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Centralized vs. Decentralized Competition for Price and Lead-time Sensitive Demand

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We study two firms that compete based on their price and lead-time decisions in a common market. We explore the impact of the decentralization of these decisions, as quoted by the marketing and production departments, respectively, comparing three scenarios: (i) Both firms are centralized, (ii) only one firm is centralized, (iii) both firms are decentralized. We find that under intense price competition, firms may suffer from a decentralized strategy, particularly under high flexibility induced by high capacity, where revenue based sales incentives motivate sales/marketing for more aggressive price cuts resulting in eroding margins. On the other hand, when price competition in the market is less intense than lead-time competition, a decentralized decision making strategy may dominate a centralized decision making strategy.

Key words: price, lead-time, competition, centralized/decentralized decision making

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1. Introduction

Recent business trends and advances in consumer behavior modeling have shown that demand for goods and services, and in turn, profits of companies, are shaped by price and lead-time decisions. Quoting effective prices and reliable lead-times to match supply and demand is especially important as many companies are moving from a make-to-stock (MTS) to a make-to-order (MTO) model to reduce costs, increase profits, and improve market responsiveness (Martin 2000, Vinas 2006). Customers want a tailor-made product that precisely fits their needs, desires, and budgets and they want it delivered without waiting (Murphy 2000). In fact, the ability to offer customized products with short lead-times is becoming an important area of competitive differentiation among suppliers in many industries (Andel 2002). Mike Eskew, the chairman and chief executive officer of UPS, explains: "Globalization has raised the competitive stakes, forcing companies to compete on more than just product features and price. Companies can achieve competitive differentiation based on how well they deliver the right product to the right place at the right time." (Eskew 2004).

Ideally, a firm should take a global perspective and coordinate its decisions on price and lead-time quotes for increased profitability. In reality, however, different divisions of large companies all too often fail to communicate on important business decisions (Kempf 2005, Chatterjee et al. 2002). One of the reasons tied to the downfall of Silicon Graphics Inc. was its highly independent product divisions, which did not coordinate introduction schedules and led to stacked products on the manufacturing floor by the end of the year. When the salespeople's assurance that products would ship on time lost credibility, customers started switching to competitor products (Hof 1997).

In addition to communication failures, conflict can arise between the marketing and operations functions as a result of the internal compensation schemes. Nell Williams, Marriott's VP of Global Revenue Management Organization, points out for the hospitality industry: "Salespeople have historically been compensated on volume and not profit, and that's part of the reason why they are at odds with revenue managers. The whole hotel wins when both disciplines work together towards the same goal and that is bringing the most profitable business into the hotel." (Williams 2006). Similarly, in several manufacturing oriented firms, manufacturing is evaluated based on costs and operational efficiency while marketing is evaluated based on revenue and volume (Balasubramanian and Bhardwaj 2004, Karmarkar and Lele 2004). From a consulting point of view, Yama et al. (2005) discuss how frequently they come across the misalignment of a company's strategic goals and the pricing performance metrics that drive individual behavior, where the sales force is incentivized on order volume with no tie to profitability metrics. Similarly, Hogan and Nagle (2005) and Preslan and Newmark (2004) point out that the key to driving profitability is to compensate sales people based on profit contribution or margin and not just for sales volume or revenue.

In many firms, the division of functional responsibilities and conflicting incentives lead to decentralization of price and lead-time decisions, meaning that these decisions are made independently by separate agents with different objectives. Marketing quotes prices so as to maximize revenue, while manufacturing quotes lead-times so as to ensure reliable delivery given the production capacity and the incurred production costs. Clearly, a firm would benefit from coordinating decentralized decisions by setting the proper incentives. Several studies have noted performance improvements when marketing and manufacturing divisions work together (Otley 2002, Malhotra and Sharma 2002, Hausman et al. 2002). However, there are very few studies that measure the impact of decentralization of price and lead-time decisions (Liu et al. 2006, Pekgün et al. 2006).

We consider a duopoly where firms compete on the basis of their prices and uniform delivery time guarantees in a common market. Pekgün et al. (2006) found that for a monopolistic firm, when price and lead-time decisions are decentralized, i.e., made by the marketing and production departments, respectively, lower prices and longer lead-times are quoted generating larger demand but lower profits as compared to a centralized setting in which prices and lead-times are quoted by a single decision maker. In this paper, we extend their work to a competitive setting. We explore if and when decentralization can be more profitable than centralization under competition. We compare three scenarios in terms of price and lead-time decisions and firm profits: (i) both firms are centralized, (ii) a hybrid scenario where only one firm is centralized, (iii) both firms are decentralized.

We show the existence of a unique Nash Equilibrium under all scenarios. Each firm responds to a price or lead-time decrease (increase) by its competitor with a price and lead-time decrease (increase), and the game is played in a monotonically decreasing (increasing) fashion until equilibrium is reached. We find that under intense price competition, firms may suffer from a decentralized strategy, particularly under high flexibility induced by high capacity, where revenue based sales incentives motivate sales/marketing for more aggressive price cuts resulting in eroding margins. Fierce price competition has been observed in several markets, where firms cut prices aggressively in response to competition. For example, Unilever suffered from fierce price competition in European supermarkets against other household and personal care suppliers such as Procter & Gamble as well as suppliers in other grocery categories, which resulted in eroding margins (Murphy 2004).

We find that *when price competition is more intense than lead-time competition*, the net effect of lower prices and longer lead-times under a decentralized strategy will be a decrease in the derived market potential of the competitor that drives prices downward, hurting the profits of both firms in the market. Nagle and Hogan (2006) discuss that fierce price competition may be more appropriate for low cost firms. We find that low cost firms may benefit from a decentralized strategy without hurting margins. However, although a decentralized strategy may generate higher market share, it may not account for the decrease in margins as the costs get higher. Particularly, losses may be significant for high capacity firms, where marketing will be more aggressive in pricing to generate more demand. Therefore, a centralized strategy becomes crucial for more profitable use of capacity, leading to shorter lead-times as a competitive advantage. For example, the threat of competition from low cost overseas manufacturers, particularly China, has been an ongoing concern for American manufacturers. Chinese manufacturers offer low prices, while domestic manufacturers can offer shorter delivery times. For the metal parts industry, intense global competition has hindered domestic producers from increasing their prices, and motivated them for shortening lead-times to improve competitiveness (Stundza 2005). Similarly, the CEO of American Leather, Bob Duncan, discusses that although it is not possible to beat the Chinese furniture makers on price, no Chinese furniture maker can deliver a sofa in four weeks: "The fact that you're across the ocean is adding a month to your lead time almost by definition... What I'm most proud of is the fact that we still do ship in two to three weeks" Postrel (2005). Thus, a centralized strategy becomes important for domestic manufacturers to offer a shorter lead-time at the expense of higher prices instead of going into aggressive price cuts.

In contrast, we find that *when price competition in the market is less intense than lead-time competition*, a decentralized decision making strategy may dominate a centralized decision making strategy. For example, a firm may choose to compete against the low prices of a higher capacity firm with a decentralized strategy to maximize its market share. A firm with an increased advantage over price competition, where customers are less sensitive to its prices in comparison to competition, can also benefit from a decentralized strategy.

The paper is organized as follows. In Section 2, we provide a review of the literature on price and lead-time competition. In Section 3, we introduce our model and assumptions. We describe the best response of a firm, given its competitor's price and lead-time decisions for both the centralized and decentralized settings in Section 4. In Section 5, we present the equilibrium solution for the duopoly problem and provide a comparison of different decision making scenarios. We also discuss the effect of capacity and production cost on the price and lead-time competition in the market. After analyzing some special cases, namely, unconstrained price competition and lead-time only competition for analytical insights in Section 5.3, we provide our conclusions in Section 6.

