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United We Stand or Divided We Stand? Strategic Supplier Alliances Under Order Default Risk

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We study the alliance formation strategy among suppliers in a framework with one downstream firm and n upstream suppliers. Each supplier faces an exogenous random shock that may result in an order default. Each of them also has access to a recourse fund that can mitigate this risk. The suppliers can share the fund resources within an alliance, but they need to equitably allocate the profits of the alliance among the partners. In this context, suppliers need to decide whether to join larger alliances that have better chances of order fulfillment or smaller ones that may grant them higher profit allocations. We first analytically characterize the exact coalition-proof Nash-stable coalition structures that would arise for symmetric complementary or substitutable suppliers. Our analysis reveals that it is the appeal of default risk mitigation, rather than competition reduction, that motivates cooperation. In general, a riskier and/or less fragmented supply base favors larger alliances, whereas substitutable suppliers and customer demands with lower pass-through rates result in smaller ones. We then characterize the stable coalition structures for an asymmetric supplier base. We establish that grand coalition is more stable when the supplier base is more homogeneous in terms of their risk levels, rather than divided among a few highly risky suppliers and other low-risk ones. Going one step further, our investigation of endogenous recourse fund levels for the suppliers demonstrates how financing costs affect suppliers' investments in risk-reducing resources and, consequently, their coalition formation strategy. Last, we discuss model generalizations and show that, in general, our insights are quite robust.

Keywords: cooperation; competition; supply risk; order default; coalition stability; supplier alliances
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1. Introduction

Strategic alliances, whereby independent but cooperating organizations pool specific resources and skills to achieve common and individual goals, have emerged as a popular strategy in the business world (Varadarajan and Cunningham 1995). Although such arrangements can be between horizontal and/or vertical partners, we focus on horizontal alliances, which we also term "coalitions" interchangeably throughout the paper. Horizontal alliances are observed between complementary firms as well as between competitors selling substitutable products. Examples of the former include the ones between Caterpillar and Mitsubishi in the earthmoving equipment sector, and among component suppliers in the automobile and electronics sectors (Nagarajan and Sošić 2009). On the other hand, substitutable-product coalitions include Renault and Nissan in the automobile industry (Yoshino and Fagan 2003), Takeda and Hoechst in the pharmaceutical sector (Garella and Peitz 2007), and collaborative organizations in the marine transportation (Girotra and Netessine 2014) and agricultural sectors (Bright et al. 2010).

There is a considerable amount of literature, especially in the strategy and organization areas, analyzing alliances from multiple perspectives. It deals with issues like alliances' governance structures (Gulati and Singh 2008) as well as the effects of alliances on firm performance (Singh and Mitchell 2005), innovation rate (Stuart 2000), knowledge transfer (Mowery et al. 1996), market access (Varadarajan and Cunningham 1995), and bargaining power (Hamel 1991). However, extant practitioner/academic literature suggests that an important reason for alliance formation might be to deal with external business risks (e.g. Girotra and Netessine 2014, Bright et al. 2010). This risk-mitigating role is particularly relevant for supply chains, given the exogenous perils they face from the demand and/or supply side. Indeed, a number of operations management (OM) papers have studied coalition formation in the presence of demand-side risk (refer to §2 for details).

However, longer and more decentralized value chains are now increasingly exposing supply-side risks. Such risks put suppliers' order fullfillment ability in jeopardy and range from relatively minor ones (e.g., due to minor maintenance or inventory problems) to really catastrophic ones like frost wiping out most of California's citrus crops (Rimal and Schmitz 1999), the recent earthquake and tsunami disrupting supply from Japan (Lohr 2011), and the default of more than 10,000 factories in China during the financial crisis of 2008 (MacLeod and Wiseman 2008) (refer to Lynch 2011 for more examples). Different strategies have been proposed to deal with supply risks including diversification (Babich et al. 2007), subsidies (Wang et al. 2010, Babich 2010, Wadecki et al. 2012), guarantees (Gümüs et al. 2012), and contracting (Swinney and Netessine 2009, Yang et al. 2009).

A number of firms, in industries as diverse as marine transportation and agriculture, have also started using "alliances" to deal with supply risks. For instance, Tankers International (TI) has developed a commercial shipping alliance whereby they charter a pool of VLCCs (Very Large Crude Carriers) from individual owners and use it to deliver crude oil to refineries. Such pools of (substitutable) tankers help to deal with order default risks caused by weather problems, refinery closings, and maintenance and port issues, all common problems in commercial maritime transportation (Girotra and Netessine 2014). TI acts as a single entity that makes the aggregate capacity available to customers, collects earnings from transportation activities, and distributes them among individual owners under a prearranged allocation system (Packard 1989, Haralambides 1996). In the agriculture industry, producers selling substitutable and/or complementary products to retailers also form alliances, e.g., farmer producer organizations (FPOs) in India. One of the main rationale for this is to share supply chain risk-management funds among partners to deal with fulfillment risks arising from factors like bad weather, transport losses and difficulty in accessing capital, and then to properly share the gains (Bright et al. 2010, Ministry of Agriculture of India 2013).

