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The Sourcing Hub and Upstream Supplier Networks

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In this paper, we explore how firms can better manage their sourcing by developing relationships not only with their suppliers but also with their suppliers' suppliers. We detail an empirical case study explaining how the firm developed relationships with its suppliers and raw material suppliers via a collaborative center, the sourcing hub. We then analytically model the scenarios encountered in our empirical work and examine two facets of upstream sourcing under uncertain demand scenarios: (a) firms can supply raw material directly to their suppliers, and this may be beneficial for the firm and its suppliers; and (b) firms can bring their suppliers together at the sourcing hub, and the resulting cooperation between suppliers is beneficial for the suppliers and the raw material suppliers. Overall, our work explores the market and economic conditions under which active management of upstream sourcing can add value to supply chains.

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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. However, we believe that with an increased focus on core business activities and the outsourcing of noncore activities, firms have slowly distanced themselves from some of the value in their supply network (like upstream raw material (RM) sourcing). For example, in some contexts, like that of an automotive firm, a large number of direct suppliers of the firm may buy their raw materials from the same sources. In this scenario, building close relationships with suppliers' suppliers may be valuable. When a firm 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 can help build an efficient supply chain.

In this paper, we explore the concept of the *sourcing hub* as a value-enabling mechanism in the upstream raw material supply chain by exploring when (i.e., under what market and economic conditions) a firm's active management of relationships with direct suppliers and raw material suppliers can result in a more efficient supply chain. Our work is motivated primarily by a four-year-long empirical investigation into the raw material supply chain practices of TDV (an automotive original equipment manufacturer (OEM)). At TDV, we found that the firm had developed relationships with its raw material supplier and was actively managing its raw material supply chain. Is such management of the raw material supply chain necessarily beneficial for firms? Our focus in this paper is to study this real and interesting problem by combining a case study with analytical modeling to explore conditions under which raw material supply chain management can be beneficial.

This paper is organized as follows: In §2, we review the extant literature and establish our motivation for this study. Then, in §3, we describe an empirical case study of TDV, a firm that has implemented a sourcing hub for its raw material sourcing, to develop two hypotheses. In particular, we explain how TDV has established relationship with its raw material supplier via a sourcing hub, how this relationship has evolved, and how the buyers and supplier firms have benefited from the hub setup. In §4, we model the sourcing hub analytically and anchor it to empirical findings to delineate under which conditions would a sourcing hub add value and under which conditions would it not. We conclude in §5 with a discussion of how firms can develop a sourcing hub, the generalizability of our results, and future research opportunities.

2. Literature and Motivation

Our work is related primarily to the literature in the area of buyer–supplier relationships. Many empirical and modeling studies span this literature. Two empirical studies related to our research are those by Nishiguchi (1994, see specifically pp. 96 and 97), who explored buyer investments and their effects on supplier relationships, and Clark and Fujimoto (1991, Chap. 4, pp. 67–96), who explored how these relationships affect product development routines. Buyer–supplier relationships may be directed at reducing the future uncertainty of costs, technology, and information (Bensaou and Venkatraman 1995), and are affected by many factors including the complexity of sourced parts (Masten 1984, Novak and Eppinger 2001), volume uncertainty related to components (Walker and Weber 1987), 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). Outsourcing can help firms benefit from competition among suppliers (Baldwin and Clark 2000), but does not work effectively without extensive internal effort (Takeishi 2001).

In papers focusing on mathematical modeling of buyer–supplier relationships, game theoretic modeling is common, with a focus on contracts that can be drawn up between buyers and suppliers. These include areas such as single or multiple sourcing (Baiman et al. 2000, Corbett et al. 2005, Balachandran and Radhakrishnan 2005) and parallel sourcing (Richardson and Roumasset 1995), in single or multiple periods (Swinney and Netessine 2006, Tunca and Zenios 2006), and replenishment including vendor managed inventories (Cachon and Fisher 2000, Aviv 2001). Overall, one stream of literature takes contract terms as given and then seeks to determine the optimal policies (as in Eppen and Iyer 1997), whereas a second stream takes optimal policies as given, but seeks to determine whether the contract terms can be modified so that the supply chain can benefit (as in Cachon and Lariviere 2005). Our work is closer to the second stream, and our focus is on detailing how changes in relationships between buyers, their suppliers, and the raw material suppliers can affect supply chain profits.

A recurring theme in the modeling and empirical literature 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. In this vein, our paper is closest in motivation to that of Majumder and Srinivasan (2008), who focus on the entire supply chain network.

In what follows, we explore two facets of the raw material supply chain of a firm. The first is whether an OEM can benefit from managing the raw material supply chain, specifically, what happens when an OEM buys raw material for its suppliers. A few scholars 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 its raw material supplier—four different firms in total. 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 pushdown approach to costs. The 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 the raw material supply to its machine shop contractor. Such a step helps build price stability between the automaker and the contractor. Wynstra et al. (1999) discuss how OEMs involve their first- and second-tier suppliers (including raw material suppliers) in their new product development process to create value. Our focus is similar, and we explore how relationships with raw material suppliers can bring in opportunities for value creation.

Second, we explore what happens when an OEM initiates cooperation between its 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 raw material supplier. There is an existing literature that relies on 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. Whipple and Russell (2007) discuss three collaborative approaches—collaborative transactions, collaborative event management, and collaborative process management that distributors and retailers can enter into for value creation. Reyniers and Tapiero (1995) integrate quality with buyer–supplier contracts under cooperative and a noncooperative bargaining scenarios 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 raw material supplier, are supplying a buyer. 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 our key motivation in this paper.

3. The TDV Korea Case Study

TDV is a commercial vehicle manufacturer in South Korea. It produces heavy-duty trucks including cargo, dumpers, mixers, and other special-purpose vehicles. TDV has 23 suppliers supplying components for which steel is the major raw material. Currently, it purchases steel from a single supplier and supplies the same to all its suppliers. It manages raw material prices, logistics, and other related transactions via a Web-based system in a department that we call the *sourcing hub* (this is our terminology, and is different from that of the firm, which is not reproduced due to confidentiality reasons). TDV's component suppliers work together with TDV and with each other to (a) continuously improve the quality of components produced and (b) develop components for new product introductions by TDV.