2. Literature Review

Most of the previous research on price and lead-time decisions in a competitive steady-state setting uses queueing models and considers centralized firms. Several researchers model lead-time decisions via a "waiting time standard" as determined by the time spent in a queue given the allocated capacity. Instead of modeling customers' sensitivity to price and lead-time independently, some researchers aggregate price and waiting time into a "full price". Loch (1991) and Armony and Haviv (2003) study two competing service providers operating as M/G/1 in the former and M/M/1 in the latter, and two customer classes, where each class has a given waiting cost rate and chooses a provider based on its full price. In the latter study, competition is modeled in two stages such that providers compete on the basis of service charges in the first stage, and customer classes compete with allocation decisions in the second stage. Chen and Wan (2003) study two M/M/1 service providers that compete for a single customer class on the basis of full price, but charge the same full price in the long run. Providers are differentiated by their capacities, values of service and unit costs of waiting. Lederer and Li (1997) consider N M/G/1 service providers, which compete for N customer classes by choosing prices, production rates and scheduling policies. They assume that providers are full price takers. While capacity is treated as constant in these studies, Cachon and Harker (2002) present the option of outsourcing to a supplier for two competing firms, which experience scale economies as their unit costs are decreasing in the demand volume. Two types of competition are analyzed: an M/M/1 queueing game with price and time sensitive demand and an EOQ game with fixed ordering costs and price sensitive demand. For the queueing game, each firm's demand rate is modeled as a function of the full prices of both firms with two forms: linear and truncated logit.

In contrast to the full price approach of the first set of papers, Allon and Federgruen (2004, 2006) treat price and waiting time as independent factors in customer demand, which decreases in own-price/time effects, increases in cross-price/time effects and accounts for other factors such as brand in the intercept. Both papers model N M/M/1 firms, the former for a single customer class and the latter for N customer classes. In Allon and Federgruen (2004), rather than using waiting time as is in the demand model, the authors use service level, which is defined as the difference between an upper bound benchmark for waiting time and the firm's actual waiting time standard, and expressed in terms of the expected waiting time or the ϕ fractile of the waiting time distribution. A cost per unit time proportional to adopted capacity is included in the profit function. Three types of competition are studied: Two-stage games, where service level is set in the first stage while price is set in the second stage and vice versa, and simultaneous price and service competition. In Allon and Federgruen (2006), waiting time is explicitly incorporated into the demand model. A class dependent cost and a cost per unit time proportional to capacity are included in the profit function. Price only competition, waiting time only competition, and simultaneous competition are studied using dedicated or shared facilities for customer classes.

Along the same line of research, So (2000) extends the work of So and Song (1998) to a competitive setting of N M/M/1 firms using a multiplicative competitive interaction model, where the market size is constant and shared among firms based on their "attraction" given their quoted prices and lead-times. Moreover, each firm needs to meet a predetermined service level so as to satisfy a certain percentage of the orders on time. Boyaci and Ray (2003) also use a service level constraint to study two substitutable products, which are differentiated in the quoted prices and lead-times and served by dedicated capacities in an M/M/1 firm. However, in this case, the objective is to maximize the overall profit generated from both products. Tsay and Agrawal (2000) study a distribution system, where a manufacturer supplies a common product to two retailers who use price and service quality (effort) to directly compete for end customers in a deterministic setting.

Some researchers model duopolies, where customers strategically choose the firm that maximizes their expected utilities. In Li and Lee (1994), the utility function is based on price, quality and response time. Customers can observe the congestion levels of the firms, may jockey from one queue to another and their choices are dynamic. Besbes and Zeevi (2005) model utility as a function of price and waiting time, where price is the only decision variable. Their focus is on the effect of uncertainty in model demand parameters on the decisions and the competition. Ho and Zheng (2004) consider a lead-time only utility model, where customers are sensitive to quoted lead-time and service quality, which is defined as the difference between the quoted lead-time and customer expectation. The objective of each firm is to maximize its demand rate.

All of the papers discussed above study competition among centralized firms. Papers that study competition among decentralized firms mainly focus on price and/or quantity decisions. Bhardwaj (2001) and Mishra and Prasad (2005) consider the problem of delegating pricing decisions to the salesforce in a duopoly within a principal agent framework. The demand for each firm is modeled as a function of the prices and the salesperson effort levels of both firms. Parlar and Weng (2006) consider a single period model for the price decision faced by the marketing department and the production quantity decision faced by the production department. They allow the two departments to coordinate their decisions to compete against another firm with a similar organizational structure for price sensitive demand. They compare the results under marketing - production coordination and no coordination. McGuire and Staelin (1983) and Boyaci and Gallego (2004) consider two supply chains, which consist of a wholesaler/manufacturer and a retailer, and compete on the basis of price in the former and customer service, namely fill rate, in the latter. McGuire and Staelin (1983) use a deterministic framework, while Boyaci and Gallego (2004) use a queueing model with generic lead-time distribution. Three scenarios are analyzed: 1) Both supply chains are uncoordinated, i.e., each party selects their own decisions (prices in McGuire and Staelin (1983) and service and inventory levels in Boyaci and Gallego (2004)), 2) a hybrid scenario where only one supply chain is coordinated, and 3) both supply chains are coordinated. Bernstein and Federgruen (2006) study a similar multi-period setting as in Bernstein and Federgruen (2004), where there exist a common supplier and competing independent retailers. Customer demand depends on all of the firms' prices and a measure of service level, namely fill rate, and is modeled in three forms: (i)

Attraction type multinomial logit (ii) linear model with own and cross effects (iii) log separable. They consider price competition only as well as simultaneous price and service competition and develop coordination mechanisms. Finally, Balasubramanian and Bhardwaj (2004) model a duopoly in which firms with decentralized marketing and manufacturing functions with conflicting objectives compete on the basis of price and quality in a deterministic setting. To the best of our knowledge, our work is the first to study centralized and *decentralized* decision making comparatively under price and lead-time *competition* in a steady state setting.

3. Model Assumptions

We consider two competing firms in a MTO setting. Capacity is assumed to be constant, while price and lead-time are decision variables. Firm operations are modeled as an M/M/1 queue. Subscripts C and D denote centralized and decentralized settings, respectively. We use the following notation throughout the text:

Parameters: $(i, j \in \{1, 2\})$

a_i : base market potential for firm i (maximum attainable demand under no cross-effects)

b_i : own price sensitivity of demand for firm i

c_i : own lead-time sensitivity of demand for firm i

β_{ij} : cross price sensitivity of demand for firm i, $j \neq i$

γ_{ij} : cross lead-time sensitivity of demand for firm i, $j \neq i$

m_i : unit production cost of firm i

μ_i : capacity of the production system (service rate) of firm i

s_i : service level (the minimum probability of meeting the quoted lead-time) for firm i

k_i : used for computational simplicity, $k_i = \ln(1/(1 - s_i))$

Decision Variables

p_{il} : price quoted by the marketing department of firm i $(l = C, D)$

L_{il} : lead-time quoted by the production department of firm i $(l = C, D)$

λ_{il} : mean demand rate for firm i $(l = C, D)$

π_{il} : profit achieved by firm i $(l = C, D)$

π_i^M, π_i^P : profit achieved by the marketing and production departments, respectively, of firm i

If the two firms are identical, i.e., have the same parameter values, we drop the firm-specific subscripts i, j. Our demand model is given by:

$$\lambda_i = a_i - b_i p_i - c_i L_i + \beta_{ij} p_j + \gamma_{ij} L_j \quad j = 3 - i,\ i = 1, 2 \tag{1}$$

Equation (1) is linear in the quoted price and lead-time and cross price and cross lead-time effects, which is similar to the demand models used in Tsay and Agrawal (2000), Boyaci and Ray (2003) and Balasubramanian and Bhardwaj (2004). However, we do not require the base market potentials, a_i, or other demand parameters of the firms to be equal, generalizing earlier models. In that respect, our demand model is closest to the one used in Allon and Federgruen (2004), where we use a linear form of their general concave waiting time function with an intercept, i.e., the base market potential, and no explicit upper bound for the waiting time standard. However, note that the research problems in the two papers are different. Allon and Federgruen (2004) use the ϕ fractile of the waiting time distribution, which would correspond to our service level s, to determine the capacity required and they incorporate it into the profit function of each firm via a linear capacity cost. On the other hand, we choose what lead-time to quote given the level of capacity and the required service level. In the next section, we show that the service level constraint is tight at optimality. Thus, for a specific capacity cost, our centralized model may generate the same solution as in their model, although different results may be obtained under different cost levels. Moreover, our focus is on the comparison of centralized and decentralized decision making, while they do not consider the decentralization of price and waiting time decisions.

