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Abstract

In this paper, we explore how sourcing costs within a firm's supply chain can be better managed by managing the upstream supply network of the firm. Building on our three-year empirical investigation in the automotive industry, we propose the concept of the OEM hub, a collaborative center involving the firm (the OEM), its suppliers and raw material suppliers, as the principal alignment mechanism for managing the value in upstream sourcing of a firm. We model non-cooperative and cooperative OEM hub scenarios, anchoring it to our empirical work, and examine the resulting profits along the supply chain for three facets of the OEM hub. (1) direct raw material supply to suppliers, (2) cooperation between suppliers, managed by the OEM and (3) financing the supply chain with capital sourced at least cost. Our results show that OEM hub operations can add value to the upstream supply chain, and help firms manage their sourcing better.

Keywords: Supplier Networks; Sourcing Strategies; Cost Management

1 Introduction

Sourcing policies are an important element of supply chain strategy and can have short-term and long-term effects on firm profitability. In the short term, they can affect purchase costs, delivery costs and costs of rejection and rework. In the long term, they can affect warranty costs and product life cycle costs, with further effects on a firm's prestige and market share.

In most firms, organizational subsystems and processes related to suppliers are focused on the firm and its immediate suppliers. In some contexts, like that of an automotive firm, it may also be beneficial to focus on the suppliers' suppliers, since a large number of direct suppliers of the firm may be buying their raw materials from the same sources. In this scenario, building close relationships with upstream members of the supply chain may be valuable.

Two observations from our three-year empirical research provide motivation for this paper. First, with increased focus on core business activities, and the outsourcing of non-core activities, firms have slowly distanced themselves from some of the value in their supply network (like upstream sourcing). Second, when a firm (OEM) brings its suppliers and suppliers' suppliers together, value is created by pooling knowledge: information about demand, process improvements, raw material sourcing, and design complexity reduction is exchanged. This helps build an efficient supply chain.

In this paper, we propose the concept of the OEM hub as a value-enabling mechanism in the upstream supply chain, and explore it analytically. Our results show that an OEM's active management of relationships with raw material suppliers and direct suppliers, can result in a more efficient supply chain. We also establish the mechanisms which can lower costs for all agents of the supply chain - the OEM, the raw material supplier and the direct suppliers.

We first review our empirical research and the related literature to establish the motivation for this paper. We than model the problem in the form of interactions between a buyer and its suppliers. We conclude with a discussion of how an alternative supply chain structure like the OEM hub can facilitate supply chain efficiency.

2 Literature Review and Our Research Problem

Our work is related primarily to the literature on make-or-buy and buyer supplier relationships. The make-or-buy literature identifies that make-or-buy decisions rest on factors such as the complexity of parts (Masten, 1984; Novak and Eppinger, 2001), volume uncertainty related to components (Walker and Weber, 1984), environmental factors (O'hUallachain and Wasserman, 1999), and the strategic decision to in-source a component or technology driven by a quest for learning (Monteverde, 1995; Ahmadjian and Lincoln, 2001).

Buyer-supplier relationships are usually modeled using game theoretic concepts, with the focus on contracts that can be drawn up between buyers and suppliers. One stream of literature assumes specific contract terms and then seeks to determine the optimal actions (Eppen and Iyer, 1997). A second stream takes optimal policies (such as ordering) as given, but seeks to determine if the contract terms can be modified so that the supply chain can be coordinated (Cachon and Lariviere, 2005). Our work falls in this second stream.

A recurring theme in the modeling and empirical literature on make-or-buy, as well as on buyer-supplier relationships, is the focus on the immediate suppliers of the firm, usually the downstream end of the supply chain. In this paper, in contrast, we model the upstream end of the supply chain and focus on the raw material links in the supplier network. We briefly review our empirical research (Agrawal and De Meyer, 2007) to set up the research problem of this paper.

We observe two specific characteristics of the supplier network of automotive firms: (1) there are only a few raw material suppliers but a large number of direct suppliers; and (2) the supply network has OEM-level material traceability. (In our discussion we use the term focal OEM or simply OEM to denote the firm whose supply chain is being studied.)

Raw material suppliers and direct suppliers

There are only a few steel suppliers, 'certified' by the OEM, who supply a large number of tier 1 or tier 2 suppliers, in different quantities. Similarly, there are only a few plastics, aluminium and copper sources for the direct suppliers of the OEM. There are transaction costs, related to purchasing and delivery, at each of these relationship nodes (see Figure 1). The same supplier may supply several different OEMs and therefore there may be material flows elsewhere than to the focal OEM. Our research shows that OEMs do not have direct relationships with this upstream part of their chain, and that developing these relationships can add value.

Material traceability

It is possible to differentiate not only the output but also the input material at supplier level, working from the model produced by the OEM. For example, at an automotive brakes manufacturer, it is easy to distinguish between, say, a Volvo or a Scania brake system. But it is also possible to differentiate which castings/forgings and related raw material (RM) are to be used for Volvo or Scania brakes at subcomponent level[1]. Since the raw material level details are

[1] OEM level material traceability refers to input material differentiation and information about end use at supplier level. For most auto suppliers, components are developed at different times for different models. Consider OEM X, and brakes supplier Y. For their new car, X's development engineers sit with Y's manufacturing engineers to develop detailed specifications for the brake, which will go into the car that X wants to produce (call it Z). As plans develop, the brake system for Z is broken into component level details that are used for detailed drawings. Usually, Y takes over at this point, and starts the process of developing the Z brake system. The component drawings, arising out of specifications for Z, are unique to Z. Next, Y generates new part numbers and a detailed bill of material for the Z brake system. The bill of material will have some small components that are common to other brake systems (for the same or another OEM): however, the sizes and specifications of material, the forgings, castings, and machining tolerances, will be specific to Z. This pattern is repeated when X develops a variant ("New Z"). Different brakes will be needed for X's different cars, requiring fresh development by Y, and culminating in specific bills of materials for X's specific car models.

Thus, at the level of Y, bills of material for customer-specific, model-specific products are available. Even when

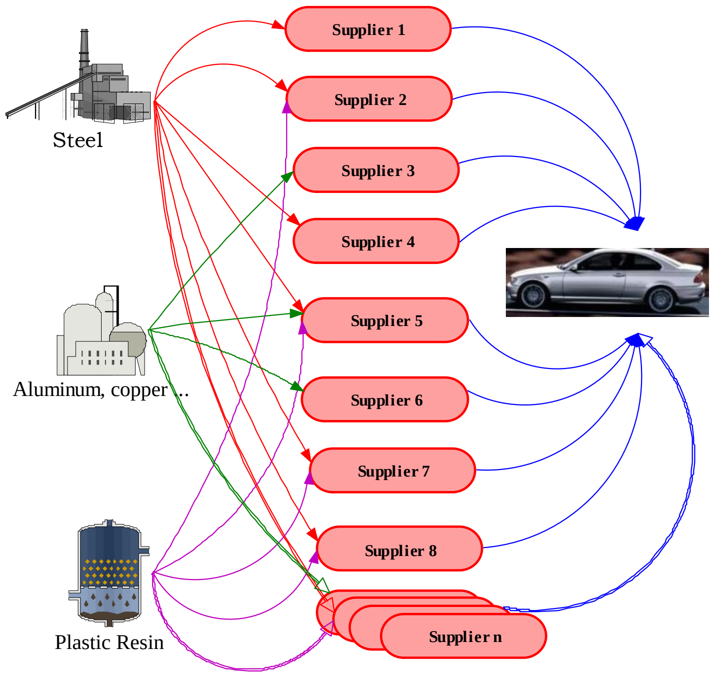

Figure 1: Typical supplier network of an automotive firm

available at a model level for each OEM, therefore, at the supplier end, it is possible to differentiate material chain for different OEMs. Thus, material flows for different OEMs are fungible at supplier level.

We now propose the concept of the OEM hub (Figure 2). *An OEM hub is an upstream entity in supply chains, focused on developing relationships with an OEM's suppliers and suppliers' suppliers.*

The OEM hub concept (Figure 2) is a critical departure from the current supply network (Figure 1). It helps in two different ways. First, it helps develop upstream relationships with RM suppliers, as well as with direct suppliers. Second, it helps build a knowledge base—this is driven by collaborative relations between suppliers, by increased understanding of RM sourcing, and by increased understanding of the complexity of the supply chain.

In this paper, we model the OEM hub as a single buyer, n component suppliers, single RM supplier entity. We have two assumptions in our model. First, there are many suppliers to the buyer, but only a single RM supplier. Second, the component suppliers supply only to the focal OEM. These assumptions are abstracted from the two empirical characteristics of the supplier networks of automotive firms. The first assumption comes from the observation that there are

the OEM has platform developments, blurring the model-level details at component level, there is little commonality in components used by different OEMs. This material information can be used for developing the resulting costs for each vendor, at the level of the OEM.

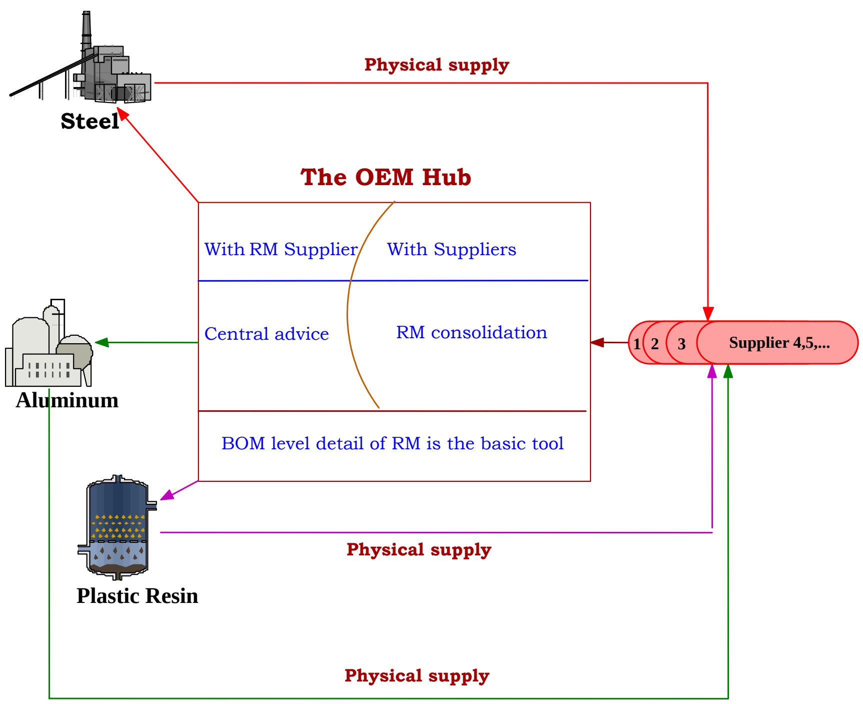

Figure 2: The research problem - the OEM hub

very few RM suppliers. We abstract this in our model and consider only a single RM supplier. The second assumption comes from the observation that at the supplier level, material flows are fungible by an OEM, and therefore we model the situation as a n supplier, single buyer setup.

We explore three facets of the OEM hub. The first is how firms can benefit from participating in their RM supply network. We explore the scenario in which the OEM buys RM for its suppliers, and discuss the operational issues. A few papers have looked at this problem. Signorelli and Heskett (1983) document that Benetton supported their policy of postponement by buying yarn for their subcontracted manufacturing. Barnes and Morris (1999) study a plastic component at an automotive firm, its first-tier supplier, its second-tier supplier and RM supplier—four different firms. The authors posit that understanding the lower tiers is important for better supply chain management, and that the automotive firm may be having problems due to its simple push-down approach to costs. The crucial difference from previous work is that the study makes the product pipeline, rather than the firm, the central focus of cost competitiveness. Ellram and Billington (2001) document how an automaker facilitates raw material supply to its machine shop contractor. Such a step helps build price stability between the automaker and the contractor. Our focus is similar. We believe that studying second- and third-tier suppliers is important, since we show that it can bring in opportunities for value creation.