Although the above implies that alliances could be an effective measure in dealing with the risk of defaulting on a supply contract, firms are aware that such partnerships require equitable sharing of risks and benefits and, consequently, are not easy to sustain (see Bright et al. 2010, Haralambides 1996). Interestingly, analytical investigation as to what types of stable coalitions (so that there is no incentive for partners to profitably deviate) will develop in the presence of such risk is sparse in the academic literature. This paper attempts to address this gap via a cooperative model framework. In particular, the model will capture three salient features of the above TI and FPO examples. First, exogenous events may result in order default risks on the part of the suppliers. Second, risk-mitigating resources can be pooled by suppliers to overcome such disruptions. Third, cohesive entities formed purely by self-incentivized individuals (i.e., supplier alliances) can make coordinated decisions and distribute earnings among their members based on certain allocation schemes.

We consider a bilevel supply chain model framework composed of n upstream suppliers and one downstream firm (henceforth referred to by masculine and feminine pronouns, respectively). The downstream firm faces a price-sensitive, deterministic demand that she needs to satisfy by procuring the required components—complements or substitutes—from the suppliers. On the other hand, there is an exogenous random shock faced by each upstream supplier that exposes him to the risk of complete order default. However, he also has access to a fund reserved by him ex ante for risk mitigation. Ex post, this fund can be used as a recourse to deal with the shock and to supply the entire order, as long as the value of the shock is lower than the reserve amount (otherwise, he still defaults). It is costly for the supplier to operate the reserve fund, and the fund is generic and liquid enough (e.g., cash) to be shared with other suppliers. The reserve amount and default risk are inversely related—the higher is the amount accessible to a supplier, the lower is his effective default risk, although the risk-mitigating benefit shows diminishing marginal returns. In this paper, we will use the fund amount and default risk interchangeably, keeping in mind their inverse relationship.

The suppliers first decide on their cooperative alliance structures by determining whether to join an alliance and, if so, with how many other partners. Since the reserve funds are shareable, the alliance partners can pool them. The relative values of the total shock facing the supplier alliance and its total reserve amount then determine whether it will fully default or deliver the whole order (like in the individual supplier case above). Each alliance then announces its supply limit for the downstream firm and competes horizontally via wholesale prices. Subsequently, the downstream firm decides on the order quantity for each alliance and on the retail price. Finally, default risks and consequent profits (if any) are realized for the alliances. Each alliance then divides its profit among the partners following a predetermined allocation rule that is proportional to the share of each partner in the pooled fund. We use the above framework to address the following.

- What is the equilibrium stable alliance that would arise under the risk of order default?
- What factors incentivize the suppliers to opt for larger (or smaller) alliances?
- How robust are these results with respect to model assumptions? For example,
  - What if the suppliers need to decide how much to ex ante invest in the reserve fund?
  - What if the profit allocation is not proportional to the partners' shares in the pooled fund?

We first focus on the case of suppliers who are symmetric in terms of their risk (i.e., fund) levels and analytically characterize the number of stable alliances and their sizes through a coalition-proof Nash-equilibrium (CPNE) technique. While making partnership decisions, the suppliers need to trade off the benefits of joining larger alliances that result in a lower probability of order default against the benefits of greater profit allocation in smaller alliances. Literature on alliances in supply chain management has until now focused primarily on the second factor, and hence suppliers usually end up forming small coalitions (see Yin 2010 for discussion). In contrast, by incorporating supply-side risks and possible order default, we are able to identify a diverse set of stable coalition structures, both large and small, depending on the business environment.

Specifically, we identify a novel risk-adjusted stability factor, which encapsulates the characteristics of both the supply base and customer demand, to determine the stable alliances. Analysis of this factor shows that, in general, larger alliances (including a grand coalition of all n suppliers) are more likely to be formed when (i) the supplier base is riskier and/or relatively small, (ii) suppliers are complementary, and (iii) retail price is more sensitive to wholesale prices (i.e., pass-through rates are higher). On the other hand, antithetical business conditions (e.g., less risky suppliers or lower pass-through rates) result in smaller alliances and might even incentivize suppliers to operate alone. Intuitively, one would expect that suppliers would prefer larger alliances since this reduces the competition within the supply base. However, this argument does not take into account the inherent difficulty in keeping larger alliances stable. Interestingly, our results show that it is risk-reduction through fund sharing that serves as the glue holding alliances together, rather than competition reduction through collaborative decision making.

Subsequently, we generalize the above model to account for an asymmetric supplier base consisting of certain riskier suppliers and some less risky ones, and once again we analytically characterize the sizes of stable coalitions. This characterization requires a modification of the stability factor to account for the asymmetry. Our previous insights still remain valid; in addition, we show that a more homogeneous (heterogeneous) supplier base results in larger (smaller) alliances.

Last, we test the robustness of the above qualitative insights through multiple generalizations of our modeling framework. First, we make the decision to invest in a reserve fund to be endogenous; i.e., suppliers choose their coalition partners as well as how much they want to invest in risk-reducing, but costly, reserves. If investment is quite costly, suppliers would like to take advantage of risk reduction through fund sharing by forming large alliances, whereas if the investment is cheap, they would like to go alone to have a higher profit allocation. The other two generalizations address (i) a profit allocation mechanism that is not proportional to shares in the pooled fund, and (ii) a nontrivial default premium for the downstream firm in the case of an order default. The main insight of the first generalization is that larger alliances are sustained for relatively fair allocations. Regarding the second generalization, all our previous insights hold as long as the premium is not too high. As one would expect, a higher default premium increases the sizes of the coalitions.

