Product Quality Choice, Competition and Supply Chain Design.

Mark Ferguson[1]　　Stylianos Kavadias[2]

September 20, 2006

---

[1] mark.ferguson@mgt.gatech.edu

[2] stelios@gatech.edu; the authors are listed in alphabetical order.

Abstract

We explore the interplay between product design choices and their effect on the supply chain transactions. A large number of industrial business-to-business transactions indicates that product design choices, and the definition of the overall product performance (quality), is relying on "off the shelf" standardized components, and it influences the component pricing. We develop a normative model that highlights the drivers for the different industrial settings and we consider end product markets with quality sensitive heterogenous consumers (vertical differentiation).

We find that depending on the industry concentration at the different tiers of the supply chain, the timing of the product definition by the OEM has a substantial effect on the transacting firms payoff, as well as on other relevant metrics (total supply chain profits, social welfare). By examining the potential action sequences across the transacting firms, we identify the incentives for each firm to accomplish a decision earlier or later in the strategic interaction. Interestingly, the standard notion of the "leader" advantage in the transaction does not hold always, due to the indirect effect of the component cost on the end-product market, through the indirect link between the product performance and the total market served. Therefore, the OEM may benefit more from finalizing the end product specifications based on known component costs. Along similar lines, the supplier may benefit from a "follower" position in the sequence of decisions. Finally, the severity of competition in any of the two tiers may be diluted by a specific sequence, depending on the available information at the monopolistic tier.

(KEYWORDS: VERTICAL DIFFERENTIATION, SUPPLY CHAIN TRANSACTIONS, PRODUCT DESIGN)

1 Introduction

The Apple iPod has been a resounding success by, practically, any financial measure. Its sleek design, high quality audio, and compact size enabled Apple to revamp the market for portable digital music players in late 2001. After establishing a firm foothold in the market, iPod sales skyrocketed to 10.4 million units in 2004 and obtained an overall market share for U.S. portable digital music players of over 80%, making Apple the third best performing stock in the Standard and Poor's 500 Index in 2004 (Guglielmo, 2004). However, the popular business press placed far less attention on the fact that the original iPod would not have been possible without the advent of an 1.8 inch miniature hard-drive, designed and manufactured by Toshiba Corporation.

The miniature hard drive was critical to the original iPod's small size and functionality and represented an estimated 50% of its total variable cost (Sherman, 2002). Designing around this key component, Apple engineers determined the overall performance and the design features of the iPod through their focus on dimensions that affected the end-consumer perception, like the audio performance, the power utilization, and the product size. More specifically, Apple made several critical design choices (especially with respect to the product size) and shared them with Toshiba's engineers before finalizing the per-unit cost for the hard drives. At the same time, Toshiba quoted a price for the hard drives that allowed Apple to retain the overall product (development and manufacturing) cost at levels that supported their retail price targets. Despite the fact that Toshiba enjoyed monopolistic power through their technological intellectual property (their ability to produce a reliable miniature hard drive), they did not abuse their power by demanding high profit margins. Instead, Toshiba set a price for the hard drive that provided them with a modest profit margin, perhaps in anticipation of a large market potential for the iPod where they would make more money based on the high sales volumes. In hindsight, this appears to have been a smart move on Toshiba's part as the success of the iPod resulted in substantial financial benefits for both companies.

The interplay between the product design decisions and the supply chain transaction relationships between an Original Equipment Manufacturer (OEM) and a key component supplier is certainly not unique to Apple's development of the original iPod. In numerous other instances, OEMs share design specifications with component suppliers before the component prices are set. Many industrial settings exhibit such interactions; e.g. Toyota finalized the key quality requirements of the Prius (their first hybrid engine car model) before negotiating with Panasonic on the price of the rechargeable batteries needed to make the product work (Liker, 2004). At the same time, we also encounter the alternative timing of decisions: the downstream OEMs account for finalized price levels of a key product component before freezing the design specifications and refining the key quality dimensions of the end-product. As an example, PC manufacturers wait until the core processor manufacturers, Intel or AMD, announce their prices for the latest microprocessor before determining the quality features of their product offerings such as the amount of memory, hard drive size, type of external drives, etc. This intentional delay allows the OEMs to adjust their respective feature choices for the final product to be in line with observed consumer price ceilings (e.g. \$1000 for a consumer desktop computer; www.cnet.com).

In this paper, we explore the effects of the timing of the product definition decision as approximated by the sequence of firm actions on the product design choices along with the ramifications on the supply chain. We explore how the timing of the final product's design quality choice (i.e. before or after negotiating the price of a key component) affects its price, the performance quality of the final product, and the total demand served. We also analyze the impact on the total (and the appropriation of) supply chain profits.

We seek to answer our research questions under various competition regimes for the component and the end-product markets. We start with the base case of a monopoly-supplier, monopoly-OEM setting, which we use as a benchmark (i.e. a single transaction specific to its members). We then extend the model to incorporate the existence of competition in either the supplier or the OEM market[1]. We assume that, whereas the end products can be differentiated with respect to their quality performance and their price, the components provided from the upstream market are standardized both with respect to their design and the associated interfaces. Yet, the components hold a central role in the end-product functionality and they are necessary to produce it. Still, without additional investment, the components by themselves are useless to the final customer (e.g. memory chips can not perform any standard computer operations without peripherals and software drivers). Thus, when more than one suppliers possess the technology to produce such components, the suppliers compete via their capacity decisions. Our assumption, albeit restrictive, captures the essential effect of upstream competition (higher supply of components at lower prices to the OEM), and follows from similar past literature (Tyagi 1999, Corbett and Karmarkar 2001, Carr and Karmarkar, 2005). As an extension to this literature, in our model, OEMs in the end-product market may compete by differentiating their offering via the product quality design choices, where a choice

---

[1] The reason for this exclusive approach stems from our intention to isolate the effects of competition.

of higher quality incurs a higher per unit cost. We posit that such industrial settings offer a more realistic structure to analyze and understand the important strategic interactions.

We find that the timing at which the product definition decision (i.e. freezing the concept and finalizing the design choices, Bhattacharya et al. 1998) takes place during the transaction affects the profit distribution between the supply chain members along with the total supply chain profit. Interestingly, the standard notion of the decision "leader," in the game theoretic sence, does not align with the profit outcomes. Under a monopoly-supplier, monopoly-OEM transaction, the OEM benefits more from finalizing the product design *after* "locking" in the component price. Symmetrically, the supplier prefers to finalize component prices *after* the OEM's design decisions and investments are set, thus refraining from a first mover advantage. These order preferences may change, however, if there exists competition at either level of the supply chain. The presence of the quality choice may amplify the severity of the upstream competition when the component prices are set before the product design is fully determined. On the other end, competing OEMs exhibit misaligned incentives to finalize their designs before the component prices are set. The later result introduces the possibility that Moorthy's (1988) observation that the simultaneous product introduction has no difference to the sequential one, may require further research. These results appear counterintuitive from a traditional economics perspective. They stem from the endogenous determination of the total market due to the product quality choice and the existence of heterogenous consumer preferences.

Overall, our findings bare managerial importance by illustrating the indirect coupling between product design decisions and the resulting supply chain transactions. In that light, we echo Fine's (1998) conjecture about the need for managers to consider product introduction decisions along three dimensions: product design, process design and supply chain design. Our study builds a comprehensive framework for assessing these interactions. In addition, we obtain some social welfare implications that may be of interest to policy makers.

The rest of the paper is organized as follows: in §2 we briefly review the relevant literature. In §3 we introduce the model structure and discuss the basic premises. We establish the importance of the sequence of decisions across the different firms in the supply chain in §4 for the monopoly-monopoly case. In §5 we extend this analysis to different supply chain structures (oligopoly-monopoly in §5.1, and monopoly-duopoly in §5.2). We conclude our presentation with the discussion of our results in §6. All proofs are provided in the Appendix.

2 Literature Review

Economic theory has traditionally reasoned that in non-differentiated products, price competition benefits the end-customer who enjoys the lowest prices (Bertrand competition). At the same time, the same literature identifies differentiation in product attributes as a driver for increased profits among competing companies. Differentiation has registered in economics and management in two possible forms: vertical and horizontal differentiation. Vertical differentiation occurs when all consumers appreciate equally the relative performance quality of a product but are heterogeneous in their willingness to pay for a given quality (see Mussa and Rosen 1978 and Tirole 1987 for discussions). A "lower" quality product may attract consumers if offered at a low enough price but all consumers desire higher quality for the same price. In vertical differentiation models, the concept of quality is assumed to be a one-dimensional variable, although it may consist of multiple dimensions such as durability or technical performance. Horizontal differentiation, in contrast, occurs when customers have different tastes with respect to the product attributes (Hotelling, 1929). Hence, companies introduce products with potentially different features, and share the market by attracting those consumers that have tastes close to the offered product attributes.

In this paper, we focus on vertical differentiation where OEMs differentiate their products along a commonly perceived performance dimension. We employ the basic structure of the vertical differentiation model introduced by Moorthy (1984), for a monopoly setting, and Moorthy's (1988) later extension to a duopoly setting. These models assume the existence of a convex (quadratic) cost of performance quality, and that the quality choice determines the maximum market potential for a given price. We build upon Moorthy's analysis to account for the operational details of the OEM cost structure: the external component costs and the internal investments in product performance quality comprise the per-unit variable cost. In addition, we position the product design[2] decisions within a supply chain transaction setting, and we explicitly consider the strategic interactions between the end-product market and its associated component market. In short, we extend the literature by operationalizing the product design decisions (division between design investments and component costs) and by explicitly capturing the strategic interactions of the supply chain (transactions between the end-product and the supplier market).