These processes at the TDV sourcing hub have evolved over time. Our studies revealed that the current supply chain setup at TDV that focuses on collaborative initiatives was preceded by a more transactional supply chain setup, which focused on cost reduction by supplying raw material to the component suppliers. In what follows, we describe the two supply chain setups and discuss the differences.

3.1. Direct Raw Material Procurement Setup at TDV

In the earlier years of its supply chain setup, TDV engaged in supplying a single raw material (steel) to its 23 steel component suppliers. It purchased steel as a single buyer from the steel supplier and managed the logistics, physical supply, inventories of raw material, and disposal or salvage of scrap/offcuts of steel generated in the manufacturing process at the suppliers. TDV's contracts with its suppliers stipulated that suppliers do not make any profit from raw materials, even when they buy the materials themselves. A representative costing sheet is shown in Figure 1. For this component, the profit element (the amount of KW 1,589, row 4, column 7) is not calculated on the raw material, irrespective of whether or not TDV is supplying the raw material. Therefore, the supplier had incentives to let TDV manage the raw material transactions and incur the associated transactional costs.

At other OEM firms, the component suppliers buy their own raw material and invest their own capital in sourcing, storing, and processing it. In such a scenario of *decentralized raw material procurement*, the OEM's component-level pricing usually includes profit on the raw material content of the component, since the component suppliers' capital is locked up in procuring the raw material. However, in TDV's *direct* raw material procurement setup, the suppliers did not need to invest in buying or storing raw materials for components destined for TDV.

In this direct raw material procurement setup, let us explore what happens to the total landed cost of any component. There are three effects. First, for any component, the raw material cost for TDV is lower than, or at most equal to, the raw material cost that any of its suppliers would incur. Second, for the same component, TDV does not pay any margin on the raw material, which avoids double marginalization on the raw material and effectively lowers the cost. Finally, TDV has to invest in managing the raw material transactions and use its own capital to purchase the raw material. This increases the cost.

In day-to-day operations, managing the raw material supply process could be challenging. Our interviews with TDV managers revealed that during the initial years, there were a lot of coordination issues with the suppliers. Many times the component suppliers used the constraints in steel supply for their failure to deliver components—"You did not supply steel on time, so how could I supply you components on time?" It was an adversarial relationship, where the focus was only on reducing the landed cost of components to TDV.

3.2. The Sourcing Hub Setup at TDV

The raw material supply process at TDV has now evolved into a systematic collaborative process involving its raw material supplier and its component suppliers. The centerpiece of this process is the sourcing hub. Physically, the sourcing hub is deployed as a separate department within TDV, which focuses on raw material sourcing and management.

The sourcing hub concept (Figure 2) is a critical departure from the typical supply network of an OEM. It helps in two different ways. First, it helps develop upstream relationships with raw material suppliers, as well as with direct suppliers. Second, it helps build collaborative relations between suppliers by an increased understanding of raw material sourcing, and by an increased understanding of the complexity of the supply chain.

Figure 1 A Representative Costing Sheet from TDV

Costing sheet adapted from TDV Korea

Part number xxx111 Vendor M/s precision Prepared by KJH
Vehicle MCV
Part name Exhaust pipe

Account	Factory cost				Administrative (20%)	Profits (15%)	Inventory (1%)	Depreciation	Royalty	Final price
	Material	Labor	Factory	TOTAL						
COST	32,606	6,374	2,455	41,435	1,766	1,589	326	0	0	45,116

	No	Subpart	RM	Specs	Unit	Quantity	Unit cost	P	Scrap	Matl cost
						(a)	(b)	(c) = (a)*(b)	(d)	(c) – (d)
Material costs	1	Flange	ss41	151*151	kg	2.19	730	1,599	290	1,309
	2	Pipe	sa1d	600 mm	kg	2.64	1,376	3,633	275	3,358
	3	Connector	sa1c	340*340*2EA	kg	3.46	1,150	3,979	481	3,498
	4	Bellows	sus304		EA	1	22,600	22,600		22,600
	5	Flange	ss41	151*151	Kg	1.46	637	930	163	767
		Paint	Silver		DM2	29.87	36	1,075		1,075
								Total material costs		32,606

	No	Partname	Process	Machine		Work time		Labor cost	Factory expenses	
				Name	Specs	Staff	M/c hour	@6,800	Rate	Costs
Factory and labor costs	1	Flange	Shearing	Sh m/c	10t	4	0.001	27	2,514	3
			BL	Press	250t	2	0.0097	132	5,570	54
			Pi-1st	Press	250t	1	0.0097	66	5,570	54
			Pi-2nd	Press	250t	1	0.0097	66	5,570	54
			Restrike	Press	250t	1	0.0097	66	5,570	54
	2	Pipe	Cutting	Saw	10t	2	0.0167	227	1,270	21
			Grinding	Grinder		1	0.0083	56	—	0
			BE	Cnc	100s	1	0.05	340	23,758	1,188
			Cut-1st	Saw	10t	1	0.025	170	1,270	32
			Cut-2nd	Saw	10t	1	0.025	170	1,270	32
	3	Connector	Shearing	Sh m/c	10t	4	0.0111	302	2,514	28
	4	Flange	Data suppressed for confidentiality							
	5	Assembly								
					TOTAL			6,374		2,455

