Moreover, the larger the market size, the larger this difference. On the other hand, the minimum investment level for which both firms adopt Technology-h is higher under strategic delegation, i.e. $F_{1d}^p > F_1^p$. And the larger the market size, the larger the difference between F_{1d}^p and F_1^p. As a result, the range of values of parameter F for which (hh) is an equilibrium is smaller under strategic delegation than under strict profit maximization. Moreover, the larger the market size, the larger this difference. We can also see that $F_1^p - F_2^p > F_{1d}^p - F_{2d}^p$. Therefore, the range of values of F for which (hl) is an equilibrium is smaller under strategic delegation. However, for the values of F for which only one firm adopts Technology-l under strict profit maximization, at least one firm adopts this technology under strategic delegation. Hence, we conclude that the incentive to adopt the cost-saving technology under strategic delegation is at least as great as under strict profit maximization.

We find various reasons for the preceding results. On the one hand, under price competition, strategic delegation leads to higher prices than strict profit maximization. As a result, when owners delegate price decisions, the positive effect (I) is reinforced. On the other hand, it can be see that $q(hl)_d < q(hl)$ for a market size, a sufficiently large[5] while $q(hh)_d < q(hh)$, $q(ll)_d < q(ll)$ and $q(lh)_d < q(lh)$ for all a. As a result, when owners delegate price decisions, the positive effect (II) is in general weakened. However, the reinforcement of effect (I) is at least as powerful as the weakening of effect (II). Hence, as $\Pi(hh)_d > \Pi(hh)$, $\Pi(hl)_d > \Pi(hl)$, $\Pi(lh)_d > \Pi(lh)$ and $\Pi(ll)_d > \Pi(ll)$ and as the negative effect (III) is equal in both cases, the incentive to adopt Technology-l is at least as large when firms' owners delegate price decisions as in the strict profit maximization case.

4   Cournot competition

We next consider the Cournot equilibrium in which firms compete by setting quantities. The inverse demand functions of both goods are assumed to be

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[5] $q(hl)_d < q(hl)$ if and only if $a > a^*$, where $a^* = \frac{2(2-b^2)^2 c_h - b(8 - 7b^2 + b^4) c_l}{8 - 8b^2 - b^3 + b^4} > c_h$.

linear:
$$p_i = a - q_i - bq_j; \ a > \overline{a}; \ 0 < b < 1; \ i,j = 1,2; \ i \neq j,$$

where p_i and q_i are the price and the quantity of good i produced by firm i, respectively.[6]

To show how strategic delegation affects firms' decisions, we first consider the simple profit maximization case.

4.1 Benchmark case: Profit-maximizer firms

In stage two, firm i's owner chooses q_i to maximize Π_i taking the competitor's quantity, q_j, as fixed. This problem leads to the following solution:

$$\widehat{q}_i = \frac{a(2-b) - 2c_i + bc_j}{4 - b^2}; \ i,j = 1,2; \ i \neq j. \tag{6}$$

In the first stage, firms' owners simultaneously choose the production technology. Firms' profits and quantities are given by Table 3.

We can see from (6) that $\widehat{q}_i$ decreases with c_i and increases with c_j. Therefore, a marginal cost reduction in firm i (j) induces firm i to behave more (less) aggressively, i.e. to produce a larger (smaller) quantity. Moreover, as $|\partial\widehat{q}_i/\partial c_i| > |\partial\widehat{q}_i/\partial c_j|$, firm i's output changes more with its own marginal cost than with that of the competing firm. As a result, we have that $q(lh) > q(ll) > q(hh) > q(hl)$. The highest output level, $q(lh)$, corresponds to a firm that adopts Technology-l when the other firm adopts Technology-h, while the lowest output level, $q(hl)$, corresponds to a firm that adopts Technology-h when the other firm adopts Technology-l. Then, firm i's marginal cost reduction is strategically advantageous for firm i and quantity competition thus creates a positive strategic incentive to adopt the cost-saving technology.