While a number of studies have explored product differentiation (and the associated issues of intro-

---

[2] From this point onwards we treat the concepts of "design performance" and "quality" choices as equivalent, and thus we use the terms interchangeably.

duction, cannibalization etc.), much less has been said about the impact of the supplier markets on the end-product market differentiation and vice versa. Recently, Corbett and Karmarkar (2001) examined the impact of the within-tier competitiveness on the adjacent tiers of a supply chain. They assume a multi-tier supply chain where each tier adds components to obtain a non-differentiated end-product. Carr and Karmarkar (2005) extend the analysis to general assembly networks. In the heart of these models, firms are assumed to be price takers and to compete in capacities (Cournot competition). The total quantity is sold to a homogenous end-customer market, expressed by the classic linear demand curve, and it propagates upstream shaping the price in the supplier markets for a given number of firms competing in each tier. They focus on the determinants of the market structure (i.e. number of firms participating, entry decisions), demonstrating the subtle role of the total number of competing firms to the end-product quantity and cost. However, their assumption on the "commodity" nature of the end-product (perfect substitutes) limits the generalization of the results. We claim that in most consumer markets, such a degree of commoditization is rare, and firms compete by differentiating their offerings. Thus, extra investment is undertaken to ensure that the product quality is higher than a competitor, or that the price is lower.

Along similar lines, Majumder and Srinivasan (2006) extend the multi-tier analysis to include contracting decisions across members of the different tiers. They retain the "commodity" assumption about the end-product and the intermediate components, and they assume single-member tiers. Their results highlight the important role of the "leader" in the supply chain, that is, the firm which first proposes contracts both to the upstream and the downstream counterparts. In contrast, we do not focus on the formal contracting process, given our account for product design choices (which to our knowledge are rarely contracted upon, unless there is an explicit co-development agreement), and we allow for differentiated end-products and heterogenous consumer preferences. Despite the different perspective, we also observe that the order of decision making plays an important role in the distribution of the supply chain profits. The consideration of the product performance as a decision variable makes this role less intuitive however.

From a product development standpoint, Bhattacharya et al. (1998) explore the timing of the product definition during the product development process, given the lack of full knowledge about the market potential. While they model the concept definition phase in detail, they do not account for any outside components required for the realization of the design, and the respective impact of such transactions on the timing of the product definition. We consider a higher level of decision making and explore how the timing of the product definition decision affects the classic supply chain transactions, and the subsequent appropriation of the economic benefits. Krishnan and Ramachnadran (2006) focus on the effect of modular upgradable components on the innovation pace of industrial markets. Whereas they account explicitly for the component performance and features, they do not consider the strategic interaction between the upstream and downstream markets. Finally, Erat et al. (2006) analyze the effect of the upstream introduction decision of specialized processes or high-tech components on the end product OEM profitability. They do not address the end consumer market in detail, and they restrict their analysis to the adoption decisions by the OEMs. Essentially, they do not assume explicit differentiation investments by the OEMs apart from adopting the new component. In contrast, we focus on the design choices of the OEMs and we allow for competition both at the upstream and downstream levels.

In summary, we explore the impact of the supplier market on the downstream competition with respect to prices and the degree of product differentiation. This setting allows us to understand the cross tier linkages and design decision sequences in a quality-based, differentiated market. Since we choose to address these issues at such a high level of analysis and decision making, we make simplifying assumptions that aim to strike the right balance between mathematical abstraction and the real world phenomena. For example, as in Corbett and Karmarkar (2001), we do not account for detailed inventory policies and/or the details of the product development process that would render the model intractable and would not necessarily reflect the strategic firm decisions.

3 Model Setup and Assumptions

Consider a two-tier supply chain structure consisting of a set of suppliers selling a single standardized component to a set of OEMs[3]. The OEMs purchase the component from the supplier market, manufacture the final product and subsequently sell it to a market of end-consumers with heterogenous valuations regarding the end-product quality.

The **end-user market** is characterized by the different valuations that consumers place on the performance levels of the products. Each consumer's utility is $u(\theta, q, p) = \theta q - p$, where θ is the consumer's valuation of a baseline product with a quality level of one, q the product quality, and p the product price. We

---

[3] Our results extend to any multi-tier supply chain with the tiers 2 to n supplying non-differentiated products. The derivations follow Corbett and Karmarkar (2001). We choose to focus on the first 2 tiers as a good proxy for the overall phenomenon.

assume the consumers' baseline valuations are uniformly distributed across the $[0, 1]$ line. This assumption is common in the literature when the firm has little knowledge of the overall distribution of the consumers' market potential. We normalize the size of the total market to one[4].

We define the **OEM market** through three key variables: (i) the index, i, of the OEM ($i = 1, 2$)[5]; (ii) the corresponding final product prices (p_1 and p_2); and (iii) the quality offering (q_1 and q_2), which describes the performance qualities offered to the end-consumers. The variables q_i represent individual firm quality choices, whereas the subscript i denotes the rank, with respect to quality, of the firm ($q_1 \leq q_2$). Thus, each firm's total cost is comprised of a wholesale price, w, for the standardized component, and the development and manufacturing cost of quality $c_i = aq_i^2$. The firm specific ratio $\frac{w}{c_i}$ determines the importance of the component cost in the overall firm cost structure.

The **supplier market** sells a standardized ("commodity") component, i.e. a component with a well understood architecture and technology such as a memory chip or a hard disk drive. Our assumption of a homogenous base of suppliers allows us to maintain tractability and to characterize the effects on the end product offering(s) and the relative market size. In addition, it retains the common observation that more intense upstream competition results in lower prices. Two variables characterize the market: (i) the number of competing firms, n; and (ii) the upstream wholesale price w determined through a market clearing mechanism.

We analyze the interactions that emerge across the supply chain tiers through a series of extensions of the basic setup, which assume different competitive conditions in each tier.

4 The Role of the Decision Sequence

We start our analysis with the base case of a monopoly-supplier selling to a monopoly-OEM (MM case). This setting, albeit stylized, is relevant because it points out right from the beginning the importance of the timing of the product definition on the supply chain transaction. From a modeling standpoint, we capture

---

[4] Our results continue to hold for cases when the size of the market is different than 1 but the notation becomes unnecessarily burdensome.

[5] Our effort is to explore different emerging equilibria for different structures of the two interacting markets. The pricing equilibria of the OEM market extend to multiple companies through structures and mechanisms described in Shaked and Sutton (1983). Yet closed form solutions for the equilibrium design choices are intractable in settings with more than two competing firms.

this timing through the sequence of actions from the different decision makers. As our results verify, the decision sequence has a significant impact on the resulting profits, both for the entire supply chain and the individual firms. In later sections, we incorporate the effects of downstream and upstream competition.

Consider a monopolist OEM who uses a specific component for the end product. A sole supplier sells the component at a wholesale price w. The component's functional role is important because without it, there can be no final product. At the same time the component cannot perform as a full product (recall the memory microchip), therefore the OEM needs to build a set of features around the component in order for an end consumer to appreciate any utility. Thus, the OEM determines the performance quality q of the product design, and the "retail" price p of the end product, while incurring a variable per-unit cost of $aq^2 + w$. Note that in the transaction, we assume a supplier powerful enough to avoid a completely constrained decision (i.e. the supplier prices his/her component before the end-product price is determined[6]).

We begin by adapting, to our setting, two basic results; the optimal decision making of the vertically integrated supply chain and the optimal pricing game of a non-integrated supply chain where the performance quality of the end-product is exogenous (i.e. a classic "Stackelberg" game). For the vertically integrated supply chain, the OEM procures the component at the marginal cost of the supplier, which is normalized to zero. Proposition 1 summarizes the result.

Proposition 1 *(a) A two-tier, vertically integrated, supply chain offers a final product of quality* $q = \frac{1}{3a}$ *at a price of* $p = \frac{2}{9a}$ *and the total profit is* $\pi^{OEM} + \pi^{S} = \frac{4}{108a}$. *Only* $\frac{1}{3}$ *of the total market is served. (adapted from Moorthy 1984)*

(b) For an exogenous quality level of $q = \frac{1}{3a}$, *a two-tier, non-integrated, supply chain offers a final product price of* $p = \frac{5}{18a}$ *and the total profit is* $\pi^{OEM} + \pi^{S} = \frac{1}{108a} + \frac{2}{108a} = \frac{3}{108a}$. *Only* $\frac{1}{6}$ *of the total market is served (adapted from the classic "Stackelberg" framework).*

Proposition 1(a) describes the decisions of an integrated supply chain where the supplier is managed essentially as a cost center. The results are an adaptation of those by Moorthy (1984) for the case of a monopolist providing a single product. Proposition 1(b) iterates the classic "Stackelberg" result, where the supplier sets the component price and reaps the majority of the supply chain profits (twice the amount

---

[6] This assumption ensures a "viable" (and more interesting from an analysis perspective) setting. Otherwise none of the parties has an interest in pursuing the transaction; a quick calculation reveals that if the supplier moves last in the game sequence, then s/he prices very high, squeezing out all the margin from the OEM and prompting her to set $p = q = 0$.

of the OEM). The latter setting confirms that, even when the quality is fixed to the optimal level of the integrated supply chain, the total supply chain profits are lower than for the vertically integrated chain (the infamous double marginalization effect). The loss is attributed to the self interest maximization of the firms. We recite these results as benchmarks for the subsequent analysis and to acquaint the reader with the main insights of the previous literature.

For the remainder of the paper, we focus exclusively on the non-integrated supply chain setting. We categorize two distinct sequences of decisions in the product development process: (i) the supplier(s) determines the component price w before the design specifications are finalized (for example, gem prices in the diamond market determine to a large extent the cost of the end refined jewels); (ii) the OEM(s) define the end-product design features (architectural and design choices that determine the overall performance) before the component price is set by the supplier market. Note, the decision sequence does not involve which supply chain member sets the wholesale price, a sequence normally associated with Stackelberg leadership in the marketing channels literature (Ingene and Parry, 2004). We assume the supplier always sets the wholesale price for her component. Thus, the traditional notion of a supply chain member becoming a Stackelberg leader or follower based on *who* sets the wholesale price is ignored in our setting. Instead, we focus on the order of other decisions made during the design process such as *when* the supplier should set her price or when the OEM should share the specific product design with the supplier. Figure 1 depicts the timely differences of the two decision sequences.