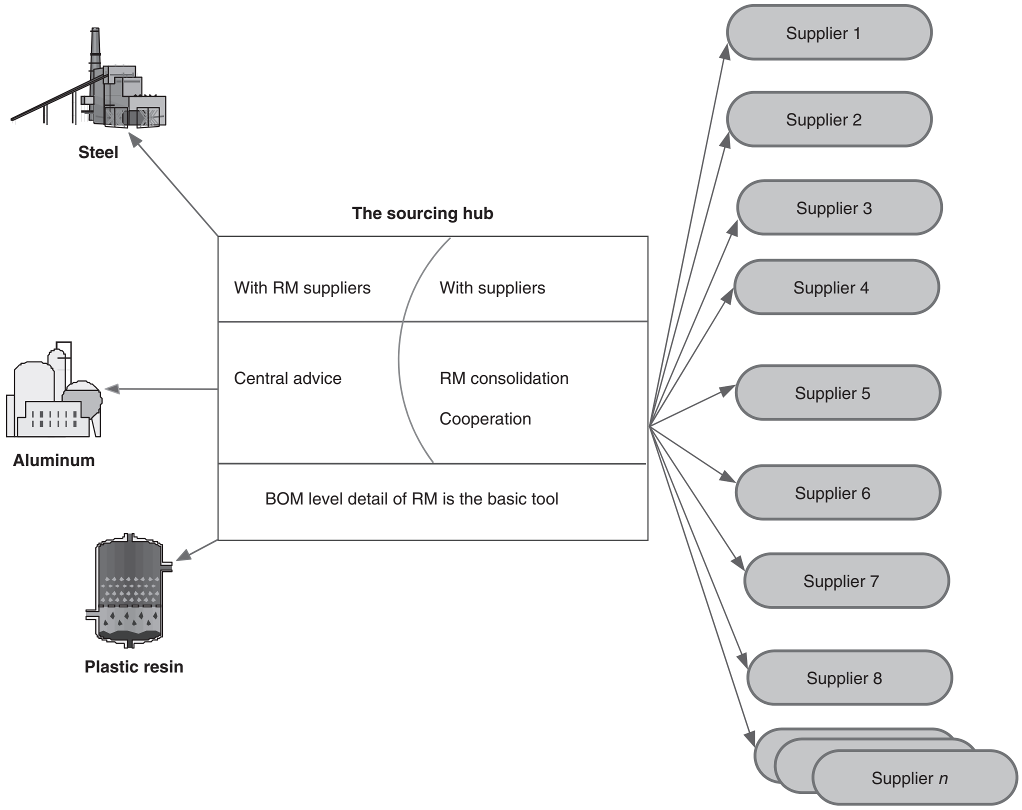
Source. First author's research notes, prepared while visiting TDV.
Notes. Such costing sheets, developed at a component level, are linked online in TDV's enterprise resource planning system for material-related changes. Note that the profit of 15% is calculated not on the raw material, but only on the labor, factory, and administrative overheads.

What happens at the sourcing hub? On an annual basis, TDV and its suppliers come together and develop the annual production plan, broken into half-yearly time frames. One of the outputs of this joint work with suppliers is a detailed raw material plan. The plan is discussed and agreed upon between TDV and the raw material supplier. Quarterly and monthly plans are drawn and on a rolling basis; contracts are settled for the following month. The contracts form the basis of physical raw material delivery. TDV settles payments with raw material suppliers on a monthly basis.

On a monthly basis, the suppliers work with each other to finesse the production of components, including components for new products and those needing joint development. On a day-to-day operating level, a lot of information is shared between the firm, the suppliers, and the raw material supplier. TDV manages this information at the sourcing hub. The hub has sourcing individuals working full time on sourcing transactions, including logistics and negotiations. The day-to-day transactions of the sourcing hub run on a Web-based system. The system has bill of material (BOM)-level details of the raw material required for each component, as well as the details of current pricing between TDV and its raw material suppliers. The specific information available on the system includes details of production plans for the coming months, new models, changes in drawings, production schedules, quantity of components required, and the quantity and grades of raw material required from the raw material supplier. This Web-based information is used by component suppliers as well as raw material suppliers, and is continually updated.

We have observed that there are two types of fixed costs in setting up the sourcing hub: start-up and ongoing. The start-up cost relates to the detailing of raw material at the component level and establishing

Figure 2 **The Sourcing Hub**



a material database so that the raw material supply is streamlined. The raw material level details at the component bill of material level are normally not a part of the day-to-day operations at other OEMs. To develop such a database, the OEM has to collate accurate raw material 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 raw material-related knowledge.

The ongoing cost consists of managing the sourcing hub—developing periodic (frequently monthly) schedules, linking supply with the payment cycle to the raw material and component suppliers, and auditing the inventory. Our study of the TDV sourcing hub shows that its ongoing costs are insignificant compared with its cost savings—TDV manages the sourcing hub (for a single raw material, for a single country) with just two full-time employees and part-time support from one person in the finance department.

Today, on a weight basis, TDV buys around 95% of its input steel directly from its steel supplier. These purchases are centered around the grades of steel that are used in most of its components, and these purchases are aligned with the choice of specific grades selected for component design. TDV also buys raw materials for other components, although steel supply chain management remains its focus.

3.3. Hypotheses

The two supply chain setups of TDV present an interesting real-world context to explore different supply chain scenarios. It is particularly interesting to analyze why TDV and its raw material and component suppliers acted the way they did, how these two setups (direct raw material procurement and sourcing hub) differ from a decentralized raw material procurement setup, and what would happen in a more generalized case. We note that TDV did not employ the option of a decentralized raw material procurement; it moved from a setup of direct raw material procurement to the sourcing hub setup. In what follows, we first present two hypotheses from the TDV case study and then explore the TDV supply chain setups analytically.

We studied the supply chain at TDV in detail by making multiple visits to the component suppliers and the raw material supplier. The component suppliers held the view that if they buy steel directly from the steel supplier, their purchase price would be higher. We checked the market prices of steel and found that there was a difference of 7% between the supply prices of steel to OEMs and to other buyers. At first glance, this seemed to be the standard volume purchasing benefit: the OEM buys more and gets a lower price. But we questioned whether there was something we were missing—TDV is a truck manufacturer and is a smaller firm compared to Hyundai, who produces cars in high volumes. If the volume purchasing arguments were correct, we would expect to find the price of steel to TDV to be much higher than that to Hyundai. However, we found very few differences in raw material prices to OEMs. Low volumes bought by TDV did not really make a difference—what seemed to matter was that TDV was an OEM.