Second, we explore how an OEM hub is beneficial as a center of cooperation between suppliers. Our analysis shows that active management of upstream sourcing by the OEM can benefit all links in the supply chain—the OEM, the component suppliers and the RM supplier. Only a few papers use cooperative game theory as a tool to analyze supply chain contracts. Kohli and Park (1989) analyze quantity discounts in the context of a two-person bargaining problem. They explore how risk aversion and the bargaining power of each party can affect the outcomes of bargaining. Reyniers and Tapiero (1995) integrate quality with buyer-supplier contracts, under a cooperative and a non-cooperative bargaining scenario and focus on the contractual terms needed for a firm to ensure a consistent quality of supply. Their main conclusion is that the quality of a supply chain is a decreasing function of the proportion of warranty cost borne by the supplier, the inspection costs of the producer, and the technology choices used by the supplier. Unlike these papers, we consider an assembly model, where suppliers, sourcing their raw material from a single agent, are supplying a buyer. Wang (2006) considers an assembly system setting, similar to ours, and explores properties of supplier interactions under sequential and simultaneous bargaining. Our model differs from the above papers in that we explore how cooperation between suppliers, managed by an OEM, can create value for the supply chain. Moreover, we model the interaction with the raw material supplier, which is the key motivation behind the OEM hub concept.

Last, we explore the financial aspects of the OEM hub. We discuss how differences in financing costs within the supply chain can cause inefficiency and how the OEM hub can help remove them. Kingsman(1983) was the first to discuss the relationship between the inventory of raw materials and the payment conditions. Carlson *et al.* (1996) use a discounted cash flow approach to obtain optimal order quantities in a EOQ setting. These papers look at the problem when suppliers finance the purchases of a buyer. In our paper, we look at the reverse problem: How can the buyers provide financing to the upstream supply chain?

Overall, we conclude that extant research on supply chain costs has focused on the boundary of the OEM and a first-tier vendor—the costs borne by the supplier or the buyer or both. However, the effect of costs beyond the first-tier vendors of the firm has been much less studied. This paper focuses on the critical question: How does the supplier network of an OEM affect the value creation in a supply chain? Specifically, we explore how a firm can leverage sourcing with and beyond its immediate suppliers. Our contribution lies in extending the sourcing literature to suppliers beyond the first-tier suppliers and in exploring how cooperation can create value for the entire chain.

3 Modeling the OEM Hub

We model an OEM and its supplier network and explore the three facets of the hub concept (RM supply, cooperation, and financing). First, we establish some straightforward results on how cooperation between supply chain agents can contribute to coordination of the supply chain. Next, we model the OEM hub and explore how profits of agents in the supply chain change depending on the situations of RM sourcing and cooperation between these agents.

3.1 Cooperation in a simple supply chain

Let us model a simple idea—that cooperation between supply chain agents is valuable. We start with the problem of inefficient trade when a single supplier and a single buyer are in a chain. This problem was treated very early on; the first exposition of the double marginalization effect is by Spengler (1950). In the textbook example of this problem, we have a supplier whose input cost is c, wholesale price to a buyer is p_m and the demand faced by the buyer is $q(p) = \frac{a-p}{b}$, where p is the market price. The most prevalent analysis in the literature is the Von Stackelberg game, where the supplier is the leader. For the decentralized chain described here, the sum of profits of supplier and buyer is $\frac{3}{16b}(a-c)^2$, while the profits of the vertically integrated chain are $\frac{1}{4b}(a-c)^2$. The decentralized chain has an efficiency of 75%.

There have been many solutions proposed to the double marginalization problem, all of which take the form of contracts between supplier and buyer. They include resale price maintenance, quantity forcing, franchising and exclusive territories (Tirole, 1998, Mathewson and Winter, 1984). The supply chain literature has also focused on solutions when the demand is stochastic and units can be left unsold or returned to supplier (Tsay *et al.*, 2004, Cachon and Lariviere, 2005) and proposed solutions such as buyback contracts or revenue sharing contracts. We examine the same setup to find a different solution to this problem.

3.1.1 The cooperative outcome

Using the Nash bargaining solution, we explore the conditions for maximization of joint profits for supplier and buyer. In such a setup, supplier and buyer play a two-person, cooperative bargaining game. We assume that the outside options of the two parties are equal to their non-cooperative profits, i.e. the two parties revert to playing the non-cooperative game if they fail to get the cooperation going. The basic setup discussed earlier remains, and we have the following results. (All proofs are in the Appendix.)

Proposition 1 : *Supplier Leader game*

(a) In the cooperative scenario, the buyer profits are

$$\Pi_{buyer}^{coop} = \frac{3}{32b}(a-c)^2,$$

the supplier profits are

$$\Pi_{supplier}^{coop} = \frac{5}{32b}(a-c)^2,$$

and the total profits for this cooperative chain are

$$\Pi_{total}^{coop} = \frac{1}{4b}(a-c)^2. \tag{1}$$

(b) *A cooperative solution attains the profits for a vertically integrated firm.* ⊡

There is a price, quantity pair that can lead to complete mitigation of the double marginalization problem. The outside options in this case pin the distribution of the surplus profits. The profits of supplier and buyer will be exactly equal (to $\frac{1}{8b}(a-c)^2$) if we assume that the two bargaining parties do not have any outside options.

We revisit the above analysis with two different gaming assumptions—the simultaneous move game and the buyer leadership game. The results are summarized in Table 1.

Summary of various scenarios	Market demand $q(p) = \frac{a-p}{b}$						
GAME	*Supplier Leader*		*Simultaneous move*		*Buyer Leader*		*Vertical Integration*
	Non-Coop	Coop	Non-Coop	Coop	Non-Coop	Coop	
Quantity	$\frac{a-c}{4b}$	$\frac{a-c}{2b}$	$\frac{a-c}{3b}$	$\frac{a-c}{2b}$	$\frac{a-c}{4b}$	$\frac{a-c}{2b}$	$\frac{a-c}{2b}$
Market price	$\frac{3a+c}{4}$	$\frac{a+c}{2}$	$\frac{2a+c}{3}$	$\frac{a+c}{2}$	$\frac{3a+c}{4}$	$\frac{a+c}{2}$	$\frac{a+c}{2}$
Supplier Π	$\frac{(a-c)^2}{8b}$	$\frac{5(a-c)^2}{32b}$	$\frac{(a-c)^2}{9b}$	$\frac{(a-c)^2}{8b}$	$\frac{(a-c)^2}{16b}$	$\frac{3(a-c)^2}{32b}$	n.a.
Buyer Π	$\frac{(a-c)^2}{16b}$	$\frac{3(a-c)^2}{32b}$	$\frac{(a-c)^2}{9b}$	$\frac{(a-c)^2}{8b}$	$\frac{(a-c)^2}{8b}$	$\frac{5(a-c)^2}{32b}$	n.a.
Efficiency	75%	100%	89%	100%	75%	100%	100%

Table 1: Summary of various buyer-supplier games versus a vertically integrated firm.

Table 1 indicates a fundamental property that we will explore further in this paper. Cooperation between supply chain agents can coordinate the supply chain (every agent gets a higher profit than that in the non-cooperative scenario) and can replace contracts like two-part tariffs.

The classic two-stage chain can be extended to three stages—one raw material supplier, one component supplier, and one buyer. This longer decentralized chain has a much higher marginalization problem—it makes less than half the profit of the vertically integrated entity (Efficiency = 43.75%). We can call this *triple marginalization.* Again, if the supplier and the buyer cooperate, their action coordinates the chain to a certain extent (Efficiency = 75%) and reduces the marginalization problem by using information about demand and moving towards efficient quantity (see Appendix for proofs).

3.2 The base case model - three stage chain

Here we develop the solution to a simple three-stage supply chain. Although our context is the automotive industry, the model is general enough to apply to any industry that has an assembly process for the final product, (e.g., digital equipment or apparel). In our model, we consider a single OEM (buyer) who is supplied with components by n different suppliers. The buyer faces an inverse demand curve $P_m = a - bq$ in the market. The suppliers provide unique (yet complementary) components that go into the buyer's final product. Supplier i supplies λ_i amount of material per unit of final product produced. Thus for quantity q of final product sold in the

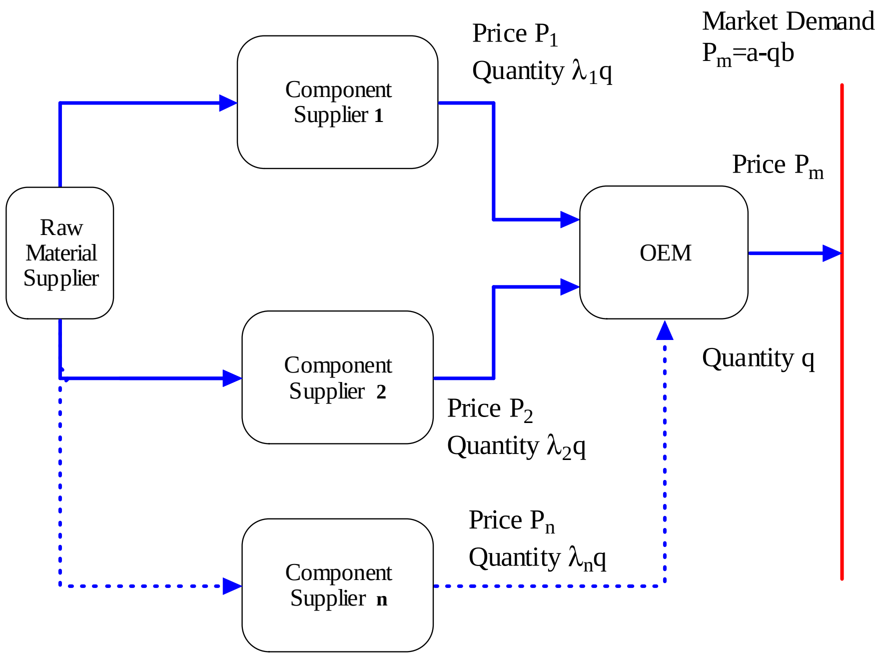

Figure 3: The Model: one RM supplier, n component suppliers and one OEM

market, $\sum_{i=1}^{n} \lambda_i q$ amount of inputs are consumed. Component suppliers supply the buyer at respective prices P_i. They get the raw material from a single RM supplier at the rates c_i, have variable costs v_i and fixed costs F_i. The RM supplier has per unit costs c_r. Figure 3 shows this scenario.

We first analyze the set up in Figure 3. In stage 1 of this game, the buyer decides on the quantity. In stage 2, the n component suppliers determine their optimal prices. The RM supplier supplies raw material to the component suppliers directly.

Proposition 2 *Base Case*

(a) The efficient quantity is given by

$$q^* = \frac{a - v_m - \sum_{i=1}^{n} \lambda_i (c_r + v_i)}{4(n+1)b}$$

and the intermediate prices for the component suppliers are

$$P_i^* = \frac{a - v_m + n\lambda_i(c_i + v_i) - \sum_{j=1, j\neq i}^{n} \lambda_j (c_j + v_j)}{(n+1)\lambda_i}, i = 1..n.$$

(b) The profit for the raw material supplier is

$$\Pi_{raw}^* = 2(n+1)bq^{*2}, \tag{2}$$

and for the buyer is

$$\Pi_m^* = bq^{*2},$$

while the profits for the component suppliers are

$$\Pi_i^* = 2bq^{*2} - F_i, i = 1..n. \boxdot$$

We note that the suppliers receive identical contributions from the business, which are twice that of the buyer. For the total chain,

$$\Pi^{total*} = (4n+3)bq^{*2} - \sum_{i=1}^{n} F_i \tag{3}$$

To compare and contrast the profits of the supply chain, we calculate the base case profits for the vertically integrated chain.

Proposition 3 *Vertically integrated entity*

(a) The efficient quantity for the vertically integrated producer is

$$q^{int*} = 2(n+1)q^*.$$

(b) Profit for the vertically integrated entity is

$$\Pi^{int*} = 4(n+1)^2 bq^{*2} - \sum_{i=1}^{n} F_i. \boxdot \tag{4}$$

Comparing equations (3) and (4), we see that the efficiency of the decentralized chain, when $\sum_{i=1}^{n} F_i = 0$, is given by $\frac{n+3/4}{(n+1)^2}$, and decreases with n.