However, this does not necessarily mean that the adoption of Technology-l becomes profitable. In fact, as (2) shows, the gains from a marginal cost reduction depend on how the following variables are affected: (I) the net price (denoted as p^*), (II) the output level and (III) the investment level. We can easily see that $p(lh)^* > p(ll)^* > p(hh)^* > p(hl)^*$ and $q(lh) > q(ll) > q(hh) > q(hl)$. Consequently, (I) and (II) lead to a positive incentive to adopt Technology-l and, on the other hand, (III) leads to a negative incentive. Solving the first stage of the game we obtain the following result.[7] Let:

$$F_1^q = \frac{4(c_h - c_l)(a(2-b) - (c_h + c_l) + bc_h)}{(4-b^2)^2}, \ F_2^q = \frac{4(c_h - c_l)(a(2-b) - (c_h + c_l) + bc_l)}{(4-b^2)^2},$$

where F_1^q and F_2^q are the investment levels such that $\Pi(lh) = \Pi(hh)$ and $\Pi(hl) = \Pi(ll)$, respectively.

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[6] The assumption $a > \overline{a}$, $\overline{a} = \frac{(4-b^2)c_h - 2bc_l}{4 - 2b - b^2} > c_h$, is necessary to assure that each firm's output will be positive in equilibrium.

[7] The same result is given by Proposition 1 in Bester and Petrakis (1993).

Lemma 4 *When firms owners do not delegate production decisions, in equilibrium:*
i) Both firms choose the low-marginal-cost technology if $F \leq F_2^q$.
ii) Both firms choose the high-marginal-cost technology if $F > F_1^q$.
iii) Only one firm chooses the low-marginal-cost technology if $F_2^q < F \leq F_1^q$.

If the adoption of Technology-l does not require any investment F, then $\Pi(lh) > \Pi(ll) > \Pi(hh) > \Pi(hl)$. This reflects the positive incentive to adopt Technology-l caused by both (I) and (II). But since in our model the adoption of Technology-l requires an investment, different investment levels will produce different results in equilibrium. In fact, if F is sufficiently low $(F \leq F_2^q)$, (I) and (II) together dominate (III) and, as a result, both firms find the adoption of Technology-l profitable. For intermediate values of F $(F_2^q < F < F_1^q)$, the adoption of the cost-saving technology by a single firm induces a higher net price and a larger market share for the firm that adopts this technology, at the expense of the other firm's net price and market share, which is large enough for (I) and (II) to offset (III) in the firm that adopts Technology-l. As a result, only one firm adopts the cost-saving technology. Finally, if F is sufficiently high $(F \geq F_1^q)$, (III) dominates (I) and (II) together and, as a result, neither firm finds the adoption of Technology-l profitable.

4.2 Equilibrium under strategic delegation

The objective function of firm i's manager can be written as:

$$O_i = (a - q_i - bq_j - c_i\alpha_i) q_i - \alpha_i F_i; \; i,j = 1,2; \; i \neq j.$$

In stage three, firm i's manager chooses q_i to maximize O_i taking the competitor's output, q_j, as fixed. The reaction functions derived from the above maximization problem are:

$$q_i = \frac{a - bq_j - c_i\alpha_i}{2}; \; i,j = 1,2; \; i \neq j.$$

Which can be solved for the equilibrium quantities:

$$\widehat{q_i} = \frac{a(2-b) - 2c_i\alpha_i + bc_j\alpha_j}{4-b^2}; \; i,j = 1,2; \; i \neq j. \tag{7}$$

In the second stage, firm i' owner chooses the incentive parameter of his manager, α_i, that maximizes his firm's profit, taking the competitor's incentive parameter, α_j, as fixed. Solving this problem we obtain the equilibrium incentive parameters:

$$\widehat{\alpha_i} = 1 - \frac{b^2\left(a\left(4 - 2b - b^2\right) + 2bc_j - \left(4 - b^2\right)c_i\right)}{(16 - 12b^2 + b^4)c_i}; \; i,j = 1,2; \; i \neq j.$$