The steel supplier executives, in repeated enquiries and detailed discussions, emphasized the importance of long-term relationships and managing a stable production schedule over price premiums. We queried the steel supplier executives at length and they replied, "You see, costs are not dependent on individual customer volumes after a base level. As long as firms procure standard products from us, our costs are really the same for TDV as for Hyundai. Costs are reduced by having a detailed plan and leveled production—that only comes from our OEM customers, because their plans do not vary too much for the next few months." Essentially, the raw material supplier argument seemed to be that the reduced costs emanating from stable plans and more information from the OEM override the lower margins due to reduced prices to OEMs. For TDV, the raw material comprises about 60% of its final product costs, and thus this price differential is important for its business. The interesting issue was that the raw material supplier was selling product at a lower price to a single buyer, instead of selling at a higher price to a multitude of buyers, and still claiming that the practice was beneficial because of reduced information asymmetry in dealing with the OEM. We can now propose our first hypothesis:

Hypothesis 1. *As the raw material content in the product increases, developing direct purchasing arrangements with the raw material supplier may be more beneficial for a buyer. This opportunity may increase as information asymmetry in the supply chain increases.*

We also talked to several TDV suppliers about the sourcing hub setup at TDV. Most of them talked about the transition from a transactional relationship to a cooperative relationship over time. A supplier remarked, "No, it is not merely a case of TDV providing the steel. TDV now also provides information about production plans as well as design changes. This helps managing the changes in tools and dies, as well as the workforce. You see, it is difficult, because our plans are now transparent to our buyer—so it is easy for them to criticize if they need to. But we think that this open relationship is better—many times TDV suggests good changes, and we also talk to other suppliers, and that also helps." Our sense was that the sourcing hub scenario was perceived to be a better arrangement by TDV and all of its suppliers. We now propose our second hypothesis:

Hypothesis 2. *Developing cooperative relationships via a sourcing hub may be more beneficial for a supply chain than transactional relationships* (*including the case of a buyer purchasing the inputs*). *This opportunity may increase as information asymmetry in the supply chain increases.*

Hypothesis 2 states that we should expect the direct purchasing arrangements (as in Hypothesis 1) to be beneficial, but we should expect the sourcing hub scenario to be even better.

4. Modeling TDV's Supply Chain

In this section, we analyze the two setups of TDV's supply chain using parsimonious models. Our main assumption comes from the observation that there are very few, and many times only a single, raw material supplier to an OEM. TDV has a single steel supplier who supplies the raw material needs of all its component suppliers. We abstract this empirical result in our models and consider only a single raw material supplier. We model the raw material supply network as a single raw material supplier, n component supplier, single OEM setup, exactly similar to TDV's steel supply chain setup.

Our focus is on exploring how the profits of agents in the supply chain change depending on the situations of raw material sourcing and cooperation between agents. Although our context is the automotive industry, the models are general enough to apply to any industry that has an assembly process for the final product.

4.1. Decentralized Raw Material Procurement

We assume that all the agents in the supply chain are capacity constrained in the sense that the overall demand q exceeds a preproduction capacity constraint $\hat{q}$, but q is distributed such that it is always greater than or equal to this preproduction capacity constraint, i.e., $q \geq \hat{q}$. We model this phenomenon by assuming that the single OEM faces a demand curve $q = \hat{q} + \epsilon((a - P_m)/b)$ in the market. Here $\hat{q}$ denotes the preproduction quantity that is guaranteed to sell, whereas $\epsilon((a - P_m)/b)$ denotes the random, price sensitive demand that depends on the random variable ϵ and price variable P_m. We assume that $E[\epsilon] = \alpha$, $\mathrm{Var}[\epsilon] = \sigma^2$, and $P_m = a - (1/\epsilon)b(q - \hat{q})$ is the production clearing price in the market.

The component suppliers see the same mean, but a higher variation in uncertain demand. The RM supplier also sees the same mean demand as the component suppliers, but being further upstream, sees an enhanced variation. Let $q_s = \hat{q} + \epsilon_s((a - P_m)/b)$ be the demand curve seen by the symmetric component suppliers, where $\epsilon_s = \beta\epsilon - (\beta - 1)E[\epsilon]$, and let $q_R = \hat{q} + \epsilon_R((a - P_m)/b)$ be the demand curve seen by the RM supplier with $\epsilon_R = \beta\epsilon_s - (\beta - 1)E[\epsilon_s]$, where $\beta > 1$ denotes the information asymmetry between supply chain partners. A higher β indicates a higher degree of information asymmetry. Thus, $E[\epsilon_R] = E[\epsilon_s] = E[\epsilon] = \alpha$, and $\text{Var}[\epsilon_s] = \beta^2\sigma^2$, $\text{Var}[\epsilon_R] = \beta^4\sigma^2$. These assumptions model information asymmetry in the supply chain, with variability of demand increasing as we move upstream in the supply chain away from the OEM. This is similar to assuming that the bullwhip effect exists in the supply chain.

We assume the following sequence of events: (i) All the agents preproduce $\hat{q}$, where $\hat{q} \le q$, the final quantity sold. (ii) The RM supplier announces a price schedule, and then the component supplier i chooses the component price. (iii) The uncertainty is revealed and the OEM chooses the final quantity q. (iv) Finally, all agents complete the production of $q - \hat{q}$, and the supply chain realizes total sales of q.

The first step in the sequence assumes that all agents preproduce the minimal safe stock $\hat{q}$, which is always guaranteed to be lower than the final quantity, yet they are not able to produce more (before they know the final quantity q) because of production limitations. This assumption is aligned with empirical observations—suppliers produce to an unconfirmed monthly production plan, and many a time get to know about the final production targets sometime during the production month itself. Therefore, quantity may be finalized at a point in time when there may not be enough time or resources to complete the entire production (starting from zero).

The second and the third steps in the sequence assume that the RM and component suppliers choose their prices before ϵ is revealed, but the OEM postpones its pricing decision after ϵ is revealed.