In Boyaci and Ray (2003) and Tsay and Agrawal (2000), the total market size is decreasing in the quoted price and lead-time (service in the latter) of both firms but is independent of cross-effects, while in Balasubramanian and Bhardwaj (2004) the total market size is constant. As we allow demand parameters to vary between the two firms, the total market size in our model is not constant:

$$\lambda_1 + \lambda_2 = (a_1 + a_2) - (b_1 - \beta_{21})p_1 - (b_2 - \beta_{12})p_2 - (c_1 - \gamma_{21})L_1 - (c_2 - \gamma_{12})L_2 \quad (2)$$

One unit decrease in the price of Firm 1, p_1, results in an increase of b_1 customers (units of demand) for Firm 1 of which β_{21} customers switch from Firm 2. Thus, the "new" customers that Firm 1 gains is given by $b_1 - \beta_{21}$. Note that, everything else being constant, one unit of decrease in the price of Firm 1 steals β_{21} customers from Firm 2, while one unit of decrease in the price of Firm 2 steals β_{12} customers from Firm 1. The difference in β_{12} and β_{21} would be determined by other attraction factors, such as brand, loyalty or location. We make the following assumptions[1]:

A1. There is a variable production cost for both firms.

A2. All parameters are positive and common knowledge to both parties:

$$a_i > 0,\ b_i > 0,\ c_i > 0,\ \beta_{ij} > 0,\ \gamma_{ij} > 0,\ m_i > 0,\ \mu_i > 0,\ 0 < s_i < 1 \quad j = 3 - i,\ i = 1, 2$$

A3. $b_i > \beta_{ji},\ c_i > \gamma_{ji} \quad (i, j \in \{1, 2\},\ j \neq i)$

A unit increase (decrease) in the price/lead-time quoted by a firm creates a larger decrease (increase) in its own demand than an increase (decrease) in its competitor's demand. This assumption also ensures that the total market size is decreasing in the price and lead-time of both firms.

A4. $b_i > \beta_{ij},\ c_i > \gamma_{ij} \quad (i, j \in \{1, 2\},\ j \neq i)$

The demand generated by a firm is affected more by a unit change in its own price/lead-time than by a unit change in its competitor's price/lead-time.

A5. (Positive Demand Assumption) There is positive demand for both firms in the market to provide their services when the smallest reasonable prices, (m_1, m_2), and the shortest lead-times that satisfy their service level constraints, $(k_1/\mu_1, k_2/\mu_2)$, are chosen:

$$\lambda_i = a_i + \beta_{ij} m_j + \gamma_{ij} k_j/\mu_j - b_i m_i - c_i k_i/\mu_i > 0 \quad j = 3 - i,\ i = 1, 2$$

Note that if this assumption is not satisfied for either firm, then, none of the firms can generate positive profits and participate in the game. If it is not satisfied for one firm only, then that firm

[1] Assumptions A3 and A4 are also used in Allon and Federgruen (2004) for the price terms.

is not going to participate in the game, which will turn the problem into a monopoly decision for the other firm. As our focus is on competition and not a monopoly setting, we only consider those cases where Assumption A5 is satisfied for both firms.

Pekgün et al. (2006) show that the marketing Stackelberg equilibrium dominates the production Stackelberg equilibrium for the monopoly. Therefore, we model marketing as the leader and production as the follower in this paper.

4. Firm i Problem

We first analyze the optimization problem for firm i, given the price and lead-time decisions of firm $j \neq i$, $i = 1, 2$. In the centralized setting, marketing and production decisions are considered simultaneously with the objective of maximizing profit:

$$\max_{(p_{iC} \geq m_i, L_{iC} \geq 0)} (p_{iC} - m_i)\lambda_{iC} \quad \text{s.t. } (\mu_i - \lambda_{iC})L_{iC} \geq k_i$$

In the decentralized setting, first, marketing makes a price decision to maximize its revenue. Then, production makes a lead-time decision as its best response to this price decision given its own profit. Marketing's problem is:

$$\max_{p_{iD} \geq m_i} p_{iD}\lambda_{iD} \tag{3}$$

Giving p_{iD} as an incentive for generating positive demand, production's problem becomes:

$$\max_{L_{iD}(p_{iD}) \geq 0} (p_{iD} - m_i)(\lambda_{iD}) \quad \text{s.t. } (\mu_i - \lambda_{iD})L_{iD} \geq k_i \tag{4}$$

Note that as $p_{j\cdot}$ and $L_{j\cdot}$ are given, we can redefine the market potential for firm i under both settings as $A_i = a_i + \beta_{ij}p_{j\cdot} + \gamma_{ij}L_{j\cdot}$. Then, the generated demand becomes $\lambda_{i\cdot} = A_i - b_i p_{i\cdot} - c_i L_{i\cdot}$, which reduces firm i problem to the monopolistic firm problem in Pekgün et al. (2006)[2].

Proposition 1. *Given $p_{j\cdot}$ and $L_{j\cdot}$, the optimal demand generated by firm i under the centralized setting, λ^*_{iC}, is given by the unique root of $f_{iC}(\lambda_{iC})$ on the interval $[0, \mu_i]$, where*

$$f_{iC}(\lambda_{iC}) = (A_i - 2\lambda_{iC} - m_i b_i)(\mu_i - \lambda_{iC})^2 - c_i k_i \mu_i \tag{5}$$

[2] All proofs can be found in the online appendix at "http://www2.isye.gatech.edu/people/faculty/Pinar_Keskinocak/competitive-appendix.pdf".

Under the decentralized setting, the optimal demand generated by firm i is given by $\lambda^*_{iD} = \min\{\lambda^0_{iD}, \bar{\lambda}\}$*, where* $\bar{\lambda} = \frac{A_i - b_i m_i + \mu_i - \sqrt{(A_i - b_i m_i - \mu_i)^2 + 4c_i k_i}}{2}$ *and* λ^0_{iD} *is the unique root of* $f_{iD}(\lambda_{iD})$ *on the interval* $[0, \mu_i]$*, where*

$$f_{iD}(\lambda_{iD}) = (A_i - 2\lambda_{iD})(\mu_i - \lambda_{iD})^2 - c_i k_i \mu_i \tag{6}$$

The optimal lead-time and price under both settings are then given by

$$L^*_{i\cdot}(\lambda^*_{i\cdot}) = \frac{k_i}{\mu_i - \lambda^*_{i\cdot}} \qquad p^*_{i\cdot}(\lambda^*_{i\cdot}) = \frac{A_i - \lambda^*_{i\cdot} - c_i L^*_{i\cdot}(\lambda^*_{i\cdot})}{b_i} \tag{7}$$

Note that the best response of firm i in a decentralized setting results in lower prices and longer lead-times as compared to a centralized setting similar to Pekgün et al. (2006).

OBSERVATION 1. *The optimal prices, lead-times, generated demand and the optimal profit under the centralized and decentralized settings increase in* $p_{j\cdot}$, $L_{j\cdot}$, β_{ij} *and* γ_{ij}.[3]

This observation directly follows from the monopolistic firm results in Pekgün et al. (2006), where it is shown that the optimal decisions and the firm profit increase in the market potential. An increase in the sensitivity of firm i's customers to its competitor's prices/lead-times and/or a direct increase in its competitor's quoted prices/lead-times results in an increase in firm i's demand as more customers switch from firm j to firm i. Thus, the quoted lead-time and price increase. (Alternatively, when its competitor cuts its prices or lead-times, firm i answers with a price and lead-time decrease.). Price cutting in response to competition has been observed in several industries. In 2002, after Sony announced that it would cut the price of its PlayStation 2 game console from $299 to $199, Microsoft matched Sony's markdown the next day for its Xbox console at E3, which was followed by Nintendo's response of reducing the price of its GameCube platform from $149 to $50 (Rudy 2002). Similarly, in 2004, Wal-Mart's price cut in its standard DVD rentals-by-mail plan by 7.5% was followed by similar price cuts in the plans of its competitors, Netflix and Blockbuster

[3] Note that under the decentralized setting, if $\lambda^*_{iD} = \bar{\lambda}$, i.e., $p^*_{iD} = m_i$, for a given range of A_i, then optimal lead-times and generated demand still increase in competitor decisions and cross sensitivities. However, the optimal price and profit are not affected within this range of A_i.

(Borland 2004). In order to gain a competitive advantage, companies have also strived to improve their processes to cut their lead-times/service times. For example, the big three of the U.S. automobile industry (Chrysler, Ford and General Motors) reduced their lead-times from 61 months to 52 months in order to compete against the low lead-times of Japanese manufacturers (Fine et al. 1996).

Note that although So (2000) uses an attraction type demand model, Observation 1 is consistent with his findings. As the "attractiveness" of its competitor increases, i.e., a decrease in the $\beta_{ij}p_{j\cdot} + \gamma_{ij}L_{j\cdot}$ term for our model, firm i needs to compete with a lower price and lead-time.