As regards the rest of the paper, §2 discusses the related literature, and §3 presents our basic modeling framework with exogenous reserve funds. The operational decisions are analyzed in §4, and §5 deals with alliance formation decisions for both symmetric and asymmetric supplier bases. Section 6 studies the three model generalizations. The concluding discussion is provided in §7.

2. Literature Review

There are two streams of literature most directly related to our work: research that deals with coalition formation but does not consider supply-side risk (or resource availability to reduce such risk), and research that studyies measures to counteract supply default risk when suppliers only compete with each other (i.e., without any consideration for cooperation).

Our modeling framework of multiple suppliers and one downstream firm channel has a long history in operations literature. Papers in this area traditionally had a competitive focus, e.g., Wang and Gerchak (2003) and Jiang and Wang (2010) for complementary suppliers, Bernstein and Federgruen (2005) and Yang et al. (2012) for substitutable suppliers, and Netessine and Zhang (2005) for both types of suppliers, to name a few. In these papers, suppliers make individual decisions that maximize their own profits, taking into account the responses of competing firms. The possibility for suppliers to communicate and jointly set their prices and/or quantities, capacities, and such, is not considered.

In recent years, a line of research studying the coalition structures that could arise among collaborating suppliers has emerged. For example, Nagarajan and Sošić (2007) investigate the stability of coalitions among suppliers selling substitutable products in a dynamic setting. Suppliers are assumed to be farsighted and take into account possible future defections when making any immediate decision. On the other hand, Nagarajan and Bassok (2008) study coalition stability among complementary suppliers when they can negotiate with the downstream assembler about profit allocations. They find that a grand coalition (no coalition) will emerge if the bargaining power of the assembler is weak (strong). Also in the context of assembly systems, Granot and Yin (2008) find that coalitions are more likely to be formed in a pull system than a push one, and find that in the latter case whether the suppliers will form a grand coalition or act independently depends on their perspective about cooperation (farsighted or myopic). Nagarajan and Sošić (2009) consider three modes of competition among complementary suppliers and analyze stable coalitions as a function of power structure, demand structure, and the number of suppliers. Under a similar framework, Sošić (2011) studies the impact of demand uncertainty on the alliance structures. Last, for a quite general market condition, Yin (2010) explicitly characterizes stable coalition structures in assembly systems and their dependence on demand conditions.

Note that all of the above papers deal only with demand-side risks. In general, the incentive for coalition formation in this literature has been attributed to the channel/market structure (Granot and Yin 2008, Nagarajan and Sošić 2009, Yin 2010), bargaining power (Nagarajan and Bassok 2008), the cooperative perspective of the players (Nagarajan and Sošić 2007, Granot and Yin 2008, Nagarajan and Sošić 2009) and the nature/extent of demand uncertainty (Yin 2010, Sošić 2011). We follow this literature by also investigating how the stability of coalitions among suppliers is affected by various business conditions, but we complement it by showing that the possibility of order default risk itself can also be a significant incentive behind cooperation.

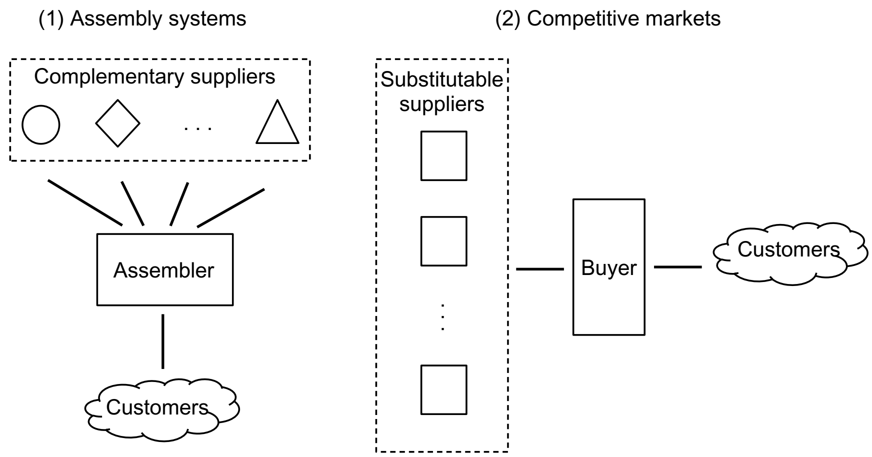
As regards the second stream, there is a vast literature related to exogenous supply risks. Although our paper deals with both minor and major supply shocks, it particularly emphasizes order default/disruption risk because of which a buyer may not receive anything from her suppliers (refer to Kleindorfer and Saad 2013 and Sodhi et al. 2011 for reviews about supply risk in general). Previous studies have taken a wide angle regarding this issue. Analyzing from the buyer's perspective, Tomlin (2006) considers several mitigation measures and contingency tools to hedge against a variety of disruptions. Babich et al. (2007) and Chopra et al. (2007) investigate the impact of risk correlation and the type of risk (recurring or disruption) facing the supplier community on optimal sourcing diversification decisions, respectively. Swinney and Netessine (2009) analyze the value of long-term versus short-term contracts in the presence of a default risk, and Yang et al. (2009) derive the optimal contract when suppliers hold private information about their reliability. Chaturvedi and Martínez-de Albéniz (2011) extend the work of Yang et al. (2009) by also including supplier's cost as private information. Last, Saghafian and Van Oyen (2012) show the value of having a flexible backup supplier in the presence of disruption risk and discuss capacity reservation issues in that context. Looking from the suppliers' perspective, Gümüs et al. (2012) study the impact of guarantees on risk mitigation and the ability of suppliers to signal their true risk levels. Wei et al. (2013) discuss the implications of default risk coming from uncertain market prices or valuations, when the buyer can use vertical subsidy as a strategic measure. There is also a vast OM literature exploring the impact of yield risk on operational decisions. Among the recent OM papers, Tomlin (2009), Kazaz and Webster (2011), and Gurnani et al. (2012) investigate the effects of learning, yield-dependent cost structure, and information asymmetry on operational/marketing decisions, respectively. In general, the papers in this research stream have had either a centralized or a competitive focus. To the best of our knowledge, the current paper is among the first that considers supply default risk in a cooperative context and is able to establish its role in suppliers' coalition formation decisions.