We can check that $\widehat{\alpha}_i$ increases with c_i $(\partial\widehat{\alpha}_i/\partial c_i > 0)$ and decreases with c_j $(\partial\widehat{\alpha}_i/\partial c_j < 0)$, with $|\partial\widehat{\alpha}_i/\partial c_i| > |\partial\widehat{\alpha}_i/\partial c_j|$. Consequently, $\alpha\left(lh\right) < \alpha\left(ll\right) < \alpha\left(hh\right) < \alpha\left(hl\right)$. If only one firm adopts Technology-l the equilibrium incentive is smaller, $\alpha\left(lh\right)$, for the firm that adopts Technology-l and larger, $\alpha\left(hl\right)$, for the firm that adopts Technology-h. We obtain intermediate values for the incentive parameter if neither firm adopts Technology-l or both firms adopt it, $\alpha\left(hh\right)$ and $\alpha\left(ll\right)$ respectively, with $\alpha\left(ll\right) < \alpha\left(hh\right)$. Note that $\widehat{\alpha}_i < 1$. Then, firm i's manager considers a lower marginal cost of production than that considered by a profit-maximizer firm. Therefore, firm i's owner makes his manager more aggressive (i.e. his manager produces a larger quantity) than a profit-maximizer firm.

>From (7) we have that $\widehat{q}_i$ decreases with α_i and increases with α_j, being $|\partial\widehat{q}_i/\partial\alpha_i| > |\partial\widehat{q}_i/\partial\alpha_j|$. We have also seen that $\alpha\left(lh\right) < \alpha\left(ll\right) < \alpha\left(hh\right) < \alpha\left(hl\right)$. As a result, we have that $q\left(lh\right)_d > q\left(ll\right)_d > q\left(hh\right)_d > q\left(hl\right)_d$ and therefore, there exists a positive strategic incentive to adopt Technology-l. Moreover, under strategic delegation equilibrium quantities are higher than those under strict profit maximization: $q\left(hh\right)_d > q\left(hh\right)$, $q\left(hl\right)_d > q\left(hl\right)$, $q\left(lh\right)_d > q\left(lh\right)$ and $q\left(ll\right)_d > q\left(ll\right)$.

However, as under strict profit maximization, this does not necessarily mean that the adoption of Technology-l becomes profitable. In fact, as (2) shows, the gains from a marginal cost reduction depend on how the following variables are affected: (I) net price (denoted as p_d^*), (II) output level and (III) investment level. We have already seen that $q\left(lh\right)_d > q\left(ll\right)_d > q\left(hh\right)_d > q\left(hl\right)_d$. We can also see that $p\left(lh\right)_d^* > p\left(ll\right)_d^* > p\left(hh\right)_d^* > p\left(hl\right)_d^*$. Consequently, when analyzing firms' technology choice, we find two opposing forces: on the one hand, (I) and (II) lead to a positive incentive to adopt Technology-l and on the other hand (III) leads to a negative incentive. To study which effect dominates, we solve the first stage of the game, in which firms' owners simultaneously choose the production technology. Firms' profits, prices and incentive parameters are given by Table 4. The first stage of the game leads to the following result. Let:

$$F_{1d}^d = \frac{2(2-b)(2+b)\left(2-b^2\right)(c_h-c_l)\left(a\left(8-4b-2b^2\right)-\left(4-b^2\right)(c_l+c_h)+4bc_h\right)}{\left(16-12b^2+b^4\right)^2},$$
$$F_{2d}^d = \frac{2(2-b)(2+b)\left(2-b^2\right)(c_h-c_l)\left(a\left(8-4b-2b^2\right)-\left(4-b^2\right)(c_l+c_h)+4bc_l\right)}{\left(16-12b^2+b^4\right)^2},$$

where F_{1d}^q and F_{2d}^q are the investment levels such that $\Pi\left(lh\right) = \Pi\left(hh\right)$ and $\Pi\left(hl\right) = \Pi\left(ll\right)$, respectively.