Our categorization couples two important determinants of firm performance: the product design choices (via the determination of the end-product performance quality) with the supply chain configurations (single versus multiple suppliers, and single versus multiple OEMs). Through this structure we puruse the "3-D product development" decisions (Fine, 1998). For notational ease, call the two sequences S and O (corresponding to the supply chain member who makes the first transaction), defined respectively below:

Sequence S: Supplier sets component price→OEM finalizes design performance→OEM sets price
Sequence O: OEM finalizes design performance→Supplier sets component price→OEM sets price

For the remainder of this paper, we use the subscripts S and O to differentiate our decision variables and parameter values between the two sequences although we drop the subscript when convenient. The

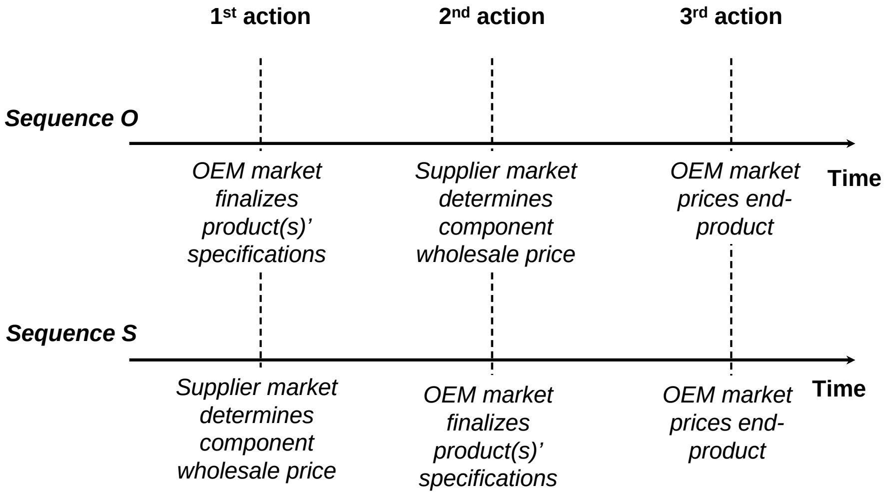

Figure 1: Different sequences in end-product finalization

following Proposition offers the comparative results across both decision sequences in the monopoly-supplier, monopoly-OEM setting.

Proposition 2 *For $j \in \{S, O\}$, the optimal end-product quality q^*, price p^* component price w^*, total market sales D^*, supplier and OEM profits π^{S*}, π^{OEM*}, supplier profit premium and total supply chain profit are higher in sequence j as follows:*

Variable	q^*	p^*	w^*	D^*	π^{S*}	π^{OEM*}	$\pi^{S*} - \pi^{OEM*}$	$\pi^{OEM*} + \pi^{S*}$	$\gamma = \frac{\pi^{OEM*}}{\pi^{S*}}$
Higher in sequence	S	S	S	O	O	S	O	O	S

Proposition 2 reveals the opposing preferences across the two firms of the supply chain. The supplier clearly prefers setting the wholesale price under full information with respect to the design (i.e. she prefers sequence O), whereas the OEM benefits more from finalizing the product quality only after the component price is determined (i.e. he prefers sequence S). At first sight, the outcome is puzzling; both members of the supply chain benefit from decision sequences that retract them from the power standpoint of the "first mover advantage." Thus, the supplier enjoys higher profit despite the fact that she gives up her first mover role, and she charges less for each component (note that $w_S^* > w_O^*$). Sequence O is a straightforward extension of the classic Stackelberg scenario: the member of the supply chain that sets the wholesale price enjoys twice the profit over the other member (see the Appendix for the exact solutions under each sequence). The supplier appropriates more of the total supply chain profits whereas the OEM has little control of the division of profits despite the fact that he determines, through q, the size of the overall demand. Thus, in sequence O, when the OEM chooses q, he determines the total supply chain profit but can not affect the percentage of the total profit he enjoys. Once the demand curve is set (based on the OEM's choice of q), the decision sequence is exactly the same as the classic Stackelberg game described in Proposition 1b and the supplier sets w to appropriate two thirds of the total supply chain profit. The only lever available to the OEM lies in trying to induce a higher demand and increase his profit. Therefore, he sets the performance quality and the price relatively low; i.e. he pursues high volume but not high margins. The high volume strategy adopted by the OEM, however, makes the supplier better off.

Interestingly, sequence S grants the supplier less power despite the fact that she operates under a wholesale price leadership role. She is obliged to set the component price without full knowledge of the demand curve, and as a result, the only lever for her to appropriate higher profits is by ensuring a high margin (i.e. high w^*), even though the latter may induce smaller demand (which it does, as attested by $D_S < D_O$). Concerning the OEM's strategy, sequence S grants him the ability to retain a higher share of the total supply chain profits when compared with sequence O (still $\gamma_S < 1$ indicating that the supplier retains the majority of the supply chain profit). Therefore, in contrast to sequence O, the OEM pursues higher margins at the expense of lower volume. The extra percentage of the total profits the OEM enjoys stems from the ability to set both the demand and the price under a known component cost, thus reserving a higher profit. In a sense, the extra gain is a rent the OEM appropriates due to full information, which dilutes the severity in the profit splitting observed when double marginalization takes effect.

The "information rent" effect is also attested by the difference in the total supply chain profits. Comparing the total profits of both sequences to the integrated supply chain's profit in Proposition 1a, there is a bigger drop in the total profit under sequence S where the supplier determines the component price first. Thus, the supplier precomitment intensifies the loss due to the double marginalization effect.

From a managerial standpoint, the results dictate a careful assessment of the ability to integrate standardized components in the product design. Note that the issue of intellectual property is at play here, since we assume a sole supplier without competition (probably protected under patent enforcement), which permits the supplier to exploit the OEM. Yet, the OEM may relax the severity of the total profit division losses by “locking” in the component prices before his design is finalized. Higher standardization in the end-product, as proxied through the inclusion of the “off-the-shelf” component, seems to come at a social cost however, as the inclusion of the independent supplier drives the end-product cost higher, rendering the end market size smaller with fewer consumers served.

There is an additional interesting insight revealed from our analysis: the quality-quantity trade-off in the social welfare. We explicitly state it in Proposition 3.

Proposition 3 *Assume that the indifferent consumer between buying or not buying is of type* θ_j *for sequence* $j \in \{O, S\}$*. There is a threshold consumer type* $\widetilde{\theta}$ *such that the individual consumer preferences for each sequence are as follows:*

Market segments	$(0, \theta_O)$	(θ_O, θ_S)	$(\theta_S, \widetilde{\theta})$	$(\widetilde{\theta}, 1)$
Sequence with higher $u(\theta)$	None	O	O	S

While sequence O results in a higher portion of the consumers satisfied (higher quantity), a segment of the “very sensitive to quality” consumers obtains higher utility from sequence S. Still, this high end segment, in combination to the higher quality offering (despite the also high price) is enough to change the result with respect to the average enjoyed consumer utility (i.e. $\int_0^1 u_S(\theta)d\theta > \int_0^1 u_O(\theta)d\theta$), indicating that, on average, the consumers enjoy higher utility under sequence S. This last result describes the impact on consumer utility. It reveals that whereas sequence O satisfies more consumers, sequence S satisfies them better. In fact, the high-end consumers benefit substantially from sequence S because it enforces a higher quality product, thus providing them with more utility. This result does not directly translate into an absolute preference for a sequence from a socal welfare perspective. Answers to the question “is providing more customers with a margin improvement in consumer utility better than substantially increasing the utility of a few customers?” relates more to public policy economics and is beyond the scope of our study.

5 The Role of Competition

In this section we depart from the base-case restriction of monopolistic markets in either the upstream or the downstream industries in the supply chain. As we introduce competition at the different tiers of the supply chain, we retain our focus on the timing of the product definition.

5.1 The case of upstream competition (OM case)

Assume the technology to produce the standardized upstream component is not subject to IP restrictions, allowing its production by n supplier firms who compete in terms of their capacity ("a la" Cournot). This underlying assumption finds immediate application in industrial settings where the upstream market supplies commodity raw products (e.g. silicon, milk, corn, steel etc.) without low concentration, and it offers a reasonable approximation for more general settings where there is mild competition (i.e. less harsh than Bertrand) at the component tier of the supply chain[7]. As in the previous section, we categorize our analysis with respect to the timing of the design decision. Sequence S represents industrial settings where the supplier market, albeit competitive, determines the component price before the performance and design quality decisions are made by the OEM. In sequence $O,$ the OEM invests and finalizes the product design details prior to receiving a component price from the suppliers. In such a setting, the OEM guarantees a major volume for the suppliers (approximated through the monopoly downstream case), therefore he can proceed with the product definition without a final upstream price; i.e. energy monopolies in European countries. As before, the monopolist OEM chooses the quality offering q and the price p. The upstream market supplies the common component at a market clearing price w. Assuming a market clearing mechanism allows tractability while retaining the essential features of competition: lower prices resulting from higher quantities of components. It also allows us to approximate the competition intensity through the number of supplying firms. In the Appendix, we derive the optimal decisions for general market structures ($n = 2, 3, ...\infty$) but in the main text we report on the opposite ends of the spectrum: in the presence of an upstream duopoly and the perfect competition case with an extremely large ($n \to \infty$) number of suppliers. As the number of suppliers approaches ∞, the results converge to the integrated supply chain results of Proposition 1a, since the upstream market ends up competing soley on price.

Let $\sum \pi_i^S$ represent the sum of the suppliers' profits for $i = 2, ...n$ where $n \in (2, 3, ...\infty)$. Proposition 4 compares the non-integrated supply chain's optimal solutions for each variable under the monopoly-supplier, monopoly-OEM (MM) setting versus the oligopoly-supplier, monopoly-OEM setting (OM). These results are independent of the design sequence and of the number of suppliers.