For the fourth step in the sequence, we further assume that since the agents do not know about the final demand, they need to put together "reactive" or flexible resources to produce the additional, random quantity that may be demanded. Because of information asymmetry in the supply chain, as we go upstream, agents need to put in more of such reactive resources. That is to say, (i) there is a higher cost to fulfill the orders $(q - \hat{q})$, because this quantity is revealed later in the production process for all agents, and (ii) this higher cost of producing $(q - \hat{q})$ increases as we go upstream: the higher the uncertainty, the higher the marginal cost of the extra production. We model this phenomenon as follows: For producing $(q - \hat{q})$, the OEM has a higher variable cost proportional to σ, the component suppliers have a higher variable cost proportional to $\sigma\beta$, whereas the RM supplier has a higher variable cost proportional to $\sigma\beta^2$. This formulation models the effect of information asymmetry in that the variable costs of extra production increase with variability in OEM's demand (ϵ) in the amount of information asymmetry (β).

The buyer's manufacturing and assembly costs are v_m. The n component suppliers supply unique components, $i = 1, 2, \ldots, n$, which go into the final product made by the buyer. We use the subscript i to denote the component suppliers as well as their components. Component supplier i supplies one component per unit of final product produced. For quantity q of final product sold in the market, $\sum_{i=1}^{n} q$ amount of input components are consumed by the buyer. Each unit of component i consumes θ_i amount of raw material. Component supplier i supplies its components at price P_i to the buyer. The component suppliers get the RM from a single RM supplier at rates c_i, have variable costs v_i, and incur fixed costs F_i in procuring RM and processing it. The RM supplier has a cost c_r per unit of RM produced. This setup is similar to that of TDV, and is also aligned with our earlier assumptions—a single raw material supplier supplies to many component suppliers, and these suppliers supply to a single OEM.

In this assembly system, we assume that the buyer sells q while the component suppliers as well as the RM supplier try to supply components and RM required for producing q units of final product. The profit functions are then given as follows:

buyer OEM:

$$\Pi_m = q\left(P_m - v_m - \sum_{i=1}^{n} P_i\right) - (q - \hat{q})k_m\sigma,$$

component supplier i:

$$E[\Pi_i] = E[q(P_i - \theta_i c_i - v_i) - (q - \hat{q})k_i\sigma\beta] - F_i,$$

RM supplier:

$$E[\Pi_R] = E\left[q\left(\sum_{i=1}^{n} \theta_i(c_i - c_r)\right) - (q - \hat{q})k_R\sigma\beta^2\right],$$

where the proportionality factors k_m, k_i, and k_R can be thought of as agent-specific scale factors that modulate the effect of information asymmetry on the higher costs of reactive production. (Proofs of all propositions are in the online appendix, available as supplemental material at http://dx.doi.org/10.1287/msom.2013.0461.)

Proposition 1 (Decentralized RM Procurement). (a) *The optimal quantity in the decentralized chain is*

$$q^* = \frac{\epsilon}{4(n+1)b}\left(a - v_m - \sum_{i=1}^{n}(\theta_i c_r + v_i) - \sigma\left(k_m + \sum_i k_i\beta + k_R\beta^2\right)\right).$$

(b) *The firm-level expected profits for the supply chain agents are as follows*:
For the buyer: $E[\Pi_m] = (b/\alpha)(E[q^*])^2$.
For supplier i: $E[\Pi_i] = 2(b/\alpha)(E[q^*])^2 - F_i$.
For the RM supplier: $E[\Pi_R] = 2(n+1)(b/\alpha)(E[q^*])^2$.

4.2. Direct RM Procurement

In this section, we focus on the case where the buyer engages in direct RM procurement. The buyer buys the RM directly from the RM supplier and gives it to the component suppliers (free of cost, like TDV used to do). We use the superscript rm for the variables related to this game. The component suppliers get the RM from the RM supplier (paid for by the OEM after the production). The RM supplier supplies RM to all the component suppliers at a rate c per unit of RM (via the OEM) and has a cost c_r per unit of RM produced.

We model this phenomenon as a four-step simultaneous-move game. In the first step, all the agents preproduce a "safe" quantity $\hat{q}$, where $\hat{q} \leq q^{rm}$, the final quantity sold. In the second step, the n component suppliers as well as the RM supplier move simultaneously to determine their price levels (of components and RM, respectively). In the third step, the uncertainty is revealed, and the buyer OEM determines the market quantity. Finally all agents complete the production of $q^{rm} - \hat{q}$, and the supply chain realizes total sales of q^{rm}. The RM supplier and the component suppliers are the leaders in this game.

Since the RM supplier and the component suppliers move simultaneously, the RM supplier also sees the same mean demand and variation as that of the component suppliers. So $q_s^{rm} = \hat{q} + \epsilon_s((a - P_m)/b)$ is the demand function for the component suppliers as well as the RM supplier. In line with the observations in the case study, we model two 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 anymore. There is a saving on the associated transaction costs of ordering and procurement. We denote the changed fixed costs of the component suppliers as $F_i^{rm} < F_i$, $i = 1, 2, \ldots, n$. Second, the buyer incurs costs to set up and operate the RM procurement, to develop relationships with the RM supplier, and to manage the associated transactions associated with managing the RM (such as delivering RM to the component suppliers, managing the financial accounting associated with the RM delivery, and the scrap recovery). We denote this new fixed cost of the buyer as F^{rm}. The F_i^{rm} and F^{rm} terms mirror the concepts of information costs (Kleindorfer and Sertel 1979) or transaction costs (Williamson 1985) in economics literature. We continue to assume that for all supply chain agents, the variable costs of production increase with variability in OEM's demand (ϵ) in the amount of information asymmetry (β). All other parameters remain similar to those in the decentralized RM procurement scenario and are not repeated.

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. The profit functions are then given for buyer OEM as

$$\Pi_m^{rm} = q^{rm}\left(P_m - \sum_{i=1}^{n} P_i - \sum_{i=1}^{n} \theta_i c - v_m\right) - (q^{rm} - \hat{q})k_m\sigma + F^{rm},$$

for component supplier i as

$$E[\Pi_i^{rm}] = E[q^{rm}(P_i - v_i - k\sigma\beta) - (q^{rm} - \hat{q})k_i\sigma\beta] - F_i^{rm},$$

and for the RM supplier as

$$E[\Pi_R^{rm}] = E\left[q^{rm}\left(\sum_{i=1}^{n} \theta_i(c - c_r) - (q^{rm} - \hat{q})k_R\sigma\beta\right)\right].$$

The buyer's choice is the quantity q^{rm} under contracts with component suppliers.