3.3 Operating the OEM hub - RM supply

In this section we focus on the case where the buyer engages in raw material supply via the OEM hub. The buyer buys the raw material directly from the RM supplier and gives it to the component suppliers. We assume that $c_i = c, \forall\ i$, where c is a constant material cost negotiated by the buyer with the RM supplier.

We model three additional conditions. First, the component suppliers' fixed costs change. They are reduced because the component suppliers are not investing in the relationship with the RM supplier any more. There is a saving on the associated transaction costs of ordering and procurement. We denote the changed fixed costs of the component suppliers as $F_i^{rm}, i = 1..n$.

Second, the buyer incurs costs to set up and operate the OEM hub, to develop relationships with the RM supplier, and to manage the associated transactions. We denote this new fixed cost of the buyer as F^{rm}.

Third, the OEM charges the component suppliers a fixed fee for taking over the RM supply role in the supply chain. Consider a hub fee equal to δ_i charged by the OEM to supplier i.

The game is akin to having $(n+1)$ suppliers, with the last supplier being the RM supplier, and the other n suppliers only having a value added component in their profit functions. We model the game in two different ways with two different sequence of events.

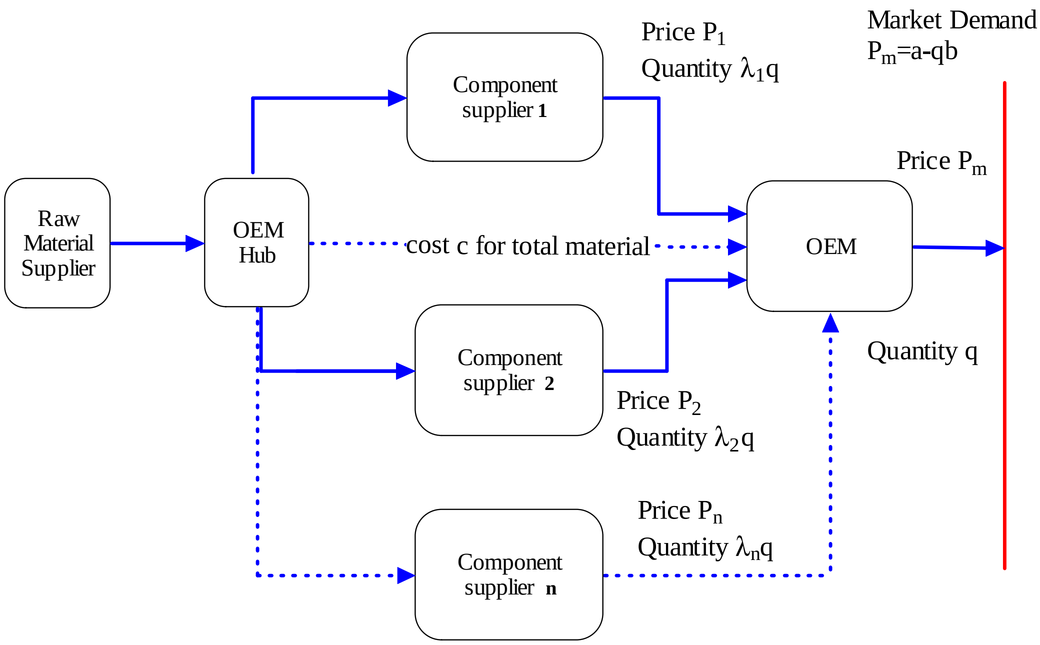

Figure 4: The OEM hub - RM supply scenario

First we model the game as a hybrid sequential-simultaneous move game. Stage 1 of the game is similar to base case. In stage 2, first the RM supplier and the buyer settle on the RM costs and then the n component suppliers move simultaneously to determine their price levels. We find that such a game does not reduce the triple marginalization problem. However, in this scenario, the OEM and the suppliers can appropriate some of the value that was going to the RM supplier.

Second, we model the game as a pure simultaneous move game. Stage 1 of the game is similar to base case. In stage 2, the n component suppliers as well as the RM supplier move simultaneously to determine their price levels. Similar to the hybrid game, the OEM and the suppliers can appropriate some of the value that was going to the RM supplier. However, this game does reduce the triple marginalization problem.

In both the games, since the components are complementary, all the n component suppliers produce exactly the same quantity in equilibrium.

Proposition 4 *Hybrid sequential-simultaneous move game*

(a) The equilibrium quantity is

$$q^{rmh*} = \frac{a - v_m - \sum_{i=1}^{n} \lambda_i (c_r + v_i)}{4(n+1)b} = q^*$$

where q^* is the quantity sold by the decentralized chain (base case). The component suppliers prices are

$$P_i^{rmh*} = \frac{1}{(n+1)\lambda_i}\left(a - v_m + n\lambda_i v_i - \sum_{j=1,j\neq i}^{n}\lambda_j v_j - c_r\sum_{i=1}^{n}\lambda_i\right), i = 1..n.$$

(b) The supply chain profits are as follows.

For RM supplier

$$\Pi_{raw}^{rmh*} = 2bq^{*2}, \tag{5}$$

for the buyer

$$\Pi_m^{rmh*} = bq^{*2} - F^{rm} + \sum_{i=1}^{n}\delta_i, \tag{6}$$

and for the component suppliers

$$\Pi_i^{rmh*} = 4bq^{*2} - F_i^h - \delta_i. \boxdot \tag{7}$$

Total supply chain profit under this scenario is exactly the same as that in the base case, except for the fixed costs.

$$\Pi^{total\_rmh*} = (4n+3)bq^{*2} - \sum_{i=1}^{n}F_i^h - F^{rm} \tag{8}$$

In this game, the OEM has an incentive to appropriate the upstream value if $\sum_{i=1}^{n}\delta_i > F^{rm}$*. Also the suppliers will join in, provided that* $2bq^{*2} > \delta_i - F_i + F_i^h$*.*

If the fixed costs are ignored, then the supply chain efficiency of this game is exactly equal to that in the base case.

Proposition 4.1 *Pure simultaneous move game*

(a) The equilibrium quantity is

$$q^{rms*} = \frac{a - v_m - \sum_{i=1}^{n}\lambda_i(c_r + v_i)}{2(n+2)b} = q^*\frac{2(n+1)}{(n+2)}$$

where q^* is the quantity sold by the decentralized chain (base case). The component suppliers prices are

$$P_i^{rms*} = \frac{1}{(n+2)\lambda_i}\left(a - v_m + (n+2)\lambda_i v_i - \sum\lambda_i v_i - \sum\lambda_i c_r\right), i = 1..n.$$

(b) The supply chain profits are as follows.

For RM supplier

$$\Pi_{raw}^{rm*} = 8(\frac{n+1}{n+2})^2 bq^{*2}, \tag{9}$$

for the buyer

$$\Pi_m^{rm*} = 4(\frac{n+1}{n+2})^2 bq^{*2} - F^{rm} + \sum_{i=1}^{n}\delta_i, \tag{10}$$

and for the component suppliers

$$\Pi_i^{rm2*} = 8(\frac{n+1}{n+2})^2 bq^{*2} - F_i^h - \delta_i.\boxdot$$

If there are no fixed costs or hub fee, then the efficiency of this chain is $\frac{2n+3}{(n+2)^2}$,and it decreases with n, but at a slower rate than that in the base case. *Note that the simultaneous move game is Pareto superior to the hybrid sequential-simultaneous move game.*

What does the hub fee do? Note that *if there are no hub fees ($\delta_i = 0$), then the component suppliers appropriate a part of the value that the RM supplier loses. Moreover, the buyer may be worse off than in the base case. (In the sequential-simultaneous move game, if $\delta_i = 0$, the component suppliers appropriate all the value that the RM supplier loses, and the buyer is always worse off.)* The hub fee plays the role of a value sharing mechanism between the component suppliers and the buyer.

How is the hub fee operationalized? The hub fee results from a change in component level pricing. When the suppliers buy RM, they invest their own capital in sourcing, storing, and processing it. In acknowledgement of this lockup of capital by the suppliers, the component level pricing (P_i) includes a component related to profit on the RM content of the component. Hence, when the RM supply is initiated, P_i changes not merely by the value of RM now being bought by the OEM (c_i), but by a higher amount. We explore this effect further in § 3.5.

The fixed cost F^{rm} relates to the establishment costs of operating the RM supply at the OEM hub. There are two types of fixed costs in setting up an RM supply scenario—startup and ongoing.

The startup cost relates to the detailing of RM at component level and establishing a material database so that RM supply is streamlined. The RM level details at the component BOM level are not a part of the ERP system at most OEMs. In order to develop such a database, the OEM has to collate accurate RM information—grades, weights and sources of material—for each component. This is not easy, but once in place, the database is an invaluable source for RM-related knowledge.

The ongoing cost consists of managing the RM supply—developing periodic (frequently monthly) RM schedules, linking RM supply with the payment cycle to the RM and component suppliers, and auditing the RM position. Our study of an OEM hub that manages the RM supply for its component suppliers shows that its ongoing costs are insignificant compared to its cost savings—this OEM manages the RM chain (for a single RM, for a single country) with just one full-time employee, and part-time support from one person in the finance department.

3.4 Operating the OEM hub - cooperation between suppliers

In this section we formulate the OEM hub problem in a hybrid cooperative/non-cooperative game theoretic setting. We model the non-cooperative node of the game at the market frontier where the buyer maximizes his own profit. At the supplier end, we model a cooperative game between n suppliers, who bargain over achievable joint profits.

Stage 1 of this game is similar to the base case. In stage 2, the suppliers bargain cooperatively, using the demand information from the buyer. For the cooperative scenario, we assume that the outside options of the suppliers are equal to their non-cooperative profits, that is to say that the suppliers revert to playing the base-case non-cooperative game if they fail to make the cooperation work.

Why should cooperation happen? The hybrid game with a cooperative solution between suppliers leads to a more efficient, lower cost supply chain, creating higher value for *all* the players in the chain. The suppliers get higher profits, and so do the OEM and the RM supplier.

Proposition 5 *Cooperation between suppliers*

(a) The cooperative quantity is

$$q^{coop*} = \frac{a - v_m - \sum_{i=1}^{n} \lambda_i (c_r + v_i)}{4b} = q^* \frac{(n+1)}{2}, \tag{11}$$

and the intermediate prices for the component suppliers are given by

$$P_i^{coop*} = \frac{1}{2n\lambda_i} \left(a - v_m - \sum_{i=1}^{n} \lambda_i c_i - \sum_{i=1}^{n} \lambda_i v_i + 2n\lambda_i (c_i + v_i) \right), i = 1..n.$$

(b) The buyer profit is

$$\Pi_m^{coop*} = b(q^{coop*})^2, \tag{12}$$

and the component suppliers' profits are

$$\Pi_i^{coop*} = b(q^{coop*})^2 - F_i, \; i = 1..n. \tag{13}$$

(c) The profit of the raw material supplier is

$$\Pi_{raw}^{coop*} = 4b(q^{coop*})^2. \tag{14}$$

(d) Since $q^{coop*} > q^*$, the game results in the following relations

$$\Pi_{raw}^{coop*} > \Pi_{raw}^*, \; \Pi_m^{coop*} > \Pi_m^*, \; \Pi_i^{coop*} > \Pi_i^* \;, i = 1..n. \tag{15}$$

Therefore,

- *All the agents in the cooperative supply chain have a higher profit compared to the decentralized chain.*
- *Overall supply chain costs are lower compared to the decentralized chain.*
- *The optimal quantity q^{coop*} increases with n, while q^* decreases with n.* ⊡

Unlike the RM supply scenario, the RM supplier in the cooperative case gains. To see this, compare equation (2) with equation (14). We get

$$\Pi_{raw}^{coop*} = \Pi_{raw}^{*} \frac{(n+1)}{2}.$$

The total supply chain profits in the cooperative operation are

$$\Pi^{total\_coop*} = \frac{1}{4} b q^{*2} (n+1)^2 (n+5) - \sum_{i=1}^{n} F_i \tag{16}$$

Ignoring the fixed costs for a moment, the efficiency is $\frac{n+5}{16}$. However, note that we have taken the same fixed costs as the base case in this section, with an assumption that the raw material supply is the same. These fixed costs will be slightly different than the base case, and will increase with n, since cooperation involves transaction costs. We do not analyze these costs in our model.