Proposition 4 *The presence of upstream competition introduces a unidirectional effect, independent of the*

---

[7] Note that in the event the upstream competition is in prices the resulting optimal choices coincide with the results of Proposition 1(a).

timing of the product definition or the number of suppliers:

Variable	p	w	D	$\sum \pi_i^S$	π^{OEM}	$\pi^{OEM} + \sum \pi_i^S$
Larger under setting	MM[8]	MM	OM	MM	OM	OM

As expected, the upstream competition alters the balance and shifts profits away from the supplier market to the downstream monopolist OEM. The shift is unidirectionaly independent of the sequence for the component price, end-product price, and total demand served. However, we show in the Appendix that the end product quality decreases (in order to increase the overall sales) only in sequence S. Hence, the OEM is able to take advantage of the supplier competition and reduce the quality only when the component price is set beforehand. This is a direct consequence of the information availability. In the event of setting the product quality before knowing the component price (sequence O), the OEM retains the same quality level as in the upstream monopoly case to ensure the suppliers do not exploit the opportunity and retain their high prices. With respect to the double marginalization effect, the total supply chain profit increases under the case of upstream competition. As competition intensifies upstream ($n \to \infty$), the marginal profit on each component decreases allowing the OEM to act as an integrated manufacturer.

Proposition 5 compares the effect of the product definition timing in the presence of duopoly suppliers.

Proposition 5 *For* $n = 2$ *and* $j \in \{S, O\}$*, the optimal end-product quality* q^**, price* p^* *component price* w^**, market size* D^**, supplier and OEM profits* π^{S*}, π^{OEM*}*, supplier profit premium and total supply chain profit are higher in sequence* j *as follows:*

Variable	q^*	p^*	w^*	D^*	$\sum \pi_i^{S*}$	π^{OEM*}	$\pi^{OEM*} - \sum \pi_i^{S*}$	$\pi^{OEM*} + \sum \pi_i^{S*}$	γ
Higher in sequence	S	S	O	O	O	S	S	O	S

Proposition 5 compares the quality offering, the social welfare, and the profits of the supply chain members, across the two sequences. Sequence O extends the original Stackelberg framework for competitive suppliers. Under the presence of competition, the upstream market is severely penalized as attested by Proposition 4. As expected, the OEM appropriates the biggest share of the total supply chain profit under both sequences since he defines the overall demand by setting q and, at the same time, enjoys lower prices due to the upstream competition (for the detailed calculations please refer to the Appendix). As opposed to

---

[8] MM stands for the monopoly supplier - monopoly OEM setting whereas OM describes the upstream oligopoly industrial setting.

the monopoly-monopoly setting, things get even worse for the supplier market under sequence S. Given that the competing suppliers face an unknown demand (no credible committment by the OEM), they intensify their competition under sequence S to ensure that, for any potential demand curve, they will at least enjoy high sales volume (achieved through lower component prices). The OEM on the other hand, experiences a lower component price under sequence S without any commitment to set for the overall demand, hence he exploits the resulting competition even more and obtains a higher rent appropriation, as the γ index shows. Thus, the supplier market is better off under sequence O, exactly because they retain the ability to determine the end-product price under a known and committed demand curve. Again, the information availability benefits the second mover in the transaction.

From a managerial standpoint, our result confirms the observations about severe competition in generic "commoditized" component markets, such as the recent price competition in the microprocessor market between Intel and AMD (Dunn, 2006). The result is also in line with the conjectures of the technology management literature (Baldwin and Clark, 2000) concerning the impact of different architectures (integratable versus modular) on the industry structure. Modular architectures require standardized interfaces, rendering the component markets more commoditized (since any upstream component is "good enough" as long as it adheres to the interface standards), therefore they intensify within tier competition.

5.2 The case of downstream competition (MO case)

Our final case is a setting where a sole supplier offers a standardized component to two competing OEMs that may differentiate their offering both in price and performance quality. This supply chain structure represents industrial settings where the upstream market is dominated by a single supplier (potentially holding law enforced patents on the component technology), but the downstream market is competitive with respect to the preferences of the end consumers. As in the previous cases, we explicitly consider the product definition timing and distinguish between the two different sequences S and O. The OEMs choose the quality offerings q_i and the prices p_i $(i = 1, 2)$. The upstream supplier prices the component used by both OEMs at w. We restrict the downstream competitors to two firms, due to the intractability to obtain closed form solutions even for this simple case (this intractability is not a peculiarity of our setting but a generally acclaimed difficulty; for more on this see the original work by Moorthy 1988). Lemma 1 presents the end-product pricing as a function of the competing quality levels and the supplier's component price.

Lemma 1 *The end-product pricing equilibrium is*

$$p_2(q_2, q_1, w) = \begin{cases} q_2 \frac{2aq_2^2+3w+2q_2-2q_1+aq_1^2}{4q_2-q_1}, \text{ if } q_2 > q_1 \\ aq_2^2 + w, \text{ if } q_2 = q_1 \\ \frac{2q_1aq_2^2+2q_1w+wq_2+q_2aq_1^2+q_2q_1-q_2^2}{4q_1-q_2}, \text{ if } q_2 < q_1 \end{cases}$$

Through Lemma 1, it becomes apparent the two competing OEMs are obliged to differentiate their products in terms of quality because in the event of the same quality, they both make zero profit (they set their prices equal to their marginal cost, a well known result of the Bertrand competition structure). Note also that the end-product pricing decisions are independent of the sequence of decision making since the end-product price is chosen last in both sequences. The Lemma indicates a separating equilibria where one firm chooses a low quality and the other firm chooses a high quality (indicated by subcripts L and H respectively). The existence of two symmetric equilibria follows directly from Moorthy 1988, as the following Corollary states.

Corollary 1 *In both sequences S and O, there exist two symmetric equilibria for the OEM market: (q_1^*, p_1^*) and (q_2^*, p_2^*) such that*

$$q_1^* = q_L \text{ and } q_2^* = q_H$$

As in the original work of Moorthy (1988), we derive the optimal quality levels numerically for given values of the quality investment cost a. By minimizing the sum of the squared differences, we determine the best fitting curves $q_1(a)$, $q_2(a)$ to the calculated numerical values (results are provided in the Appendix). In Proposition 6, we compare the effect of the decision sequence in the presence of duopoly OEMs. Then, in Proposition 7, we discuss the effects of upstream versus downstream competition on the overall supply chain performance and the social welfare.

Proposition 6 *For two OEMs and $j \in \{S, O\}$, the optimal product performance qualities $q_{H,j}^*, q_{L,j}^*$, the corresponding end-product prices $p_{H,j}^*, p_{L,j}^*$, the component price w_j^*, the market size $D_{H,j}^*, D_{L,j}^*$ the supplier and OEM profits $\pi_j^{S*}, \pi_{H,j}^{OEM*}, \pi_{L,j}^{OEM*}$, the supplier profit premium and the total supply chain profit are higher in sequence j as follows:*

Variable	q_H^*	q_L^*	p_H^*	p_L^*	w^*	D_H^*	D_L^*	π^{S*}	π_H^{OEM*}	π_L^{OEM*}	$\sum \pi_i^{OEM*}$	$\sum \pi_i^{OEM*} + \pi^{S*}$
Sequence	S	S	S	S	S	O	O	S	S	O	O	O

Proposition 6 highlights the conflicting incentives across the competing OEMs. The low quality OEM benefits more from sequence O where he defines his product quality before knowing the supplier's component price. In contrast, the high quality OEM prefers knowing in advance the component price. The difference stems from a similar logic as in the duopoly suppliers case. A predetermined component cost (sequence S) essentially restricts the overall market by inflating the overall product costs. Thus, the component price determines the total market size, increasing the competition among the OEMs trying to differentiate themselves in a given market. With a smaller total market, the low quality OEM is obliged to increase his quality and price to retain an acceptable level of profits, thus reducing his market size.

The severity of the competition among the OEMs is also attested by the magnitude of the product differentiation (i.e. $q_H - q_L$), which is smaller in sequence S. This is also seen through the total supply chain profits. Once competition intensifies, the total profit in the supply chain declines. Note however, the different effect of the locus of competition on the total supply chain profits: When the competition takes place in the supplier market, the maximum total supply chain profits are attained under sequence S. Here, the same result is achieved when the OEMs set their qualities first (sequence O). The underlying phenomenon is the same although it manifests itself differently. In either case, when the competing parties commit to their decisions with less information, the competition among them intensifies, benefiting the other supply chain tier. In the second case (OEMs competing), higher intensity implies that qualities are set higher and that fewer consumers buy, but at a higher margin. Finally, due to the stronger OEM competition, sequence O results in higher total demand $D_H + D_L$.

From the supplier's perspective, her prefered choice of the design sequence changes when there is competition at the OEM level. For the MM and OM cases, the supplier(s) prefers full knowledge of the product design before setting the component price (sequence O). With duopoly competition among the OEMs however (the MO case), she prefers to set the component price before the OEMs set their qualities (sequence S). To see why, consider the MM base case If the supplier moves first in this scenario, she must price the component low so the OEM will invest in a large enough quality level and price the end-product low enough to ensure sufficient demand. When there is competition at the OEM level however, the OEMs already have an incentive to differentiate their products (through their price and quality choices) as much as possible. Thus, the supplier can price the component higher and still enjoy the benefits of large end-product demand. Thus, a volume-based strategy becomes attractive.

The managerial take away once more emphasizes the component nature. Standardized components with fixed prices render differentiation a less attractive “device” for profit appropriation, and the OEMs compete more intensively. Especially for components with patented technologies, the impact on product differentiation results in social welfare loss, potentially opening up market space for additional competitors (since a larger part of the total demand remains unsatisified).

Proposition 7 compares the duopoly-supplier, monopoly-OEM structure with the monopoly-supplier, duopoly-OEM structure.

Proposition 7 *The component cost (w^*), the total demand served (D^*), and the total supply chain profits are higher under the MO case than the OM case. These results hold under both design sequences.*

Proposition 7 compares the key indices across the two competition scenarios. When compiled together, the results reveal an interesting insight: despite the fact that the end-product demand increases (signaling lower on average prices) and the component price is higher under the MO case, the total supply chain profits are also higher. The increase is driven by the existence of vertical differentiation which allows the OEMs to retain (on average) some of the value even though they pay higher prices to the monopoly-supplier upstream. Thus, vertical differentiation downstream dilutes the upstream monopoly power, allowing higher rent appropriation. From a social welfare standpoint, when components are commodities but end-products are quality differentiated, it is better to allow monopolies at the supplier level than at the OEM level (at least in terms of total demand served).