Note that, although our focus is on horizontal collaboration, there is a rich stream of literature dealing with vertical collaboration (refer to Paulraj et al. 2008, Kim and Netessine 2013). There are also two other growing streams that are in spirit related to our work: (i) empirical analysis of the causes of horizontal alliance formation (e.g., Li and Netessine 2011), and (ii) horizontal mergers in supply chains (e.g., Cho 2014). However, these streams differ from this paper in terms of methodology as well as model setting.

3. Model Framework

Consider a supply chain with a single downstream firm procuring components from n upstream suppliers and selling a final product to end consumers.

Figure 1 **Channel Structures with Complementary and Substitutable Suppliers**



Let $N = \{1, 2, \ldots, n\}$ denote the set of n suppliers. In our setting, the components can either be complements or substitutes. If they are complements, the final product is an assembly consisting of one component each from the n suppliers; if they are substitutes, the final product consists of only one component available from any of the n suppliers. The downstream firm—an assembler or a buyer depending on the component type—acquires the components and then (costlessly) assembles/produces the end product to satisfy customer demand (refer to Figure 1). Below, we describe the salient features of the stakeholders in our supply chain. A glossary of notations is provided in Table A1 of the online appendix (available as supplemental material at http://dx.doi.org/10.1287/mnsc.2015.2175).

Downstream firm. We model the end product demand facing the downstream firm as a price-sensitive deterministic function $D(p)$, where p is the retail price set by the firm. We assume that $D(p)$ is positive and decreasing in p, and its price elasticity satisfies the following form:

$$\eta(p) = -\frac{D'(p)}{D(p)/p} = \frac{p}{\alpha + \beta p}, \tag{1}$$

where $\alpha \geq 0$ and $\beta \leq 1$ (as in Song et al. 2007). Note that the class of demand functions that satisfy (1) is quite general and subsumes most of the specific demand forms assumed in the related literature, such as isoelastic (Wang 2006), linear (Nagarajan and Sošić 2007, 2009) and linear-power and exponential (Yin 2010); see Table A2 in the online appendix for details.

Upstream suppliers. The n upstream suppliers in our model decide whether to operate independently or join a coalition. Each coalition acts as one entity in the context of our interest, where the partners coordinate their pricing and capacity decisions. This aligns with the description of shipping pools in Haralambides (1996), and that of certain FPOs with the farmers as the shareholders (Ministry of Agriculture of India 2013). So, all upstream entities, whether independent suppliers or coalitions, set a single wholesale price and a single capacity limit that is available for the buyer. The buyer then decides on the order quantities from each entity (and the retail price, as described above).

Each of the n suppliers is also subject to an exogenous environmental shock. These shocks open them up to the risk of entirely defaulting on the buyer's order. For example, the buyer might specify in the contract that she requires the whole order by a certain date; if it is not available by then, she will procure it from an outside source and not accept supply of a partial order. Some of the shocks (e.g., equipment problems) might be small in impact, whereas some others (e.g., natural disasters and financial crises) might be catastrophic. The suppliers then require funds to recover to their normal state from the shock. We use the random variable ξ_i to denote the shock or, equivalently, the (minimum) amount in funds needed by supplier i to recover from the shock and fully satisfy the buyer's contract (Lynch 2011, SCDigest 2012). We assume that $\{\xi_i\}_1^n$ are independent and identically distributed with cumulative distribution function (CDF) $G(\cdot)$ with $E[\xi_i] = \mu$.

Furthermore, suppose that each supplier has ex-ante reserved a risk-management fund F_i that he can use as a recourse for the purpose of recovery after a shock (SCDigest 2012). As long as the reserve amount is more than the funds needed to recover, the supplier can fulfill the entire order ("survive") and gain the associated profits. Otherwise, he "defaults," earning zero profits as well as incurring the monetary loss from the shock. The supplier also incurs costs to maintain the fund ($c_f(F_i)$), irrespective of the magnitude of the shock. The above principle holds true even for a coalition after accounting for the pooling of reserve funds and shocks for the partners (see below). We model the net cash flow of a supply entity, whether a single supplier or a coalition, as follows:

$$\text{Net cash flow for a supply entity}$$
$$= \overbrace{-\text{Operating expenses of reserve fund}}^{\text{Cost of ex ante recourse investment}} + \underbrace{\begin{cases} -\text{Shock}+\text{Profits} \\ \quad \text{if Shock} \le \text{Reserve fund} \quad \text{(survive state)} \\ -\text{Shock} \\ \quad \text{if Shock} > \text{Reserve fund (default state)} \end{cases}}_{\text{Ex post net earnings}}. \tag{2}$$

The above cash flow model follows Swinney and Netessine (2009). Similar to their paper, ours assumes that (existing capital + loans − interest payment − fixed operating expenses = 0) for activities beyond our context, and only the damage ξ_i (loss on existing capital), the reserve fund operating cost $c_f(F_i)$ (operating expenses), and survival-state profit (revenue − production expenses) are considered in cash flows. Unlike those in Swinney and Netessine (2009), suppliers or coalitions in our paper are all self-sustained; i.e., no external creditor or lender is involved in financing. Thus a positive (negative) cash flow implies an increase (reduction) in existing equity. Next we describe the expected cash flow for an individual supplier and that of a coalition in more details.