In our analysis above, we have ignored the possibility of cooperation among a subset of suppliers—what happens when some suppliers would like to break away? In other words, is the OEM hub a stable solution concept in the cooperative scenario?

Let us now suppose that a subset of suppliers with $n-m$ members wants to break away from the central coalition, which is managed by the OEM. Let the original coalition be denoted by A and the breakaway coalition by B. Then, there are m members left in the coalition managed by the OEM. We note that irrespective of this breakup, the members of B need to produce the quantity being produced by A, since it is the quantity for the assembly process at the OEM. In this scenario, we get the following results

Proposition 5.1 *Breakaway groups*

(a) The quantity bargained by both the coalitions (A and B) is

$$\begin{aligned} q^{new*} &= \frac{a - v_m - \sum_{i=1}^{n}(\lambda_i c_i + \lambda_i v_i)}{6b} \\ &= \frac{q^*(n+1)}{3} < q^{coop*} \end{aligned}$$

and the intermediate prices for the component suppliers are given by

$$P_i^{new} = \begin{cases} \frac{1}{3m\lambda_i}\left(a - v_m - \sum_{i=1}^{m} \lambda_i c_i - \sum_{i=1}^{m} \lambda_i v_i + 3m\lambda_i(c_i+v_i)\right), i \in A \\ \frac{1}{3(n-m)\lambda_i}\left(a - v_m - \sum_{i=1}^{n-m} \lambda_i c_i - \sum_{i=1}^{n-m} \lambda_i v_i + 3(n-m)\lambda_i(c_i+v_i)\right), i \in B \end{cases}.$$

(b) The profits made by the members of the two supplier groups are

$$\Pi_i^{new*} = q^{new*}\lambda_i(P_i^{new} - c_i - v_i) - F_i, \; i \in A, B.$$

(c) If the total profits made by the two groups of size m and $n-m$ is denoted by Π^{A+B} , then

$$\Pi^{A+B} < n\Pi_i^{coop*} \; \forall \; m$$

(d) For the two groups

$$\begin{aligned}\Pi_i^{new} &< \Pi_i^{coop*}, i \in A \\ \Pi_j^{new} &< \Pi_j^{coop*}, j \in B\end{aligned}$$

Therefore,

- *The total profit for all the suppliers goes down whenever a group of suppliers break away,*
- *The breakaway group as well as the remaining group of suppliers have lower profits compared to their profits in a single cooperative group.* ⊡

Note that we have taken only two subgroups for analysis. The quantity contracted between the OEM and the component suppliers goes down as the number of groups increase, and equals q^* when all suppliers bargain separately, which is the base case scenario.

This analysis of the cooperative OEM hub also holds if the OEM supplies RM to its suppliers - the profit contributions are the same. Also, the analysis holds even if we move away from our assumption of a deterministic demand - while removing of information asymmetry increases supply chain profits, agents can do better by cooperating (this property is easy to prove, and we do so in the Appendix). This is why the OEM hub concept is so powerful—cooperation between suppliers not only helps to remove demand-related inefficiencies, but also reduces quantity-related inefficiencies in production.

3.5 Financial flows and the OEM hub

In our analysis of the OEM hub in the previous section, we assumed that the suppliers and the OEM have the same cost of capital. However, our empirical studies show a different picture. For example, in India, most suppliers are smaller than the OEMs and have a much higher cost of capital. Typical weighted average cost of capital (WACC) is around 10% for Indian OEMs, but for typical suppliers in India, the WACC is $> 14\%$. In such a scenario, there may be additional value that can be captured by setting up an OEM hub. The supply chain might be able to run at a lower cost if it is financed by capital sourced at a lower cost. We explore this effect in this section.

Direct RM purchasing by the OEM (Figure 5) creates two effects. First, the component level pricing changes. When the OEM buys the RM, component level pricing depends only on the value added by the components supplier. This is the effect that we observed in § 3.3.

The second effect is more subtle. In general, P_i takes into account the money blocked in RM inventory as well as the profits that the component supplier has to earn. However, in the revised scenario (Figure 5), the supplier does not need to invest in buying or storing RM for components

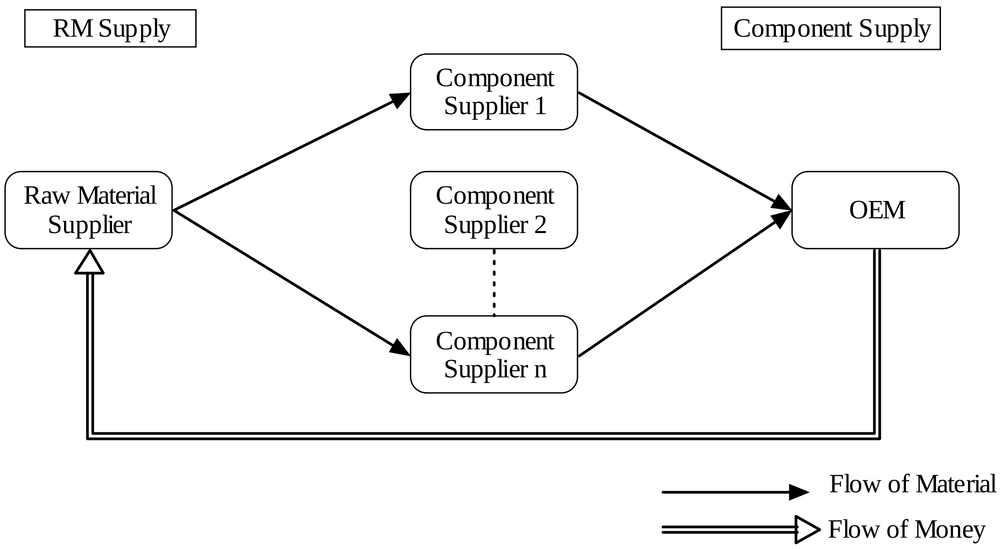

Figure 5: A possible result of establishing an OEM hub—RM financing

destined for the focal OEM. Therefore, working capital used by the component supplier in its business with the OEM declines. Consequently, P_i needs to be revised to take into account the changed working capital requirement of the component supplier. We can understand this by writing the pricing contract of the OEM with its suppliers as follows:

$$P_i = k_i c_i + k_{ii} v_{i,}\ i = 1..n\ ;\ k_i, k_{ii} > 0, \tag{17}$$

where k_i and k_{ii} are the mark-ups that the buyer provides on the raw material and value-adding costs v_i of supplier i. Therefore when RM supply is initiated, P_i does not change merely by c_i but by $k_i c_i$.

We now model the OEM hub differently, by introducing a time variable (Our model is in line with the models of trade credit in finance literature, specifically Schwartz (1974) and Ferris (1981)). Let the average inventory (units) of components at supplier i for a single period be I_i (including work in process and finished goods) and that of the final product at the OEM be I_m. Consider only the capital locked up in RM within the inventory levels of all agents. Let the rate at which the OEM borrows capital be $r_m(t)$ and that for supplier i be $r_i(t)$, where t denotes time. We now explore the conditions under which RM financing is related to these two sources of capital. In our analysis we assume that $r_i(t)$ and $r_m(t)$ are differentiable functions of time and $r_i(t) \neq r_m(t)$.

Consider a case where the OEM advances money to the component supplier i for a time period t to finance raw material purchasing. In return, the OEM demands a lower price than P_i. The component supplier i will agree to a lower price $P_i^{s\_accept}$, if

$$P_i^{s\_accept} = \frac{k_i c_i}{(1 + r_i(t))^t} + k_{ii} v_{i,}\ i = 1..n$$

Note the way we have modeled the situation— the OEM is not buying the RM, but merely giving a short term loan to the component supplier i. Let us define a new variable $c_i^{s\_accept} = \frac{c_i}{(1+r_i(t))^t}$. Then, since the OEM sources money at the rate $r_m(t)$, it will be indifferent between an RM price of $c_i^{s\_accept}$ for the component supplied t days later and a price today of c^{m_accept} ,where

$$\frac{c^{m\_accept}}{(1 + r_m(t))^t} = c_i^{s\_accept}$$

Therefore the net benefit to the OEM of making a prepayment only for the RM will be

$$(\frac{1 + r_m(t)}{1 + r_i(t)})^t,\ i = 1..n \tag{18}$$

Maximization of equation (18) gives us the optimal time period for the loan of money:

$$t^* > 0 \text{ if } \frac{d}{dt}(\frac{r_m(t) - r_i(t)}{1 + r_i(t)}) < 0.$$

which happens when

$$\frac{d}{dt} r_m(t) < 0 \text{ and } \frac{d}{dt} r_i(t) \geq 0. \tag{19}$$

The money that finances the RM part of the inventories throughout the supply chain can be financed by capital sourced at the rate $r_m(t)$ if (19) holds. Note that t^* is a maxima when

$$\frac{d^2}{dt^2}(\frac{r_m(t) - r_i(t)}{1 + r_i(t)}) < 0. \tag{20}$$

Finally, note that the rate for the buyer, $r_m(t)$, does not remain static, after the buyer decides on financing the RM chain. Since the RM inventory in the supply chain is financed by the buyer, the risk profile of the buyer changes in the eyes of the lending institutions. Therefore, the capital is now available at a new rate of interest to the buyer - say $r_m^{new}(t)$.

Is $r_m^{new}(t) > r_m(t)$? It may seem so, as the buyer is exposed to higher stock. However, RM supply by the OEM hub may have a positive effect (see §3.3). Therefore, it is not possible to say whether $r_m^{new}(t) > r_m(t)$ in all cases.

One of the metrics used by lending institutions to gauge the risk profile of any firm is the total returns on the net assets (RONA) figure for the firm. In simple terms, RONA is the total profits made by the firm divided by the assets it owns and uses for making the profits. In §3.3, we discussed how the OEM's profits can change, depending on the decision to finance the RM. Let the assets of the OEM in the base case (before it decides to finance RM) be A. One of the decision rules that can be used for refining the condition (19) is:

$$Is\ \frac{\Pi_m^{rm*}}{A + \sum_{i=1}^{n} I_i \lambda_i c_i + I_m(\sum_{i=1}^{n} k_i \lambda_i c_i)} > \frac{\Pi_m^*}{A}? \tag{21}$$

If so, then the money for RM financing may be available at a rate $r_m^{new}(t)$ such that $r_m^{new}(t) < r_m(t)$. Indeed, if the decision rule in equation (21) results in a scenario where the OEM can obtain financing at a lower rate than before, then RM financing at the OEM hub becomes even more attractive. If not, the OEM must evaluate the benefits of RM financing against the effects of increase in the cost of capital.

4 Discussion

In this paper, we detail how buyers can recapture value from their supply networks by focusing on their suppliers and their suppliers' suppliers. We first discuss two interesting characteristics of the supply network surrounding automotive OEMs, and use them as assumptions for modeling the OEM hub as a n supplier, single buyer, single RM supplier setup.

We explore three different ways in which the OEM hub is useful: (1) as a center for RM supply; (2) as a center for cooperation between suppliers; and (3) as a center for financing the supply chain at least cost. These three aspects make the OEM hub a powerful way of unlocking the value in upstream sourcing.

Our analysis shows that the OEM and its suppliers may have motivation for initiating supply of raw material directly from the RM supplier. The possible benefits accruing to the OEM and the suppliers in this scenario result from a reduction of the profits of the RM supplier. Therefore the RM supply scenario is beneficial for only some members of the chain. If the RM supplier faces competition (as is usually the case), then the OEM and the suppliers may have an advantageous position, and can benefit by initiating RM supply at the OEM hub.

There can be cooperation at the OEM hub— the OEM can bring its suppliers together. Our analysis shows that such active management of upstream sourcing by the OEM is beneficial for all links of the supply chain - the OEM, the component suppliers and the RM supplier. Another interesting result of our analysis is that the quantity produced in the cooperative scenario is higher than that in the decentralized case and it increases with the number of suppliers. Therefore, cooperative operation leads to higher market power for the OEM - it sells more quantity (produced at lesser cost). Moreover, cooperation at the hub can also lead to exchange of ideas on design as well as process improvements between the suppliers.