Lemma 5 *When firms owners delegate production decisions, in equilibrium:*
i) Both firms choose the low-marginal-cost technology if $F \leq F_{2d}^q$.
ii) Both firms choose the high-marginal-cost technology if $F > F_{1d}^q$.
iii) Only one firm chooses the low-marginal-cost technology if $F_{2d}^q < F \leq F_{1d}^q$.

If the adoption of Technology-l does not require any investment F, $\Pi\left(lh\right)_d > \Pi\left(ll\right)_d > \Pi\left(hh\right)_d > \Pi\left(hl\right)_d$. This reflects the positive incentive to adopt Technology-l caused by both (I) and (II). But since in our model the adoption of the cost-saving technology requires an investment, different investment

levels will produce different results in equilibrium. In fact, if F is sufficiently low $(F \leq F_{2d}^q)$, (I) and (II) together dominate (III) and, as a result, both firms find the adoption of Technology-l profitable. The same argument used in Lemma 4 justifies the fact that for intermediate values of F $(F_{2d}^q < F < F_{1d}^q)$ only one firm adopts Technology-l. Finally, if F is sufficiently high $(F \geq F_{1d}^q)$, (III) dominates (I) and (II) together and, as a result, neither firm finds the adoption of Technology-l profitable.

4.3 Results

Now we compare the results obtained under strict profit maximization and strategic delegation.

Let $\bar{b} = 0.8466$ and a_1, a_2, a_3 and a_4 defined in Table 5, with $\bar{b}$ being the value of parameter b such that the slopes of functions F_1^q, F_2^q, F_{1d}^q and F_{2d}^q are equal and a_1, a_2, a_3 and a_4 the values of parameter a such that $F_1^q = F_{1d}^q$, $F_2^q = F_{1d}^q$, $F_2^q = F_{2d}^q$ and $F_1^q = F_{2d}^q$, respectively. Comparing Lemmas 4 and 5 we obtain the following result, which is illustrated by Figures 3a and 3b.

Lemma 6 *If* $b < \bar{b}$, *then* $F_1^q > F_2^q \geq F_{1d}^q > F_{2d}^q$ *when* $a \geq a_2$, $F_1^q > F_{1d}^q > F_2^q > F_{2d}^q$ *when* $a_1 < a < a_2$ *and* $F_{1d}^q \geq F_1^q > F_2^q > F_{2d}^q$ *when* $a \leq a_1$. *If* $b = \bar{b}$, *then* $F_{1d}^q > F_1^q > F_2^q > F_{2d}^q$ *for all* a. *Finally, if* $b > \bar{b}$, *then* $F_{1d}^q > F_{2d}^q \geq F_1^q > F_2^q$ *when* $a \geq a_4$, $F_{1d}^q > F_1^q > F_{2d}^q > F_2^q$ *when* $a_3 < a < a_4$ *and* $F_{1d}^q > F_1^q > F_2^q \geq F_{2d}^q$ *when* $a \leq a_3$.

Thus, from Lemmas 4 to 6 we can verify the following result.

Proposition 2 *Under quantity competition, the incentive to adopt the cost-saving technology is at least as large when firms' owners delegate production decisions as under strict profit maximization in the following cases: i) if* $b < \bar{b}$ *and* $F_1^q < F < F_{1d}^q$ *and ii) if* $b \geq \bar{b}$ *with the exception of the case* $F_{2d}^q < F < F_2^q$. *In all other cases the incentive to adopt the cost-saving technology is strictly smaller when firms owners delegate production decisions than under strict profit maximization.*

The result obtained in Proposition 2 is illustrated in Figures 3a and 3b.