Individual supplier. Following (2), if an individual supplier's reserve fund is more than the shock (i.e., $\xi_i < F_i$), he delivers the full order per the contract and receives the profit associated with the order, π_i. Otherwise, if $\xi_i \ge F_i$, then he defaults; i.e., his profit from the order is zero. Thus, theexpected net cash flow for supplier $i = -c_f(F_i) - \mathbf{E}[\xi_i] + G(F_i)\pi_i$.

Coalitions. Suppose a set of suppliers $S \subseteq N$ forms a coalition. Recall that we focus on risks that would inhibit a coalition from fulfilling even a partial order. Since the coalition acts as one entity, the reserve funds of the partners are pooled ($F_S = \sum_{i\in S} F_i$), and the coalition faces the total exogenous shock of its partners ($\xi_S = \sum_{i\in S}\xi_i$). Denote by $|S|$ the number of suppliers in S, and by $G_{|S|}(\cdot)$ the CDF of $\sum_{i\in S}\xi_i$. If the coalition can mitigate the damage from the total shock by using the pooled fund, i.e., if $\xi_S \le F_S$, then it survives and receives the payment for the order from the downstream firm. This happens with probability $G_{|S|}(F_S)$. Otherwise, if $\xi_S > F_S$, the coalition defaults, which takes place with probability $\bar{G}_{|S|}(F_S) = 1 - G_{|S|}(F_S)$, and receives no payment. In other words, for a coalition to fail, the amount of shock that they collectively face needs to be more than their total reserve funds, irrespective of whether individual shocks are more or less than individual reserve funds. Following the same logic as before, expected net cash flow for the coalition $= -\sum_{i\in S} c_f(F_i) - \xi_S + G_{|S|}(F_S)\pi_S$.

Since suppliers' contributions to the pooled fund (F_i) directly affect the coalition's ability to deliver the order ($G_{|S|}(\sum_{i\in S}F_i)$), we allocate the expected profit for the coalition among the partners proportional to these contributions. This mechanism has real-life support in the weighing system used for shipping pools (Haralambides 1996[1]). We also discuss more general profit allocation rules in §6. Although pooled funds can be transferred among partners for recovery purposes, providing increased accessibility to resources, note that each supplier retains the financial ownership of his reserve fund throughout the process; so, the reserve fund amount itself does not need to be included in the cash flows for individual suppliers. However, the operating cost of maintaining the reserve fund, $c_f(F_i)$, is a sunk cost borne by individual suppliers and needs to be accounted for. In summary, given a structure of m coalitions $\{S_1, S_2, \ldots, S_m\}$ among n suppliers, where $\cup_{k=1}^m S_k = N$ and $S_k \cap S_{k'} = \varnothing$ for any $1 \le k < k' \le m$,

$$\text{Expected net cash flow for supplier } i \text{ in coalition } k$$
$$= -\text{Operating expenses } c_f(F_i) - \text{Expected shock } \mathbf{E}[\xi_i] + \frac{F_i}{\sum_{j\in S_k} F_j} \times (\text{Expected profit for coalition } k). \tag{3}$$

Each supplier will independently make his expected-cash-flow-maximizing decision about whether to join a coalition, and if so with how many partners, based on the above expression.

There are two other elements of the model—a technical assumption about the survival probability of an entity and the sequence of game among the stakeholders—that we discuss below.

Assumption. We use $G_l(F)$ to represent the survival probability for a coalition of l suppliers if their total risk-management fund is F, where l is a positive integer. Thus, for individual suppliers, we have $G_1(\cdot) = G(\cdot)$. Furthermore, denote by $V_l(F) = G_l(F)/F$ the ssurvival probability per unit of funds for a coalition of l suppliers with reserve fund F. We restrict our attention to funds that are at least sufficient to cover the expected loss; i.e., for each supplier i, $F_i \ge \mathbf{E}[\xi_i] = \mu$. For technical tractability, we also use the following assumption for values of F and l of our interest

[1] In tanker pools like TI (see §1), the net revenue of the total pool is allocated among the partner tankers proportional to their shares of the effective cargo carrying capacity (which takes into account factors like the base capacity, hiring period, tankers' efficiency and suitability for the pool's main trades, and operations and fuel consumption) in the total pool's carrying capacity. For the exact formula used for allocation of net revenues in the case of tanker pools, please refer to Haralambides (1996).