The cooperative operation is Pareto superior to the RM supply from the view of the total supply chain profits. *However, we cannot say that the cooperative operation is Pareto superior to RM supply from the view of the individual agents' profits.* The OEM, for example, may benefit more in the RM supply scenario.

A related aspect of these operating scenarios of the OEM hub is the change in the fixed costs of the suppliers and the OEM. For initiating RM supply, the OEM needs to invest in creating a material database at component level. This is not easy, since it means revisiting BOM for all components; however, once completed and aligned with the OEM's IT system, such a material database acts as an important competitive lever. It helps promote relationships with RM suppliers, since the OEM can identify its current RM requirements and project its future purchases in a much easier and more efficient way. Thus strategic partnerships with RM suppliers can be built up, based on deep knowledge of the RM.

The operating scenarios of the OEM hub are linked with the third effect: RM financing. When the OEM finances RM purchases, then in cases where its suppliers borrow money at a higher cost, savings may be accrued at the hub. Our analysis shows that RM financing is useful when the OEM can source capital at a rate which is decreasing with an increase in the time-period of borrowing, but the suppliers cannot. This condition holds in many markets where the suppliers are small and cannot access the same financial market that the OEM can.

What is the extent of savings that can accrue to different agents? The exact answer depends on the relationship between the raw material and the overall cost of the OEM and the suppliers. Our case studies show that direct RM purchasing, cooperative sourcing and the cost of capital effect at the OEM hub lead to savings of three to six percent on the costs of RM for the OEM.

The OEM hub is a new concept that can help firms create value from upstream sourcing. We believe that firms that invest in building relationships at RM level will certainly create cost differentials with their competitors. This may help managers recapture some of the value that has been lost in the race to become a lean manufacturer.

We have not detailed one important aspect of the OEM hub—knowledge creation. Since the OEM needs to delve deep into the BOM of its components suppliers, it amasses a knowledge base about suppliers and sourcing. The OEM hub can develop into a powerful center for streamlining new product development by sharing process information —however this exciting area is not covered in this paper.

We have also not looked at modeling cooperative interaction at the OEM hub under other scenarios such as different demands, or non-assembly supplier networks. These would make interesting areas for future research.

The hypothesis of supply network reconfiguration via the OEM hub can lead to more levels of enquiry. An interesting future avenue of research for us lies in the area of firm-level learning. As firms outsource more and more, in-house competence may diminish in areas that are outsourced. A reconfiguration of the supply network may provide opportunities for the OEM to revisit these sources of knowledge. As closer relationships are built in at RM level, there will be opportunities for detailing material efficiencies at primary process levels like forging and casting. These can provide further avenues of value addition for the OEM and its suppliers.

5 Acknowledgments

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Appendix for "Supplier Networks, Cooperation and Sourcing Efficiency"

Proof of Proposition 1 - The cooperative outcome of classical double marginalization problem

The profit functions of the buyer and the supplier are as under,

$$\Pi_{\text{buyer}} = (p - p_m)q,\ \Pi_{\text{supplier}} = (p_m - c)\,q$$

The non-cooperative profits for the two agents are as under

$$\Pi^0_{\text{buyer}} = \frac{1}{16b}\,(a-c)^2\,, \Pi^0_{\text{supplier}} = \frac{1}{8b}\,(a-c)^2$$

However, in the cooperative bargaining phase, the suppliers try to maximize the joint utility. The Nash bargaining solution N is given as under

$$N = \max_{p,p_m}(\Pi_{\text{buyer}} - \Pi^0_{\text{buyer}})(\Pi_{\text{supplier}} - \Pi^0_{\text{supplier}})$$

The Nash product then is equal to

$$N = \max_{p,p_m}((p-p_m)q - \frac{1}{16b}\,(a-c)^2)((p_m-c)\,q - \frac{1}{8b}\,(a-c)^2)$$

From the Pareto optimality property of the Nash Bargaining solution, the maximum of the Nash product will occur at a q^{c*}such that

$$q^{c*} \in \arg\max_{q\in Q}((p-p_m)q - \frac{1}{16b}\,(a-c)^2 + (p_m-c)\,q - \frac{1}{8b}\,(a-c)^2)$$

where Q is the set of all feasible quantities.

Since the threat options are given , this condition reduces to

$$q^{c*} \in \arg\max_{q\in Q}(p-c)q$$

giving us the result that the optimal quantity is that for the vertically integrated manufacturer. Furthermore for symmetry of the Nash bargaining solution we must have at q^{c*}

$$\Pi_{\text{buyer}}(q^{c*})\ - \Pi^0_{\text{buyer}} = \Pi_{\text{supplier}}(q^{c*}) - \Pi^0_{\text{supplier}}$$

which gives us the condition that

$$(p-p_m)q^{c*} - \frac{1}{16b}\,(a-c)^2 = (p_m-c)\,q^{c*} - \frac{1}{8b}\,(a-c)^2$$

solving, we get

$$q^{c*} = \frac{a-c}{2b}, p^* = \frac{a+c}{2},\ p^*_m = \frac{5a+11c}{16},$$

whence

$$\Pi^{coop}_{buyer} = (p^* - p^*_m)\,q^{c*} = \frac{3}{32b}\,(a-c)^2\,.$$

For the supplier

$$\Pi^{coop}_{supplier} = \left(p^*_m - c\right) q^{c*} = \frac{5}{32b}\left(a-c\right)^2,$$

so that the total profits for this cooperative chain are

$$\Pi^{coop}_{total} = \frac{1}{4b}\left(a-c\right)^2 \tag{22}$$

which is the same as vertically integrated chain from equation **??** !

⊡

Simultaneous move game

We now take the assumptions that the buyer and the supplier move simultaneously. The buyer must now choose a price p and the supplier should take it into account while computing the quantities. The retail demand is still given by $q = \frac{a-p}{b}$. Suppose the buyer earns the margin $m = p - p_m$.The supplier now maximizes

$$\max_{p_m} \left(p_m - c\right) q,$$

and the buyer maximizes

$$\max_{m} mq(p_m + m).$$

Solving these two programs gives us

$$p^*_m = \frac{a+2c}{3}, m^* = \frac{a-c}{3}$$

whence the buyer price is

$$p^* = p^*_m + m^* = \frac{2a+c}{3}$$

The quantity sold in the market at this price is

$$q^* = \frac{a-c}{3b}$$

The buyer and supplier profits are then as follows: For the buyer

$$\Pi^{simult}_{\text{buyer}} = m^* q^* = \frac{1}{9b}\left(a-c\right)^2 \tag{23}$$

and for the supplier

$$\Pi^{simult}_{\text{supplier}} = \left(p^*_m - c\right) q^* = \frac{1}{9b}\left(a-c\right)^2 \tag{24}$$

equal to that of the buyer. The supplier loses part of his profits since he has less information, the buyer however gains. We see that the simultaneous move game also has a marginalization problem, however the channel profits are higher than in the Stackelberg scenario.

⊡

The cooperative outcome of Simultaneous move game

Once again employing the *Nash bargaining solution*, we compute the result of joint profits for the supplier and the buyer. However, we now assume that the outside options of the two suppliers are equal to their non-cooperative profits under the simultaneous move scenario. Since both the channel members make equal profits in their outside options, the optimal quantity is that for the vertically integrated supplier.

$$q^{c*} = \frac{a-c}{2b} \tag{25}$$

Also the profits will be equally shared and

$$\Pi_{buyer}(q^{c*}) \ = \Pi_{supplier}(q^{c*}) = \frac{1}{8b}\left(a-c\right)^2$$

The total profits for the cooperating chain will be same irrespective of the outside options, and as shown in the previous section, it is equal to $\frac{1}{4b}\left(a-c\right)^2$, which is equal to the profits of a vertically integrated chain.

⊡

Buyer leadership game

We now take the assumption that the buyer first decides on the margin required and then the supplier takes the resulting quantity into consideration. Hence the buyer is the leader in this game. The retail demand is still given by $q(p) = \frac{a-p}{b}$. We again assume that the buyer earns the margin $m = p - p_m$.

The supplier now has this information about m and therefore maximizes

$$\max_{p_m} \left(p_m - c\right) q \tag{26}$$

giving

$$p_m^* = \frac{a+c-m}{2}, p = \frac{a+c+m}{2} \tag{27}$$

The buyer now maximizes

$$\max_{m} mq \tag{28}$$

which gives us

$$m^* = \frac{a-c}{2} \tag{29}$$

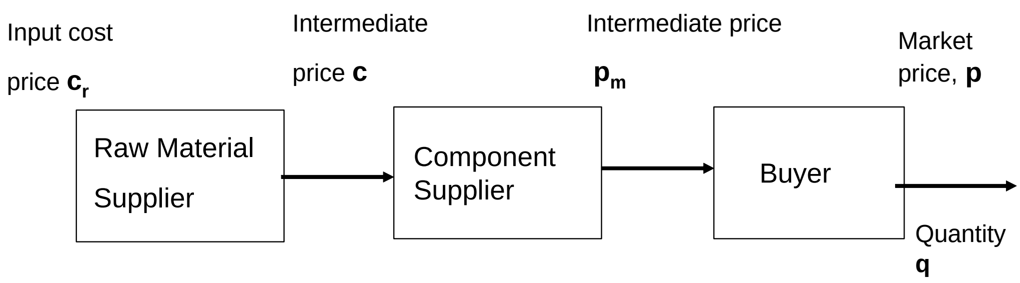
The buyer price is then $\frac{1}{4}(3a+c)$ and the quantity sold at this price in the market is $\frac{1}{4b}(a-c)$.The buyer and the supplier profits are then as follows:

$$\Pi_{\text{buyer}}^{ret\_lead} = m^* q^* = \frac{1}{8b}\left(a-c\right)^2,$$

$$\Pi_{\text{supplier}}^{ret\_lead} = \left(p_m^* - c\right) q^* = \frac{1}{16b}\left(a-c\right)^2. \tag{30}$$

which is the opposite distribution of scenario of the supplier leadership Stackelberg game. The total profits for this chain are

$$\Pi_{total}^{simult} = \frac{3}{16b}\left(a-c\right)^2. \tag{31}$$



⊡

The cooperative outcome of the Buyer leadership game

Once again employing the *Nash bargaining solution*, we compute the result of joint profits for the buyer and the supplier. Proceeding as in the proof of Proposition 1, we get

$$p_m^* = \frac{3a + 13c}{16} \tag{32}$$

whence

$$\Pi_{\text{buyer}}^{coop} = (p^* - p_m^*)\, q^{c*} = \frac{5}{32b}\,(a-c)^2 \tag{33}$$

and

$$\Pi_{\text{supplier}}^{coop} = (p_m^* - c)\, q^{c*} = \frac{3}{32b}\,(a-c)^2 \tag{34}$$

and the total profits for this cooperative chain are,

$$\Pi_{total}^{coop} = \frac{1}{4b}\,(a-c)^2 \tag{35}$$

The total profits for the cooperating chain are equal to the profits of a vertically integrated chain as in the previous section, however, the distribution of profits is now reversed. Since the buyer has higher outside option in the buyer leadership game, he gets the higher share of cooperative profits.

⊡

Extending the classical case - 3 stage chain

We assume the RM supplier leadership game. Hence c and p_m are first communicated.