[INSERT FIGURES 3a and 3b AROUND HERE]

We find a number of reasons for the result obtained in Proposition 2. On the one hand, strategic delegation leads to lower prices than strict profit maximization. As a result, when owners delegate quantity decisions, positive effect (I) is weakened. On the other hand, it can be demonstrated that $q(hl)_d > q(hl)$ for a market size, a, sufficiently large[8] while $q(hh)_d > q(hh)$, $q(ll)_d > q(ll)$ and $q(lh)_d > q(lh)$ for all a. Consequently, when owners delegate quantity decisions, positive effect (II) is, in general, reinforced. However, depending on the

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[8]$q(hl)_d > q(hl)$ if and only if $a > a^{**}$, where $a^{**} = \frac{8c_h - b(8-b^2)c_l}{8-8b+b^3} > \bar{a}$.

parameter values, the weakening of effect (I) may be more/less powerful than the reinforcement of effect (II). It can be shown that $\partial F_i^q/\partial a > 0$, $\partial F_{id}^q/\partial a > 0$, $\partial^2 F_i^q/\partial a \partial b < 0$ and $\partial^2 F_{id}^q/\partial a \partial b > 0$ for $i = 1, 2$. As a result, F_i^q and F_{id}^q all increase with a. However, the larger the degree of product substitutability, the smaller (larger) the increase that a provokes in F_i^q (F_{id}^q). We can explain this result by the fact that the larger the degree of product substitutability is (i.e. the larger the value of parameter b), the higher the market competition will be. Consequently, for a given value of parameter a, the larger the value of parameter b, the smaller the firms' profits. This last effect is reinforced under strategic delegation: under quantity competition firms' owners make their managers more aggressive than under strict profit maximization, which in turn leads to a higher level of market competition. As a result, when products are highly differentiated $(b < \overline{b})$, then $\partial F_i^q/\partial a > \partial F_{id}^q/\partial a$ for $i = 1, 2$. By contrast, when products are close substitutes $(b > \overline{b})$ we have that $\partial F_i^q/\partial a < \partial F_{id}^q/\partial a$ for $i = 1, 2$. This is illustrated by the slopes of functions F_i^q and F_{id}^q in Figures 3a and 3b. Let us analyze these results in more detail.

If the degree of product substitutability is sufficiently low $(b < \overline{b})$, we find that $F_2^q > F_{2d}^q$ for all a. As a result, the range of values of F and a for which both firms adopt Technology-l is larger under strict profit maximization than that under strategic delegation (see Figure 3a). It can also be shown that $F_1^q > F_{1d}^q$ if and only if $a > a_1$. Consequently, for a sufficiently large market size, the range of values of F and a for which neither firm adopts Technology-l is smaller under strict profit maximization. The opposing result is obtained for $a < a_1$. However, as Figure 3a shows, the area for which both firms adopt Technology-h is larger under strategic delegation. Moreover, since $F_{1d}^q - F_{2d}^q > F_1^q - F_2^q$, the range of values of F and a for which only one firm adopts Technology-l is larger under strategic delegation. Lastly, the only range of values for which more adoption of Technology-l is attained under strategic delegation than under strict profit maximization is given by $a < a_1$ and $F_1^q < F < F_{1d}^q$ (under strategic delegation one firm adopts Technology-l while under strict profit maximization both firms adopt Technology-h). However, as figure 3a shows, this last area is smaller than the sum of areas in which more adoption of Technology-l is attained under strict profit maximization. As a result, we can conclude that when the degree of product substitutability is sufficiently low the incentive to adopt the cost-saving technology is at least as large when firms owners do not delegate production decisions as when they do.

If the degree of product substitutability is sufficiently high $(b > \overline{b})$, we find that $F_{1d}^q > F_1^q$ for all a. As a result, the range of values of F and a for which neither firm adopts Technology-l is larger under strict profit maximization than that under strategic delegation (see Figure 3b). It can also be shown that $F_{2d}^q > F_2^q$ if and only if $a > a_3$. Consequently, for a sufficiently large market size, the range of values of F and a for which both firms adopt Technology-l is larger under strategic delegation. The opposing result is obtained for $a < a_3$. However, as Figure 3b shows, the area for which both firms adopt Technology-l is larger under strategic delegation. Moreover, since $F_{1d}^q - F_{2d}^q > F_1^q - F_2^q$, the range of values of F and a for which only one firm adopts Technology-l is larger under