(refer to the online appendix for details) throughout the paper:

Assumption 1. (a) *Assume that $V_l(lF)$ decreases in F for $l = 1$ and decreases in l for any given F.*

(b) *Assume that $G_l(lF)/G_1(F)$ is unimodal in F for any given l.*

As shown in the online appendix, Assumption 1 holds for several commonly used distributions, including exponential, Erlang, and normal. Specifically, Assumption 1(a) posits how the reserve fund level F and the size of the coalition l affect the survival probability. F has a diminishing rate of impact on the survival probability of an individual supplier, and, for symmetric suppliers each holding F, the impact of the fund level on the survival probability of a coalition also diminishes in the scale of the coalition (i.e., the survival probability per unit of funds is higher for a smaller coalition). For symmetric suppliers, Assumption 1(b) concerns the benefit in terms of survival probability of joining an l supplier coalition, with $l > 1$,versus that of operating alone. It requires that such benefit increases in the average fund level F on $[\mu, F_0]$ for some $F_0 \geq \mu$ and decreases thereafter. Therefore, the relative benefit of joining an alliance increases when the reserve fund level is relatively low but does not further increase beyond a threshold reserve fund level.

Game sequence. The sequence of the events in our framework is as follows (refer to Figure 2).

Stage 1. n upstream suppliers strategically form m coalitions $\mathcal{S} = \{S_1, S_2, \ldots, S_m\}$, by playing a cooperative game among themselves.

Stage 2. Each coalition S_k commits to its supply limit Q_{S_k}, which caps the amount it will produce for the downstream firm. For exposition purposes, we assume zero commitment cost, which, as shown in the online appendix, is without loss of generality. Each coalition then determines the wholesale price w_{S_k} it will charge to the downstream firm. This stage involves competitive decision making.

Stage 3. The downstream firm maximizes her profit by determining the retail price p for the final product and the order quantities $\{q_{S_k}\}$, $q_{S_k} \leq Q_{S_k}$, from each coalition S_k.

Stage 4. The exogenous supply shock resolves. If a coalition S_k survives, the entire order from the downstream firm is delivered. Each unit produced by coalition S_k incurs a marginal cost c_{S_k}, where c_{S_k} is equal to $|S_k|c$ and c for complementary and substitutable cases, respectively. The resulting profit is shared among the coalition members based on their respective contributions to the pooled fund. Otherwise, in the case of an order default, the coalition receives no payment, and the downstream firm has to utilize an emergency source for the shortfall that charges the firm a premium δ_{S_k} on top of the coalition's wholesale price w_{S_k}. When the components are complementary, there is a unit premium $\delta \geq 0$ for each component; so, $\delta_{S_k} = |S_k|\delta$. If they are substitutes, there is only one component from the coalition; so, $\delta_{S_k} = \delta$. A similar premium emergency sourcing option has been used before in the related literature (e.g., Dong and Tomlin 2012). Subsequently, the downstream firm sells the final product to the end customers at price p and collects her revenue.

4. Operational Decisions Under a Given Coalition Structure

In this section, using backward induction, we characterize the equilibrium operational decisions of each coalition and the downstream firm (i.e., Stages 2 and 3 of the game) for a given coalition structure $\mathcal{S} = \{S_1, \ldots, S_m\}$, where a coalition of size one represents an individual supplier.

We start with the optimal ordering and pricing decisions of the downstream firm (i.e., Stage 3). To make her ordering and pricing decisions, the downstream firm will take into account the possibility that each coalition S_k might default with certain probability, in which case she would have to pay a premium δ_{S_k} to ensure supply as discussed in the last section. This

Figure 2 **Game Sequence of the Model Framework**

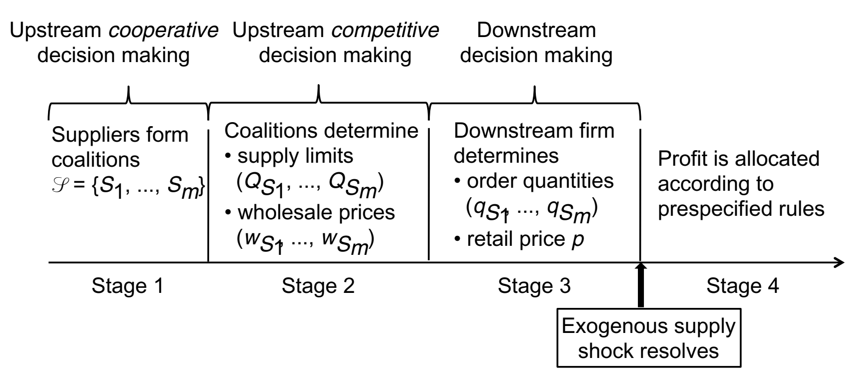


Table 1 Equilibrium Operational Decisions for Stages 2 and 3

	Complementary suppliers	Substitutable suppliers
Retail price (p^*)	$\dfrac{m\alpha+\tilde{C}}{(1-m\beta)(1-\beta)}+\dfrac{\alpha}{1-\beta}$	$\dfrac{\alpha+m\tilde{c}}{(m-\beta)(1-\beta)}+\dfrac{\alpha}{1-\beta}$
Order quantity ($q^*_{S_k}=Q^*_{S_k}$)	$D(p^*)$	$D(p^*)\left(\dfrac{1}{m}+\dfrac{m-\beta}{m}\dfrac{\tilde{c}-\hat{c}_{S_k}}{\alpha+\beta\tilde{c}}\right)$
Wholesale price ($w^*_{S_k}$)	$\dfrac{\alpha+\beta\tilde{C}}{1-m\beta}+c_{S_k}$	$\dfrac{\alpha+\beta\tilde{c}}{m-\beta}+c+\tilde{c}-\hat{c}_{S_k}$

