

# THE STRATEGIC PERILS OF DELAYED DIFFERENTIATION

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ABSTRACT. The value of *delayed differentiation* (aka *postponement*) for a monopolist has been extensively studied in the Operations literature. We analyze the case of (imperfectly) competitive markets with demand uncertainty, wherein the choice of supply chain configuration (early/delayed differentiation) is endogenous to the competing firms. We characterize firms' choices in equilibrium and analyze the effects of these choices on prices, quantities, profits, consumer surplus and welfare. We demonstrate that *purely strategic considerations* not identified previously in the literature play a pivotal role in determining the value of delayed differentiation. In the face of either entry threats or competition, these strategic effects can significantly diminish the value of delayed differentiation. In fact, under plausible conditions, these effects may dominate the traditional risk-pooling benefits associated with delayed differentiation, in which case early differentiation may be the preferred (and even *dominant*) strategy for firms. Finally, we develop a model allowing firms to employ varying degrees of delayed or early differentiation (along a continuum) rather than the polar cases alone. The analysis of this model further buttresses our results, and demonstrates the strategic impact of firms' choices of supply chain configurations.

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## 1. INTRODUCTION

*'Companies must be flexible to respond rapidly to competitive and market changes.'*

- *Michael Porter (1996)*

Contemporary businesses face uncertainty due to a variety of factors— changing regulatory environments, increasing globalization, proliferation in product varieties, continuous threats to their markets from entrants, disruptive changes in technology, evolving relations with stakeholders, and most importantly, uncertain demands from customers. Given this increased dynamism in a firm's environment, a firm's responsiveness to manage these changes is key to its success. In this context,

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approaches to incorporate operational flexibility in a firm's supply chain, to better match supply and demand, have received considerable attention. One such approach is delayed differentiation or postponement. Using delayed differentiation, a firm delays or postpones the final customization of a related bundle of products (and/or shipment of product to different geographical markets) to the extent possible, pending more accurate product and market-specific demand information. This is a form of 'risk pooling' across markets.

The basic idea behind delayed differentiation is very well-known in the Operations field. Nevertheless, in the interest of completeness, we illustrate the idea using the celebrated example of Hewlett-Packard (HP) (Feitzinger and Lee (1997); Lee (1996); Lee and Billington (1992, 1993, 1995); Lee et al. (1993); Lee and Billington (1994); Lee and Tang (1999); Lee and Whang (1998)). HP manufactured its Desk-jet-Plus printers in its Vancouver, Washington facility, and shipped the printers to three distribution centers in North America, Europe and Asia. The transit time by sea, to the two non-U.S. distribution centers, was about a month. Depending on the eventual destination country, different power supply modules had to be installed in the printers to accommodate local voltage, frequency and plug conventions. The manuals and labels also had to be localized due to language differences. HP redesigned the printer so that the power module could be added as a simple plug-in, manufactured a generic Desk-jet-Plus printer in the U.S. (sans power supply module, manual and labels) and later localized the generic product in Europe, based on observed demand conditions. Restructuring its printer production process in this fashion enabled HP to maintain the same service-levels with an 18% reduction in inventory, saving millions of dollars (Lee et al. (1993)).

A recent study carried out by APICS, Cap Gemini-Ernst and Young, and the Oracle corporation documents the use of postponement strategies at both large and mid-sized companies across numerous industries including aerospace, automotive, education, health care, retail, high-tech and telecommunications (Mathews and Syed (2004)). The study found high levels of awareness of postponement as a concept, and 9% of all organizations surveyed employed some form of postponement.

Most of the extant academic literature focuses on postponement as a cost-minimization strategy (Aviv and Federgruen (2001); Eppen and Schrage (1981); Federgruen and Zipkin (1984); Gavirneni and Tayur (1997); Lee (1996); Lee and Tang (1999); Lee and Whang (1998); Schwarz (1989); Swaminathan and Tayur (1996)), with exogenously-fixed retail prices. In other models (Van Mieghem and Dada (1999), Chod and Rudi (2002), Wang and Kapuscinski (2004) and Anand and Mendelson (1998)), prices and sales revenues are *endogenously* determined as a function of quantities, and the

resulting profit-maximization problem is not reducible to an equivalent cost-minimization problem. In an excellent article, Swaminathan and Lee (2003) categorize the literature along three key postponement enablers: process standardization, process re-sequencing and component standardization. Rather than duplicate their efforts here, the reader is referred to Swaminathan and Lee (2003) as well as Anand and Mendelson (1998) and Hoek (2001) for extensive reviews of the postponement literature. The setting is a monopoly in all these models; only Wang and Kapuscinski (2004) extend their model to competition among multiple firms, wherein each firm sells a single, partially substitutable product. In our duopolistic setting, each firm sells multiple products, enabling risk-pooling. Further, the analysis in Wang and Kapuscinski (2004) assumes that *all* firms implement price postponement or not; in their numerical studies, price postponement is always beneficial. In our setting, each firm chooses its supply chain configuration (early/delayed differentiation), and we prove that delayed differentiation is often a strategically inferior choice for firms.

Some other recent research more broadly related to delayed differentiation focuses on *flexible versus dedicated production technologies* (cf. Goyal and Netessine (2003); Roller and Tombak (1993); Boyer and Moreaux (1997)) and *component commonality* (cf. Desai et al. (2001); Ramdas and Randall (2004)). Grenadier (2002) develops a real options model for deriving equilibrium investment strategies in a competitive framework to study *temporal flexibility* (invest now or later). On the effects of component commonality on quality and product position in the marketplace, the interested reader is referred to Desai et al. (2001); Ramdas and Randall (2004) and the references therein.

The main model in this paper builds on Anand and Mendelson (1998) and extends their research to a competitive setting. In Anand and Mendelson (1998), a monopoly firm's supply chain consists of a production facility, a distribution center and two differentiated markets. Demand information is used to mitigate the effects of uncertainty in the output markets. They compare a firm's performance under two alternative supply chain configurations— early and delayed differentiation— to quantify the value of postponement. They compute the optimal shipping and production policies in a dynamic (multi-period) setting, and study the various comparative static properties of the value of postponement.

In the current study, we model delayed differentiation as a decision variable in a competitive scenario. Each firm in our duopoly model chooses between two different supply chain configurations— *delayed differentiation* and *early differentiation*. We derive the resulting equilibrium in supply chain configurations, and analyze the equilibrium sales, production, consumer surplus, welfare and profits

for each firm under the different choices. While the conventional risk pooling benefits of the monopoly models persist in our setup, additionally, we identify *strategic* consequences of the supply chain configuration employed. We show that for a wide variety of settings of the demand parameters, firms may prefer to deploy early rather than delayed differentiation even under cost parity between the two options. Further, under plausible conditions, *we find a dominant strategy equilibrium in early differentiation, i.e., each firm's dominant strategy (independent of the other firm's choice) is to employ early differentiation.* We observe this even though we set all cost and demand parameters to be identical under early and delayed differentiation. To understand the drivers of these results, we parse the profits of each firm into two additively separable components. The first is the *risk-pooling premium* that favors delayed differentiation and drives the results under monopoly; as might be expected, it is a function of the variance of demand and the coefficient of correlation across markets. The risk-pooling premium vanishes when the variance is zero (i.e., there is no demand uncertainty) or when the markets are perfectly positively correlated. We term the second component, unique to our competitive setting, the *strategic premium*, which is a function only of the *scale* of demand, and is higher under early differentiation. As the demand variance falls and/or the correlation across markets rises, the strategic premium begins to dominate the risk premium, leading to the results discussed above. It is important to emphasize that, in our model, the relative disadvantage of delayed differentiation with respect to early differentiation does not arise out of different process costs, but purely due to *endogenous strategic effects*.

To gain further insight into these drivers, we develop a model allowing one firm to employ varying degrees of delayed or early differentiation (along a continuum), while the other firm employs early differentiation. In this model, the first firm can reconfigure products developed for one market into products for the other market, at some cost. The cost parameter is itself a (continuous) decision variable for the firm, and extreme points on the sliding scale correspond to the pure early differentiation process (when reconfiguration costs are prohibitively high), or the pure delayed differentiation process (when reconfiguration is costless). Our results- that the firm under equilibrium may well prefer to set its cost parameter at a value greater than zero purely for strategic reasons, further highlight the strategic impact of the choice of supply chain configuration.

To summarize, our results demonstrate that the conventional wisdom, supported by previous academic research, regarding the benefits of delayed differentiation for a firm facing uncertainty, is very strongly a function of the monopoly assumption. A firm's choice of supply chain configuration

needs to take into account both internal (operational) factors and its market power (driven by the industry structure).

The rest of this paper is organized as follows. In Section 2, we describe our modeling framework. Section 3 derives and compares the equilibrium production, sales and profits under each possible supply chain configuration. In Section 4, we characterize the equilibrium choices in supply chain configurations. In Section 5, we extend our model to analyze the case wherein one firm can costlessly deploy an intermediate degree of early/delayed differentiation, while the other firm chooses early differentiation.

## 2. SETTING

The market demand structure we use is similar to Anand and Mendelson (1998), who study postponement or delayed differentiation in a monopolistic setting. We analyze a competitive setting wherein each firm can choose between two possible supply chain configurations: early or delayed differentiation. The focus of our study is on the effect of competitive or strategic interactions on a firm's choice of supply chain configuration. We identify three minimal requirements for an analytical model to meet these objectives: *(i)* For delayed differentiation to be meaningful, a firm must operate in a minimum of two related markets (or equivalently, sell two related products with a common intermediate good); *(ii)* As shown in Anand and Mendelson (1998), there must be some prior uncertainty (commonly, demand uncertainty) that gets resolved or at least reduced downstream in the production process, to merit investments in delayed differentiation. This requires a multi-stage production process; and *(iii)* To model competition, there must be two firms at a minimum, that compete in at least one market. We develop a parsimonious model that meets these three minimal requirements.