5. Duopoly Problem

Under competition, both firms simultaneously announce their price and lead-time decisions to the market. Equilibrium is reached when none of the firms has an incentive to deviate from its decisions. We compare three scenarios: (i) both firms are centralized (CC), (ii) only one firm is centralized (where CD denotes Firm 1 as centralized and Firm 2 as decentralized and DC vice versa), (iii) both firms are decentralized (DD). We assume that in a decentralized firm, marketing first sets the price and then production sets the lead-time before announcing the quotes to the market and demand is realized. Note that this decentralized game framework is different from the one in McGuire and Staelin (1983) and Boyaci and Gallego (2004), where competition occurs in two stages; retail competition followed by manufacturer competition with manufacturer as the Stackelberg leader. As we model marketing and production as functions of the same firm, we consider one unified stage of competition after prices and lead-times are determined within each firm in a Stackelberg framework with marketing as the leader.

The equilibrium solution is given by the simultaneous solution of the price and lead-time equations for $i = 1, 2$ for the related settings in Proposition 1. As these equations do not have a closed-form solution, to draw insights about the equilibrium decisions and profits, we solve this game using an iterative procedure, similar to the one in So (2000), where the game is repeatedly played starting at an initial solution until the Nash Equilibrium is reached. Note that this procedure is also generalizable to the N-firm problem. We present the procedure only for two firms under centralized and decentralized settings:

Iterative Procedure for Computing the Nash Equilibrium:

1. (Initialization) Set $p_{il} = m_i$ and $L_{il} = k_i/\mu_i$ for $i = 1, 2$ and $l = C, D$.

2. (Iterative Step) Without loss of generality, start with firm $i = 1$. Calculate the best response of firm i, p_{il} and L_{il}, as given by the solution of Equations (5) and (7) for $l = C$, and of Equations (6) and (7) for $l = D$ using the current values of p_{jl} and L_{jl} for firm $j = 3 - i$. Update the values of p_{il} and L_{il}. Repeat this for i=2.

3. (Convergence criteria) Repeat Step (2) until the profits of both firms differ from their previous values by less than a predetermined tolerance level ϵ.

PROPOSITION 2. *The iterative procedure described above converges to the unique Nash Equilibrium for the simultaneous price and lead-time competition game under all decision making scenarios.*

Given that prices and lead-times are bounded below and above, when the game is iteratively played, the optimal decisions and profits monotonically increase or decrease (depending on the starting point) for both firms converging to the unique Nash Equilibrium.

PROPOSITION 3. *For identical firms, the Nash Equilibrium solution is symmetric under CC and DD. As compared to scenario CC, the lead-time quoted under DD is longer, the price is lower and the demand generated is larger. On the other hand, under a hybrid scenario, the centralized firm quotes higher prices and lower lead-times than the decentralized firm, which leads to lower demand and not always higher profits.*

We demonstrate the second part of Proposition 3 with the following example in Table 1.

The first point to note from Table 1 is the significant decrease in profits when β (cross-price sensitivity) decreases. It follows from Observation 1 that the best response of firm i to its competitor's decisions decreases as β decreases, which in turn, results in a decrease in its competitor's best response and profit. When they sequentially play the game, the optimal decisions and profits

Table 1 Equilibrium Decisions and Profits under CD for Identical Firms.

	Firm 1 (C)				**Firm 2 (D)**			
β	L^*_{1CD}	p^*_{1CD}	λ^*_{1CD}	π^*_{1CD}	L^*_{2CD}	p^*_{2CD}	λ^*_{2CD}	π^*_{2CD}
3	0.252	32.214	63.108	1080.007	0.741	30.743	70.957	1109.984
2	0.086	25.198	40.001	403.933	0.395	20.370	67.420	355.318

$a = 100,\ b = 4,\ c = 4,\ m = 15.1,\ s = 0.95, \mu = 75, \gamma = 1.$

are monotonically decreasing until the equilibrium is reached. Thus, we observe lower profits under a lower β. Conversely, we can explain this phenomenon as follows. When the intensity of price competition (β/b) increases, the number of customers lost through "net own" effects ($(b-\beta)/b$) decreases. It can be seen from Equation (2) that the total market size is decreasing in the quoted price of each firm by a factor of $b-\beta$. Both firms desire to capture as much demand as possible from the total market potential ($2a$) to maximize profit (revenue) in a centralized (decentralized) setting. Thus, as β increases, $b-\beta$ decreases and each firm can charge higher prices. Furthermore, as more customers switch between the two firms but fewer customers leave the market, the generated demand by both firms increases. Thus, profits increase in β.

We also observe that the centralized firm generates higher profits than the decentralized firm when $\beta = 2$, while the opposite is true when $\beta = 3$. Under both cases, the centralized firm prices higher than the decentralized firm, which puts the decentralized firm at an advantage[4]. However, when the intensity of price competition decreases, "net own" effects become more significant and quoted prices decrease as explained above. As the capacity is high and flexible, the decentralized firm makes a more aggressive price decrease than the centralized firm, which generates a larger demand but lower profits given its lower margin. One should also note for this example that both firms would be better off under scenario CC, where each firm would achieve a profit of 1211.509 at $\beta = 3$ and 539.054 at $\beta = 2$.

In order to compare different scenarios, we use $\succ$ to represent the dominance of one scenario over the other with a scenario subscript of 12 indicating dominance for both firms.

[4] Although the decentralized firm quotes a longer lead-time than the centralized firm, the effect of lead-times on the generated demand is smaller than the effect of prices, as lead-times are already short under high capacity and the cross lead-time sensitivity is low.

Proposition 4. *Under condition (8), $CC_{12} \succ [CD, DC]_{12} \succ DD_{12}$ holds.*

$$\frac{\beta_{12}}{b_2} \geq \frac{\gamma_{12}}{c_2} \text{ and } \frac{\beta_{21}}{b_1} \geq \frac{\gamma_{21}}{c_1} \tag{8}$$

Proposition 4 states that when the percentage of customers lost through price competition (with respect to the total number of customers lost through own price effects) is greater for both firms than that lost through lead-time competition, both firms are better off under CC than under a hybrid scenario and worse off under DD. For identical firms or firms with the same sensitivity parameters of demand, this condition reduces to $\frac{\beta}{b} \geq \frac{\gamma}{c}$, which can be interpreted as in the following observation.

Observation 2. *When price competition is more intense than lead-time competition in the market, a centralized decision-making strategy is dominant for both firms.*

The best response of firm i to its competitor's decisions is lower prices and longer lead-times under a decentralized strategy as compared to a centralized strategy. When price competition is more intense than lead-time competition, the net effect of this price decrease and lead-time increase is a decrease in the derived market potential of the competitor, which results in lower prices, lead-times, demand and profits for the competitor. As the game continues in a monotonically decreasing fashion for decisions and profits, both firms end up with lower profits. Wanless (2005) suggests that firms need to coordinate pricing decisions with operational decisions under intense price competition. Nagle and Hogan (2006) discuss that matching any price cut without considering whether the cost is justified by the benefit can lead to a downward price spiral, where each competing firm cuts prices in response to one another until one stops, and it might be better to let the competitor have a price advantage at a high price than at a low one, which is consistent with our findings. Not only will each firm prefer to operate with a centralized strategy but also will prefer its competitor to employ a centralized strategy. Note that under a hybrid scenario, either firm may generate higher profits as we saw in the previous example.

We next consider condition (9):

$$\frac{\beta_{12}}{b_2} \geq \frac{\gamma_{12}}{c_2} \text{ and } \frac{\beta_{21}}{b_1} < \frac{\gamma_{21}}{c_1} \tag{9}$$

In other words, the percentage of customers that Firm 2 loses through price competition is higher than that by lead-time competition, while the opposite holds for Firm 1. We may observe this when Firm 2's reputation is based more on low prices, while Firm 1's reputation on speed of delivery, and thus, customers are more aware of competitor prices for Firm 2 and competitor lead-times for Firm 1. For example, in the express postal delivery industry, generally, FedEx has been perceived as the most time sensitive carrier in the business along with its successful tracking system, while the U.S. Postal Service (USPS) offers speed at a relatively low cost without the time guarantee and accurate tracking capability (Strout 2003, Rush Order 2006). Therefore, customers expect delivery speed and reliability from FedEx and low prices from the USPS, and are in general more sensitive to when their package is delivered by FedEx and what they pay for their delivery to USPS. In this respect, FedEx competes for time sensitive customers more intensely against UPS and DHL for which the USPS prices can be viewed as "the floor level [of pricing]" (Berman 2006). On the other hand, the USPS may face competition in price sensitive market segments through different products offered by these carriers. For example, catalog retailers who would trade delivery speed for lower rates were some of the biggest customers of the USPS "Parcel Select" service. UPS decided to target those price-sensitive large-volume shippers offering inexpensive products who do not need expedited or guaranteed delivery through its "UPS Basic" Service, which was soon followed by a similar service from FedEx (Keane 2003, Logistics Management 2004). In our context, condition (9) could apply to FedEx as Firm 1 vs. the USPS as Firm 2 in express mail services, while the latter case of catalog retailers would correspond to a market, where price competition is in general more intense than lead-time competition, i.e., condition (8).