The buyer maximizes profit

$$\max_q\,(a - bq - p_m)\, q \tag{36}$$

giving the quantity decision $q^* = \frac{a-p_m}{2b}$. Now, the component supplier maximizes profit

$$\max_{p_m}\,(p_m - c)\,(\frac{a - p_m}{2b}) \tag{37}$$

giving $p_m^* = \frac{c+a}{2}$. The raw material supplier also maximizes profit

$$\max_c\,(c - c_r)\,(\frac{a - p_m^*}{2b})$$

giving $c = \frac{a+c_r}{2}$,whence $p_m^* = \frac{3a+c_r}{4}$ and $q^* = \frac{a-c_r}{8b}$. Therefore $p^* = \frac{c_r+7a}{8}$. Now we can compute the profits. For the buyer

$$\Pi_{\text{buyer}} = (p^* - p_m^*)q^* = \frac{1}{64b}\,(a-c_r)^2 \tag{38}$$

for the supplier

$$\Pi_{\text{supplier}} = (p_m^* - c)\,q^* = \frac{1}{32b}\,(a-c_r)^2 \tag{39}$$

and for the raw material supplier

$$\Pi_{raw\_material} = (c - c_r)\,q^* = \frac{1}{16b}\,(a-c_r)^2 \tag{40}$$

and the total profits for this decentralized chain are

$$\Pi_{total}^{decent} = \frac{7}{64b}\,(a-c_r)^2\,. \tag{41}$$

Now let us look at the profits when the chain is vertically integrated

$$\Pi_{total} = (p - c_r)(\frac{a-p}{b}) \tag{42}$$

FOC gives the maximum profits of vertically integrated chain as follows, with price $\frac{a+c_r}{2}$ and quantity $\frac{a-c_r}{2b}(= 4q^*)$

$$\Pi_{total}^{vertint} = (p^* - c_r)(\frac{a-p^*}{b}) = \frac{1}{4b}\,(a-c_r)^2 \tag{43}$$

Thus the efficiency of the decentralized chain is equal to 43.75%.

Now consider the case when the buyer and the supplier cooperate and together talk to the RM supplier, then $q^* = \frac{a-c}{2b}$. RM supplier maximizes his profits for this quantity

$$\max_c\,(c - c_r)\,(\frac{a-c}{2b})$$

giving

$$c^* = \frac{a+c_r}{2} \text{ and so } q^* = \frac{1}{4b}\,(a-c_r)\,.$$

Supply chain profits are

$$\begin{aligned} & \Pi_{\text{buyer}} + \Pi_{\text{supplier}} + \Pi_{raw\_material} && (44)\\ = \; & (p^* - p_m^*)q^* + (p_m^* - c)\,q^* + (c - c_r)\,q^* && (45)\\ = \; & \frac{3}{16b}\,(a-c_r)^2 && (46) \end{aligned}$$

We note that the profits for the buyer, the component supplier and the RM supplier increase, as well as the total chain profits increase in presence of cooperation. The efficiency of this cooperative chain is 75%.

⊡

Proof of Proposition 2

The buyer maximizes profit

$$\Pi_a = \max_{P_m} \ q(P_m - \sum_{i=1}^{n} \lambda_i P_i - v_m)$$

FOC gives as in the base case

$$P_m = \frac{a + v_m + \sum_{i=1}^{n} \lambda_i P_i}{2}, q = \frac{a - v_m - \sum_{i=1}^{n} \lambda_i P_i}{2b}$$

Component supplier i maximizes his profit Π_i, where

$$\Pi_i = \lambda_i q(P_i - c_i - v_i) - F_i \tag{47}$$

Our focus variables are P_i; and we try to find how the component suppliers maximize their profits with respect to the markup provided by the buyer on their costs. For this, we try to maximize Π_i with respect to P_i. Assuming that $c_i, \lambda_i, v_i \neq 0$, the first order condition for maximizing (47) for all suppliers $i, i = 1..n$, gives a system of n independent linear equations with a symmetric solution, in which the prices for each supplier are as follows:

$$P_i^* = \frac{a - v_m + (n+1)\lambda_i(c_i + v_i) - \sum_{i=1}^{n} \lambda_i(c_i + v_i)}{(n+1)\lambda_i} . \tag{48}$$

Putting in expressions for buyer's price and quantity, we get the equilibrium quantity as

$$\begin{aligned} q &= \frac{a - v_m - \sum_{i=1}^{n} \lambda_i P_i}{2b} \\ &= \frac{a - v_m - \sum_{i=1}^{n} \frac{a - v_m + (n+1)\lambda_i(c_i+v_i) - \sum_{i=1}^{n} \lambda_i(c_i+v_i)}{(n+1)}}{2b} \\ &= \frac{(n+1)a - (n+1)v_m - \sum_{i=1}^{n} a - v_m + (n+1)\lambda_i(c_i + v_i) - \sum_{i=1}^{n} \lambda_i(c_i + v_i)}{2(n+1)b} \\ &= \frac{a - v_m - \sum_{i=1}^{n} (n+1)\lambda_i(c_i + v_i) - \sum_{i=1}^{n} \lambda_i(c_i + v_i)}{2(n+1)b} \\ &= \frac{a - v_m - (n+1)\sum_{i=1}^{n} (\lambda_i(c_i + v_i)) + n\sum_{i=1}^{n} \lambda_i(c_i + v_i)}{2(n+1)b} \\ &= \frac{a - v_m - \sum_{i=1}^{n} (\lambda_i(c_i + v_i))}{2(n+1)b} \end{aligned}$$

The raw material supplier also maximizes his profits which are given by

$$\Pi_{raw} = q^*(\sum_{i=1}^{n} \lambda_i(c_i - c_r))$$

where c_r is the production cost of the raw material supplier, including all value added costs. The FOC give us

$$\sum_{i=1}^{n} \lambda_i c_i = \frac{a - v_m + \sum_{i=1}^{n} \lambda_i(c_r - v_i)}{2} \tag{49}$$

thereby

$$q^* = \frac{a - v_m - \sum_{i=1}^{n} \lambda_i (c_r + v_i)}{4(n+1)b}$$

whence the equilibrium price is given by

$$P_m^* = \frac{(4n+3)a + v_m + \sum_{i=1}^{n} \lambda_i (c_r + v_i)}{4(n+1)}. \tag{50}$$

So that

$$\Pi_{raw} = \frac{q^*}{2}(a - v_m - \sum_{i=1}^{n} \lambda_i v_i - \sum_{i=1}^{n} \lambda_i c_r)) \tag{51}$$

Other results follow.

⊡

Proof of Proposition 3

The vertically integrated buyer maximizes profit, or

$$\Pi_m^{int*} = \max_{p_m} \; q(P_m - v_m - \sum_{i=1}^{n} \lambda_i (c_r + v_i)) - \sum_{i=1}^{n} F_i$$

FOC gives

$$P_m^{int*} = \frac{a + v_m + \sum_{i=1}^{n} \lambda_i (c_r + v_i)}{2}$$

giving equilibrium quantity

$$q^{int*} = \frac{a - P_m^{int*}}{b} = \frac{a - v_m - \sum_{i=1}^{n} \lambda_i (c_r + v_i)}{2b} \tag{52}$$

and we see that

$$q^{int*} = 2(n+1)q^* \tag{53}$$

so

$$P_m^{int*} = a - 2b(n+1)q^*$$

The profit results follow.

⊡

Proof of Proposition 4

The buyer buys the raw material at a rate of c per unit from the RM supplier. For the buyer, proceeding as in the base case, we get

$$\Pi_m^{rmh*} = \max_{P_m} \; q^h(P_m - \sum_{i=1}^{n} \lambda_i P_i^h - v_m - \sum_{i=1}^{n} \lambda_i c) - F^h$$

FOC gives

$$P_m^{rmh} = \frac{a + v_m + \sum_{i=1}^{n} \lambda_i c + \sum_{i=1}^{n} \lambda_i P_i^h}{2} \tag{54}$$

Thereby

$$q^{rmh*} = \frac{a - P_m}{b} = \frac{a - v_m - c\sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{n} \lambda_i P_i^h}{2b} \tag{55}$$

and

$$\Pi_m^{rmh*} = b(q^{h*})^2.$$

Component supplier i has profit function Π_i^{rmh} , where

$$\Pi_i^{rmh} = \lambda_i q^h (P_i^h - v_i) - F_i^h \tag{56}$$

The raw material producer also maximizes his profits which are given by

$$\Pi_{raw}^{rmh} = q^h (c - c_r) \sum_{i=1}^{n} \lambda_i \tag{57}$$

Our focus variables are now P_i^h and c; and we try to find how the component suppliers maximize their profits with respect to the markup provided by the OEM on their variable costs when the hub is operating. As discussed, the OEM first moves sequentially with the RM supplier and then simultaneously with all the suppliers.

The sequential step gives

$$\Pi_{raw}^{rmh} = \frac{a - v_m - c\sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{n} \lambda_i P_i^h}{2b} (c - c_r) \sum_{i=1}^{n} \lambda_i \tag{58}$$

and the input raw material price to the buyer hub

$$c^{rmh*} = \frac{1}{2\sum_{i=1}^{n} \lambda_i} \left(a - v_m - \sum_{i=1}^{n} \lambda_i P_i^h + c_r \sum_{i=1}^{n} \lambda_i \right) \tag{59}$$

Hence the quantity to be produced is

$$q^{rmh*} = \frac{a - v_m - c\sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{n} \lambda_i P_i^h}{2b} \tag{60}$$

$$= \frac{a - v_m - c_r\sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{n} \lambda_i P_i^h}{4b} \tag{61}$$

Now, we try to maximize Π_i^h with respect to P_i^h. Assuming that $\lambda_i, v_i \neq 0$, we get from FOC,

$$P_i^{rmh*} = \frac{1}{(n+1)\lambda_i} \left(a - v_m + n\lambda_i v_i - \sum_{j=1, j\neq i}^{n} \lambda_j v_j - c_r \sum_{i=1}^{n} \lambda_i \right) \tag{62}$$

and the input raw material price to the buyer hub

$$c^{rmh*} = \frac{1}{2\sum_{i=1}^{n}\lambda_i}\left(a - v_m - \sum_{i=1}^{n}\lambda_i P_i^{h*} + c_r\sum_{i=1}^{n}\lambda_i\right) \quad (63)$$

$$= \frac{1}{2(n+1)\sum_{i=1}^{n}\lambda_i}\left(a - v_m - \sum_{i=1}^{n}\lambda_i v_i + (2n+1)c_r\sum_{i=1}^{n}\lambda_i\right) \quad (64)$$

whence the equilibrium quantity is

$$q^{rmh*} = \frac{a - v_m - c_r\sum_{i=1}^{n}\lambda_i - \lambda_i v_i}{4b(n+1)} = q^* \quad (65)$$

and the equilibrium price is

$$P_m^{rmh*} = \frac{(2n+3)a + v_m + c_r\sum_{i=1}^{n}\lambda_i + \sum_{i=1}^{n}\lambda_i v_i}{2(n+2)} \quad (66)$$

We now compute the revised Supply chain profits. We get for the RM supplier

$$\Pi_{raw}^{rmh} = q^h(c - c_r)\sum_{i=1}^{n}\lambda_i \quad (67)$$

$$= \frac{q^h}{2(n+1)}(a - v_m - \sum_{i=1}^{n}\lambda_i v_i - \sum_{i=1}^{n}\lambda_i c_r) \quad (68)$$

$$= 2bq^{*2} \quad (69)$$

for the buyer

$$\Pi_m^{rmh*} = bq^{*2} - F^h \quad (70)$$

and for the component suppliers

$$\Pi_i^{rmh} = \lambda_i q^h(P_i^h - v_i) - F_i^h - \delta_i \quad (71)$$

$$= 4bq^{*2} - F_i^h - \delta_i. \quad (72)$$

⊡

Proof of Proposition 4.1

Proceeding just like in Proposition 4, we get,

$$q^{rms*} = \frac{a - P_m}{b} = \frac{a - v_m - c\sum_{i=1}^{n}\lambda_i - \sum_{i=1}^{n}\lambda_i P_i^{rms}}{2b} \quad (73)$$

and

$$\Pi_m^{rms*} = b(q^{rms*})^2$$

Component supplier i has profit function Π_i^h , where

$$\Pi_i^{rms} = \lambda_i q^{rms}(P_i^{rms} - v_i) - F_i^{rm} \quad (74)$$

The raw material producer also maximizes his profits which are given by

$$\Pi_{raw}^{rms} = q^{rms}(c - c_r) \sum_{i=1}^{n} \lambda_i \tag{75}$$

where c_r is the production cost of the raw material supplier, including all value added costs.