6 Conclusions and discussion

In this paper, we provide a normative perspective on earlier conjectures in the literature about the potential interdependence between product design decisions and supply chain transactions (Fine 1998). We consider the strategic interplay between the upstream supplier market and the downstream end-product market given that (i) the end customers value quality heterogenously, and (ii) the product design requires a standardized component to offer complete functionality. In such a setting, the OEM(s) must decide on the product design features by taking into account the entire product architecture (i.e. component sourcing, or IP component integration) and the timing of the associated decisions (before or after the prices have been set for the components). There can be two possible times for this decision, which we proxy through the sequence of actions taking place during our game theoretic abstraction of the phenomenon. In the first sequence, the supplier market defines the component price before the dowstream firm(s) finalize the product design specifications (i.e. the performance quality level) of the end-product. In the second sequence, the downstream OEM(s) determines the product design details (through irreversible investments in product development and resources) before the supplier market sets the component price.

The OEM's choice of the end-product quality influences the resulting market potential (and differentiates the product offerings in the case of competing OEMs) at a cost that is increasing in the level of quality. The supplier's choice of the component price influences the OEM's total marginal cost, and subsequently, the end-product price, thus indirectly determining the supplier's demand. We explore how the timing of the product design definition influences the component wholesale pricing, the product performance quality, the final selling price of the end-product, and profits for both the supplier, OEM, and the total supply chain. We extend our analysis to account for competitive settings within the different tiers in the supply chain.

From the outset, our model offers a comprehensive framework for identifying the interactions between the product design definition and the transaction structure across the supply chain tiers. To our knowledge, no other study has concurrently analyzed both design related decisions and supply chain strategic interactions, the latter considered within and across tiers. Still, as in any normative model, our results should be viewed with caution when translating them into managerial actions. Our goal is not to offer a decision support system but rather to provide directional insights as to the impact on specific decision variables.

We find the timing of the design definition affects the profits of the supply chain members in managerially relevant ways. The standard notion of the decision "leader," in the game theoretic sence, does not always align with the payoff outcomes. Under a monopoly-supplier, monopoly-OEM setting, the OEM benefits from defining the product quality before the component price is set by the supplier. Symmetrically, the supplier prefers to finalize component prices after the OEM's design decisions and investments are set, thus also refraining from a leader advantage. These timing preferences may change however, if there is competition at either tier of the supply chain. Thus, in a monopoly-supplier, duopoly-OEM setting, the supplier and the OEM producting the high quality product benefit more from fixed upfront component prices, while the OEM producing the low-quality product prefers to finalize the product performance as early as possible. Thus, the locus of competition in the supply chain is strongly related to the timing of product definition. The results reflect the endogeneity of the total market determination due to the product quality choice and the heterogenous consumer preferences.

In addition, the classic double marginalization effect may be diluted under specific design decision sequences. These sequences, however, do not always offer a "fairer" division of profits. Finally, from a social welfare standpoint, we identify two important insights: (i) Depending on the timing of the product finalization, more consumers may be served at a lower average utility or less consumers may be served but at a higher average utility, and (ii) In two-tier markets with the upstream market providing a standardized component, a larger part of the total market is served when monopolies exist at the supplier tier instead of the downstream end-product market.

7 Appendix

Proof of Proposition 1. (a) We write the payoff function of the integrated supply chain as follows (for an integrated supply chain, the supplier's price equals her cost which is normalized to equal zero). The integrated firm decides with respect to the price for a given quality level, thus let the consumer type that is indifferent between purchasing the end-product or not be $\theta = \frac{p}{q}$ (that stems from finding for a given (p, q) the consumer type θ such that $u(\theta) = 0$):

$$\pi^{OEM}(q,p) = (1 - \frac{p}{q})(p - aq^2)$$

Then, we get from the first order conditions:

$$\begin{aligned} \frac{\partial \pi^{OEM}}{\partial p} &= 0 \\ p(q) &= \frac{q + aq^2}{2} \end{aligned}$$

and

$$\begin{aligned} \pi^{OEM}(q) &= (1 - \frac{q + aq^2}{2q})(\frac{q + aq^2}{2} - aq^2) \\ &= \frac{q(1 - aq)^2}{4} \end{aligned}$$

which eventually leads to the optimal quality level:

$$\begin{aligned} \frac{\partial \pi^{OEM}}{\partial q} &= 0 \\ \frac{(1 - aq)(1 - 3aq)}{4} &= 0 \end{aligned}$$

with only one solution that renders profits higher than zero for the integrated supply chain: $q = \frac{1}{3a}$. Further substitution yields the rest of the values.

(b) Consider the two profit functions for a given level of quality q:

$$\begin{aligned}\pi^{OEM}(p) &= (1-\frac{p}{q})(p - aq^2 - w)\\ \pi^S &= (1-\frac{p}{q})w\end{aligned}$$

The supplier sets the wholesale price and the OEM decides on his pricing. Thus, we solve the sequential game backwards and obtain:

$$\begin{aligned}\frac{\partial \pi^{OEM}}{\partial p} &= 0\\ p(q,w) &= \frac{q + aq^2 + w}{2}\end{aligned}$$

and subsequently

$$\pi^S(w) = w(1 - \frac{q + aq^2 + w}{2q}) = \frac{w(q - aq^2 - w)}{2q}$$

with

$$\begin{aligned}\frac{\partial \pi^S}{\partial p} &= \frac{q - aq^2 - 2w}{2q} = 0\\ w^* &= \frac{q - aq^2}{2}\end{aligned}$$

Substitution back to the $p(q,w)$ yields the optimal price and the rest of the results follows. (QED)

Proof of Proposition 2. We analyze each one of the two configurations separately. Hence, we solve each game structure backwards. The last stage (i.e. the OEM determines the end-product price) is common across both configurations. The OEM maximizes her/his profits given the other two decision variables, i.e. the product quality q and the component price w:

$$\max_p \int_\theta^1 (p - aq^2 - w)dt = \max_p (1-\theta)(p - aq^2 - w) \tag{1}$$

Solving first order conditions results in an optimal OEM price and profit (assuming $aw < \frac{1}{4}$[9]) of:

$$p^*(q,w) = \frac{w + q + aq^2}{2}, \quad and \quad \pi^{OEM*}(q,w) = \frac{1}{4}\frac{\left(aq^2 + w - q\right)^2}{q}. \tag{2}$$

---

[9] The inequality ensures that the supplier benefits (even Paretto-wise) from supplying the end product market.

Sequence S: Supplier's price→OEM's quality→OEM's price. The choice of the optimal performance quality offering q is determined by the maximization of $\pi^{OEM*}(q, w)$. The first-order conditions result[10] in an optimal quality level of:

$$q_S^*(w) = \frac{1 + \sqrt{1 + 12aw}}{6a} \tag{3}$$

which by substitution into (2) results in a closed-form expression for the end-product price of:

$$p_S^*(w) = \frac{1 + \sqrt{(1 + 12aw)} + 6aw}{9a}. \tag{4}$$

The total quantity sold in the downstream market is

$$D_S^{down*}(w) = 1 - \frac{p_S^*(w)}{q_S^*(w)} = \frac{1 + \sqrt{(1 + 12aw)} - 12aw}{3 + 3\sqrt{(1 + 12aw)}} \tag{5}$$

resulting in an OEM profit of

$$\pi_S^{OEM*}(w) = \frac{1}{5832} \frac{\left(-17 - 6\sqrt{\left(11 + 4\sqrt{7}\right)} + 2\sqrt{7} + 162wa\right)^2}{a\left(3 + \sqrt{\left(11 + 4\sqrt{7}\right)}\right)} \tag{6}$$

Finally, the associated upstream market equilibrium maximizes the monopolistic supplier profits given that s/he provides the totality of components, i.e. $D_S^{down*} = D_S^{up*} = D_S^*$. In this situation:

$$\pi_S^{S*}(w) = wD_S^* = w\left(\frac{1}{3}\frac{1 + \sqrt{(1 + 12aw)} - 12aw}{1 + \sqrt{(1 + 12aw)}}\right) \tag{7}$$

Again, the first-order conditions provide the optimal price set by the supplier:

$$w_S^* = \frac{1}{18}\frac{\frac{1}{3} + \frac{2}{3}\sqrt{7}}{a} \tag{8}$$

Additional note: The optimal price w^* should satisfy the $aw^* < \frac{1}{4}$ condition. The condition becomes:

$$a\frac{1}{18}\frac{\frac{1}{3}+\frac{2}{3}\sqrt{7}}{a} < \frac{1}{4} \Rightarrow 4 + 8\sqrt{7} < 18$$

which holds. Substituting (8) into (4), (3), (5), (6), and (7) gives the following results:

---

[10] The profit function is concave in s ensuring that the maximum is unique, and given by the FOC.

p_S^*	$\frac{1}{81}\frac{10+3\sqrt{11+4\sqrt{7}}+2\sqrt{7}}{a} = \frac{0.360\,85}{a}$
q_S^*	$\frac{1}{18}\frac{3+\sqrt{\left(11+4\sqrt{7}\right)}}{a} = \frac{0.424\,76}{a}$
D_S^*	$\frac{1}{9}\frac{7+3\sqrt{11+4\sqrt{7}}-4\sqrt{7}}{3+\sqrt{11+4\sqrt{7}}} = 0.15047$
π_S^{OEM*}	$\frac{1}{1458}\frac{\left(7+3\sqrt{11+4\sqrt{7}}-4\sqrt{7}\right)^2}{a\left(3+\sqrt{11+4\sqrt{7}}\right)} = \frac{9.617\,4\times10^{-3}}{a}$
π_S^{S*}	$\frac{1}{486}\left(1+2\sqrt{7}\right)\frac{7+3\sqrt{\left(11+4\sqrt{7}\right)}-4\sqrt{7}}{a\left(3+\sqrt{11+4\sqrt{7}}\right)} = \frac{1.753\,1\times10^{-2}}{a}$

*Sequence O: OEM's quality→Supplier's price→OEM's price***.** As in the previous sequence, the supplier maximizes her profit:

$$\pi_O^S(q,w) = w(1-\frac{p^*(q,w)}{q}) = w(1-\frac{\frac{w+q+aq^2}{2}}{q})$$

which leads through the first order conditions to

$$w_O^*(q) = \frac{q-aq^2}{2}, \quad \text{and} \tag{9}$$

$$\pi_O^{S*}(q) = \frac{1}{8}q\left(aq-1\right)^2. \tag{10}$$

Finally, the OEM chooses the product quality performance. The choice of the optimal performance quality offering q is determined by the maximization of $\pi^{OEM*}(q)$ where

$$\begin{aligned}\pi_O^{OEM*}(q) &= \frac{1}{4}q\left(aq+\frac{1-aq}{2}-1\right)^2 \\ &= \frac{1}{16}q(1-aq)^2\end{aligned} \tag{11}$$

Again through the first-order conditions we obtain:

$$q_O^* = \frac{1}{3a} \tag{12}$$

Substituting (12) into (9), (2), (**??**), (11), and (10) gives the following results:

w_O^*	$\frac{1}{9a}$
p_O^*	$\frac{5}{18a}$
D_O^*	$\frac{1}{6}$
π_O^{OEM*}	$\frac{1}{108a}$
π_O^{S*}	$\frac{1}{54a}$

Additional note. As before, the condition $aw_O^* > \frac{1}{12}$ holds.