As price competition is more effective than lead-time competition for Firm 2 under condition (9), the net effect of lower prices and longer lead-times of Firm 2's decentralized strategy is a decrease on the derived market potential of Firm 1. Thus, it holds that $CC_{12} \succ CD_{12}$ and $DC_{12} \succ DD_{12}$, as discussed in the proof of Proposition 4, and a centralized strategy is dominant for Firm 2. Similarly, if the net effect of Firm 1's decentralized strategy on the derived market potential of Firm 2 is a decrease, $CC_{12} \succ DC_{12}$ and $CD_{12} \succ DD_{12}$ and a centralized strategy is also dominant for Firm 1. On the other hand, if the net effect is positive, Firm 2 generates higher profits under DC than CC and under DD than CD. We can observe this ordering of scenarios for Firm 2 in the example in Table 2. As the percentage of customers Firm 1 loses through lead-time competition is high, Firm 2 benefits from the longer lead-times quoted by a decentralized competitor and generates the highest profits under DC. On the other hand, for Firm 1, we observe that a centralized strategy is dominant under $\beta_{12} = 2$, while a decentralized strategy is dominant under a higher $\beta_{12} = 3.9$, which is consistent with our expectations based on the previous example. Under $\beta_{12} = 3.9$, the cross-price sensitivity of customers is much lower for Firm 1 than for Firm 2, and a unit price increase by Firm 2 results in a larger number of customers to switch to Firm 1 than vice versa. Thus, Firm 1 can not only charge prices higher than Firm 2, but it can also charge prices high enough such that a decentralized strategy does not hurt margins. We can summarize our findings with the following observation.

OBSERVATION 3. *The firm with a competitive advantage over the quoted prices can benefit from a decentralized strategy in which case the competitor prefers a centralized strategy.*

Table 2 Comparison of Scenarios for Non-identical Firms with Different Cross Sensitivities.

β_{12}	γ_{12}	**Firm 1**	**Firm 2**
2	1	$CC_1 \succ DC_1 \succ CD_1 \succ DD_1$	$DC_2 \succ CC_2 \succ DD_2 \succ CD_2$
3.9	1	$DC_1 \succ CC_1 \succ DD_1 \succ CD_1$	

$a = 100,\ b = 4,\ c = 4,\ m = 15.1,\ s = 0.95,\ \mu = 30,\ \beta_{21} = 2,\ \gamma_{21} = 3.$

In the next two sections, we analyze the effect of capacity and unit production cost on the price and lead-time competition in the market.

5.1. Effect of Capacity

In this section, we analyze the effect of capacity on the competition and firm profits. First, we consider identical firms. In Figure 1, we demonstrate the change in the optimal profit of Firm 1 as capacity increases. As the firms are identical, Firm 2 generates the same profits as Firm 1 under CC and DD, while the profit curve of Firm 2 under CD corresponds to the profit curve of Firm 1 under DC. Note that in this example, the decentralized firm in a hybrid scenario generates higher profits than the centralized firm since β is high as in the first example.

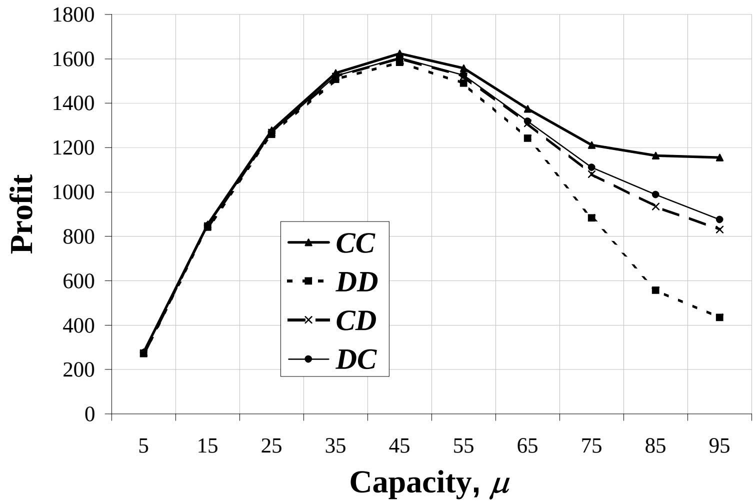
OBSERVATION 4. *Higher capacity does not always result in higher profits under competition even if it comes for free.*

In the monopolistic firm setting studied in Pekgün et al. (2006), it was found that higher capacity led to higher flexibility and in turn, higher profits for a centralized firm. However, in a competitive setting, we observe that the profit generated under CC increases up to a certain capacity level and then decreases. Thus, under competition, high capacity may increase the aggressiveness of competition as higher demand can be met and result in lower profits for both firms. This phenomenon is also observed in the industry. For example, Western Digital, one of the largest hard disk drive suppliers in the world, notes the following as a risk factor in their business: "... the hard disk drive market has experienced periods of excess capacity which can lead to liquidation of excess inventories and intense price competition. If intense price competition occurs, we may be forced to lower prices sooner and more than expected, which could result in lower revenue and gross margins." (Western Digital 2006). Note that a similar result was also found in So (2000) for firms competing in a centralized setting.

OBSERVATION 5. *A centralized strategy dominates under high capacity.*

This observation is consistent with the result in Pekgün et al. (2006), which states that the gap between the centralized and decentralized settings increases under high capacity. However, we also observe that even if one firm employs a centralized strategy under high capacity, it may suffer if its competitor employs a decentralized strategy.

Figure 1 Profit vs. Capacity for Identical Firms.



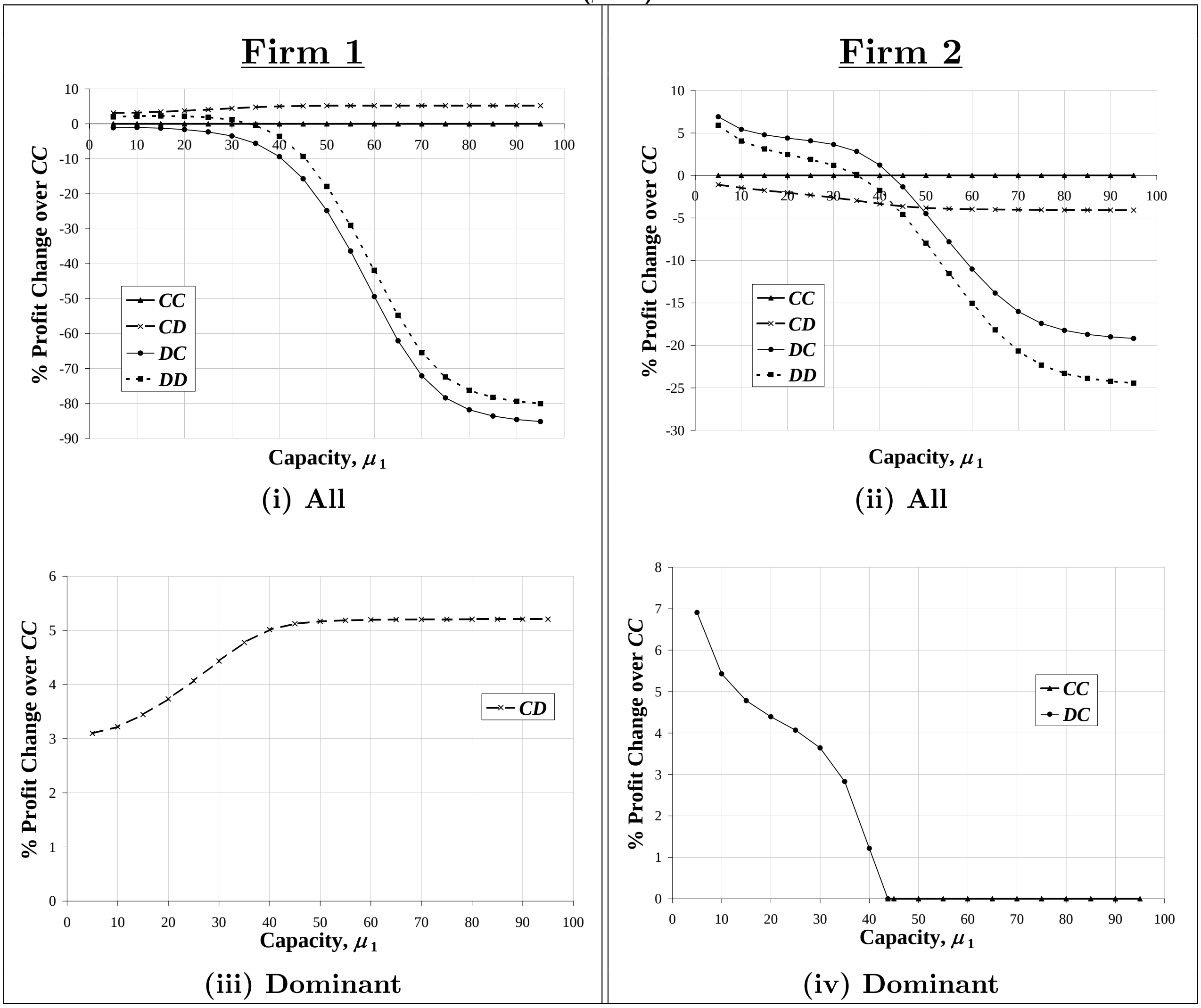
Note. Parameter values are $a=100$, $b=4$, $c=4$, $m=15.1$, $s=0.95$, $\beta=3$, $\gamma=1$.