strategic delegation. Lastly, the only range of values for which Technology-l is attained less under strategic delegation than under strict profit maximization is given by $a < a_3$ and $F_{2d}^q < F < F_2^q$ (under strategic delegation one firm adopts Technology-l while under strict profit maximization both firms adopt Technology-l). However, as figure 3b shows, this last area is smaller than the sum of areas in which Technology-l is attained more under strategic delegation. As a result we can conclude that when the degree of product substitutability is sufficiently high, the incentive to adopt the cost-saving technology is at least as large when firms owners delegate production decisions as in strict profit maximization.

If $b = \overline{b}$, then $F_{1d}^q > F_1^q > F_2^q > F_{2d}^q$ for all a. Thus, if $F_1^q < F < F_{1d}^q$, the incentive to adopt Technology-l is larger under strategic delegation while if $F_{2d}^q < F < F_2^q$, the incentive to adopt Technology-l is larger under strict profit maximization.

5 Conclusions

This work analyzes how strategic incentives may play a fundamental role in firms' decisions to adopt cost-saving technologies in a context of duopolistic competition. The results suggest that it may be important to take into account the incentive scheme that profit-maximizing owners design for their managers. These incentives imply that managers' objective functions differ from strict profit maximization.

We identify three different effects that determine the effectiveness of a cost-saving technology adoption. First, equilibrium net prices increase when firms' production marginal costs are lower. Second, equilibrium outputs increase when firms' production marginal costs are lower. We find that these two effects lead to a positive incentive to adopt the cost-saving technology. Third, the investment needed to acquire a low marginal cost technology is larger than for a high-marginal-cost technology. This last effect weakens the incentive to adopt the cost-saving technology.

In this work we determine conditions under which firms are more inclined to adopt cost-saving technologies and find that these conditions depend on the type of market competition in which firms are involved. Comparing the results obtained under strict profit maximization and strategic delegation yields to the following. Under price competition, the incentive to adopt the cost-saving technology is at least as large when firms owners delegate price decisions as in the case of strict profit maximization. However, under quantity competition the results depend on the values of the market parameters. More precisely, the degree of product substitutability plays an important role in this result. We show that if the degree of product substitutability is sufficiently low the incentive to adopt the cost-saving technology is larger under strict profit maximization than under strategic delegation. By contrast, when products are perceived by consumers as being close substitutes, the incentive to adopt the cost-saving technology is larger under strategic delegation.

6 Appendix

6.1 Tables

	Π	p
ll	$\frac{(a-(1-b)c_l)^2}{(2-b)^2} - F$	$\frac{a+c_l}{2-b}$
lh	$\frac{\left(a(2+b)-\left(2-b^2\right)c_l+bc_h\right)^2}{\left(4-b^2\right)^2} - F$	$\frac{a(2+b)+2c_l+bc_h}{4-b^2}$
hl	$\frac{\left(a(2+b)-\left(2-b^2\right)c_h+bc_l\right)^2}{\left(4-b^2\right)^2}$	$\frac{a(2+b)+2c_h+bc_l}{4-b^2}$
hh	$\frac{(a-(1-b)c_h)^2}{(2-b)^2}$	$\frac{a+c_h}{2-b}$