Our focus variables are now P_i^{rms} and c. In this game, the RM supplier and component suppliers move simultaneously to determine their price levels (price for the RM supplier is c). The first order conditions for maximization of the two profit functions, (74) and (75) again gives us a symmetric system and we get the following results,

$$\begin{aligned} c^* &= \frac{1}{(n+2)\sum \lambda_i} \Big(a - v_m - \sum \lambda_i v_i + (n+1) \sum \lambda_i c_r \Big) \\ P_i^{rms} &= \frac{1}{(n+2)\lambda_i} \Big(a - v_m + (n+2)\lambda_i v_i - \sum \lambda_i v_i - \sum \lambda_i c_r \Big) \end{aligned}$$

whence from equation (73), we get the equilibrium quantity as

$$q^{rms*} = \frac{a - v_m - \sum_{i=1}^{n} \lambda_i (c_r + v_i)}{2(n+2)b} = q^* \frac{2(n+1)}{(n+2)}. \tag{76}$$

Other results follow.

⊡

Proof of Proposition 5

Let us employ the Nash Bargaining solution to determine the Pareto optimal quantities. In the noncooperative stage, the buyer maximizes profit, or

$$\Pi_a = \max_{P_m} \; q(P_m - \sum_{i=1}^{n} \lambda_i P_i - v_m)$$

FOC gives as in the base case

$$P_m = \frac{a + v_m + \sum_{i=1}^{n} \lambda_i P_i}{2}, q = \frac{a - v_m - \sum_{i=1}^{n} \lambda_i P_i}{2b}$$

We will first detail the non-cooperative profits of such a scenario. Component supplier i maximizes his profit Π_i, where

$$\Pi_i = \lambda_i q (P_i - c_i - v_i) - F_i \tag{77}$$

The raw material producer also maximizes his profits which are given by

$$\Pi_{raw} = q^* (\sum_{i=1}^{n} \lambda_i (c_i - c_r))$$

The first order conditions gives us the resultant quantity

$$q^* = \frac{a - v_m - c_r \sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{n} \lambda_i v_i}{4(n+1)b} \tag{78}$$

Therefore the profits of each individual supplier can be given as

$$\Pi_i^* = 2bq^{*2} - F_i \tag{79}$$

In stage 2, the suppliers bargain cooperatively. Assuming that the outside options of all suppliers are equal to their non-cooperative profits and in the cooperative bargaining phase, the suppliers try to maximize the joint utility, we get the Nash bargaining solution

$$N = \max_{P_i, i=1..n} \prod_{i=1}^{n} (\Pi_i - \Pi_i^*) \tag{80}$$

The Nash product is then equal to

$$N = \max_{P_i, i=1..n} \prod_{i=1}^{n} (\lambda_i q(P_i - c_i - v_i) - 2bq^{*2})$$

From the Pareto optimality property of the Nash Bargaining solution, the maximum of the Nash product will occur at a q^{coop*}such that

$$q^{coop*} \in \arg\max_{q \in Q} \sum_{i \in L} ((\lambda_i q(P_i - c_i - v_i) - 2bq^{*2})$$

where Q is the set of all feasible quantities. Since the threat options are given, this condition reduces to

$$q^{coop*} \in \arg\max_{q \in Q} \sum_{i=1}^{n} \lambda_i q(P_i - c_i - v_i). \tag{81}$$

For symmetry of the Nash bargaining solution we must have

$$\Pi_i(q^{coop*}) - \Pi_i^* = \Pi_j(q^{coop*}) - \Pi_j^*, j \neq i$$

which gives us the condition that

$$\lambda_i(P_i - c_i - v_i) = \lambda_j(P_j - c_j - v_j), j \neq i \tag{82}$$

Utilizing the conditions of 82, the result from the first stage in equation 78 and the conditions of equation 81 we get, after some algebra,

$$\begin{aligned} P_i &= \frac{1}{2n\lambda_i}\left(a - v_m - \sum_{j=1, j\neq i}^{n} \lambda_j c_j - \sum_{j=1, j\neq i}^{n} \lambda_j v_j + (2n-1)\lambda_i(c_i + v_i)\right) \\ &= \frac{1}{2n\lambda_i}\left(a - v_m - \sum_{i=1}^{n} \lambda_i c_i - \sum_{i=1}^{n} \lambda_i v_i + 2n\lambda_i(c_i + v_i)\right) \end{aligned}$$

therefore, the optimal quantity is

$$\begin{aligned}
q^{coop*} &= \frac{a - v_m - \sum_{i=1}^{n} \lambda_i P_i}{2b} \\
&= \frac{a - v_m - \sum_{i=1}^{n} \lambda_i \frac{1}{2n\lambda_i}\left(a - v_m - \sum_{i=1}^{n} \lambda_i c_i - \sum_{i=1}^{n} \lambda_i v_i + 2n\lambda_i(c_i + v_i)\right)}{2b} \\
&= \frac{2na - 2nv_m - \sum_{i=1}^{n} \left(a - v_m - \sum_{i=1}^{n} \lambda_i c_i - \sum_{i=1}^{n} \lambda_i v_i + 2n\lambda_i(c_i + v_i)\right)}{4nb} \\
&= \frac{na - nv_m + \sum_{i=1}^{n} \left(\sum_{i=1}^{n} \lambda_i c_i + \sum_{i=1}^{n} \lambda_i v_i - 2n\lambda_i(c_i + v_i)\right)}{4nb} \\
&= \frac{na - nv_m - n\sum_{i=1}^{n} \lambda_i c_i - n\sum_{i=1}^{n} \lambda_i v_i}{4nb}
\end{aligned}$$

Now, for the RM supplier,

$$\Pi_{raw} = q^{coop*}\left(\sum_{i=1}^{n} \lambda_i c_i - \sum_{i=1}^{n} \lambda_i c_r\right)$$

where c_r is the production cost of the raw material supplier, including all value added costs. The FOC give us

$$\sum_{i=1}^{n} \lambda_i c_i = \frac{a - v_m + \sum_{i=1}^{n} \lambda_i(c_r - v_i)}{2} \tag{83}$$

so

$$q^{coop*} = \frac{a - v_m - \sum_{i=1}^{n} \lambda_i(c_r + v_i)}{8b} = q^* \frac{(n+1)}{2}$$

and therefore

$$\begin{aligned}
\Pi_{raw} &= q^{coop*}\left(\frac{a - v_m - \sum_{i=1}^{n} \lambda_i(c_r + v_i)}{2}\right) \\
&= q^{coop*2}(4b) \qquad (84)
\end{aligned}$$

Other results follow.

⊡

Proof of Proposition 5.1

(a) For any supplier i, of either coalition,

$$\Pi_i = \lambda_i q(P_i - c_i - v_i) - F_i \tag{85}$$

For the buyer, at the market front,

$$\Pi_a = \max_{P_m} \; q\left(P_m - \sum_{i \in A} \lambda_i P_i - \sum_{i \in B} \lambda_i P_i - v_m\right)$$

FOC gives as in the base case

$$P_m = \frac{a + v_m + \sum_{i \in A} \lambda_i P_i + \sum_{i \in B} \lambda_i P_i}{2}$$

Thereby

$$\begin{aligned} q &= \frac{a - v_m - \sum_{i\in A}\lambda_i P_i - \sum_{i\in B}\lambda_i P_i}{2b} \\ &= \frac{a - v_m - \lambda_1 P_1 - \lambda_2 P_2 - \lambda_3 P_3 - \lambda_4 P_4 - \lambda_5 P_5}{2b} \end{aligned}$$

The noncooperative profits are given as

$$\Pi_i^* = 2bq^{*2} - F_i \tag{86}$$

In the cooperative bargaining phase, the suppliers try to maximize the joint utility, and we get the Nash bargaining solution for the two coalitions

$$N_A = \max_{P_i, i=1..m} \prod_{i\in A}(\Pi_i - \Pi_i^*), N_B = \max_{P_i, i=1..n-m} \prod_{i\in B}(\Pi_i - \Pi_i^{coop*}) \tag{87}$$

Note that the outside option for the coalition A is just the decentralized chain profit, while for coalition B, we take the outside option as the profit that the members can achieve if they were in the original coalition. The Nash products are then equal to

$$N_A = \max_{P_i, i=1..m} \prod_{i=1}^{m}(\lambda_i q(P_i - c_i - v_i) - 2bq^{*2}),\ N_B = \max_{P_i, i=1..n-m} \prod_{i=1}^{n-m}(\lambda_i q(P_i - c_i - v_i) - bq^{coop*2})$$

From the Pareto optimality property of the Nash Bargaining solution, the respective maximums of the Nash product will occur at q^{A*} and q^{B*} such that

$$\begin{aligned} q^{A*} &\in \arg\max_{q\in Q} \sum_{i\in A}((\lambda_i q(P_i - c_i - v_i) - 2bq^{*2}), \\ q^{B*} &\in \arg\max_{q\in Q} \sum_{i\in B}((\lambda_i q(P_i - c_i - v_i) - bq^{coop*2}). \end{aligned}$$

where Q is the set of all feasible quantities. Since the threat options are given , these conditions reduce to

$$\begin{aligned} q^{A*} &\in \arg\max_{q\in Q} \sum_{i\in A}\lambda_i q(P_i - c_i - v_i), \\ q^{B*} &\in \arg\max_{q\in Q} \sum_{i\in B}\lambda_i q(P_i - c_i - v_i). \end{aligned} \tag{88}$$

for symmetry of the Nash bargaining solution we again end up with the following condition for both coalitions

$$\lambda_i(P_i - c_i - v_i) = \lambda_j(P_j - c_j - v_j), j \neq i, i, j \in A \tag{89}$$

$$\lambda_i(P_i - c_i - v_i) = \lambda_j(P_j - c_j - v_j), j \neq i, i, j \in B \tag{90}$$

Now consider that coalition B is the 'breakaway' coalition. The buyer produces the product which demands an assembly operation. Hence, the weighted quantities from all suppliers must be same - or there can be a single quantity of the final product produced. We take q^{new*} as the quantity of final product. Therefore, all members of both coalitions produce the exact quantity needed, and by the above condition, get exactly the same contributions from business.

Utilizing the conditions of 89, the result from the first stage in equation 78 and the conditions of equation 88, we get, after some algebra,

$$P_i = \begin{cases} \frac{1}{3m\lambda_i}\left(a - v_m - \sum_{j=1,j\neq i}^{m} \lambda_j c_j - \sum_{j=1,j\neq i}^{m} \lambda_j v_j + (3m-1)\lambda_i(c_i+v_i)\right), i \in A \\ \frac{1}{3(n-m)\lambda_i}\left(a - v_m - \sum_{j=1,j\neq i}^{n-m} \lambda_j c_j - \sum_{j=1,j\neq i}^{n-m} \lambda_j v_j + (3(n-m)-1)\lambda_i(c_i+v_i)\right), i \in B \end{cases} \tag{91}$$

(b) Now

$$\begin{aligned} q^{new*} &= \frac{\begin{array}{c} a - v_m - \frac{1}{3m}\sum_{i=1}^{m}\left(a - v_m - \sum_{i=1}^{m}\lambda_i c_i - \sum_{i=1}^{m}\lambda_i v_i + 3m(\lambda_i c_i + \lambda_i v_i)\right) - \\ \frac{1}{3(n-m)}\sum_{i=1}^{n-m}\left(a - v_m - \sum_{j=1,j\neq i}^{n-m}\lambda_j c_j - \sum_{j=1,j\neq i}^{n-m}\lambda_j v_j + (3(n-m)-1)\lambda_i(c_i+v_i)\right) \end{array}}{2b} \\ &= \frac{\begin{array}{c} a - v_m - \frac{1}{3m}\left(ma - mv_m - m\sum_{i=1}^{m}\lambda_i c_i - m\sum_{i=1}^{m}\lambda_i v_i + 3m\sum_{i=1}^{m}(\lambda_i c_i + \lambda_i v_i)\right) - \\ \frac{1}{3(n-m)}\left((n-m)a - (n-m)v_m - (n-m)\sum_{i=1}^{n-m}\lambda_i c_i - (n-m)\sum_{i=1}^{n-m}\lambda_i v_i + (3(n-m))\sum_{i=1}^{n-m}\lambda_i(\right. \end{array}}{2b} \\ &= \frac{a - v_m - \frac{1}{3}\left(a - v_m + 2\sum_{i=1}^{m}(\lambda_i c_i + \lambda_i v_i)\right) - \frac{1}{3}\left(a - v_m + 2\sum_{i=1}^{n-m}\lambda_i(c_i+v_i)\right)}{2b} \\ &= \frac{a - v_m - \sum_{i=1}^{n}(\lambda_i c_i + \lambda_i v_i)}{6b} \end{aligned}$$

Also

$$\Pi_{raw} = q\sum_{i=1}^{n}\lambda_i(c_i - c_r)$$

The FOC give us

$$\sum_{i=1}^{n}\lambda_i c_i = \frac{a - v_m + 4\sum_{i=1}^{n}\lambda_i(c_r - v_i)}{8} \tag{92}$$

so

$$\begin{aligned} q^{new*} &= \frac{a - v_m - \sum_{i=1}^{n}(\lambda_i c_i + \lambda_i v_i)}{6b} \\ &= \frac{q^*(n+1)}{3} \end{aligned} \tag{93}$$

and the results follow.