Consider a firm that sells two related products. For concreteness, we will assume that each product is sold in a distinct product market. The firm is the monopoly supplier in one of the two markets. We call this the *monopoly market* (denoted by the superscript M). In the other market, the firm faces a similar competitor (who also sells two related products, and is a monopoly in one product market). We call this the *competitive market* (denoted by the superscript C). Thus, there are two firms, each with their own monopoly (captive) market, which compete in a common, competitive market. This structure meets the minimal requirements *(i)* and *(iii)* listed above. The remaining requirement *(ii)* is met in our two-stage model discussed below.

*Market Model.* Following Anand and Mendelson (1998), each market faces a linear and downward-sloping demand curve  $p(q) = a - q$ , where the intercept  $a$  is random, and drawn from a distribution with mean  $\bar{a}$  and variance  $\hat{a}$ .<sup>2</sup> We assume that this distribution has compact support over the interval  $[a_l, a_h]$ , where  $a_l, a_h \geq 0$  and  $a_h - a_l \leq 1.2\bar{a}$ .<sup>3</sup> Demand is correlated between the competitive market and each monopoly market, with a correlation coefficient  $\rho \in [-1, 1]$ .

We build on the Cournot (quantity-setting) model of imperfect competition. In the conventional Cournot setting, firms decide on quantities to be released into the market, and prices adjust to clear the total quantity. However, many other settings have been found to be isomorphic to Cournot, leading to various alternative, reasonable and appealing reinterpretations of this competitive model (cf. Tirole (1988)). Notable among these reinterpretations is a setting where firms with differentiated but partially substitutable products compete on prices.

*Supply Chain Configurations.* Each firm's supply chain consists of a production facility, a distribution center (DC) and two retail outlets— one for each market. There are two stages in the firm's supply chain activities: in the first (production) stage, the firm decides on production quantities and ships these to the DC. In the second (distribution) stage, the firm allocates these quantities to its outlets. In the production stage, the firm estimates the demand for its products using the prior distribution discussed above. In the distribution stage, the firm observes the demand realizations; hence subsequent decisions (allocation to the two outlets) are based on perfect demand information. This two stage supply chain structure, wherein the uncertainty is resolved in the second stage, is a reasonably accurate model for products with long production lead-times relative to the selling cycle, such as fashion goods (cf. Fisher et al. (1994)), in which much of the uncertainty is resolved based on early season sales or orders.

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<sup>2</sup> The linear downward sloping demand curve also has an appealing interpretation as the demand arising from the utility-maximizing behavior of consumers with quadratic, additively separable utility functions (Singh and Vives (1984)).

<sup>3</sup> We need to impose this restriction on the maximum spread of demand relative to the mean, to ensure that firms have an incentive to sell positive quantities of their products in all markets (post-demand realization). Absent this assumption, the trivial case can arise wherein a firm completely withdraws from one market and operates only in one of the two markets.

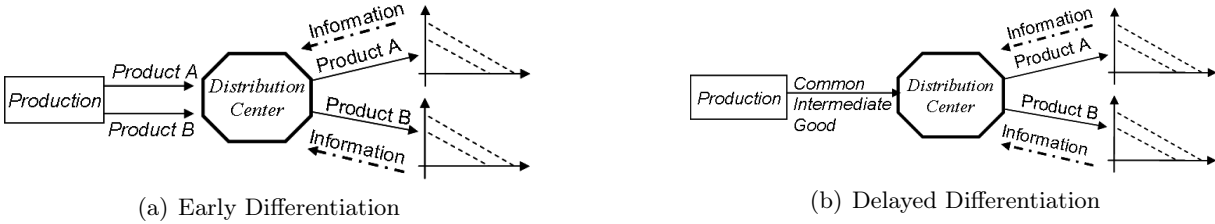


FIGURE 2.1. Alternate Supply Chain Configurations for a Monopoly Firm

The firms may employ one of two alternate supply chain configurations: *early differentiation* (*e*) or *delayed differentiation* (*d*). For a firm employing an early differentiation strategy, (Figure 2.1 (a)), the products are differentiated in the production stage. Thus the DC receives intermediate goods specialized for each product market. In the second stage, the firm then ships these goods from the DC to the appropriate market.

For a firm employing a delayed differentiation strategy (Figure 2.1 (b)), the intermediate good is common to both products. Thus, at the production stage, the firm has to decide only on the total production quantity of the *common intermediate good*. In the distribution stage, after observing the realizations of demand, each unit of the common intermediate good is customized at the DC and shipped to the appropriate market.

Typically, adoption of delayed differentiation entails higher costs arising out of the need for reconfiguration of the organizational processes, process and component standardization, design modularization (Schwarz (1989)) and longer lead-times (Lee and Tang (1999)). To isolate the *strategic* issues related to the choice of supply chain configuration (which is the focus of our paper), we assume that all production and process costs for early and delayed differentiation are identical. At the very least, this gives us an upper bound on the benefits from postponement. Without loss of generality, we normalize these costs to zero.

In the interests of analytical tractability, we assume that firms follow a *clearance strategy*— After demand is realized, the firm must allocate all available stock at the distribution center to either of the markets. Similar assumptions have been made by Goyal and Netessine (2003), Chod and Rudi (2002) and Deneckere et al. (1997). Chod and Rudi (2002) in their monopoly model of postponement, test this assumption numerically and find that this restriction yields solutions that are very close to optimal. In practice, many firms find it hard to change production levels in the short run owing to long term contracts with labor unions and suppliers. For example, several

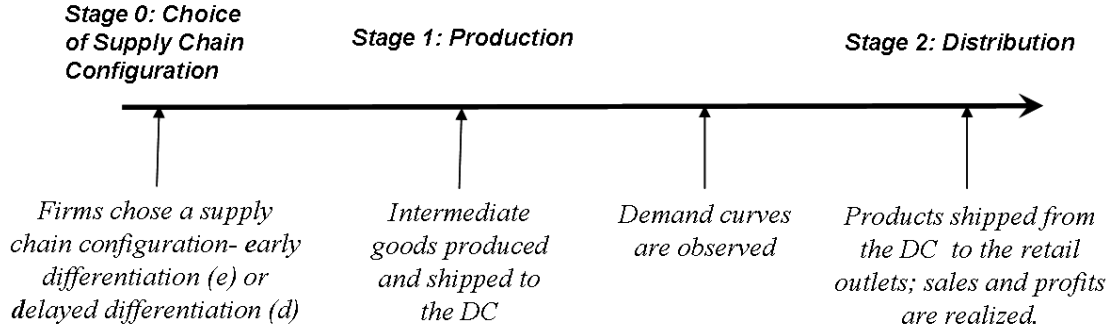


FIGURE 2.2. The Time-line

car makers were forced recently to slash prices to maintain production levels, rather than keeping capacities idle, in effect following a clearance strategy (Mackintosh (2003)).

*Sequence of Events.* The sequence of events is provided in Figure 2.2. In stage 0, the firms choose a supply chain configuration ( $e$  or  $d$ ). Then in the production stage (stage 1), the firms produce the intermediate good(s) and ship these to their respective DCs. After production commitments have been made, accurate demand information becomes available. In the distribution stage (stage 2), the DCs decide on the allocation of the intermediate good to each of their markets, based on the demand information. We assume that the supply chain configuration choices as well as the demand information on all markets are common knowledge.

In the *production stage*, a firm choosing an early differentiation configuration produces and ships differentiated quantities  $q_{e|}^C$  and  $q_{e|}^M$  to the distribution center.<sup>4</sup> On the other hand, a firm employing delayed differentiation produces and ships a quantity  $Q_{d|}$  of the common intermediate good to the distribution center.

In the *distribution stage*, a firm employing delayed differentiation can allocate its common intermediate good  $Q_{d|}$  to its two markets optimally, based on the realized market demands, whereas an early differentiator is *a priori* committed to the quantities allocated to each of its markets. A

<sup>4</sup> We use the notation ' $x|y$ ' (or,  $x$  given  $y$ ) to refer to a firm with supply chain configuration  $x$  facing a competitor with supply chain configuration  $y$ , where where  $x$  and  $y$  can each be set to  $e$  (for early differentiation) or  $d$  (for delayed differentiation). We index a particular industry structure by ' $xy$ '. The superscripts ' $C$ ' and ' $M$ ' denote the Competitive and Monopoly markets respectively. Finally, the profits earned by the firms are denoted by the Greek letter  $\Pi_{i,j}$ .