Table 1
Price competition under strict profit maximization

	Π	p	α
ll	$\frac{2\left(2-b^2\right)(a-(1-b)c_l)^2}{\left(4-2b-b^2\right)^2} - F$	$\frac{2a+\left(2-b^2\right)c_l}{4-2b-b^2}$	$\frac{ab^2+(2-b)\left(2-b^2\right)c_l}{\left(4-2b-b^2\right)c_l}$
lh	$\frac{2\left(2-b^2\right)\left(a\left(4+2b-b^2\right)-\left(4-3b^2\right)c_l+b\left(2-b^2\right)c_h\right)^2}{\left(16-12b^2+b^4\right)^2} - F$	$\frac{2a\left(4+2b-b^2\right)+\left(2-b^2\right)\left(2bc_h+\left(4-b^2\right)c_l\right)}{16-12b^2+b^4}$	$\frac{ab^2\left(4+2b-b^2\right)+\left(2-b^2\right)\left(4\left(2-b^2\right)c_l+b^3c_h\right)}{\left(16-12b^2+b^4\right)c_l}$
hl	$\frac{2\left(2-b^2\right)\left(a\left(4+2b-b^2\right)-\left(4-3b^2\right)c_h+b\left(2-b^2\right)c_l\right)^2}{\left(16-12b^2+b^4\right)^2}$	$\frac{2a\left(4+2b-b^2\right)+\left(2-b^2\right)\left(2bc_l+\left(4-b^2\right)c_h\right)}{16-12b^2+b^4}$	$\frac{ab^2\left(4+2b-b^2\right)+\left(2-b^2\right)\left(4\left(2-b^2\right)c_h+b^3c_l\right)}{\left(16-12b^2+b^4\right)c_h}$
hh	$\frac{2\left(2-b^2\right)(a-(1-b)c_h)^2}{\left(4-2b-b^2\right)^2}$	$\frac{2a+\left(2-b^2\right)c_h}{4-2b-b^2}$	$\frac{ab^2+(2-b)\left(2-b^2\right)c_h}{\left(4-2b-b^2\right)c_h}$

Table 2
Price competition under strategic delegation

	Π	q
ll	$\frac{(a-c_l)^2}{(2+b)^2} - F$	$\frac{a-c_l}{2+b}$
lh	$\frac{(a(2-b)-2c_l+bc_h)^2}{(4-b^2)^2} - F$	$\frac{a(2-b)-2c_l+bc_h}{4-b^2}$
hl	$\frac{(a(2-b)-2c_h+bc_l)^2}{(4-b^2)^2}$	$\frac{a(2-b)-2c_h+bc_l}{4-b^2}$
hh	$\frac{(a-c_h)^2}{(2+b)^2}$	$\frac{a-c_h}{2+b}$

Table 3

Quantity competition under strict profit maximization

	Π	q	α
ll	$\frac{2\left(2-b^2\right)(a-c_l)^2}{\left(4+2b-b^2\right)^2} - F$	$\frac{2(a-c_l)}{4+2b-b^2}$	$\frac{2(2+b)c_l-ab^2}{(4+(2-b)b)c_l}$
lh	$\frac{2\left(2-b^2\right)\left(a\left(4-2b-b^2\right)-\left(4-b^2\right)c_l+2bc_h\right)^2}{\left(16-12b^2+b^4\right)^2} - F$	$\frac{2a\left(4-2b-b^2\right)-2\left(4-b^2\right)c_l+4bc_h}{16-12b^2+b^4}$	$\frac{2\left(4\left(2-b^2\right)c_l-b^3c_h\right)-ab^2\left(4-2b-b^2\right)}{\left(16-12b^2+b^4\right)c_l}$
hl	$\frac{2\left(2-b^2\right)\left(a\left(4-2b-b^2\right)-\left(4-b^2\right)c_h+2bc_l\right)^2}{\left(16-12b^2+b^4\right)^2}$	$\frac{2a\left(4-2b-b^2\right)-2\left(4-b^2\right)c_h+4bc_l}{16-12b^2+b^4}$	$\frac{2\left(4\left(2-b^2\right)c_h-b^3c_l\right)-ab^2\left(4-2b-b^2\right)}{\left(16-12b^2+b^4\right)c_h}$
hh	$\frac{2\left(2-b^2\right)(a-c_h)^2}{\left(4+2b-b^2\right)^2}$	$\frac{2(a-c_h)}{4+2b-b^2}$	$\frac{2(2+b)c_h-ab^2}{(4+(2-b)b)c_h}$