Next, we consider the effects of a capacity difference between the two firms with all other parameters being equal. In Figures 2 (i-ii) and 3 (i-ii), we provide a comparison of all scenarios for each firm as the capacity of Firm 1 changes, while Firm 2 has a fixed capacity ($\mu_2=25$). We display the dominant scenario right below each figure on a different scale for better visibility (Figures 2 (iii-iv) and 3 (iii-iv)). Instead of providing absolute profit figures, we measure the profit generated under each scenario in the percent profit increase over CC. Note that all the following examples have price competition less intense than lead-time competition ($\frac{\beta}{b}<\frac{\gamma}{c}$) so that we can explore cases, where a decentralized strategy may be more profitable than a centralized strategy.

Figure 2 represents a parameter setting, where the intensity of price competition is low ($\beta/b=1/4$) and the significance of "net own" price effects is high ($(b-\beta)/b=3/4$). Under this setting, both firms need to quote low prices to keep customers in the market and concentrate more on their own prices than competitor prices. As the intensity of lead-time competition is high ($\gamma/c=3.9/4$), the firm with higher capacity will be able to use its competitive advantage through lower lead-times. Given that the significance of "net-own" price effects is high, both firms prefer a centralized strategy regardless of the capacity level at Firm 1, which is consistent with our observations based on Table 1[5]. Similar to our observations in the identical firm case (Figure 1), not only does Firm 1

[5] $CC_1\succ DC_1$ and $CD_1\succ DD_1$ for Firm 1, and $CC_2\succ CD_2$ and $DC_2\succ DD_2$ for Firm 2.

Figure 2 Comparison of Scenarios with respect to Firm 1 Capacity when the intensity of price competition is low ($\beta = 1$)



Note. $a = 100$, $b = 4$, $c = 4$, $m = 15.1$, $s = 0.95$, $\mu_2 = 25$, $\beta = 1$, $\gamma = 3.9$.

lose significantly with a decentralized strategy under high capacity, but it also harms its competitor (Figure 2 (i-ii)).

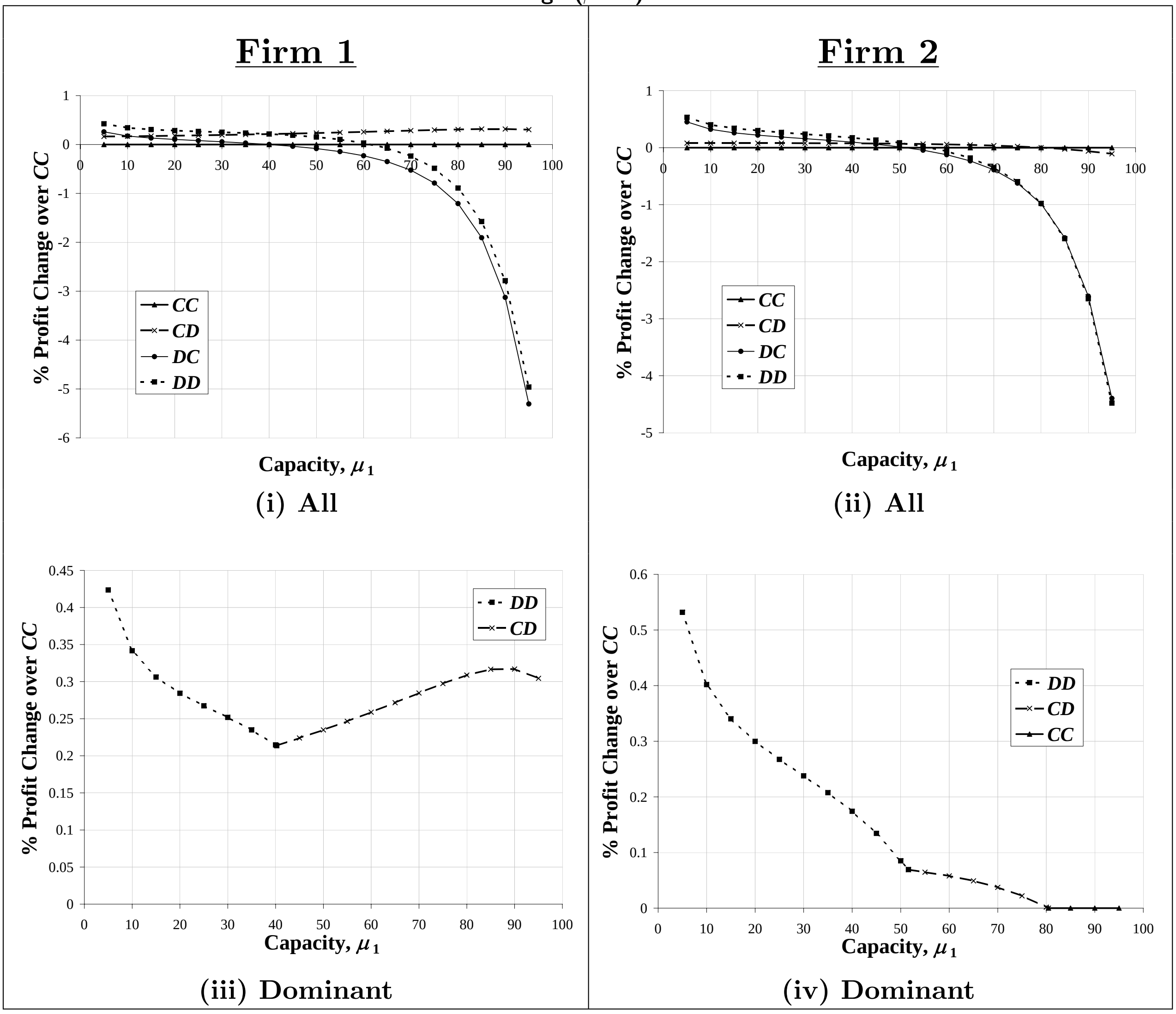
We also observe that CD is the dominant scenario for Firm 1 at all capacity levels. As more capacity becomes available, Firm 1 prefers a centralized strategy to make better use of the capacity. As the unit production cost is high, it is not able to cut prices aggressively. However, it prefers a decentralized competitor to use its competitive advantage through lead-times, as Firm 2 will quote longer lead-times with a decentralized strategy than a centralized strategy and lose more market share to Firm 1[6]. For Firm 2, DC is the dominant scenario until the capacity level at Firm 1 becomes a competitive disadvantage. In other words, Firm 2 also benefits from a decentralized competitor initially. However, after a certain point, Firm 2 loses its lead-time advantage and starts to hurt from Firm 1's decentralized strategy, as Firm 1 gains a larger market share given its aggressively low prices.