For comparison, we provide the results in a side-by-side layout.

Sequence S		Sequence O
$q_S^* = \frac{0.42476}{a}$	$>$	$q_O^* = \frac{0.33333}{a}$
$p_S^* = \frac{0.36085}{a}$	$>$	$p_O^* = \frac{0.27778}{a}$
$w_S^* = \frac{0.11651}{a}$	$>$	$w_O^* = \frac{0.11111}{a}$
$D_S^* = 0.15047$	$<$	$D_O^* = 0.16667$
$\pi_S^{S*} = \frac{1.75 \times 10^{-2}}{a}$	$<$	$\pi_O^{S*} = \frac{1.85 \times 10^{-2}}{a}$
$\pi_S^{OEM*} = \frac{9.62 \times 10^{-3}}{a}$	$>$	$\pi_O^{OEM*} = \frac{9.26 \times 10^{-3}}{a}$
$\pi_S^{S*} - \pi_S^{OEM*} = \frac{7.88 \times 10^{-3}}{a}$	$<$	$\pi_O^{S*} - \pi_O^{OEM*} = \frac{9.26 \times 10^{-3}}{a}$
$\pi_S^{OEM*} + \pi_S^{S*} = \frac{2.72 \times 10^{-2}}{a}$	$<$	$\pi_O^{OEM*} + \pi_O^{S*} = \frac{2.788 \times 10^{-2}}{a}$
$\frac{\pi_S^{OEM*}}{\pi_S^{S*}} = 0.550$	$>$	$\frac{\pi_O^{OEM*}}{\pi_O^{S*}} = 0.5$

(QED).

Proof of Proposition 3. From the proof of Proposition 2 we find that

$$\theta_S > \theta_O$$

which implies that the market size under decision sequence O is larger. Consider, then, the resulting utility functions, i.e. $u_j(\theta) = \theta q_j^* - p_j^*$ where j is the decision sequence. We get:

$$\begin{aligned} u_O(\theta) &= \frac{\theta}{3a} - \frac{5}{18a} \\ u_S(\theta) &= \frac{0.42\theta}{a} - \frac{0.36}{a} \end{aligned}$$

It is straight forward that for $\theta \in (\theta_O, \theta_S)$, only under sequence O do consumers enjoy a positive utility. However, for $\theta \in (\theta_S, 1)$ the comparison reveals an additional threshold ($\widetilde{\theta} = \frac{57-3\sqrt{7}}{54} \simeq 0.91$), such that $u_S(\theta) > u_O(\theta)$ only if $\theta > \widetilde{\theta}$. (QED)

Proof of Proposition 4. We proceed with the two distinct sequences as before.

Sequence S:.

The OEM's optimal quality and price as a function of the suppliers' price is the same as in the monopoly-monopoly case and are thus given by (3) and (4) respectively. Differentiation between the two supply chain models arises from the upstream competition. Since the suppliers are competing in quantities, the resulting analysis follows the steps of a non-linear demand Cournot competition. The quantity sold to the end consumer is $D_S^{down} = 1 - \theta$, or

$$D_S^{down} = \frac{1 + \sqrt{(1+12aw)} - 12aw}{3 + 3\sqrt{(1+12aw)}}.$$

Thus, the demand is the same as in the monopoly-monopoly setting where D_S^{down} is given by (5). To determine the equilibrium quantities for each supplier, we need to define the inverse demand function. Let $\xi = 1 + \sqrt{(1+12aw)}$, which implies

$$w_S = \frac{1}{12a}\xi(\xi - 2)$$

Then, $D_S^{down} = K = \frac{1}{3}\frac{(\xi - \xi(\xi-2))}{\xi} = \frac{1}{3}(3-\xi)$. Our transformation allows us to calculate the inverse demand function. Since $\xi = 3 - 3K$, then

$$\begin{aligned} w_S(Q) &= \frac{1}{12a}(3-3K)(1-3K) \\ &= \frac{1}{4a}(1-K)(1-3K). \end{aligned} \tag{13}$$

Given the inverse demand function, each supplier maximizes her profit through

$$\pi_{S,i}^S(k_i, K_{-i}) = k_i w_S(K) = k_i[\frac{1}{4a}(1-k_i-K_{-i})(1-3k_i-3K_{-i})]$$

where K_{-i} is the sum of the quantities set by the competitors (our assumption at this stage is that the suppliers are competing in quantities; if instead they compete in prices then a simple analysis shows that their prices would drive down to their cost and eventually the OEM would set quality and price as in the integrated supply chain case). The first-order condition determines the best response function:

$$\begin{gathered} \frac{1}{4a}(1-k_i-K_{-i})(1-3k_i-3K_{-i}) + \\ k_i[-\frac{1}{4a}(1-3k_i-3K_{-i}) - \frac{3}{4a}(1-k_i-K_{-i})] = 0 \end{gathered}$$

which through algebra becomes

$$\frac{1}{4a}(1-k_i-K_{-i})(1-3k_i-3K_{-i}) - \frac{k_i}{4a}[4-6k_i-6K_{-i}] = 0.$$

The latter provides (when solving for k_i) the best response strategy of firm i, i.e. $k_i(K_{-i})$. We assume symmetric competitors in the upstream supplier market, since we aim to study the impact of the upstream industry on end-market quality and pricing. Henceforth, we obtain the equilibrium quantities that determine the upstream prices. We proceed as follows: we substitute in the best response equation $q_i = q$ for every $i = 1, 2, ..., n$, and $k_i + K_{-i} = nk$ to get

$$\begin{aligned} (1 - nk)(1 - 3nk) - q(4 - 6nk) &= 0 \\ \text{or, } 3n(n+2)k^2 - 4(n+1)k + 1 &= 0. \end{aligned}$$

The equilibrium equation is a second-order polynomial with at most two roots[11] given by the equation

$$k_S^* = \frac{4(n+1) \pm \sqrt{16(n+1)^2 - 12n(n+2)}}{6n(n+2)}.$$

Note the non-linear nature of the demand created by the monopolist OEM renders viable the possibility there exist two distinct equilibria for the optimal quantities. The total optimal quantities are:

$$K_S^* = \frac{4(n+1) \pm \sqrt{16(n+1)^2 - 12n(n+2)}}{6(n+2)}$$

In order to specify whether any of the equilibria is likely to occur, we incorporate two additional constraints in our calculations. First, the total quantity should be positive, $K^* \geq 0$, otherwise the supplier market does not supply. Second, $K^* \leq \frac{1}{3}$, the total supplied quantity should be small enough to ensure the component price is positive, $w(K^*) \geq 0$, for the suppliers to have positive profits. If we consider the solution

$$K_S^* = \frac{4(n+1) + \sqrt{16(n+1)^2 - 12n(n+2)}}{6(n+2)} \leq \frac{1}{3}$$

we obtain

$$3n + 3\sqrt{(n+1)^2 + 3} \leq 0$$

which can never hold for any n. Therefore, the game has only one feasible equilibrium:

$$\begin{aligned} K_S^* &= \frac{4(n+1) - \sqrt{16(n+1)^2 - 12n(n+2)}}{6(n+2)} \qquad (14) \\ &= \frac{2(n+1) - \sqrt{(n + 2n + 4)}}{3(n+2)} \end{aligned}$$

To check our results, note that (14) reduces to $K_S^* = .15047$ when $n = 1$ which is the same as D_S^{down*} in the monopoly-monopoly case.

For the duopoly case, substituting $n = 2$ into (14) gives $K_S^* = .21132$. Substituting K_S^* into (13) gives $w_S^* = \frac{.07217}{a}$. The optimal end-product quality and price and the OEM's optimal profit are determined from

---

[11] The specific polynomial has always two real roots, as verified by straightforward expansion (available from the authors).

substituting w_S^* into (3), (4), and (6) to give $k_S^* = \frac{.39434}{a}$, $p_S^* = \frac{.31100}{a}$, and $\pi_S^{OEM*} = \frac{.01745}{a}$. Finally, the suppliers' optimal profits are $\pi_{S,1}^{S*} = \pi_{S,2}^{S*} = w_S^* \frac{K_S^*}{n} = \frac{.007625}{a}$ (QED).