Proposition 2 (Direct RM Procurement). (a) *The equilibrium quantity is*

$$q^{rm*} = \epsilon\left(\frac{a - v_m - \sigma(k_m + \sum_i k_i\beta - k_R\beta) - \sum_{i=1}^{n}(\theta_i c_r + v_i)}{2(n+2)b}\right) > q^*.$$

(b) *The firm-level expected profits for the supply chain agents are as follows*:
For the buyer: $E[\Pi_m^{rm}] = (b/\alpha)(E[q^{rm*}])^2 - F^{rm}$.
For supplier i: $E[\Pi_i^{rm}] = 2(b/\alpha)(E[q^{rm*}])^2 - F_i^{rm}$.
For the RM supplier: $E[\Pi_R^{rm}] = 2(b/\alpha)(E[q^{rm*}])^2$.

First, Proposition 2 states that $q^{rm*} > q^*$, and therefore in the direct RM procurement scenario, the component suppliers have higher expected profits compared with that in the decentralized RM procurement scenario (since $F_i^{rm} < F_i$ and $q^{rm*} > q^*$, $E[\Pi_i^{rm}] > E[\Pi_i]$). In this scenario, the value for the component suppliers results from a change in component-level pricing. When component supplier i does not buy the RM, the working capital used in its business with the buyer declines. Consequently, the buyer revises the purchase price to take into account the changed working capital requirement of the component supplier. From a contract standpoint, the decentralized RM procurement differs from the direct RM procurement because direct RM procurement eliminates the double marginalization on RM and is therefore more efficient. Second, note that the direct RM procurement case is only beneficial for the OEM when its higher revenues (resulting from increased supply chain efficiencies) are more than the additional fixed costs F^{rm}.

4.3. The Sourcing Hub

In this section, we formulate the sourcing hub problem in a five-step hybrid cooperative/noncooperative game setting. This setup is similar to the setup under the decentralized RM procurement in terms of the player profit equations, but the game and the sequence of events is different. In the first step, all the agents preproduce a "safe" quantity $\hat{q}$, where $\hat{q} \le q^{\text{coop}}$, the final quantity sold. Next, the RM supplier announces the price for the RM. Next, the n component suppliers play a cooperative game between themselves and bargain over achievable joint profits. Then, the uncertainty is revealed, and the OEM chooses the final quantity q^{coop}. Finally, all agents complete the production of $q^{\text{coop}} - \hat{q}$, and the supply chain realizes total sales of q^{coop}.

In the bargaining game *between* suppliers, which we model using the Nash bargaining solution, we assume that the outside options of the suppliers are equal to their noncooperative profits (decentralized RM procurement); that is to say that the suppliers revert to playing the base-case noncooperative game if they fail to make the cooperation work. The parameters related to uncertainty and information asymmetry are similar to that in the decentralized procurement setup and are not repeated.

We empirically find that the fixed costs of the suppliers reduce in the cooperative scenario compared with the decentralized procurement scenario, since all suppliers come together to deal with issues related to production as well as RM. We denote the changed fixed costs of the component suppliers as $F_i^{\text{coop}} < F_i$, $i = 1, 2, \ldots, n$. Cooperation between suppliers leads to a more efficient, lower-cost supply chain, creating higher value. However, as we saw in the TDV case study, such cooperation does not "happen" between the suppliers, but is actively managed by the OEM via the sourcing hub. Cooperation is not free—TDV incurs costs for managing the sourcing hub (to set up and operate the hub, and to develop relationships between the component suppliers). In our model, we denote this new cost of the buyer as F^{coop}. This cost again mirrors the concepts of information costs or transaction costs in economics literature.

The profit functions are then given for buyer OEM as

$$\Pi_m^{\text{coop}} = q^{\text{coop}}\left(P_m^{\text{coop}} - \sum_{i=1}^{n} P_i - v_m\right) - (q^{\text{coop}} - \hat{q})k_m\sigma - F^{\text{coop}},$$

for component supplier i as

$$E[\Pi_i^{\text{coop}}] = E[q^{\text{coop}}(P_i - \theta_i c_i - v_i) - (q^{\text{coop}} - \hat{q})k_i\sigma\beta] - F_i^{\text{coop}},$$

and for the RM supplier as

$$E[\Pi_R^{\text{coop}}] = E\left[q^{\text{coop}}\left(\sum_{i=1}^{n}\theta_i(c_i - c_r)\right) - (q^{\text{coop}} - \hat{q})k_R\sigma\beta^2\right],$$

where the OEM's choice is quantity q^{coop} under contracts with component suppliers.

Proposition 3 (Sourcing Hub: Cooperation Between Suppliers). (a) *The optimal quantity in the sourcing hub scenario is*

$$q^{\text{coop}*} = \frac{\epsilon}{8b}\left(a - v_m - \sum_{i=1}^{n}(\theta_i c_r + v_i) - \sigma\left(k_m + \sum_i k_i\beta + k_R\beta^2\right)\right).$$

(b) *The firm-level expected profits for the supply chain agents are as follows*:
For the buyer: $E[\Pi_m^{\text{coop}}] = (b/\alpha)(E[q^{\text{coop}*}])^2 - F^{\text{coop}}$.
For supplier i: $E[\Pi_i^{\text{coop}}] = (b/\alpha)(E[q^{\text{coop}*}])^2 - F_i^{\text{coop}}$.
For the RM supplier: $E[\Pi_R^{\text{coop}}] = 4(b/\alpha)(E[q^{\text{coop}*}])^2$.
(c) *When* $n > 2$, $E[q^{\text{coop}*}] > E[q^{rm*}] > E[q^*]$, *and the game results in the following relations*:

$$E[\Pi_R^{\text{coop}\alpha}] > E[\Pi_R^{rm*}] > E[\Pi_R^*],\qquad E[\Pi_i^{\text{coop}\alpha}] > E[\Pi_i^{rm*}] > E[\Pi_i^*],\quad i = 1, 2, \ldots, n. \tag{1}$$

Proposition 3 states the following:
- The component suppliers as well as the RM supplier in the sourcing hub supply chain have a higher expected profit compared with the decentralized RM procurement or the direct RM procurement scenario.
- All the agents—the buyer OEM, the component suppliers, and the RM supplier—have a higher expected contribution from businesses.