Note. In the above, $\tilde{C}=nc+\sum_{k=1}^m \bar{G}_{|S_k|}(F_{S_k})\delta_{S_k}$, $\tilde{c}=c+\sum_{k=1}^m \bar{G}_{|S_k|}(F_{S_k})\delta/m$, $\hat{c}_{S_k}=c+\bar{G}_{|S_k|}(F_{S_k})\delta$, and $\bar{G}_{|S_k|}(F_{S_k})=1-G_{|S_k|}(F_{S_k})$.

allows us to determine the expected wholesale price $\tilde{w}_{S_k}=w_{S_k}+\bar{G}_{|S_k|}(F_{S_k})\delta_{S_k}$ paid by the downstream party to coalition S_k for both complementary and substitutable cases. Based on the expected wholesale prices, the downstream firm then determines the expected-profit-maximizing order quantities from the coalitions (which determine the retail price based on the inverse demand function), specifically as follows.

- For an assembler dealing with complementary suppliers, the same order quantity applies to all coalitions and $q_{S_1}=q_{S_2}=\cdots=q_{S_m}=q$. The assembler's expected profit Π_0 is then

$$\Pi_0(q)=\max_{0\le q\le \min\{Q_{S_k}\}} q\left(D^{-1}(q)-\sum_{k=1}^m \tilde{w}_{S_k}\right).$$

- For a buyer dealing with substitutable suppliers, the total order to place with the suppliers is $q=\sum_{k=1}^m q_{S_k}$. The buyer's expected profit Π_0 can be expressed as

$$\Pi_0(q_{S_k}, k=1,2,\ldots,m)$$
$$=\max_{0\le q_{S_k}\le Q_{S_k},\, k=1,2,\ldots,m} \sum_{k=1}^m q_{S_k}(D^{-1}(q)-\tilde{w}_{S_k}).$$

In either case, let $q^*_{S_k}(\mathbf{w},\mathbf{Q})$ be the optimal order quantity that solves the optimization problems. Given $(w_{S_{-k}}, Q_{S_{-k}})$ and coalition structure $\mathcal{S}=\{S_1,\ldots,S_m\}$ and provided that coalition S_k survives, the profit expressions for coalition S_k (denoted by π_{S_k}) and a supplier i within that alliance (denoted by π_i) can be written as follows:

$$\pi_{S_k}(\mathcal{S}\mid w_{S_{-k}}, Q_{S_{-k}})=\max_{0\le w_{S_k},\,0\le Q_{S_k}} (w_{S_k}-c_{S_k})q^*_{S_k}(\mathbf{w},\mathbf{Q}),$$

$$\pi_i(\mathcal{S}\mid w_{S_{-k}}, Q_{S_{-k}})=\frac{F_i}{F_{S_k}}\pi_{S_k}(\mathcal{S}\mid w_{S_{-k}}, Q_{S_{-k}}).$$

The equilibrium pricing and ordering decisions for the suppliers and the buyer are given in Proposition 1. All the technical proofs are provided in the online appendix.

Proposition 1 (Equilibrium Operational Decisions). *Given a coalition structure $\mathcal{S}=\{S_1,\ldots,S_m\}$, the equilibrium decisions for Stages 2 and 3 are as shown in Table 1.*

The equilibrium solution inherits a structure similar to those without supply risk (e.g., see Yin 2010 for the complementary case) with adjustments to account for the risk-reducing funds F_{S_k} of the coalitions, i.e., their effective supply risks. Indeed, F_{S_k} significantly impacts the decisions for both complementary and substitutable suppliers, albeit somewhat differently. For example, in the complementary case, the equilibrium coalition production quantity $q^*_{S_k}=Q^*_{S_k}$ is affected by the effective total production cost $\tilde{C}$ reflecting the aggregated effect of all reserve funds, $\{F_{S_k}\}_{k=1}^m$. Thus, higher reserve levels result in higher order quantities for every complementary coalition ($\tilde{C}$ and $q^*_{S_k}$ are inversely related). However, under the substitutable case, $q^*_{S_k}$ is affected via both effective average production cost $\tilde{c}$ (another representation of $\{F_{S_k}\}_{k=1}^m$) and effective individual production cost $\hat{c}_{S_k}$ (related to F_{S_k} only), which determine the total order quantity and the order allocation among coalitions. In this case, although higher reserves still result in total quantity expansion, the order of coalition S_k also depends on its own resource level compared to its competitors.

The sensitivity of the profits with respect to coalition structures is also different for upstream and downstream firms. For complementary suppliers, as the number of coalitions m decreases (i.e., larger coalitions), the ex post profit of each coalition increases, and the expected profit of the downstream firm (i.e., assembler) and the consumer surplus increase as well. For substitutable suppliers, however, this might not be true. Particularly, when the default premium δ is small, both the expected profit of the downstream firm and consumer surplus may actually decrease, although the ex post profit of each coalition still increases with the formation of larger coalitions (smaller m). In essence, although upstream suppliers are always better off with more cooperation, the same may not be true for the downstream firm. Notably, a downstream firm that deals with complementary suppliers would generally prefer larger coalitions (e.g, highly integrated subassemblies) because they indirectly reduce the cost of default risk for the suppliers as well as the intensity of indirect competition (Jiang and Wang 2010). This enables the coalitions to sustain lower equilibrium wholesale prices. On the other hand, for substitutable suppliers a buyer would prefer smaller coalitions (e.g., a highly fragmented market) to strengthen the competition that would depress the equilibrium wholesale prices. Obviously, lower wholesale prices result in lower retail prices to improve consumer surplus (and vice versa). Given the optimal decisions for a given coalition structure (Stages 2 and 3), we next analyze how the individual suppliers strategically choose their equilibrium coalition structures (Stage 1).