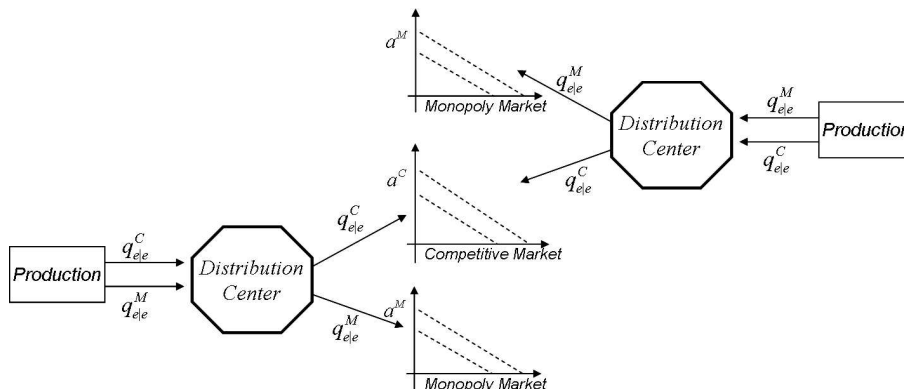
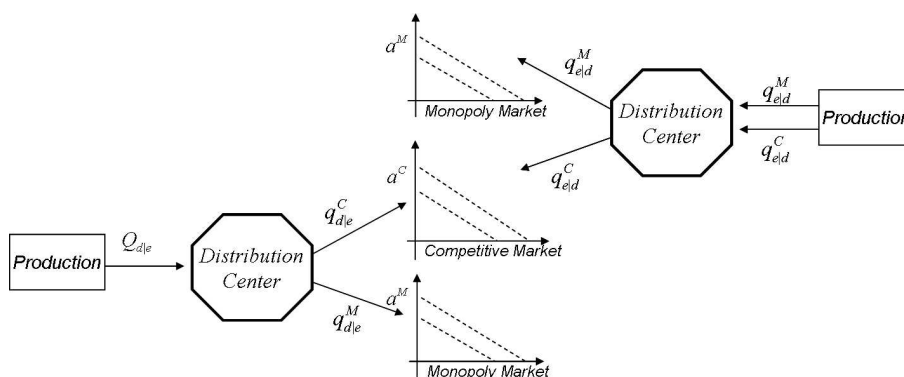
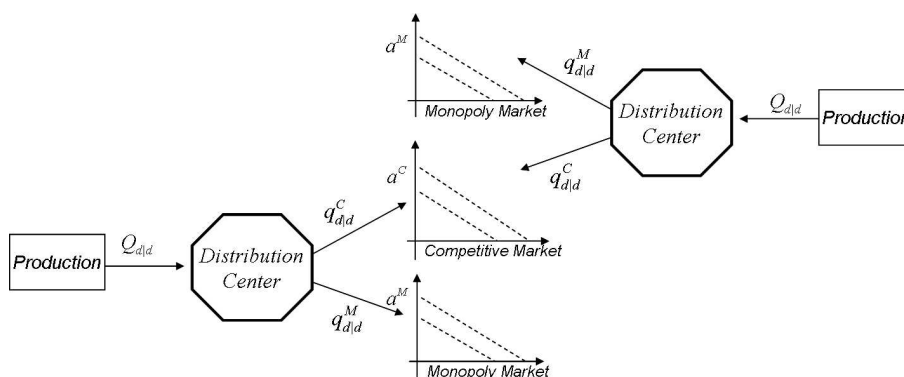
<i>Symbol</i>	<i>Meaning</i>
$a^C, a^M$	Realized value of the demand intercept.
$\bar{a}$	Mean of the demand intercept distribution.
$\hat{a}$	Variance of the demand intercept distribution.
$\rho$	Correlation between the demand intercepts in each of the Monopoly markets and the Competitive market.
$\gamma$	The coefficient of variation of the demand intercept distribution which is $\frac{\sqrt{\hat{a}}}{\bar{a}}$
<b>e</b>	Subscript to denote a firm deploying early differentiation
<b>d</b>	Subscript to denote a firm deploying delayed differentiation
$q_{x y}^A$	Quantity sold by a firm employing $x$ , facing a competitor employing $y$ , to market $A$ ; where $x, y \in \{e, d\}$ , $A \in \{C, M\}$
$Q_{x y}$	Quantity of intermediate good produced by a firm employing $x$ , facing a competitor employing $y$ ; where $x, y \in \{e, d\}$
$p_{xy}^A$	The clearing prices in market $A$ , in the setting where one firm employs $x$ and the other firm employs $y$ ; where $x, y \in \{e, d\}$
$\Pi_{x y}$	Profits earned by a firm employing $x$ , facing a competitor employing $y$ ; where $x, y \in \{e, d\}$
$CS_{xy}$	The expected consumer surplus in the setting where one firm employs $x$ and the other firm employs $y$ ; where $x, y \in \{e, d\}$
$W_{xy}$	The expected welfare in the setting where one firm employs $x$ and the other firm employs $y$ ; where $x, y \in \{e, d\}$

TABLE 1. Symbols Used

firm employing delayed differentiation sells quantities  $q_{\cdot|e}^C(a^C, a^M)$  and  $q_{\cdot|e}^M(a^C, a^M)$  in the competitive and monopoly markets respectively, where  $a^C$  and  $a^M$  are the observed realizations of the demand intercepts. The clearance strategy implies  $q_{\cdot|e}^C(a^C, a^M) + q_{\cdot|e}^M(a^C, a^M) = Q_{\cdot|e}$ . An early differentiating firm, on the other hand sells its pre-committed quantities,  $q_{e|e}^C$  and  $q_{e|e}^M$  in the two markets.

The notation is summarized in Table 1.

Thus, the choices of supply chain configuration can lead to three different industry structures– (i) **e-e**, when both firms employ early differentiation (Figure 2.3); (ii) **d-e** (or equivalently, **e-d**), when one firm employs early differentiation and the other employs delayed differentiation (Figure 2.4); and lastly, (iii) **d-d**, when both firms choose delayed differentiation (Figure 2.5).

FIGURE 2.3. Alternate Supply Chain Configurations under Competition- The **e-e** CaseFIGURE 2.4. Alternate Supply Chain Configurations under Competition- The **d-e** CaseFIGURE 2.5. Alternate Supply Chain Configurations under Competition- The **d-d** Case

### 3. ANALYSIS OF SUPPLY CHAIN CONFIGURATIONS

In this Section, we derive and compare the equilibrium sales and production quantities for the different supply chain configurations. We analyze the drivers of our results, and study their implications for firm and industry profits, consumer surplus and welfare.

**3.1. Equilibria under different Supply Chain Configurations.** In order to compare firms' sales quantities in equilibrium under combinations of different supply chain configurations, we use the sales in a traditional monopoly or Cournot duopoly setting, under the same demand assumptions, as benchmarks. In a Cournot duopoly with uncertain demand, the equilibrium sales quantities for each (profit-maximizing) firm are  $C = \bar{a}/3$ , where  $\bar{a}$  is the mean of the intercept of the demand curve. Similarly, in the monopoly setting, a profit-maximizing firm sells  $M = \bar{a}/2$  units. Theorem 3.1 compares the sales under the different supply chain configurations.

**Theorem 3.1. *Expected Sales***

- (1) *The equilibrium expected quantities sold by a firm in the competitive market, under the different supply chain configurations, follow the relationship in 3.1.*

$$(3.1) \quad \mathbf{E} \left[ q_{d|e}^C \right] < \mathbf{E} \left[ q_{e|e}^C \right] = C < \mathbf{E} \left[ q_{d|d}^C \right] < \mathbf{E} \left[ q_{e|d}^C \right]$$

- (2) *The equilibrium expected quantities sold by a firm in the monopoly market, under the different supply chain configurations, follow the relationship in 3.2.*

$$(3.2) \quad \mathbf{E} \left[ q_{d|e}^M \right] = \mathbf{E} \left[ q_{e|e}^M \right] = \mathbf{E} \left[ q_{e|d}^M \right] = M < \mathbf{E} \left[ q_{d|d}^M \right]$$

*Proof.* Proofs for all results are available in the technical supplement. □

The results of Theorem 3.1 derive from Table 2, which shows the exact quantities sold by firms under the different combinations of supply chain configurations, in the monopolistic and competitive markets. We discuss the intuition behind these results, for each setting, below.

(i) *The e-e supply chain configuration:* The analysis of the **e-e** supply chain configuration is a relatively straight-forward extension of the traditional Cournot and Monopoly analyses. Under **e-e**, both firms produce differentiated products at the production stage itself. Thus, the decisions on production quantities for the competitive and monopoly markets are separable and independent. The sales quantity in equilibrium corresponds to the traditional Cournot duopoly in the competitive market ( $\mathbf{E} \left[ q_{e|e}^C \right] = C = \bar{a}/3$ ), and to the traditional monopoly in the monopoly market ( $\mathbf{E} \left[ q_{e|e}^M \right] = M = \bar{a}/2$ ). In fact, for a firm employing early differentiation, decisions for its monopoly market are independent of those for the competitive market, irrespective of the supply chain configuration adopted by the competitor. Thus,  $\mathbf{E} \left[ q_{e|e}^M \right] = \bar{a}/2$ .