Note that the sourcing hub scenario is more beneficial for the OEM compared with the decentralized RM procurement or the direct RM procurement scenario when the higher revenues (coming from cooperation between suppliers) are more than the additional fixed costs incurred for deploying a sourcing hub. Our empirical data show that these fixed costs for TDV are very small compared to 3%–6% savings on the cost of goods sold achieved by deploying a sourcing hub. Further note that direct RM procurement can be combined with the cooperative scenario at the sourcing hub. For example, if we combine the direct RM procurement analysis with the sourcing hub analysis, then the component suppliers' expected profits will be $(b/\alpha)(E[q^{\text{coop}*}])^2 - F_i^{rm}$, and we will get similarly modified expressions for other members of the supply chain.

Empirically, we observe that the overall supply chain structure of TDV is getting closer to the cooperative sourcing hub structure. The firm gets its suppliers together and shares demand information and annual plans with them, and the suppliers, in turn, discuss cost reductions and design improvements with each other in monthly meetings. However, it is not possible to precisely measure the actual game being played by the agents. We can therefore assert that the actual industrial practice (at TDV) is somewhere between the simultaneous-move noncooperative game in the direct RM procurement scenario and the cooperative game between suppliers.

4.4. Analysis of the Three Scenarios

We now analyze the results of the two models of TDV's supply chain scenarios and compare them with the decentralized RM procurement scenario. Table 1 depicts the supply chain agents' profits on a common scale of the expected quantity sold by the OEM in the decentralized procurement ($E[q^*]$). For notational ease, denote $\Omega = (\alpha\sigma k_R \beta(\beta+1))/(4b(n+1))$. We note that the differences between various scenarios depend on the number of suppliers, n, since the optimal quantity $E[q^*]$ is a decreasing function of n.

In the following propositions, we explore how the sourcing hub setup creates value for the agents and how this value depends on the supply chain variables such as the information asymmetry, the number of suppliers, and the RM needed.

Proposition 4 (Effect of RM and Information Asymmetry on the Value of the Sourcing Hub). *The difference in the expected profits of all agents—the buyer, the RM supplier, and the component suppliers—in the decentralized RM procurement and the sourcing hub scenarios has increasing differences in* (θ_i, β).

Recall that component i consumes θ_i amount of raw material, and β denotes the information asymmetry between supply chain agents. Therefore, Proposition 4 states that managing RM sourcing via a sourcing hub is more beneficial for firms who have a higher RM content in their costs. Furthermore, as sourcing becomes more RM dominant (as θ_i increases), increasing information asymmetry of demand (β) in the supply chain increases the value of the sourcing hub for all agents in the supply chain.

Proposition 5 (Effect of Number of Suppliers on the Value of the Sourcing Hub). *The difference in the expected profits of all agents—the buyer, the RM supplier, and the component suppliers—in the decentralized RM procurement and the sourcing hub scenarios is increasing in* n*, but has decreasing differences in* (β, n).

Proposition 5 states that when buyers manage upstream RM sourcing, an increase in the number of suppliers has a greater effect on increasing the profits for all agents in the supply chain, but this effect decreases with increasing information asymmetry (β).

We now revisit our hypotheses to explore how our modeling results can inform the empirical observations and vice versa. We first hypothesized that as RM becomes more important in the sourcing of an OEM, the OEM may benefit from sourcing directly from the RM supplier. Our interviews with the RM supplier of TDV indicated that the RM supplier may also be a winner in this arrangement, even though there may be a reduction in the selling price of RM due to volume purchasing.

We then hypothesized that an OEM may benefit more from developing cooperative relationships with its suppliers and the RM supplier than from developing transactional relationships. Our interviews with the suppliers indicated that the component suppliers find the cooperative mode of the sourcing hub to be a superior way of working.

We see that our modeling results support these hypotheses only in part, and attract our attention to more subtle aspects of managing the upstream RM sourcing. Summarizing the results from Propositions 1–5, we can assert the following:

- When an OEM procures RM directly for its suppliers, such an arrangement can benefit the component suppliers, but may not benefit the OEM in certain situations. The OEM can benefit if it can manage the transaction costs of RM supplies (i.e., investment in procuring RM) to be lower than the benefit arising from the reduction ensuing from direct purchase of RM. Otherwise, the OEM loses. Thus, Hypothesis 1 does not have full support from our modeling.
- Building cooperative relationships with component suppliers and the RM supplier via a sourcing hub is increasingly beneficial for all the agents as RM becomes important in sourcing. Thus, Hypothesis 2 is supported. Furthermore, the agents benefit more from a sourcing hub as information asymmetry increases.
- As the RM content in the sourcing increases, managing RM becomes more valuable for all agents

Table 1 Summary of Firm-Level Expected Profits in Different Game Scenarios

Game	Decentralized RM	Direct RM	Sourcing hub
RM supplier	$2(n+1)\frac{b}{\alpha}(E[q^*])^2$	$8\left(\frac{n+1}{n+2}\right)^2\frac{b}{\alpha}(E[q^*]+\Omega)^2$	$(n+1)^2\frac{b}{\alpha}(E[q^*])^2$
Supplier i	$2\frac{b}{\alpha}(E[q^*])^2 - F_i$	$8\left(\frac{n+1}{n+2}\right)^2\frac{b}{\alpha}(E[q^*]+\Omega)^2 - F_i^{rm}$	$\left(\frac{n+1}{2}\right)^2\frac{b}{\alpha}(E[q^*])^2 - F_i^{coop}$
Buyer OEM	$\frac{b}{\alpha}(E[q^*])^2$	$4\left(\frac{n+1}{n+2}\right)^2\frac{b}{\alpha}(E[q^*]+\Omega)^2 - F^{rm}$	$\left(\frac{n+1}{2}\right)^2\frac{b}{\alpha}(E[q^*])^2 - F^{coop}$

in the supply chain. Moreover, this increased value increases for all agents as information asymmetry increases in the supply chain.