Sequence O:

In the last stage the OEM chooses the appropriate pricing for the end-product. Provided the end-product quality is q, and the component price supplied by the upstream market is w, the end-product price is chosen to maximize

$$\max_p \int_\theta^1 (p - aq^2 - w)dt = \max_p (1-\theta)(p - aq^2 - w).$$

Solving first order conditions results in the optimal price

$$p_O(q, w) = \frac{q + aq^2 + w}{2}.$$

This price determines the marginal consumer to be: $\theta = \frac{q+aq^2+w}{2q}$ and the total demand $D^{down} = D^{up} = 1-\theta$, or

$$D_O^{down} = \frac{q - aq^2 - w}{2q}.$$

Since we assume the upstream market is a Cournot competitive setting, we get

$$D_O^{down} = K = \frac{q - aq^2 - w}{2q}$$

and

$$w_O(K) = q - aq^2 - 2qK.$$

The latter formulation represents the inverse demand function of a typical Cournot linear demand situation. Hence,

$$\pi_{O,i}^S = (q - aq^2 - 2qK)k_i \tag{15}$$

where k_i is the capacity produced by supplier i ($i = 1, ..., n$). The first order conditions provide the best response function

$$k_i(K_{-i}) = \frac{q - aq^2 - 2qK}{4q}$$

where K_{-i} is the total quantity produced by the competitors of the i-th supplier. Thus, assuming symmetric suppliers (with respect to their cost structure), we obtain

$$k_{O,i}^* = k_O^* = \frac{q - aq^2}{2q(n+1)} \tag{16}$$

resulting in the component price

$$w_O^*(q) = \frac{q - aq^2}{n+1}, \tag{17}$$

and the end-product price

$$p_O^*(q) = \frac{q + aq^2 + \frac{q-aq^2}{n+1}}{2} = \frac{(n+2)q + naq^2}{2(n+1)}. \tag{18}$$

The resulting OEM profit as a function of the quality is

$$\begin{aligned}\pi_O^{OEM*}(q) &= (1 - \frac{(n+2)q + naq^2}{2q(n+1)})(\frac{(n+2)q + naq^2}{2(n+1)} - aq^2 - \frac{q - aq^2}{n+1}) \\ &= ... \\ &= \frac{nq(1-aq)^2}{4(n+1)^2} = \frac{n}{4(n+1)^2}q(1-aq)^2.\end{aligned}$$

The optimal end product quality stems from the first order conditions to give

$$q_O^* = \frac{1}{a} \text{ or } q_O^* = \frac{1}{3a}.$$

Since the former renders the OEM zero profit, it is a non-desirable quality level. Thus, we obtain a single solution, namely $q_O^* = \frac{1}{3a}$.The optimal OEM profit thus becomes

$$\pi_O^{OEM*} = \frac{n}{4(n+1)^2}\frac{1}{3a}\frac{4}{9} = \frac{1}{27a}\frac{n}{(n+1)^2}. \tag{19}$$

For the duopoly case, $n = 2$, substituting $q_O^* = \frac{1}{3a}$ into (18) gives $p_O^* = \frac{7}{27a}$, and into (17) gives $w_O^* = \frac{2}{27a}$. The percent of the market that purchases the product is $D_O^{down} = D_O^* = 1 - \frac{p}{q} = \frac{2}{9}$, thus the quantity is split evenly between the two suppliers, $D_{O,1}^* = D_{O,2}^* = \frac{1}{9}$. The suppliers' profits are determined using (15) to be $\pi_{O,1}^{S*} = \pi_{O,2}^{S*} = \frac{2}{243a}$. Finally, substituting $n = 2$ into (19) gives $\pi_O^{OEM*} = \frac{4}{243a}$. A summary of the results from the two sequences is presented in the Tables below:

Comparisons over sequence S :

Variable \ No. of Suppliers	$n = 1$	$n = 2$	$n = \infty$
q_S^*	$\frac{.42476}{a}$	$\frac{.39434}{a}$	$\frac{1}{3a} = \frac{.33333}{a}$
p_S^*	$\frac{.36085}{a}$	$\frac{.31100}{a}$	$\frac{2}{9a} = \frac{.22222}{a}$
w_S^*	$\frac{.11651}{a}$	$\frac{.07217}{a}$	0
D_S^*	$.15046$	$.21132$	$\frac{1}{3} = .33333$
$\sum\limits_{k=1}^{n} \pi_{S,k}^{S*}$	$\frac{.0175}{a}$	$\frac{.01525}{a}$	0
π_S^{OEM*}	$\frac{.00962}{a}$	$\frac{.01745}{a}$	$\frac{1}{27a} = \frac{.03704}{a}$
$\pi_S^{OEM*} - \sum\limits_{k=1}^{n} \pi_{S,k}^{S*}$	$\frac{-.00788}{a}$	$\frac{.0022}{a}$	$\frac{1}{27a} = \frac{.03704}{a}$
$\pi_S^{OEM*} + \sum\limits_{k=1}^{n} \pi_{S,k}^{S*}$	$\frac{.02712}{a}$	$\frac{.03270}{a}$	$\frac{1}{27a} = \frac{.03704}{a}$

Comparisons over sequence O :

Variable \ No. of Suppliers	$n = 1$	$n = 2$	$n = \infty$
q_O^*	$\frac{1}{3a} = \frac{0.33333}{a}$	$\frac{1}{3a} = \frac{.33333}{a}$	$\frac{1}{3a} = \frac{.33333}{a}$
p_O^*	$\frac{5}{18a} = \frac{0.27778}{a}$	$\frac{7}{27a} = \frac{.25926}{a}$	$\frac{2}{9a} = \frac{.22222}{a}$
w_O^*	$\frac{1}{9a} = \frac{0.11111}{a}$	$\frac{2}{27a} = \frac{.07407}{a}$	0
D_O^*	$\frac{1}{6} = .16667$	$\frac{2}{9} = .22222$	$\frac{1}{3} = .33333$
$\sum\limits_{k=1}^{n} \pi_{O,k}^{S*}$	$\frac{1}{54a} = \frac{.01852}{a}$	$\frac{4}{243a} = \frac{.01646}{a}$	0
π_O^{OEM*}	$\frac{1}{108a} = \frac{.00926}{a}$	$\frac{4}{243a} = \frac{.01646}{a}$	$\frac{1}{27a} = \frac{.03704}{a}$
$\pi_O^{OEM*} - \sum\limits_{k=1}^{n} \pi_{O,k}^{S*}$	$\frac{1}{108a} = \frac{.00926}{a}$	0	$\frac{1}{27a} = \frac{.03704}{a}$
$\pi_O^{OEM*} + \sum\limits_{k=1}^{n} \pi_{O,k}^{S*}$	$\frac{1}{36a} = \frac{.02778}{a}$	$\frac{8}{243a} = \frac{.03292}{a}$	$\frac{1}{27a} = \frac{.03704}{a}$

The proof follows from the previous results by comparison of the respective quantities (QED).

Proof of Proposition 5. For comparison, we provide the results of the $n = 2$ case in a side-by-side layout.

Sequence S		Sequence O
$q_S^* = \frac{.39434}{a}$	$>$	$q_O^* = \frac{0.33333}{a}$
$p_S^* = \frac{.31100}{a}$	$>$	$p_O^* = \frac{.25926}{a}$
$w_S^* = \frac{.07217}{a}$	$<$	$w_O^* = \frac{.07407}{a}$
$D_S^* = 0.21132$	$<$	$D_O^* = 0.22222$
$\sum_{k=1}^{n} \pi_{S,k}^{S*} = \frac{.01525}{a}$	$<$	$\sum_{k=1}^{n} \pi_{O,k}^{S*} = \frac{.01646}{a}$
$\pi_S^{OEM*} = \frac{.01745}{a}$	$>$	$\pi_O^{OEM*} = \frac{.01646}{a}$
$\pi_S^{OEM*} - \sum_{k=1}^{n} \pi_{S,k}^{S*} = \frac{.0022}{a}$	$>$	$\pi_O^{OEM*} - \sum_{k=1}^{n} \pi_{O,k}^{S*} = 0$
$\pi_S^{OEM*} + \sum_{k=1}^{n} \pi_{S,k}^{S*} = \frac{.03270}{a}$	$<$	$\pi_O^{OEM*} + \sum_{k=1}^{n} \pi_{O,k}^{S*} = \frac{.03292}{a}$
$\frac{\pi_S^{OEM*}}{\pi_S^{S*}} = 1.14$	$>$	$\frac{\pi_O^{OEM*}}{\pi_O^{S*}} = 1.00$

(QED).

Proof of Lemma 1. Consider, independent of the sequence, the last stage of the game where the two OEMs set their prices. It is immediately obvious that if the two OEMs have set equal quality levels, $q_1 = q_2$, then the competition is a Bertrand competition, and the optimal choices are to price at the marginal cost ($p_i = aq^2 + w$) However, if this is not the case, then we will get the market split into two "local" monopolies, with each OEM selling to different sets of consumers. In that event the marginal consumers (i.e. the consumers that are indifferent between buying or not, and the consumers that are indifferent between buying from OEM 1 or OEM 2) are:

$$\begin{aligned}\theta_1 &= \frac{p_1}{q_1}\\ \theta_2 &= \frac{p_2 - p_1}{q_2 - q_1}\end{aligned}$$

The low quality firm chooses price p_1 for a given exogenous quality q_1 and the high quality firm chooses price p_2 for a given exogenous quality q_2. Each firm i must pay aq_i^2, as well as a per-unit cost for each component used of w. Note that the formulations above hold for the case where $q_2 > q_1$. The symmetric setting has exactly the same structure, apart from the variable indices that are swapped.

Assuming consumer types are distributed uniformly on $[0, 1]$, the high quality firm's problem is

$$\max_{p_2} \pi_2(p_2|p_1, q_1, q_2, w) = \int_{\theta_2}^{1} (p_2 - aq_2^2 - w)dt = (1 - \theta_2)(p_2 - aq_2^2 - w). \tag{20}$$

and the low quality firm's problem is

$$\max_{p_1} \pi_1(p_1|p_2, q_1, q_2, w) = \int_{\theta_1}^{\theta_2} (p_1 - aq_1^2 - w)dt = (\theta_2 - \theta_1)(p_1 - aq_1^2 - w). \tag{21}$$

Solving the first order conditions simultaneously, results in the pricing equilibrium:

$$\begin{aligned} p_2(q_1, q_2, w) &= q_2 \frac{2aq_2^2 + 3w + 2q_2 - 2q_1 + aq_1^2}{4q_2 - q_1}, \\ p_1(q_1, q_2, w) &= \frac{2q_2 aq_1^2 + 2q_2 w + wq_1 + q_1 aq_2^2 + q_1 q_2 - q_1^2}{4q_2 - q_1}. \end{aligned}$$

QED.