<i>Setting</i>	$\mathbf{E} \left[ q_{\cdot \cdot}^M \right]$
d e	$\frac{\bar{a}}{2} = 0.5\bar{a}$
e e	$\frac{\bar{a}}{2} = 0.5\bar{a}$
d d	$\frac{45}{86}\bar{a} = 0.52\bar{a}$
e d	$\frac{\bar{a}}{2} = 0.5\bar{a}$

*Monopoly Benchmark*,  $M = \frac{\bar{a}}{2} = 0.5\bar{a}$

(a) Sales in the monopoly market

<i>Setting</i>	$\mathbf{E} \left[ q_{\cdot \cdot}^C \right]$	<i>Market Share (firm 1/firm 2)</i>
d e	$\frac{3}{10}\bar{a} = 0.3\bar{a}$	42%/58%
e e	$\frac{1}{3}\bar{a} = 0.33\bar{a}$	50%/50%
d d	$\frac{30}{86}\bar{a} = 0.35\bar{a}$	50%/50%
e d	$\frac{2}{5}\bar{a} = 0.4\bar{a}$	58%/42%

*Cournot Benchmark*,  $C = \frac{\bar{a}}{3} = 0.33\bar{a}$

(b) Sales in the Competitive market

$\bar{a}$ - mean of the intercept distribution

TABLE 2. Expected sales by firms in equilibrium under the different supply chain configurations

(ii) *The d-e (or e-d) supply chain configuration:* As Table 2 shows, in the competitive market, the d|e firm sells a quantity lower than the Cournot quantity ( $\mathbf{E} \left[ q_{d|e}^C \right] = 3\bar{a}/10 < C = \bar{a}/3$ ), whereas the e|d firm sells a quantity higher than Cournot ( $\mathbf{E} \left[ q_{e|d}^C \right] = 4\bar{a}/10 > C = \bar{a}/3$ ). Under the asymmetric supply chain configuration,<sup>5</sup> in equilibrium, the delayed differentiating firm loses market share to the early differentiating firm in the competitive market. At the production stage, the early differentiating firm can commit to sales in each market; the delayed differentiator on the other hand, commits only to a quantity of the common intermediate good. Furthermore, at the shipment stage, the delayed differentiator can divert some of its production (of the intermediate good) to its monopoly market, whereas the early differentiator is unable to do so, due to its commitment to each market arising from its inflexible production process. Knowing this, the early differentiating firm can *credibly commit* at the production stage to supplying a higher quantity (even more than the Cournot quantity  $C = \bar{a}/3$ ) to the competitive market. Given this commitment by the early differentiating firm, and the strategic substitutability (decreasing best response functions) of each firm's production quantity, the delayed differentiating firm has no choice but to divert some of its intermediate good from the competitive market to its monopoly market, thus giving up market share to the early differentiator. This withdrawal by the delayed differentiator makes it an equilibrium strategy for the early differentiator to 'oversupply' the competitive market. Thus,  $\mathbf{E} \left[ q_{d|e}^C \right] < C = \bar{a}/3 < \mathbf{E} \left[ q_{e|d}^C \right]$ . Further, our analysis shows that for each extra unit supplied by the early differentiating firm, the

<sup>5</sup> Where one firm employs delayed differentiation and the other early differentiation.

delayed differentiating firm reduces its supply by half a unit. Consequently, for each unit of forced withdrawal the total quantity supplied to the competitive market increases by a unit, thus decreasing the price. This leads to diminishing marginal returns for the early differentiator, restraining it from forcing the delayed differentiator to entirely withdraw from the competitive market. The optimal level of forced withdrawal is such that the early differentiator increases its supply by  $\bar{a}/15$  units and the delayed differentiator decreases its supply by  $\bar{a}/30$  units (as seen in Table 2).

Although the d|e firm's sales in the competitive market fall on account of its post-production diversion of goods to the monopoly market, the firm is unable to recoup the losses entirely via sales in the monopoly market. If the firm supplies more than  $M$  (the optimal quantity for a traditional monopoly), it will lose revenues and profits from the monopoly market. Thus, anticipating the threat of oversupply from the early differentiator and its own subsequent partial withdrawal from the competitive market, the d|e firm reduces its total production of the intermediate good. In fact, the production of the intermediate good is decreased to the extent that, on average, the post-diversion quantity put on the monopoly market is equal to  $M$ , the profit-maximizing quantity under monopoly. Thus,  $\mathbf{E} \left[ q_{d|e}^M \right] = M = \bar{a}/2$ . Note here that, although the d|e firm is diverting stock *post-production* from the competitive market to its monopoly market, the *equilibrium* production levels anticipate this. This leads to a decrease in the quantity it supplies to the competitive market (hence,  $\mathbf{E} \left[ q_{d|e}^C \right] = \bar{3}a/10 < \bar{a}/3 = C$ ) but not to an increase in its supply to the monopoly market ( $\mathbf{E} \left[ q_{d|e}^M \right] = \bar{a}/2 = M$ ).

(iii) *The d-d supply chain configuration:* When both firms employ delayed differentiation, two factors drive the firms' production levels in opposite directions. The first (traditional) factor, that drives the production levels downward as in Anand and Mendelson (1998) (henceforth referred to as AM), is risk pooling across markets. However, strategic (competitive) effects operate in the opposite direction. Specifically, if any firm lowers its production, its competitor will increase its production, since the production reaction curves are decreasing functions. This might lead to lower profits for the firm that lowers its production. Overall, as it turns out, the strategic effect dominates the risk-pooling effect; hence firms' expected sales under the **d-d** configuration are greater than Cournot in the competitive market ( $\mathbf{E} \left[ q_{d|d}^C \right] > C$ , as shown in Theorem 3.1) (directly due to the strategic effect) and greater than the Monopoly optimal in the Monopoly market ( $\mathbf{E} \left[ q_{d|d}^M \right] > M$ ), again from Theorem 3.1) (indirectly due to the strategic effect- due to a spillover from the competitive market).

<i>Setting</i>	<i>Production, <math>Q_{\cdot \cdot}</math></i>
d e	$\frac{4}{5}\bar{a} = 0.8\bar{a}$
e e	$\frac{5}{6}\bar{a} = 0.83\bar{a}$
d d	$\frac{75}{86}\bar{a} = 0.87\bar{a}$
e d	$\frac{9}{10}\bar{a} = 0.9\bar{a}$

Production Benchmark,  $C + M = \frac{5}{6}\bar{a} = 0.83\bar{a}$

$\bar{a}$ - mean of the intercept distribution

TABLE 3. Quantities produced by firms

The strategic effect in the competitive market is so dominant over the risk-pooling effect that, in equilibrium, each delayed differentiating firm sells more than the monopoly optimal quantity  $M$  in its captive market, which we know is clearly sub-optimal from standard microeconomics, since revenues (and profits) are decreasing in sales quantities at any level of sales above  $M$ .

Our next Theorem analyzes firms' production quantities under the different supply chain configurations.

**Theorem 3.2. *Production quantities***

- (1) *Firms' production quantities under the different supply chain configurations, follow the relationship in 3.3.*

$$(3.3) \quad Q_{d|e} < Q_{e|e} = (C + M) < Q_{d|d} < Q_{e|d}$$

- (2) *The total quantities produced (by both firms) under the different supply chain configurations, follow the relationship in 3.4*

$$(3.4) \quad 2(C + M) = Q_{ee}^{Tot} < Q_{dd}^{Tot} < Q_{de}^{Tot}$$

where  $Q_{ee}^{Tot} = 2Q_{e|e}$ ,  $Q_{dd}^{Tot} = 2Q_{d|d}$ ,  $Q_{de}^{Tot} = Q_{d|e} + Q_{e|d}$ .

Theorem 3.2 is derived from Table 3, which provides the exact production quantities under the different supply chain configurations. The analysis of production quantities reinforces the intuition provided by the previous analysis of sales quantities. In the **e-e** configuration, each firm's production

quantity  $Q_{e|e}$  is exactly  $(C+M)$ , which is the sum of the classical Cournot and Monopoly profit-maximizing quantities. Indeed, each firm supplies exactly  $C$  to the competitive market and  $M$  to its captive market. In the **d-d** configuration, as seen previously, both firms produce in excess due to strategic imperatives arising from competition, and oversupply the markets relative to the optimal Cournot and Monopoly levels. Thus, each firm's total production under the **d-d** supply chain configuration is  $Q_{d|d} = \left( \mathbf{E} \left[ q_{d|d}^C \right] + \mathbf{E} \left[ q_{d|d}^M \right] \right) > (C + M)$ , *in spite of risk pooling across markets, enabled by delayed differentiation*. Finally, the *least* total production corresponds to the d|e firm (since the early differentiator under **d-e** aggressively drives the delayed differentiator away from the competitive market through credible production commitments) and the e|d firm produces the maximum quantity (since this firm uses its production to drive its competitor out of the common market). However, recall also that for each extra unit supplied by the early differentiating firm, the delayed differentiating firm reduces its supply by only half a unit, leading to an increase in the total quantity supplied to the market. Thus, the **d-e** configuration, leading to a supply of  $Q_{de}^{Tot} = Q_{d|e} + Q_{e|d}$  to the market, maximizes the total production in the industry.

**Comparisons with the monopoly setting:** In the monopoly setting, analyzed by Anand and Mendelson (1998) (AM), delayed differentiation enables risk-pooling, which helps a firm maximize its profits at a lower level of production, through better allocation of production to markets. In our competitive model, production quantities are driven by two competing effects (in addition to those driving quantities in the classical Cournot and monopoly settings). The first is that (as in AM), delayed differentiation enables risk-pooling, which tends to lower production for the firm employing delayed differentiation. A second, additional factor we see in our model is a *strategic imperative* to raise production under competition— for both offensive and defensive reasons. Offensively, a higher level of production commitment serves as a credible (albeit costly) signal of a firm's seriousness of intent in the competitive market; defensively, higher production commitments are needed to discourage this predatory behavior.<sup>6</sup> Lowering one's production (or inventory) levels, even if mandated by risk-pooling considerations, can be strategically counter-productive. Due to its limited flexibility, early differentiation can signal greater commitment to a particular market or product, and is

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<sup>6</sup> Mathematically, each firm's induced production reaction function is a decreasing function of the other firm's production level.

hence preferable to delayed differentiation in delivering on this strategic imperative. Thus, the risk-pooling effect favors the delayed differentiation configuration, while the strategic imperative favors early differentiation. While this tension is most clearly seen in the **d-e** supply chain configuration, it plays a role even in **d-d**. If a delayed differentiating firm decides to lower inventory levels (as in AM), it may be exploited by its competitor. This leads to both firms stocking and selling higher quantities in both the monopoly and competitive markets, even under **d-d**, than one might infer from the monopoly analysis of AM.

### 3.2. Prices, Profits, Consumer Surplus and Welfare.

(i) *Prices:* Theorem 3.3 analyzes the prices in each market under the various supply chain configurations.