Table 4

Quantity competition under strategic delegation

$\widetilde{a}$	$\frac{\left(512-896b^2+32b^3+544b^4-32b^5-136b^6+8b^7+2b^8-b^9\right)c_l-\left(512-768b^2-32b^3+352b^4+32b^5-48b^6-8b^7+2b^8+b^9\right)c_h}{2(b^3-4b^2-4b+8)(2+b)(b^2-2b-4)b^2}$
a_1	$\frac{\left(128-96b-64b^2+80b^3-8b^4-16b^5+2b^6+b^7\right)c_h-\left(96b-80b^3+16b^5-b^7\right)c_l}{2(2-b)(4-2b-b^2)(8-4b-8b^2+b^3+b^4)}$
a_2	$\frac{\left(512-640b^2-96b^3+288b^4+80b^5-56b^6-16b^7+4b^8+b^9\right)c_h-\left(512-768b^2+96b^3+352b^4-80b^5-48b^6+16b^7+2b^8-b^9\right)c_l}{2b^2(2-b)(4-2b-b^2)(8-4b-8b^2+b^3+b^4)}$
a_3	$\frac{\left(128-96b-64b^2+80b^3-8b^4-16b^5+2b^6+b^7\right)c_l-\left(96b-80b^3+16b^5-b^7\right)c_h}{2(2-b)(4-2b-b^2)(8-4b-8b^2+b^3+b^4)}$
a_4	$\frac{\left(512-640b^2-96b^3+288b^4+80b^5-56b^6-16b^7+4b^8+b^9\right)c_l-\left(512-768b^2+96b^3+352b^4-80b^5-48b^6+16b^7+2b^8-b^9\right)c_h}{2b^2(2-b)(4-2b-b^2)(8-4b-8b^2+b^3+b^4)}$

Table 5
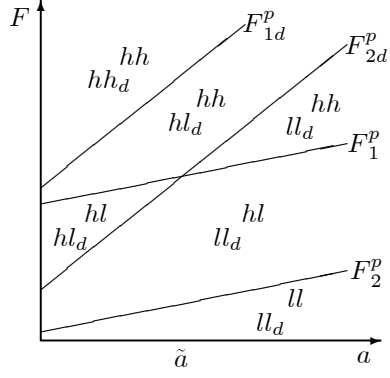
Critic values of parameter a

6.2   Graphs

Figure 2a
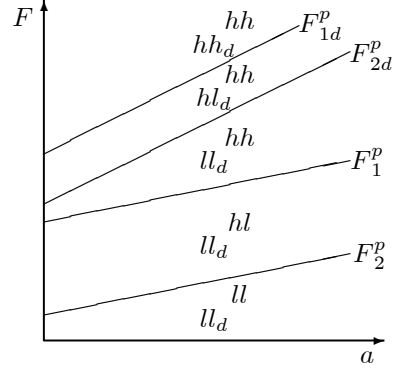Bertrand competition: $\tilde{a} > c_h$

Figure 2b
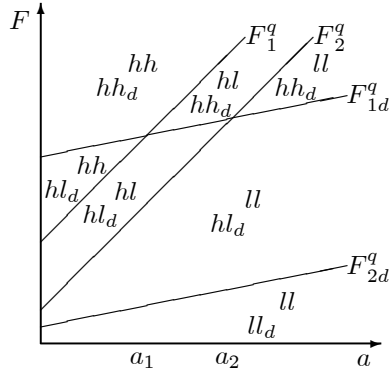Bertrand competition: $\tilde{a} \leq c_h$
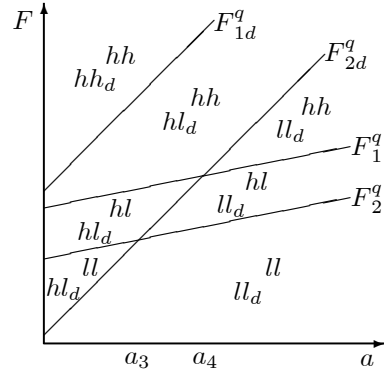

Figure 3a
Cournot competition: $b < \bar{b}$

Figure 3b
Cournot competition: $b > \bar{b}$

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