Proof of Proposition 6. The equilibrium profits are:

$$\hat{\pi}_2^{OEM}(q_1, q_2, w) = \left(2aq_2^2 + q_2 q_1 a - 2q_2 + w\right)\left(-2q_2^2 + 2q_2 q_1 + 2aq_2^3 + q_2 w - q_1^2 q_2 a - wq_1 - aq_2^2 q_1\right) \frac{1}{(4q_2 - q_1)^2} \text{ and}$$

$$\hat{\pi}_1^{OEM}(q_1, q_2, w) = \left(q_2 q_1 a + q_1 - q_1^2 a - 2w\right)\left(aq_2^2 q_1 + 2wq_1 + q_2 q_1 - q_1^2 + q_1^3 a - 2q_1^2 q_2 a - 2q_2 w\right) q_2 \frac{1}{q_1 (4q_2 - q_1)^2}.$$

We analyze the optimal component pricing by the monopolist supplier in the event of sequence O. Recall that under this sequence the competing OEMs set their quality levels before the component price is determined. First, we determine how much the total quantity of components that the supplier provides is. The total market is

$$D_q = (1 - \theta_1)$$

or in other words the total market depends fully on the marginal consumer that is indifferent between purchasing and not. The quantity of the previous equation becomes

$$\begin{aligned} D_q &= 1 - \frac{p_1^*}{q_1} \\ &= 1 - \frac{\frac{2q_2 aq_1^2 + 2q_2 w + wq_1 + q_1 aq_2^2 + q_1 q_2 - q_1^2}{4q_2 - q_1}}{q_1} \\ &= 1 - \frac{2}{4q_2 - q_1} q_1 q_2 a - \frac{1}{4q_2 - q_1} aq_2^2 - \frac{1}{4q_2 - q_1} q_2 + \frac{1}{4q_2 - q_1} q_1 - \frac{2}{(4q_2 - q_1) q_1} q_2 w - \frac{1}{4q_2 - q_1} w \end{aligned}$$

Solving for the component price as a function of q_1 and q_2:

$$\begin{aligned}\pi^S(a, w; q_1, q_2) &= w[1 - \frac{2}{4q_2 - q_1} q_1 q_2 a - \frac{1}{4q_2 - q_1} a q_2^2 - \frac{1}{4q_2 - q_1} q_2 + \frac{1}{4q_2 - q_1} q_1 - \frac{2}{(4q_2 - q_1)\, q_1} q_2 w - \frac{1}{4q_2 - q_1} w] \\ &= w \left[\frac{3q_2 q_1 - 2q_1^2 q_2 a - a q_2^2 q_1 - 2q_2 w - w q_1}{(4q_2 - q_1)\, q_1} \right]\end{aligned}$$

Solving the first order conditions gives the supplier's optimal price:

$$w^*(q_1, q_2) = \frac{1}{2} \frac{3q_2 q_1 - 2q_1^2 q_2 a - a q_2^2 q_1}{2q_2 + q_1}.$$

The last optimization step involves the two OEMs' quality decisions. The reaction functions are calculated by substituting in the supplier's optimal price into the OEMs' profits:

$\pi_2^{OEM}(q_1, q_2, w) = \left(2aq_2^2 + q_2 q_1 a - 2q_2 + w\right) \left(-2q_2^2 + 2q_2 q_1 + 2aq_2^3 + q_2 w - q_1^2 q_2 a - w q_1 - a q_2^2 q_1\right) \frac{1}{(4q_2 - q_1)^2} =$
$\frac{1}{4} \left(8aq_2^3 + 7aq_2^2 q_1 - 8q_2^2 - q_2 q_1\right) \left(-8q_2^3 + 7q_2^2 q_1 + q_1^2 q_2 + 8aq_2^4 - aq_2^3 q_1 - 7q_1^2 q_2^2 a\right) \frac{1}{(2q_2 + q_1)^2 (4q_2 - q_1)^2}$

$\pi_1^{OEM}(q_1, q_2, w) = \left(q_2 q_1 a + q_1 - q_1^2 a - 2w\right) \left(a q_2^2 q_1 + 2w q_1 + q_2 q_1 - q_1^2 + q_1^3 a - 2q_1^2 q_2 a - 2q_2 w\right) q_2 \frac{1}{q_1 (4q_2 - q_1)^2} =$
$\left(3aq_2^2 q_1 + q_1^2 q_2 a - q_2 q_1 + q_1^2 - q_1^3 a\right) \left(3aq_2^3 q_1 - 2q_1^2 q_2^2 a + 2q_1^2 q_2 - 2q_1^3 q_2 a - q_2^2 q_1 - q_1^3 + a q_1^4\right) q_2 \frac{1}{(2q_2 + q_1)^2 q_1 (4q_2 - q_1)^2}$

As in the classic work of Moorthy (1988) these reaction functions do not have "meaningful" closed form solutions. Hence, for further characterization of the optimal quality levels and the degree of downstream differentiation we reside on numerical calculations, and fit the curves $q_i(a)$ to the numerical results. The full results for the monopoly-supplier, duopoly-OEM scenario are as follows:

Variable \ Sequence	S	O	Larger
$q^*_{j,1}$	$\frac{.3546}{a}$	$\frac{.2998}{a}$	S
$q^*_{j,2}$	$\frac{.4830}{a}$	$\frac{.4584}{a}$	S
$p^*_{j,1}$	$\frac{.2565}{a}$	$\frac{.2128}{a}$	S
$p^*_{j,2}$	$\frac{.3677}{a}$	$\frac{.3456}{a}$	S
w^*_j	$\frac{.1172}{a}$	$\frac{.1097}{a}$	S
$D^*_{j,1}$	.2767	.2902	O
$D^*_{j,2}$	.2387	.2461	O
π^{S*}_j	$\frac{.0324}{a}$	$\frac{.0318}{a}$	S
$\pi^{OEM*}_{j,1}$	$\frac{.0019}{a}$	$\frac{.0017}{a}$	S
$\pi^{OEM*}_{j,2}$	$\frac{.0023}{a}$	$\frac{.0042}{a}$	O
$\pi^{OEM*}_{j,1} + \pi^{OEM*}_{j,2}$	$\frac{.0042}{a}$	$\frac{.0059}{a}$	O
$(\pi^{OEM*}_{j,1} + \pi^{OEM*}_{j,2}) - \pi^{S*}_j$	$-\frac{.0282}{a}$	$-\frac{.0259}{a}$	O
$(\pi^{OEM*}_{j,1} + \pi^{OEM*}_{j,2}) + \pi^{S*}_j$	$\frac{.0366}{a}$	$\frac{.0377}{a}$	O

(QED).

Proof of Proposition 7. Follows from the previous results by comparison of the respective quantities (QED).

8 References

References

[1] Bhattacharya S., V. Krishnan, and V. Mahajan. 1998. “Managing New Product Definition in Highly Dynamic Environments” *Management Science*, 44 (11), S50-S64.

[2] Carr S. C., and U. S. Karmarkar 2005. “Competition in Multiechelon Asembly Supply Chains,” *Management Science*, 51 (1), 45-59.

[3] Corbett C. J., and U. S. Karmarkar 2001. “Competition and Structure in Serial Supply Chains with Deterministic Demand,” *Management Science*, 47 (7), 966-978.

[4] Desai, P. 2001. "Quality Segmentation in Spatial Markets: When Does Cannibalization Affect Product Line Design?" *Marketing Science.* 20(3), 265 – 283.

[5] Desai, P and D. Purohit. 1998. "Leasing and Selling: Optimal Marketing Strategies for a Durable Goods Firm," *Management Science,* 44:11(Part 2), 19-34.

[6] Dunn, D. 2006. "Price War Makes Intel, AMD Chip Industries Biggest Losers," *Information Week*, July 31st 2006.

[7] Erat S., S. Kavadias, and C. Gaimon. 2006. "Licensing of Component Technologies". Working Paper. Georgia Institute of Technology.

[8] Ferguson, M. and O. Koenigsberg. 2006. "How Should a Firm Manage Deteriorating Inventory?" To appear in *Production and Operations Management.*

[9] Fine C. H. 1998. *Clockspeed: Winning Industry Control in the Age of Temporary Advantage*, Perseus Books, Reading MA.

[10] Guglielmo, C. 2004. "Apple's Jobs Taps Teen iPod Demand to Fuel Sales, Stock Surge," www.bloomberg.com, October 11, 2004.

[11] Hotelling H., 1929. "Stability in Competition" *Economic Journal*, 153 (March), 41-57.

[12] Ingene, C. and M. Parry. *Mathematical Models of Distribution Channels.* ISQM Kluwer Academic Publishers, NY, NY.

[13] Katz, M. 1984. "Firm Specific Differentiation and Competition Among MultiProduct Firms." *Journal of Business.* 57 149-166.

[14] Krishnan V., and K .Ramachandran 2006. "Design Architecture and Introduction Timing of Rapid Improving Industrial Products" Rady School of Management Working Paper.

[15] Liker, J. 2004. "The Toyota Way: 14 Management Principles From the Worlds Greatest Manufacturer." McGraw-Hill.

[16] Majumder P. and A. Srinivasan. 2006. "Leader Location, Cooperation, and Coordination in Serial Supply Chains". *Production and Operations Management*, 15(1), 22-39.

[17] Moorthy, K. 1984. “Market Segmentation, Self-Selection and Product Line Design." *Marketing Science*. 3(4), 288 – 305.

[18] Moorthy, K. 1988. “Product and Price Competition in a Duopoly." *Marketing Science*. 7(2), 141 – 168.

[19] Mussa, M., S. Rosen. 1978. Monopoly and Product Quality. *Journal of Economic Theory* 18, 301 – 317.

[20] Shaked, A. and J. Sutton. 1983. “Natural Oligopolies.” *Econometrica*. 51, 1469-1483.

[21] Sherman, E. 2002. “Inside the Apple iPod Design Triumph.” *Electronics Design Chain Magazine*. Vol. 1, Summer.

[22] Tirole, J. 1988. *The Theory of Industrial Organization*. The MIT Press, Cambridge, MA.

[23] Tyagi, R. K. 1999. “On the Effects of Downstream Entry,” *Management Science*, 45 (1), 59-73.