#### **Theorem 3.3. *Clearing Prices in the Markets***

(1) *The clearing prices in the competitive market, under different supply chain configurations, follow the relationship in 3.5.*

$$(3.5) \quad \mathbf{E} [p_{de}^C] < \mathbf{E} [p_{dd}^C] < \mathbf{E} [p_{ee}^C]$$

(2) *The clearing prices in the monopoly market, under different supply chain configurations, follow the relationship in 3.6.*

$$(3.6) \quad \mathbf{E} [p_{dd}^M] < \mathbf{E} [p_{de}^M] = \mathbf{E} [p_{ee}^M]$$

The prices in each market under the different supply chain configurations are inversely correlated to the quantities supplied. As shown in Theorem 3.1 and the ensuing discussion, both **d-d** and **e-e** lead to oversupply relative to Cournot in the competitive market, whereas the **e-e** configuration leads to exactly the Cournot and Monopoly outcomes in the competitive and captive markets respectively. When both firms employ delayed differentiation, there is a spillover of supply into the monopoly markets, leading to lower-than-monopoly prices in the monopoly markets under **d-d**. As discussed before, when one of the the firms employs delayed differentiation, the equilibrium production levels anticipate and eliminate this price-reducing spillover under **d-e**.

<i>Setting</i>	<i>Strategic Premium</i>	<i>Risk Pooling Premium</i>	<i>Total Expected Profit</i>
e e	$\frac{13}{36}\bar{a}^2 = 0.3611\bar{a}^2$	0	$\frac{13}{36}\bar{a}^2$
d e	$\frac{17}{50}\bar{a}^2 = 0.34\bar{a}^2$	$\frac{\hat{a}}{4}(1 - \rho)$	$\frac{17}{50}\bar{a}^2 + \frac{\hat{a}}{4}(1 - \rho)$
e d	$\frac{37}{100}\bar{a}^2 = 0.37\bar{a}^2$	0	$\frac{37}{100}\bar{a}^2$
d d	$\frac{2625}{7396}\bar{a}^2 = 0.3549\bar{a}^2$	$\frac{4\hat{a}}{25}(1 - \rho)$	$\frac{2625}{7396}\bar{a}^2 + \frac{4\hat{a}}{25}(1 - \rho)$

$\bar{a}$ - mean of the intercept distribution,  $\hat{a}$ - variance of the intercept distribution.

TABLE 4. Profits Earned

(ii) *Profits*: The expected profits earned by firms under the different supply chain configurations are shown in Table 4, and are determined by two additively-separable factors- (i) the strategic effect of competition (which we term the *strategic premium*) and (ii) the benefits arising out of efficient allocation (*risk-pooling premium*). The first term in the profit expressions, the strategic premium, is a function of the mean of the demand intercept  $\bar{a}$ , and of course, of the supply chain configurations of both competing firms. The second term in the profit expressions measures the risk pooling benefit and is a factor only for firms employing delayed differentiation. The risk pooling premium is a function of the demand variance and the correlation across markets. It is increasing in the variance  $\hat{a}$  and decreasing in the coefficient of correlation  $\rho$ . Notice that when there is no ability to diversify risks ( $\rho = 1$  or  $\hat{a} = 0$ ), the risk pooling premium vanishes and the profits are driven solely by the strategic premium.

Table 4 shows that the strategic premium is always higher for early differentiation than for delayed differentiation for any configuration that the rival firm employs (Compare the strategic premiums for e|e ( $0.3611\bar{a}^2$ ) versus d|e ( $0.34\bar{a}^2$ ), and similarly for e|d ( $0.37\bar{a}^2$ ) versus d|d ( $0.3549\bar{a}^2$ )). Additionally, the strategic premium of an early differentiating firm when the competitor follows delayed differentiation is  $0.37\bar{a}^2$ , which is better than when the competitor is an early differentiator  $0.3611\bar{a}^2$ . Thus, on all counts, early differentiation dominates delayed differentiation from a strategic perspective. However, this dominance is tempered by the fact that only delayed differentiating firms earn a risk pooling premium.

It is interesting to compare the relative magnitudes of the risk-pooling premium from Table 4. The risk-pooling premium earned by a delayed differentiator is higher when the competitor does

<i>Setting</i>	<i>Consumer Surplus</i>	<i>Industry profits</i>	<i>Welfare</i>
<i>e-e</i>	$\frac{17}{36}\bar{a}^2 = 0.4722\bar{a}^2$	$\frac{13}{18}\bar{a}^2 = 0.722\bar{a}^2$	$\frac{43}{36}\bar{a}^2 = 1.1944\bar{a}^2$
<i>d-e</i>	$\frac{99}{200}\bar{a}^2 + \frac{\hat{a}(1-\rho)}{8} =$ $0.495\bar{a}^2 + 0.125\hat{a}(1-\rho)$	$\frac{71}{100}\bar{a}^2 + \frac{\hat{a}(1-\rho)}{4} =$ $0.71\bar{a}^2 + 0.25\hat{a}(1-\rho)$	$\frac{241}{200}\bar{a}^2 + \frac{3\hat{a}(1-\rho)}{8} =$ $1.205\bar{a}^2 + 0.375\hat{a}(1-\rho)$
<i>d-d</i>	$\frac{3825}{7396}\bar{a}^2 + \frac{6\hat{a}(1-\rho)}{25} =$ $0.517\bar{a}^2 + 0.24\hat{a}(1-\rho)$	$\frac{2625}{3698}\bar{a}^2 + \frac{8\hat{a}(1-\rho)}{25} =$ $0.7098\bar{a}^2 + 0.32\hat{a}(1-\rho)$	$\frac{9075}{7396}\bar{a}^2 + \frac{14\hat{a}(1-\rho)}{25} =$ $1.227\bar{a}^2 + 0.56\hat{a}(1-\rho)$

$\bar{a}$ - mean of the intercept distribution,  $\hat{a}$ - variance of the intercept distribution.

TABLE 5. Consumer Surplus, Industry Profits and Welfare

not follow delayed differentiation ( $1/4 > 4/25$ ). When both firms employ delayed differentiation, strategic considerations prevent the firms from fully appropriating the benefits of risk pooling.

(iii) *Consumer Surplus, Industry Profits, Welfare*: Table 5 shows the *consumer surplus* across all markets, *industry profits* and *welfare* for different supply chain configurations, where industry profits are the sum of the profits for the two firms and welfare is the sum of the industry profits and the consumer surplus. This leads to the following Theorem.

**Theorem 3.4. *Consumer Surplus and Welfare***: *The Expected Consumer Surplus under different supply chain configurations follows the relationship in 3.7 .*

$$(3.7) \quad CS_{ee} < CS_{de} < CS_{dd}$$

*The welfare ranking of the various supply chain configurations is identical to that of Consumer Surplus.*

The ranking of consumer surplus is inversely related to the average prices under the different configurations. The welfare ranking is also unambiguous. Because of the interaction of the strategic and risk-pooling premiums in determining profits, the ordering of industry profits under the different configurations depends on the variance of demand as well as the correlation across markets (which, as discussed above, determine the effectiveness of risk-pooling; see Table 5).

**Comparison with the monopoly setting:** In AM's monopoly setting, the delayed differentiating firm uses the efficiency in allocation (enabled by risk-pooling) to reduce inventory levels without compromising on revenues, leading to lower costs and higher profits. In the competitive setting, firms cannot decrease inventory levels without provoking a response (increased supply) from the competition. This leads to higher supply and lower prices than in AM. This strategic imperative forces firms employing delayed differentiation to share a portion of their risk pooling premium with consumers- lest their competitor does so. *Thus, competition leads to appropriation by consumers of some of the benefits of risk pooling.*

#### 4. META-GAME: ENDOGENIZING CHOICE OF SUPPLY CHAIN CONFIGURATION

In the previous Section, we analyzed the equilibrium solution, profits, consumer surplus and welfare for each possible supply chain configuration. We now analyze the implications of endogenizing firms' choice of supply chain configurations (early or delayed differentiation), i.e., treating a firm's supply chain configuration as a strategic decision variable. We first analyze the *simultaneous meta-game*, in which firms simultaneously determine their supply chain configurations. We derive the equilibria for the entire meta-game consisting of firms' simultaneous choice of supply chain configurations followed by production and sales decisions. We then analyze the *sequential meta-game*, in which one firm chooses its supply chain configuration in response to the other firm's choice. Finally, we study the implications of an incumbent firm's choice of supply chain configuration for entry deterrence. Theorem 4.1 below, which derives the best response functions for each firm, is the essential building block for the rest of this Section.

**Theorem 4.1. Best Responses:** *A firm's best response strategy to its competitor's supply chain configuration is as given below*

$$(4.1) \quad \mathbf{BR}(x) = \begin{cases} \mathbf{d} & \text{if } \rho < \rho_4 \quad \mathbf{or} \\ & \text{if } x = e \text{ and } \rho \in [\rho_4, \rho_1) \\ \mathbf{e} & \text{if } \rho \geq \rho_1 \quad \mathbf{or} \\ & \text{if } x = d \text{ and } \rho \in [\rho_4, \rho_1) \end{cases}$$

where  $x \in \{\mathbf{e}, \mathbf{d}\}$ . Here,  $\rho_1 = \max\left\{-1, 1 - \frac{19}{(15\gamma)^2}\right\} \geq \rho_4 = \max\left\{-1, 1 - \frac{697}{(86\gamma)^2}\right\}$  and  $\gamma = \frac{\sqrt{a}}{a}$ , the coefficient of variation.