(c) and (d)

The profits made by a member of any of the groups is

$$\begin{aligned} \Pi_i^{A,B} &= \lambda_i q^{new*}(P_i - c_i - v_i), i \in A, B \\ &= (q^{new*})^2 \end{aligned}$$

after some algebra from equations (91) and (93). Since $q^{new*} < q^{coop*}$, the results follow.

$\boxdot$

Exploring the Stochastic demand -assembly system

For analyzing the stochastic demand case, consider the market demand as $q = \frac{\alpha - P_m}{b}$ where α is a random variable.

The buyer maximizes profit

$$\max E[\Pi_m^*|P_i] = E[\max_{p_m} \; q(P_m - \sum_{i=1}^{n} \lambda_i P_i - v_m)]$$

FOC gives

$$P_m = \frac{\alpha + v_m + \sum_{i=1}^{n} \lambda_i P_i}{2}$$

Thereby

$$q = \frac{\alpha - P_m}{b} = \frac{\alpha - v_m - \sum_{i=1}^{n} \lambda_i P_i}{2b} \tag{94}$$

Component supplier i maximizes his expected profit Π_i, where

$$E[\Pi_i] = E[\lambda_i q_s (P_i - c_i - v_i) - F_i]$$

Here, the quantity q_s is the demand estimated by the supplier , and is given by

$$q_s = \frac{\alpha_s - P_m}{b} = \frac{\alpha_s - v_m - \sum_{i=1}^{n} \lambda_i P_i}{2b} \tag{95}$$

Note that the supplier is using the final market variables to estimate the within chain variables.

The raw material producer also maximizes his profits which are given by

$$E[\Pi_{raw}] = E[q_s^* (\sum_{i=1}^{n} \lambda_i (c_i - c_r))]$$

For simplicity, we assume that there are no informational asymmetries between the component suppliers and the RM producer. The FOC gives us the resultant quantity

$$q_s^* = \frac{\alpha_s - v_m - c_r \sum_{i=1}^{n} \lambda_i - \sum_{i=1}^{n} \lambda_i v_i}{4(n+1)b} \tag{96}$$

and

$$P_i^* = \frac{\alpha_s - v_m + n\lambda_i (c_i + v_i) - \sum_{j=1, j \neq i}^{n} \lambda_j (c_j + v_j)}{(n+1)\lambda_i} \;, \; i = 1..n \tag{97}$$

Let,

$$\Omega = v_m + \sum_{i=1}^{n} \lambda_i v_i + c_r \sum_{i=1}^{n} \lambda_i$$

then

$$q_s^* = \frac{\alpha_s - \Omega}{4(n+1)b}$$

$$\sum_{i=1}^{n} \lambda_i c_i = \frac{\alpha_s - v_m + \sum_{i=1}^{n} \lambda_i (c_r - v_i)}{2}$$

$$P_m = \frac{\alpha}{2} + \frac{\Omega + (2n+1)\alpha_s}{4(n+1)}$$

At the buyer end, the quantity produced is

$$q^* = \frac{2(n+1)\alpha - \Omega - (2n+1)\alpha_s}{4(n+1)b}$$

The supply chain profits can now be computed for each link and for the total chain. We get the following results.

For the RM supplier

$$E[\Pi^*_{raw}] = 2(n+1)E[bq_s^2] \tag{98}$$
$$= \frac{1}{8b(n+1)} E[(\alpha_s - \Omega)^2] \tag{99}$$

For the buyer

$$E[\Pi^*_m] = E[bq^{*2}] = \frac{1}{16(n+1)^2 b} E[(2(n+1)\alpha - \Omega - (2n+1)\alpha_s)^2] \tag{100}$$

q^* is the quantity which is sold to the buyer. The quantity $(q_s^* - q^*)$ must be carried over as inventory if the vendor produces more, else there needs to be a penalty cost. Let us denote the inventory carryover cost as h_1. Usually, the penalty is in the form of rushed production or overtime production, which costs more to the vendor. Let us denote it by h_2. Then,

$$\begin{aligned} E[\Pi^*_i] &= E[\lambda_i q^*(P_i - c_i - v_i) - F_i] + \lambda_i h_1 E[(q_s^* - q^*)^+] + \lambda_i h_2 E[(q_s^* - q^*)^-] \\ &= E[\lambda_i (\frac{2(n+1)\alpha - \Omega - (2n+1)\alpha_s}{4(n+1)b})(P_i^* - c_i - v_i) - F_i] + \lambda_i h_1 E[(q_s^* - q^*)^+] + \lambda_i h_2 E[(q_s^* - q^*)^-] \\ &= E[(\frac{2(n+1)\alpha - \Omega - (2n+1)\alpha_s}{8(n+1)^2 b})(\alpha_s - \Omega) - F_i] + \lambda_i h_1 E[(q_s^* - q^*)^+] + \lambda_i h_2 E[(q_s^* - q^*)^-] \end{aligned}$$

For the total chain, we note that the information asymmetry affects the profits of buyer and suppliers. In such a general case, we get

$$\begin{aligned} E[\Pi^*_{chain}] = {} & \frac{1}{8b(n+1)^2}(E[(n+1)(\alpha_s - \Omega)^2] + \frac{1}{2}E[(2(n+1)\alpha - \Omega - (2n+1)\alpha_s)^2] + \\ & nE[(2(n+1)\alpha - \Omega - (2n+1)\alpha_s)(\alpha_s - \Omega)]) - \sum_{i=1}^{n}(F_i - h_1\lambda_i E[(q_s^* - q^*)^+] - h_2 \lambda_i E[(q_s^* - q^*)^-]) \end{aligned}$$

For the total chain, if $\alpha = \alpha_s$, ie. if there are no informational asymmetries, then in the noncooperative interaction,

$$E[\Pi^*_{chain}] = \frac{(4n+3)E[(\alpha - \Omega)^2]}{16b(n+1)^2} - \sum_{i=1}^{n} F_i$$

which is similar to the expression of the base case.

Cooperative solution for the stochastic demand -assembly system

In the noncooperative stage,

$$q = \frac{\alpha - P_m}{b} = \frac{\alpha - v_m - \sum_{i=1}^{n} \lambda_i P_i}{2b} \tag{101}$$

In stage 2, the suppliers bargain cooperatively. Assuming that the outside options of the suppliers are equal to their non-cooperative profits,the expected profit functions of the two suppliers are still given as under,

$$E[\Pi_i] = E[\lambda_i q(P_i - c_i - v_i)] - F_i$$

and the non-cooperative profits for the suppliers are as under from our base case of decentralized chain of the buyer

$$E[\Pi_i^*] = E[(\frac{2(n+1)\alpha - \Omega - (2n+1)\alpha_s}{8(n+1)^2 b})(\alpha_s - \Omega) - F_i] + \lambda_i h_1 E[(q_s^* - q^*)^+] + \lambda_i h_2 E[(q_s^* - q^*)^-] \text{ , } i = 1..n \tag{102}$$

with

$$q_s^* = \frac{\alpha_s - \Omega}{4(n+1)b}$$

Proceeding just like in Proposition 5, we get, after some algebra,

$$P_i = \frac{1}{2n\lambda_i}\left(\alpha - v_m - \sum_{i=1}^{n} \lambda_i c_i - \sum_{i=1}^{n} \lambda_i v_i + 2n\lambda_i(c_i + v_i)\right) i = 1..n$$

and the optimal quantity as

$$q^{coop*} = \frac{\alpha - v_m - \sum_{i=1}^{n} \lambda_i c_i - \sum_{i=1}^{n} \lambda_i v_i}{4b}$$

Note that the suppliers produce the same quantity as required by the OEM (or $q_s^{coop*} = q^{coop*}$), since at the OEM hub, there are no information asymmetries.

Now, for the RM supplier,

$$E[\Pi_{raw}] = E[q^{coop*}(\sum_{i=1}^{n} \lambda_i c_i - \sum_{i=1}^{n} \lambda_i c_r)]$$

where c_r is the production cost of the raw material supplier, including all value added costs. The FOC give us

$$\sum_{i=1}^{n} \lambda_i c_i = \frac{\alpha - v_m + \sum_{i=1}^{n} \lambda_i (c_r - v_i)}{2} \tag{103}$$

so

$$q^{coop*} = \frac{\alpha - v_m - \sum_{i=1}^{n} \lambda_i (c_r + v_i)}{8b}$$

using

$$\Omega = v_m + \sum_{i=1}^{n} \lambda_i v_i + c_r \sum_{i=1}^{n} \lambda_i$$

we get

$$q^{coop*} = \frac{\alpha - \Omega}{8b}$$

and therefore

$$\begin{aligned} E[\Pi_{raw}] &= E[q^{coop*}(\frac{a-\Omega}{2})] \\ &= 4bE[q^{coop*2}] \qquad (104) \\ &= \frac{1}{16b}E[(\alpha-\Omega)^2] \qquad (105) \end{aligned}$$

The equilibrium price is

$$\begin{aligned} P_m^{coop*} &= \alpha - bq^{coop*} \\ &= \frac{7\alpha+\Omega}{8} \qquad (106) \end{aligned}$$

The Supply chain profits using the cooperative game model for each link and for the total chain is as follows,

$$\begin{aligned} E[\Pi_m^{coop*}] &= E[q^{coop*}(P_m^{coop*} - \sum_{i=1}^{n}\lambda_i P_i^{coop*} - v_m)] \\ &= E[bq^{coop*2}] \qquad (107) \\ &= \frac{1}{64b}E[(\alpha-\Omega)^2] \qquad (108) \end{aligned}$$

Furthermore,

$$\Pi_i^{coop*} = E[bq^{coop*2} - F_i] = \frac{1}{64b}E[(\alpha-\Omega)^2] - F_i, i = 1..n \qquad (109)$$

Total profits of the supply chain

$$E[\Pi_{chain}^{coop*}] = (\frac{n+5}{64b})E[(\alpha-\Omega)^2] - \sum_{i=1}^{n} F_i$$

We see that the deterministic demand results are unaltered in that

$$E[\Pi_{chain}^{coop*}] > E[\Pi_{chain}^*],\ E[\Pi_m^{coop*}] > \ E[\Pi_m^*],\ \ E[\Pi_i^{coop*}] > \ E[\Pi_i^*]\ ,, i = 1..n \qquad (110)$$

(for example, if $\alpha = \alpha_s$, we have $q_s^* = q^*$,and

$$\begin{aligned} E[\Pi_i^*] &= E[(\frac{2(n+1)\alpha - \Omega - (2n+1)\alpha}{8(n+1)^2 b})(\alpha-\Omega) - F_i] + \lambda_i h_1 E[(q^*-q^*)^+] + \lambda_i h_2 E[(q^*-q^*)^-] \\ &= \frac{1}{8(n+1)^2 b}E[(\alpha-\Omega)^2] - F_i \end{aligned}$$

For example, for $n = 2$, $E[\Pi_1^*] = E[\Pi_2^*] = \frac{1}{72b}E[(\alpha-\Omega)^2] - F_i < \Pi_1^{coop*} = \Pi_2^{coop*}$.)

Thus, the expected profits of every member of the cooperative chain is higher than the case when every member maximizes his own profit. Note that we have taken the assumption that the hub uses the value of the variable α instead of α_s, since the suppliers get the information from the OEM at the hub. However, what the analysis also tells us is that the effect of cooperation between suppliers in improving the profits of the supply chain are higher than that brought about by only removing the information asymmetry between buyer and suppliers.

⊡

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