OBSERVATION 6. *When the intensity of lead-time competition is high and the intensity of price competition is low, the firm with higher capacity benefits from a centralized strategy and a decentralized competitor, while a centralized strategy is dominant for its competitor.*

In Figure 3, the intensity of price competition is high ($\beta/b = 3/4$), while the significance of "net own" price effects is low. Under this setting, higher prices can be quoted, and thus, both firms will be more aware of competitor prices and make their decisions accordingly. The firm with higher capacity will be able to use its competitive advantage through not only lower lead-times but also lower prices. We still observe that a decentralized strategy for Firm 1 under high capacity results in loss of profits for its own as well as its competitor. Moreover, Firm 1 still benefits from a decentralized competitor, however, it now prefers to employ a decentralized strategy up to a certain capacity. Lower prices under a decentralized strategy can compete with Firm 2 prices effectively without hurting profits, given that the margins are already high. Beyond this point, aggressive prices driven by the marketing department generates too much demand given the flexibility provided by high capacity, which makes a centralized strategy dominant. Firm 2 also benefits from a decentralized competitor until increasing capacity at Firm 1 becomes a disadvantage with a large number of customers switching to Firm 1, given its aggressively low prices and lead-times. Even though a decentralized strategy provides Firm 2 lower prices to compete against Firm 1, in order to keep its market share as high as possible given its limited capacity, a centralized strategy becomes more profitable when it cannot lower its prices further in response to Firm 1 ($\mu_1 \approx 80$), and instead chooses to compete with lower lead-times.

[6] Note that although Firm 2 quotes lower prices in a decentralized setting, Firm 1 is able to match those given its high capacity.

Figure 3 Comparison of Scenarios with respect to Firm 1 Capacity when the intensity of price competition is high ($\beta = 3$)



Note. $a = 100$, $b = 4$, $c = 4$, $m = 15.1$, $s = 0.95$, $\mu_2 = 25$, $\beta = 3$, $\gamma = 3.9$.

Observation 7. *When price competition is highly intense but less effective than lead-time competition, each firm may benefit from a decentralized decision making strategy until increasing capacity at one firm becomes a disadvantage.*

Concisely, although a firm may benefit from a decentralized strategy under limited capacity facing a limited capacity competitor, a centralized strategy is dominant under high capacity or while competing against a high capacity firm. Docters et al. (2004) discuss that employing centralized or decentralized pricing depends on the market, i.e., competitors, customers and economics, and point out the case of Home Depot. When Home Depot was at the stage of expansion following its foundation, it did not face strong competitors and employed decentralized pricing at the local store level. However, after starting to encounter strong and comparable competitors such as Lowe's, it switched to a centralized pricing strategy tightly controlling prices and costs at the corporate level, which is consistent with our findings.

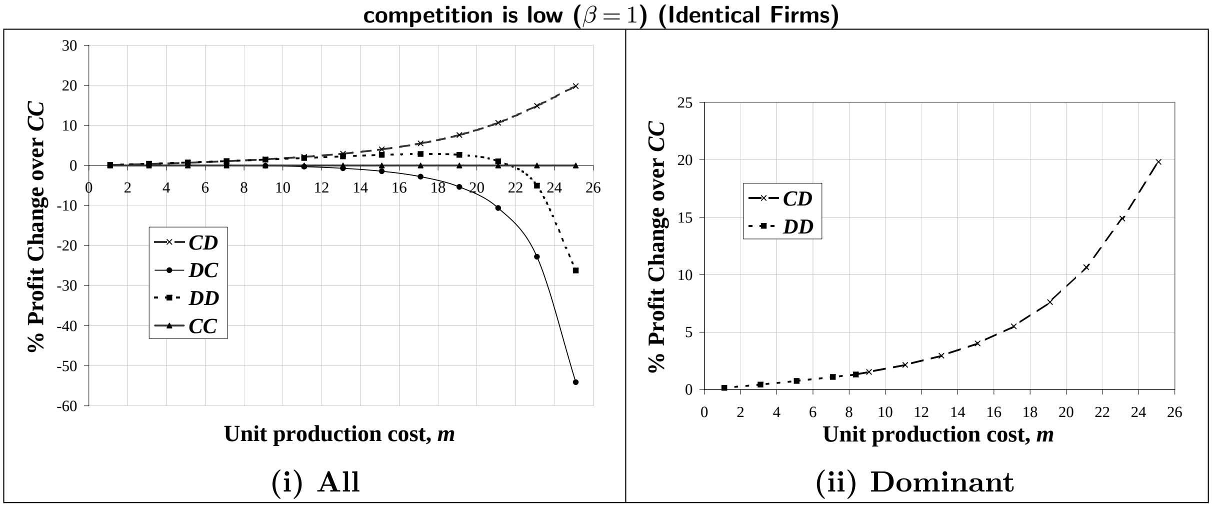
5.2. Effect of Unit Production Cost

In this section, we analyze the effect of unit production cost for identical firms. In Figures 4 and 5, we provide a comparison of scenarios as measured in the percent profit increase over CC. Part (ii) in each figure uses a different scale and displays the dominant scenario at different cost levels. As we noted in the previous section, both firms generate the same profits under CC and DD, and one firm's profit under CD corresponds to the profit of the other under DC. We also choose parameters such that $\frac{\beta}{b} < \frac{\gamma}{c}$ and the production capacity is relatively tight.

In Figure 4, the intensity of price competition is low. Similar to our observations for capacity, we see that firms may lose significantly under a decentralized strategy, when the unit production cost is high as a result of eroding margins. Moreover, a centralized firm benefits more from competition if its competitor is decentralized. The gap between the centralized and decentralized firms in a hybrid scenario increases as the unit production cost increases. On the other hand, even when the operating costs are high, firms may benefit from a decentralized strategy when the intensity of price competition is high as displayed in Figure 5. Note that under DD, the equilibrium decisions do not change with respect to the unit production cost, while the profits decrease as the margins decrease. Thus, in this case, we can argue that a centralized strategy behaves over-protective of margins up until the unit production cost reaches around 19.

Figures 4 and 5 also show that as the unit production cost gets very low, the profit difference between the scenarios becomes insignificant, which is expected as the best response function under the centralized setting, Equation (5), approaches the one under the decentralized setting, Equation (6), as the unit production cost decreases. In fact, a margin based incentive for marketing will generate the same best response function for both settings. Thus, even under high capacity or high production costs, firms may benefit from a decentralized decision making strategy, where the incentive for marketing incorporates the margin and not just revenue. Michael V. Marn, a partner in McKinsey's Cleveland office, mentions that companies can be very successful with centralized or decentralized pricing. However, when they employ decentralized pricing, it is important to tie a higher level of incentives to the compensations of the salespeople (Marn and Reibstein 2004). Indeed, many firms are starting to employ price optimization software, where they can control pricing centrally specifying metrics such as revenue, volume and profit and leaving the execution to salespeople (Marn and Reibstein 2004, Reese 2001).

Figure 4 Comparison of Scenarios with respect to Unit Production Cost when the intensity of price competition is low ($\beta = 1$) (Identical Firms)



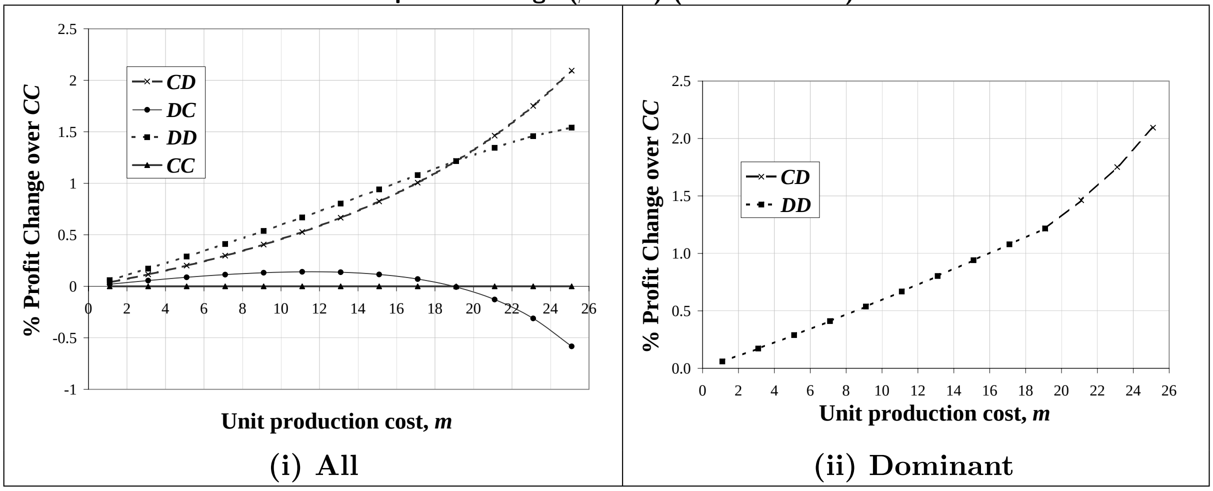
Note. $a = 100$, $b = 4$, $c = 4$, $\mu = 20$, $s = 0.95$, $\beta = 1$, $\gamma = 3.9$.