Theorem 4.1 derives from profit comparisons made in Table 6. The best response to delayed differentiation is a result of comparing  $\Pi_{e|d}$  and  $\Pi_{d|d}$ , and the best response to early differentiation is found by comparing  $\Pi_{e|e}$  and  $\Pi_{d|e}$ . Note that the threshold values for the coefficient of correlation  $(\rho_1, \rho_4)$ , given in Theorem 4.1, are increasing functions of the coefficient of variation,  $\gamma$  (ratio of the standard deviation and the mean). Thus, early differentiation is the dominating strategy when  $\gamma$  is low and/or  $\rho$  is high. Further,  $\gamma$  is a measure of demand variability controlled for scale: a low  $\gamma$  corresponds to a low standard deviation  $\sqrt{\hat{a}}$  (relative to the mean demand  $\bar{a}$ ). But, as Table 4 showed, a relatively low  $\hat{a}$ , a high  $\bar{a}$  and a high  $\rho$  correspond precisely to the case where the *strategic premium* (which is an increasing function of  $\bar{a}$ ; recall Table 4) dominates the *risk pooling premium* (which is increasing in  $\hat{a}$  and decreasing in  $\rho$ ). For this range of parameter values, delayed differentiation leads to a loss in market share to early differentiating competitors (Theorem 3.1) or low prices on account of increased production, to counter delayed differentiating competitors (Theorem 3.3). Moreover, these losses are more than the risk pooling benefits. Hence, early differentiation is the preferred configuration. However, when the standard deviation,  $\sqrt{\hat{a}}$  is high relative to the mean  $\bar{a}$  and the coefficient of correlation is low ( $\rho < \rho_4$ ), the benefits arising out of risk pooling dominate the strategic premium, and delayed differentiation is preferred under these circumstances. As was shown in Table 4, the relative magnitudes of the strategic and risk pooling premiums also depends on the configuration of the competitor; this determines the best response strategy in the intermediate range of parameter values ( $\rho \in [\rho_4, \rho_1]$ ). Thus, under delayed differentiation, the risk pooling premium is higher but the strategic premium is lower when the competitor employs early rather than delayed differentiation. This trade-off drives the best response function in the intermediate range: here,  $\mathbf{BR}(d) = e$  and  $\mathbf{BR}(e) = d$ .

To summarize, Theorem 4.1 demonstrates that *early differentiation is the dominant strategy, vis-a-vis delayed differentiation, whenever the strategic effects play a prominent role relative to risk pooling as a driver of profits* ( $\rho \geq \rho_1$ ). The extant literature in Operations Management, by focusing on the monopoly analysis, effectively drove the strategic premium to zero; hence, previous results in the literature were driven by the risk pooling premium from delayed differentiation.

The next Theorem characterizes the equilibrium supply chain configuration choices for the simultaneous meta-game.

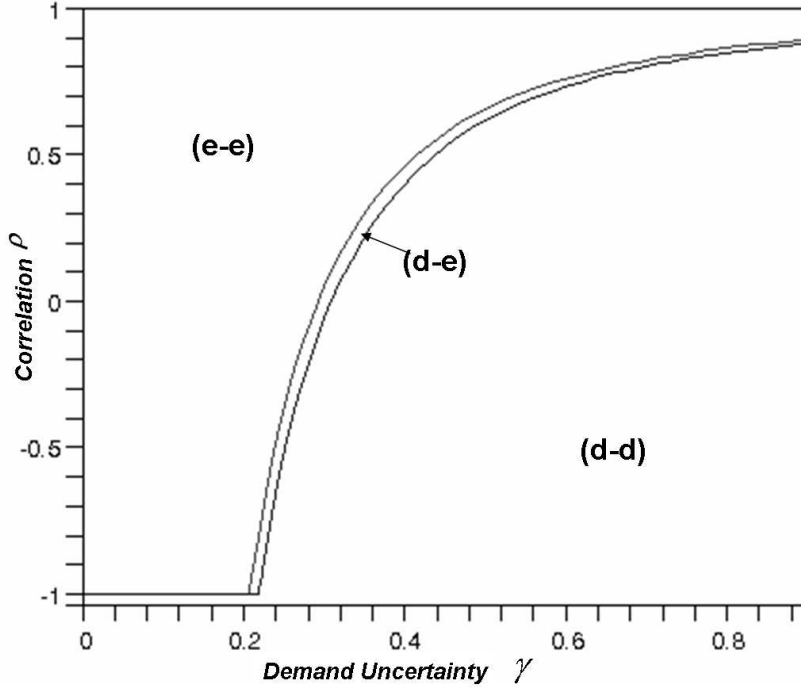


FIGURE 4.1. Equilibrium Supply Chain Configurations

**Theorem 4.2. Equilibrium Characterization for the Simultaneous Meta-Game:** *The unique dominant strategy equilibrium is  $(\mathbf{d} - \mathbf{d})$ , when  $\rho < \rho_4$  and  $(\mathbf{e} - \mathbf{e})$  when  $\rho \geq \rho_1$ . For  $\rho \in [\rho_4, \rho_1)$ , the unique pure strategy sub-game perfect equilibrium is  $(\mathbf{d} - \mathbf{e})$ .*<sup>7</sup>

The derivation is straight-forward from the best-response mappings of Theorem 4.1. In the range of parameters for which a firm's best response is  $\mathbf{d}$  (or  $\mathbf{e}$ ) *irrespective* of the other firm's choice,  $\mathbf{d}-\mathbf{d}$  (or,  $\mathbf{e}-\mathbf{e}$ ) is not just a sub-game perfect equilibrium, but in fact the dominant strategy equilibrium. In the range where the firm's best response is  $\mathbf{d}$  for  $\mathbf{e}$  and  $\mathbf{e}$  for  $\mathbf{d}$ ,  $(\mathbf{d} - \mathbf{e})$  is an equilibrium. Figure 4.1 shows the equilibrium supply chain configurations for different values of the coefficient of correlation and the coefficient of variation. We see that for a very large range of parameter values, either  $\mathbf{d}-\mathbf{d}$  or  $\mathbf{e}-\mathbf{e}$  are the equilibria. For a narrow sliver of intermediate values of  $\gamma$  and  $\rho$ , the equilibrium is asymmetric  $(\mathbf{d} - \mathbf{e})$ . In this range ( $\rho \in [\rho_4, \rho_1)$ ), the game in supply chain

<sup>7</sup> *Sub-game Perfection* is the refinement of the basic Nash equilibrium concept for dynamic games. All sub-game perfect equilibria are also Nash equilibria, but the converse is not true. A dominant strategy equilibrium is of course even stronger than Nash, and a rare occurrence in models (cf. Fudenberg and Tirole (1991)).

$\rho \in$	$[-1, \rho_5)$	$[\rho_5, \rho_2)$	$[\rho_2, \rho_4)$	$[\rho_4, \rho_1)$	$[\rho_1, \rho_3)$	$[\rho_3, 1]$
<b>Profits Earned</b>	$\Pi_{d e} >$ $\Pi_{d d} >$ $\Pi_{e d} >$ $\Pi_{e e}$	$\Pi_{d d} \geq$ $\Pi_{d e} >$ $\Pi_{e d} >$ $\Pi_{e e}$	$\Pi_{d d} >$ $\Pi_{e d} \geq$ $\Pi_{d e} >$ $\Pi_{e e}$	$\Pi_{e d} \geq$ $\Pi_{d d} >$ $\Pi_{d e} >$ $\Pi_{e e}$	$\Pi_{e d} >$ $\Pi_{d d} >$ $\Pi_{e e} \geq$ $\Pi_{d e}$	$\Pi_{e d} >$ $\Pi_{e e} \geq$ $\Pi_{d d} >$ $\Pi_{d e}$
<b>Best Responses</b>	$\longleftrightarrow \mathbf{d} \longrightarrow$			$BR(e) = d$ $BR(d) = e$	$\longleftrightarrow \mathbf{e} \longrightarrow$	
<b>Equilibria</b>	$\longleftrightarrow (\mathbf{d} - \mathbf{d}) \longrightarrow$			$(\mathbf{d} - \mathbf{e})$	$\longleftrightarrow (\mathbf{e} - \mathbf{e}) \longrightarrow$	

$\rho_i = \max\{-1, \rho'_i\}$ , where  $\rho'_5 = 1 - 2579 \left(\frac{1}{129\gamma}\right)^2$ ,  $\rho'_2 = 1 - 3 \left(\frac{1}{5\gamma}\right)^2$ ,  $\rho'_4 = 1 - 697 \left(\frac{1}{86\gamma}\right)^2$ ,  $\rho'_1 = 1 - 19 \left(\frac{1}{15\gamma}\right)^2$ ,  $\rho'_3 = 1 - 2575 \left(\frac{1}{258\gamma}\right)^2$ ;  $-1 \leq \rho_5 \leq \rho_2 \leq \rho_4 \leq \rho_1 \leq \rho_3 < 1$ ;  $\gamma = \frac{\sqrt{a}}{a}$ - coefficient of variation of the intercept distribution.

TABLE 6. Characterizing Profits, Best Responses and Equilibria

choices is isomorphic to the well-known ‘*battle of the sexes*’ game, where ‘coordinated’ moves are an equilibrium. Interestingly, for  $\rho \in [\rho_1, \rho_3)$ , both firms are better off with **d-d**, i.e., if they each follow delayed differentiation (see the profit comparisons in Table 6). However, early differentiation is the dominant strategy for each firm individually, and so there is no way for either firm to credibly commit to **d**. Hence firms do not cooperate and end up in the Pareto-dominated outcome **e-e**. This setting is isomorphic to the traditional ‘*prisoner’s dilemma*’.