What is the extent of savings that can accrue to an OEM from managing its RM sourcing? The exact answer depends on the relationship between the RM and the fixed costs of the OEM and the suppliers. Our empirical research shows that direct RM purchasing and cooperative sourcing at the sourcing hub lead to savings of 3%–6% on the costs of RM for the OEM. This is a huge benefit, considering that RM costs amount to over 50% of the cost of goods sold for automotive OEMs, and the margins on the auto products are very low—the industry-level net profit estimate for auto industry is 3.5% (Damodaran 2013). Let us relate these empirical findings to our modeling results for the sourcing hub. The difference in the expected profits of the OEM between the sourcing hub and the decentralized RM procurement is

$$\Delta_m^{\text{coop}} = \frac{b}{\alpha}\left(\left(\frac{n+1}{2}\right)^2 - 1\right)(E[q^*])^2 - F^{\text{coop}}.$$

Therefore, the benefits from managing the RM sourcing depend on how efficiently a buyer manages its fixed costs of RM sourcing, and also on the complexity of its upstream network (specifically, the number of suppliers). Recall that TDV manages its sourcing hub—comprising 27 component suppliers and one RM supplier—with two full-time employees and one part-time employee. Since the fixed costs of TDV are low, TDV manages to therefore capture significant savings from actively managing its RM supply chain.

5. Discussion—Deploying a Sourcing Hub

In this paper, we detail how buyers can recapture value from their supply networks by focusing on their suppliers and their suppliers' suppliers. We use our four-year empirical investigation to motivate our research problem. We first detail the case study of an OEM, TDV, and explain how this firm evolved its current supply chain setup (sourcing hub) in two stages. In its first stage, TDV bought RM from a single steel supplier and supplied the same to its component suppliers. This helped the firm run its supply chain at lower costs. In its second stage, TDV developed the sourcing hub as an upstream entity in supply chains, focused on developing relationships with its suppliers and its RM supplier. The sourcing hub was deployed at TDV as an organizational department that facilitated interaction with and between upstream agents. Such interaction helped disseminate information about market demand, production schedules, new product introduction, and cost reduction.

We then use these empirical observations of TDV as assumptions for modeling a single buyer, n component supplier, single RM supplier setup. We explore two different setups: (1) buyers procuring RM and supplying it to the suppliers and (2) buyers creating a sourcing hub—a center for cooperation between suppliers. Our analysis and empirical observations show that managing RM sourcing is more beneficial for firms who have a higher RM content in their costs, and who have a large number of suppliers.

A wide range of industries can lend themselves to the sourcing models in this paper. Specifically, our insights are more useful for such industries that have RM as an important part of the cost of goods sold and need to deploy assembly of components from multiple suppliers. Examples of such industries are automotive, apparel and footwear, machinery, furniture, aerospace, and appliances. On the other hand, sourcing hubs may not be very useful for industries such as electronics, information technology, chemicals, or entertainment. Because of the crisis/tough global competition in many (mature) sectors, managers are forced to screen their supply chains continuously for potential cost savings or other benefits. Oftentimes industry tends to go too far. In this case, squeezing the upstream supply chain by transactional behavior with first-tier suppliers may have led to inefficiencies. Revisiting the upstream RM supply chain may provide opportunities for value addition for all agents in the supply chain. This will not be true for all industries and will also not be true for all OEMs in any industry, but certainly for some (like TDV). Thus, for mature industries such as automotive, apparel and footwear, machinery, aerospace, etc., upstream RM sourcing management should be revisited, and our paper suggests a possible way to do that. Our empirical findings suggest that firms can achieve 3%–6% savings in their cost of goods sold by deploying initiatives such as the sourcing hub. The industry-level net profit figures for automotive, apparel and footwear, machinery, furniture, aerospace, and appliances are 3.5%, 6.6%, 7.7%, 8.7%, 6.7%, and 2.4%, respectively (Damodaran 2013). In such scenarios, upstream RM management should be investigated for opportunities of value creation.

An interesting question is this: Why have we not seen more of this policy in practice? We contend that to initiate direct RM procurement, the OEM needs to invest in creating a material database at the component level. This is not easy because it means revisiting the BOM for all components. A BOM comprises information about the raw materials, components, and assemblies, as well as their respective quantities to manufacture an end product. Revisiting the BOM is the only way to find out answers to questions such as the following: (a) Which current products of an OEM require a particular RM? (b) What quantities of this RM are needed at the firm level? (c) What is the quality (or grade) of the most important RMs needed at the firm level? (d) Which processes must exist at the RM supplier for supplying these RMs? Only after this information is collated can one estimate how much RM of which quality (or grade) is needed. Our experience with some firms who are deploying the sourcing hubs in their supply chains indicate that this is an exhaustive and very time-consuming exercise. Additionally, when there might be many possible suppliers of the RM, or the choice of the RM supplier might be subject to significant change over time, the return to the OEM of developing the infrastructure and relationships required to deploy a sourcing hub might not be sufficient to justify the investment. We suggest that we do not see such hubs in many industries because of these features. Consumer electronics and food are examples of such industries, where the benefits of adopting a sourcing hub scenario may be limited.

Overall, in scenarios where RM supplies are monopolistic (or oligopolistic) and relatively stable, and the buyers have a larger dependency on RM in their cost of goods sold, deployment of a sourcing hub can help firms create value from upstream sourcing and recapture some of the value that has been lost in the race to become a lean manufacturer. This value can come from developing relationships with supply chain partners at the periphery of the firm—partners, who may not supply directly to the firm, but may affect the knowledge of the firm and its operations, including factors such as design complexities and costs. Firms can capture this value from their supply chains by deploying the upstream entity, the sourcing hub. The sourcing hub helps in many ways. Such a structure facilitates generation and use of RM sourcing knowledge by helping develop collaborative relations with RM suppliers. Building a relationship with RM suppliers encourages sharing of demand, production, and design information. Sharing of information leads to improved sourcing processes, which helps drive down costs of inputs. Thus, active management of upstream RM sourcing can help managers capture more value from their upstream supplier network.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/msom.2013.0461.

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