5.3. Special Cases

In this section, we discuss some special cases for analytical insights.

5.3.1. Price Competition for Uncapacitated Firms In this section, we assume that both firms have constant lead-times, $L_i, i = 1, 2$, and no capacity restrictions, and thus, no reliability constraints. This corresponds to a pure marketing problem with the objective of profit maximization in the centralized setting and revenue maximization in the decentralized setting. The best response of firm i to firm j's price decision is given by

Figure 5 Comparison of Scenarios with respect to Unit Production Cost when the intensity of price competition is high ($\beta = 2.2$) (Identical Firms)



Note. $a = 100$, $b = 4$, $c = 4$, $\mu = 20$, $s = 0.95$, $\beta = 2.2$, $\gamma = 3.9$.

$$p^*_{iD} = \frac{a_i - c_i L_i + \gamma_{ij} L_j + \beta_{ij} p_{j\cdot}}{2b_i} \quad \text{and} \quad p^*_{iC} = p^*_{iD} + \frac{m_i}{2}$$

We solve for the unique equilibrium and observe the following:

- $p^*_{i\cdot}$ decreases in L_j if $\frac{\beta_{ij}}{b_j} > 2\frac{\gamma_{ij}}{c_j}$: If the percentage of customers that switch by price differentiation is twice the percentage of customers that switch by lead-time differentiation, price should be decreased as the lead-time of the competitor increases. Otherwise, price should be increased.

- $p^*_{i\cdot} - p^*_{j\cdot}$ increases in $L_j - L_i$: The intensity of price differentiation increases in the intensity of lead-time differentiation.

In Table 3, we compare all four scenarios for the optimal quoted prices and generated demand, where $A_1 = \frac{\beta_{12} b_2}{2b_1 b_2 - \beta_{12}\beta_{21}}$ and $A_2 = \frac{2b_1 b_2 - \beta_{12}\beta_{21}}{\beta_{21} b_1}$. We observe the following:

- Prices and profits are highest when both firms are centralized and lowest when both are decentralized.

- The lowest demand for firm 1 (2) and highest demand for firm 2 (1) are generated in a hybrid scenario when firm 1 (2) is centralized and firm 2 (1) is decentralized. Moreover, being the centralized firm in a hybrid scenario does not always result in higher prices or profits than being the decentralized firm.

- In the case of identical firms, where all parameters are equal for both firms including $L_1 =$

Table 3 Unconstrained Price Competition

$\mathbf{m_1/m_2}$	Price	Demand
$(0, \frac{\beta_{12}}{2b_1})$	$p_{1CC} > p_{1DC} > p_{1CD} > p_{1DD}$	$\lambda_{1CD} < \lambda_{1DD} < \lambda_{1CC} < \lambda_{1DC}$
	$p_{2CC} > p_{2DC} > p_{2CD} > p_{2DD}$	$\lambda_{2DC} < \lambda_{2CC} < \lambda_{2DD} < \lambda_{2CD}$
$[\frac{\beta_{12}}{2b_1}, A_1)$	$p_{1CC} > p_{1CD} \geq p_{1DC} > p_{1DD}$	$\lambda_{1CD} < \lambda_{1DD} < \lambda_{1CC} < \lambda_{1DC}$
	$p_{2CC} > p_{2DC} > p_{2CD} > p_{2DD}$	$\lambda_{2DC} < \lambda_{2CC} < \lambda_{2DD} < \lambda_{2CD}$
$[A_1, A_2)$	$p_{1CC} > p_{1CD} > p_{1DC} > p_{1DD}$	$\lambda_{1CD} < \lambda_{1CC} \leq \lambda_{1DD} < \lambda_{1DC}$
	$p_{2CC} > p_{2DC} > p_{2CD} > p_{2DD}$	$\lambda_{2DC} < \lambda_{2CC} < \lambda_{2DD} < \lambda_{2CD}$
$[A_2, \frac{2b_2}{\beta_{21}})$	$p_{1CC} > p_{1CD} > p_{1DC} > p_{1DD}$	$\lambda_{1CD} < \lambda_{1CC} < \lambda_{1DD} < \lambda_{1DC}$
	$p_{2CC} > p_{2DC} > p_{2CD} > p_{2DD}$	$\lambda_{2DC} < \lambda_{2DD} \leq \lambda_{2CC} < \lambda_{2CD}$
$[\frac{2b_2}{\beta_{21}}, -)$	$p_{1CC} > p_{1CD} > p_{1DC} > p_{1DD}$	$\lambda_{1CD} < \lambda_{1CC} < \lambda_{1DD} < \lambda_{1DC}$
	$p_{2CC} > p_{2CD} \geq p_{2DC} > p_{2DD}$	$\lambda_{2DC} < \lambda_{2DD} < \lambda_{2CC} < \lambda_{2CD}$

$L_2 = L$, we have $m_1 = m_2$ and $m_1/m_2 = 1 \in (A_1, A_2)$. We observe that being decentralized generates higher demand for both firms than being centralized. Although the decentralized firm in a hybrid scenario quotes lower prices than the centralized firm, it may generate higher profits if

$$\frac{bm}{a-(b-\beta)m-(c-\gamma)L} < \frac{\beta}{b}$$

Note that as β increases, the term on the left-hand side decreases, while the term on the right-hand side increases making it more likely for the inequality to hold. This result is consistent with our findings based on Table 1 that as the intensity of price competition, (β/b), increases, the decentralized firm in a hybrid scenario may generate higher profits than the centralized firm.

We finally note that if the firms can also choose their lead-times optimally, then $L_{1\cdot}^* = L_{2\cdot}^* = 0$.

5.3.2. Lead-time Competition When prices are constant, the problem turns into a pure production problem. As long as $p_i \geq m_i$, $i = 1, 2$, which we can assume to avoid triviality, the problem for the best response of firm $i = 1, 2$ under the centralized and decentralized settings is given by Equation (4) for $i = 1, 2$. Therefore, the equilibrium solution under all decision making scenarios is equal and given by the simultaneous solution of Equation (10) for $i, j = 1, 2$, $j \neq i$.

$$c_i L_i^2 - (a_i + \beta_{ij} p_j + \gamma_{ij} L_j - b_i p_i - \mu_i) L_i - k_i = 0 \tag{10}$$

For identical firms with the same parameters and prices, the optimal lead-times are given by:

$$L_1^* = L_2^* = \frac{a-(b-\beta)p-\mu+\sqrt{(a-(b-\beta)p-\mu)^2+4k(c-\gamma)}}{2(c-\gamma)}$$

We observe that the optimal lead-time decreases in the quoted price, increases in the cross price sensitivity and cross lead-time sensitivity.

6. Conclusions

In this paper, we study two firms that compete on the basis of price and lead-time decisions in a common market. We analyze the impact of the decentralization of price and lead-time decisions, as quoted by the marketing and production departments, respectively, when one or both firms compete with a decentralized strategy. We show the existence of a unique Nash Equilibrium under all decision making scenarios. We observe that a firm's preference for a centralized or decentralized decision making strategy, given its competitor's strategy, may change depending on market and firm characteristics. Our key findings are as follows:

- When price competition is more intense than lead-time competition in the market, a centralized decision-making strategy is dominant for both firms.
- The firm with an increased advantage over price competition can benefit from a decentralized strategy in which case the competitor prefers a centralized strategy.
- A centralized strategy is dominant under high capacity. Moreover, higher capacity does not always result in higher profits under competition even if it comes for free. For non-identical firms, when price competition is highly intense but less effective than lead-time competition, each firm may benefit from a decentralized decision making strategy until increasing capacity at one firm becomes a disadvantage.
- For identical firms, when the intensity of price competition is high but less effective than lead-time competition, firms may benefit from a decentralized strategy even under high production costs.

As an extension of this research, one can compare the results of the linear demand model with a constant elasticity model to see how the decisions and the impact of decentralization change. Another extension would be including capacity as a decision variable. Finally, competition under dynamic price and lead-time quotations would also be of interest for future work.

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