*Sequential Meta-Game:* The analysis of the *sequential meta-game*, in which one firm chooses its supply chain configuration in response to the other firm’s choice, follows straight-forwardly from the preceding results. Dominant strategy equilibria are invariant to the timing of moves, and so, **d-d** (or **e-e**) is the equilibrium in the sequential meta-game for the same range of parameter values as in the simultaneous meta-game (as given by Theorem 4.2). The one twist with respect to the simultaneous meta-game analyzed previously is that, in the range  $\rho_4 \leq \rho < \rho_1$ , the first-mover computes that  $\Pi_{e|d} > \Pi_{d|e}$ , and so it always picks **e** as its supply chain configuration. The follower-firm then chooses **d** as its best response.

*Entry Deterrence:* We conclude this Section by comparing the effectiveness of the two supply chain configurations (**e** and **d**) for an incumbent firm seeking to deter entry in one of its markets. Consider the case of a firm being a monopoly in two (related) markets. It may choose to serve the two markets by employing early or delayed differentiation. The firm faces a potential entrant in one of the

two markets. The entrant trades off the various entry costs (Capital and Labor investments in Operations and Marketing infrastructure) with its potential profits, in making its entry decision. Of course, the incumbent prefers to deter competition and retain its monopoly power in both its markets.

**Theorem 4.3. *Entry Deterrence and Supply Chain Configuration:*** *For an incumbent wishing to deter entry, early differentiation is preferable to delayed differentiation.*

The profits of an entrant in a market are higher when the incumbent employs delayed differentiation in serving its two markets. As analyzed previously, a delayed-differentiating incumbent concedes a higher market share to the entrant than an incumbent employing early differentiation, leading to higher profits for the potential entrant, and making its entry more attractive.

## 5. THE RECONFIGURATION( $\theta$ ) BUSINESS PROCESS

This Section extends the analysis of the previous Sections to allow for a *via media* in a firm's choice of supply chain configuration. To do this, we introduce a 'reconfiguration cost' parameter that is a decision variable for the firm. Our motivation is two-fold. Firstly, the supply chain configuration choices available to the competing firms in our model (as in much of the extant academic research) were binary, i.e., early or delayed differentiation. We now extend the model so that one firm has a continuous range of configuration options, with early and delayed differentiation being merely the two *polar* cases. A second reason relates to some of the previous research under monopoly assumptions. Previous models assumed that the adoption of delayed differentiation entails higher costs arising out of the need for reconfiguration of the organizational processes, process and component standardization, design modularization (Schwarz (1989)) and longer lead-times (Lee and Tang (1999)), and studied the trade-offs between these increased costs and risk pooling under delayed differentiation. In contrast, our model thus far assumed cost parity between early and delayed differentiation, in order to focus the spotlight on the strategic effects of these choices. In this Section, *by introducing a parameter for reconfiguration costs, we tilt the scales further, since early differentiation is (implicitly) more costly than delayed differentiation.* Thus, the more a firm moves towards early rather than delayed differentiation, the greater its reconfiguration costs (and hence, the greater its costs of doing business, since all other cost and demand parameters are identical). We take this contrarian approach in order to further illustrate the powerful strategic

impact of firms' choice of supply chain configurations, which we have argued has been neglected in the previous literature.

**5.1. Setting.** In this Section, we propose a generalization of the early and delayed differentiation models discussed above. One firm produces quantities of specialized goods for each market (as in early differentiation); however it may reconfigure production intended for the monopoly market to sell in the competitive market (or vice-versa), after realization of the actual demands in the two markets. The other firm is an early differentiator. The setting is otherwise identical to the previous model. The firm employing a 'reconfiguration business process' produces quantities  $q_{r|e}^C, q_{r|e}^M$ <sup>8</sup> of specialized goods for the competitive and monopoly markets respectively, which it may reconfigure at the distribution center. After observing the realized demand curves; the firm decides to reconfigure a quantity  $q^r$  ( $-q_{r|e}^C \leq q^r \leq q_{r|e}^M$ ). Positive (negative) values of  $q^r$  reflect a transformation of goods produced for the monopoly (competitive) market into goods for the competitive (monopoly) market. We assume that the firm incurs a quadratic reconfiguration cost given by  $\theta \cdot (q^r)^2$ , if it reconfigures a quantity  $q^r$ ; where  $\theta \geq 0$ .<sup>9</sup> Further, we allow the reconfiguring firm to set its reconfiguration cost parameter  $\theta \in [0, \infty)$  costlessly; the parameter  $\theta$  is common knowledge (observed by the competing firm as well). One polar case is that the firm sets  $\theta$  to zero, which allows for costless (free) reconfiguration of the goods and corresponds to delayed differentiation. The other polar case corresponds to early differentiation, wherein the firm sets  $\theta$  to be prohibitively high. Intermediate, positive values of  $\theta$  correspond to intermediate supply chain configurations, a *via media* between early and delayed differentiation. Thus, lowering  $\theta$  both lowers costs and increases flexibility, facilitating risk-pooling.<sup>10</sup>

<sup>8</sup> The subscript  $r$  refers to the reconfiguring firm;  $e$  refers to early differentiation as before.

<sup>9</sup> Our results are robust to alternative cost assumptions. We use the quadratic cost function rather than the linear function  $\theta \cdot |q^r|$  to ensure differentiability in the entire range  $[-q_{r|e}^C, q_{r|e}^M]$  of the feasible values of  $q^r$ , which simplifies the algebra.

<sup>10</sup> Conventional wisdom would predict that  $\theta = 0$  (costless delayed differentiation) is the obvious dominant choice for the reconfiguring firm. As we demonstrate in our equilibrium analysis of the  $r$ - $e$  configuration, this (simplistic) argument fails to take the strategic implications of the choice of  $\theta$  into account.

<i>Setting</i>	$\mathbf{E} [q^M]$	$\mathbf{E} [q^C]$
$\mathbf{r e}$	$\frac{\bar{a}}{2}$	$\frac{1}{2} \frac{(3+2\theta)\bar{a}}{5+3\theta}$
$\mathbf{e r}$	$\frac{\bar{a}}{2}$	$\frac{(2+\theta)\bar{a}}{5+3\theta}$

TABLE 7. Equilibrium Expected Sales / Production

We now analyze the  $\mathbf{r-e}$  scenario wherein one firm is an early differentiator and the other can reconfigure its products across markets at a quadratic reconfiguration cost, with  $\theta$  the quadratic cost parameter set endogenously.

**5.2. Analysis.** The analysis of the  $\mathbf{r-e}$  configuration follows along the lines of the previous Sections; detailed derivations of all results are available in the technical supplement. Table 7 shows the expected sales quantities for each firm in each market as a function of  $\theta$ . On observation of the realized demands, the  $\mathbf{r}$  firm reconfigures the quantity,  $q^r = (a^C - a^M) / (4 + 2\theta)$ , where  $a^C$  and  $a^M$  are the *realized* demand intercepts in its competitive and monopoly markets respectively. Since the demand distributions are assumed identical in the two markets,  $E[q^r] = 0$ ; i.e., the firm on average reconfigures equally from each market ( $C$  or  $M$ ) to the other. Equivalently, the equilibrium production for each market is identical to the expected sales.<sup>11</sup> The solution and profits under the  $\mathbf{r-e}$  analysis reduce to those for  $\mathbf{d-e}$  when we set  $\theta = 0$ , and to those for  $\mathbf{e-e}$  in the limit  $\theta \rightarrow \infty$ , as we might expect.

The previous results apply for any  $\theta \in [0, \infty)$ . We now analyze the equilibrium that arises when  $\theta$  is a decision variable for the reconfiguring firm. We saw that a lower  $\theta$  lowers the reconfiguration costs and improves the firm's risk-pooling by increasing its flexibility. Countering these effects is the *strategic premium* from credible commitment to a competitive market. It is clear that the strategic premium plays a pivotal role at least in those cases where the optimal  $\theta$  for the reconfiguring firm (in equilibrium) is bounded away from 0. Theorem 5.1 shows that this holds for a fairly wide range of values of the market correlation parameter  $\rho$ .

<sup>11</sup> The symmetry in reconfiguration quantities arises because both production and sales quantities are decision variables in our model. Thus, both production quantities (which are determined pre-reconfiguration) as well as sales (which are determined post-reconfiguration) are adjusted to equalize expected marginal revenues in the two markets ( $C$  and  $M$ ).

**Theorem 5.1. *Equilibrium Characterization***

- (1) *When competing with an early differentiator, a firm employing the reconfiguration process chooses the cost parameter  $\theta > 0$  for all values of  $\rho > \rho_6$  where  $\rho_6 = \max \left\{ -1, 1 - \frac{12}{125\gamma^2} \right\}$ .*
- (2) *The equilibrium choice of  $\theta$  by the firm employing the reconfiguration process increases with  $\rho$ .*

Theorem 5.1 reflects the trade-off between the risk-pooling premium and the strategic premium in the choice of supply chain configuration. As the cost parameter  $\theta$  falls, the ability to share production across the two markets increases, which drives up the risk-pooling premium. Further, the actual reconfiguration costs also fall, and the overall effect is to drive the reconfiguring firm's profits higher. However, there is one countervailing factor: the strategic premium (vide Section 3.2). As the cost parameter  $\theta$  falls, the ability of the reconfiguring firm to credibly commit to any level of sales in the competitive market by setting its production levels also falls, and the early differentiator is correspondingly more aggressive in this market. The overall direction of profits is driven by the trade-off between the risk-pooling and strategic premiums. As we might expect, the risk-pooling premium is greater when the correlation  $\rho$  between the markets is lower. Hence the strategic premium dominates the risk-pooling premium for higher  $\rho$ . As Theorem 5.1 shows, for high enough  $\rho$  ( $\rho > \rho_6$ ), the strategic premium is large enough relative to the risk-pooling premium that the optimal  $\theta$  for the reconfiguring firm is unambiguously bounded away from zero, even though a higher  $\theta$  would increase its processing costs. Figure 5.1 illustrates this tension further, by plotting the profits  $\Pi_{r|e}$  earned by the reconfiguration firm as a function of the cost parameter  $\theta$  and the correlation coefficient,  $\rho$ . For low values of  $\rho$ , the risk-pooling premium is higher, and so profits are *decreasing* in  $\theta$ . On the other hand, when the correlation is high, the strategic premium dominates the risk-pooling premium, and so profits *increase* as  $\theta$  increases. It is interesting to note that the threshold value of the correlation coefficient  $\rho_6$ , is lower than the threshold value  $\rho_1$  when the firm's choices are limited to the two polar cases (see Theorems 4.1 and 4.2). As one would expect, expanding the set of available choices for the firm, from the two polar cases to a continuum of intermediate choices, reduces the scenarios when delayed differentiation is the preferred strategy to counter an early differentiating competitor.

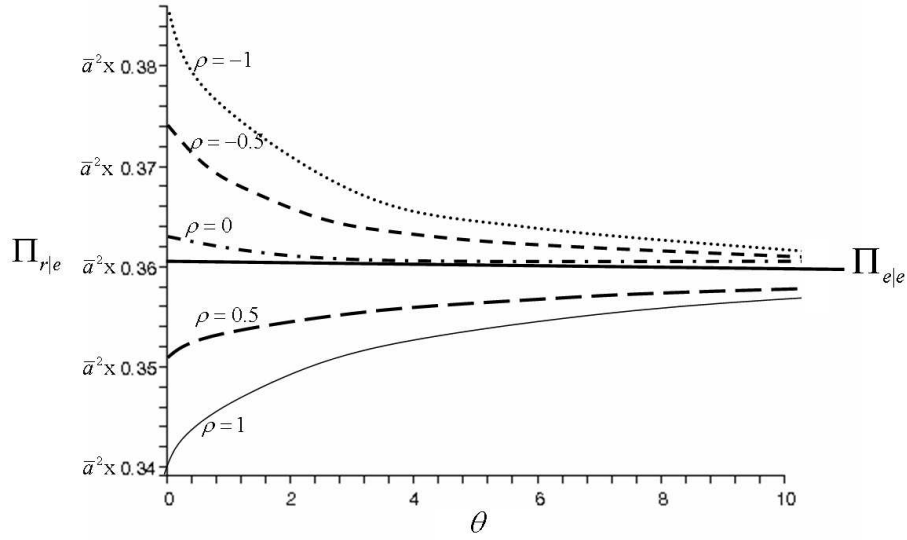


FIGURE 5.1. Profits earned by the firm employing the reconfiguration process,  $\Pi_{r|e}$ . The curves are drawn for  $\gamma = 0.3$ , and are similar for other values of  $\gamma$ .

The second part of Theorem 5.1 confirms the role played by the risk pooling premium. With increasing values of  $\rho$ , the risk pooling premium is lower, thereby tilting the scales in favor of the strategic premium. As a consequence, the firm prefers higher  $\theta$  with higher  $\rho$ .

**Theorem 5.2.** *The profits of an early differentiating firm competing with a reconfiguring firm are monotonically decreasing in the latter’s reconfiguration costs.*

Theorem 5.2 shows that the e|r firm also prefers that its competitor have lower reconfiguration costs. The early differentiator drives its competitor partially out of the competitive market, by virtue of its superior ability to credibly commit to sales in this market via its production. Figure 5.2 shows the profits of the early differentiating firm,  $\Pi_{e|r}$  as a function of the reconfiguration cost of its competitor. Unlike the conventional Cournot case, where higher costs for the competitor lead to higher profits, in our setting, higher costs for the competitor lead to lower profits for the firm. The early differentiating firm does not earn any risk pooling premium and its profits are driven solely by the strategic premium. This strategic premium is maximized when the competitor follows delayed differentiation ( $\theta = 0$ ), and monotonically decreases as the competitor moves towards early differentiation.

It could be argued that the firms are collectively worse off as the reconfiguration costs increase, since reconfiguration costs are a direct drain on industry profits. If so, we would expect industry profits

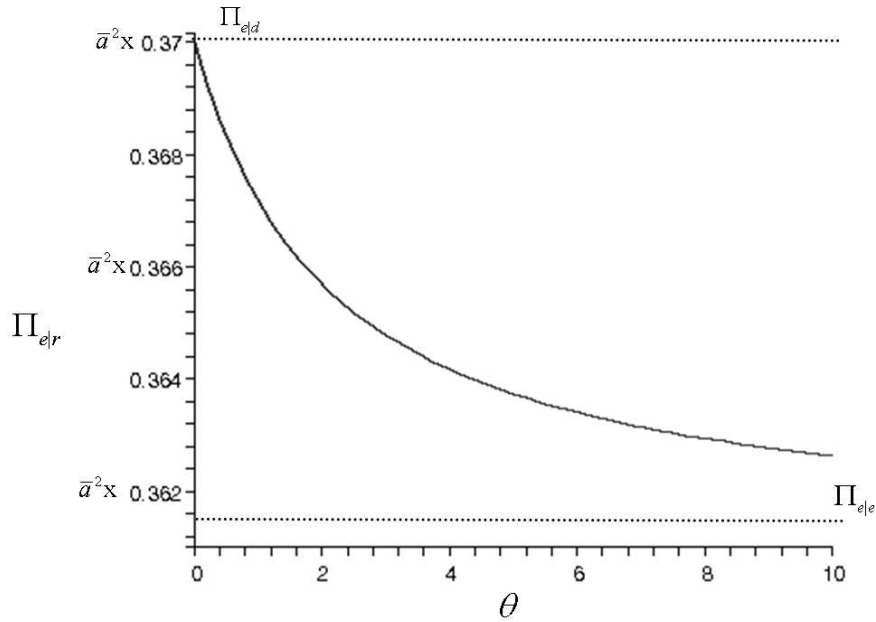


FIGURE 5.2. Profits earned by the early differentiating firm,  $\Pi_{e|r}$

to be maximized at  $\theta = 0$ , the lowest possible reconfiguration costs. The next Theorem sheds light on this question.

**Theorem 5.3. Industry Profits:** *The total industry profits are maximized at a reconfiguration cost  $\theta > 0$ , for high enough values of  $\rho$  ( $\rho > \rho_7$ , where  $\rho_7 = \max \left\{ -1, 1 - \frac{8}{125\gamma^2} \right\}$ ).*

As discussed in Section 3.1, when firms deploy asymmetric supply chain configurations, the early differentiating firm has the incentive to drive out a delayed differentiating firm from the competitive market. Also, recall that the total quantity supplied to the competitive market increases during this process. Similarly, in the **r-e** case, the **e** firm may drive out a firm that is more flexible (the **r** firm, for  $\theta < \infty$ ), while increasing the total quantity supplied. Moreover, for lower values of  $\theta$ , the ability to drive a firm out is more pronounced (since the firm is more like a **d** firm). Thus, with decreasing values of  $\theta$  the expected quantity supplied to the market increases, thereby leading to a decrease in the strategic component of the industry profits.<sup>12</sup> However, there is also a countervailing effect:

<sup>12</sup> Actually, the strategic component of the **e** firm's profits increases (since it can make up for depressed prices by its higher market share), but that of **r** firm's profits falls more (on account of lower prices and lower market share) than the gain for the **e** firm.

when the reconfiguring cost parameter  $\theta$  decreases, the costs of matching supply and demand fall, and the risk pooling premium increases. The trade-off between these two competing effects leads to the industry profits being maximized at a  $\theta$  bounded away from zero, for high enough values of  $\rho$ .

## 6. CONCLUDING REMARKS

In this study, we identified *endogenous strategic effects* that significantly diminish the value of delayed differentiation under competition. We isolated these strategic effects from the conventional risk pooling benefits, and identified conditions under which the strategic effects dominate the risk pooling benefits from postponement. Under these conditions, our results depart significantly from those of the extant literature: delayed differentiation is then not the preferred supply chain configuration to manage the effects of demand uncertainty across multiple markets under competition.

The strategic weakness under delayed differentiation arises from the limited ability to commit to supply quantities. Competitors with an early differentiating structure exploit this to their advantage. When both firms deploy delayed differentiation, the lack of commitment leads to both firms oversupplying the markets to preempt aggression by the other. The consumers gain in the process. Moreover, markets served by delayed differentiating firms are attractive targets for entry. The equilibrium choices of supply chain configuration derive as a result of the tension between the loss due to this inferior strategic position and the benefits arising from the superior ability to manage uncertainty with delayed differentiation.

Our analytical approach was geared to demonstrate these strategic consequences in a parsimonious model. Further investigation of the scope of these effects is a promising (and challenging) area for future research. A key driver of our results is the *strategic substitutability* of products: when one firm increases the quantities it supplies to a market, the other firm reacts by decreasing its supply. This is true for most (non-linear) demand curves. Our intuition suggests that the analysis should yield the same qualitative results for such general demand models, asymmetric market sizes and elasticities, and the possibility of salvaging intermediate produce. One promising extension looks at the interaction of the strategic effects of supply chain choice with the information structure deployed by firms. In our model, the demand information received by each firm in stage 2 (the distribution stage) is perfect. A generalization to allow for useful but imperfect information (which would require explicit modeling of information parameters) is an interesting avenue for further research.

The theory developed in this study also leads to a number of interesting empirically testable predictions. Notable among these would be to relate the operational processes deployed by firms with the intensity of competition (or market concentration), the resultant prices and the extent of the threat of competitive entry. A cross-sectional study of the choice of operational configuration by firms may provide evidence of the effects demonstrated above.

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