5. Coalition Structure and Stability

In this section, we focus on characterizing the stable equilibrium coalition structures among upstream suppliers for the scenario where the amount invested in the risk-mitigating reserve fund by each of them is exogenously known. (We discuss the endogenous case in §6.1.) In this context, we first analyze the case of symmetric fund amounts for all suppliers and then the asymmetric case. We initiate our analysis by first discussing the stability concept used in this paper.

5.1. Coalition-Proof Nash Equilibrium (CPNE)

An often-used concept to characterize coalition stability is the Nash equilibrium (NE). A Nash-stable coalition is defined as one in which there is no individual profitable deviation for any party. Although NE allows for a simple verification, it does not account for profitable deviations as a group. As a remedy, the concept has been proposed of strong Nash equilibrium (SNE), which requires that a coalition structure is immune to deviation by any arbitrary set of suppliers. However, this concept suffers from imposing too strong of conditions on the coalitions and lacks consistency in definition (Bernheim et al. 1987). As an alternative, this paper adopts a refined stability concept, the coalition-proof Nash equilibrium (CPNE; refer to Bernheim et al. 1987 for details). In general,

- a CPNE must be self-enforcing and not strictly dominated by another self-enforcing strategy; and
- a strategy among a group of players is self-enforcing if every subgroup playsa CPNE strategy in its component game.

Therefore, unlike NE, CPNE allows suppliers to communicate and deviate as a group. However, CPNE does not consider all potential deviations as does SNE, but only the valid (by definition, self-enforcing) deviations that no proper subset of the defecting players can reach a mutually beneficial agreement to deviate from the deviation. In this sense, CPNE is more consistent and forward-looking than SNE. In particular, it allows for explicit characterization of all stable outcomes. For these reasons, CPNE has been used in the literature for analyzing coalition formation in a number of settings, including some involving generic risks (Bernheim and Whinston 1987, Genicot and Ray 2003). Henceforth in the paper, we use "stable" to denote "coalition-proof Nash-stable," unless specified otherwise.

5.2. Key Trade-Off in Coalition Formation

For a given coalition structure $\mathcal{S} = \{S_1, \ldots, S_m\}$, the expected profit of supplier i in a coalition alliance S_k is given by

$$\Pi_i(\mathcal{S}) = \pi_{S_k}(\mathcal{S}) G_{|S_k|}(F_{S_k}) \frac{F_i}{F_{S_k}}, \quad \forall\, i \in S_k. \tag{4}$$

When the reserve fund amount is known, based on (3), we know that supplier i should make his decision about whether or not to join a coalition based on the above profit expression. The expression involves three terms. The first term $\pi_{S_k}(\mathcal{S})$ denotes the profit for coalition S_k, if it survives, and can be derived from Proposition 1. The second term, $G_{|S_k|}(F_{S_k})$, measures the survival probability of a coalition, i.e., its probability of successfully fulfilling the order. So, $\pi_{S_k}(\mathcal{S}) G_{|S_k|}(F_{S_k})$ is the expected profit of coalition S_k taking into account the order default risk. Last, F_i/F_{S_k} denotes the share of coalition profit allocated to supplier i.

The above profit function reveals the key trade-off between joining large or small coalitions for supplier i. On one hand, joining a large coalition has the strategic benefit of increasing his survival probability $G_{|S_k|}(F_{S_k})$. On the other hand, a large coalition may not yield a satisfying profit share for him, because $\pi_{S_k}(\mathcal{S}) F_i/F_{S_k}$ may decrease in $|S_k|$. This represents the operational disadvantage of a large coalition. By focusing mainly on the operational disadvantage, existing literature (e.g., Granot and Yin 2008, Yin 2010) provides evidence that large coalitions are often not sustainable among firms where there is no supply risk. Also taking into account the strategic benefit, our model provides a more comprehensive account that generates new insights. The key lies in how suppliers leverage the two opposing forces above during the course of a coalition-formation decision.

To focus on the key trade-off, for now, we assume that the price premium δ that the downstream firm has to pay in the case of order default is minimal; i.e., $\delta = 0$. So, our basic framework represents a scenario where, if a supply entity fails, then there are plenty of external options available to "match" his price. This assumption is reasonable as long as the components are relatively commoditized. Nevertheless, we discuss the impact of $\delta > 0$ in §6.3.

5.3. Symmetric Suppliers

Suppose that all n suppliers have the same amount of fund F for dealing with order default risk (so they are equally risky). We first characterize the stable equilibrium coalition structure that will develop in this case and then discuss the factors that shape the coalition formation decision.

Our first result states that possible stable coalitions should be of similar sizes. In particular, stability disallows any two coalitions to differ by more than one supplier. Therefore, if the suppliers form m coalitions, there is only one configuration that is possibly stable. It is the one that has $n - m\lfloor n/m \rfloor$ coalitions of size $\lceil n/m \rceil$, and $m + m\lfloor n/m \rfloor - n$ coalitions of size $\lfloor n/m \rfloor$, where $\lfloor n/m \rfloor$ and $\lceil n/m \rceil$ denote the nearest integers that are (weakly) smaller and larger than n/m, respectively.

Proposition 2. *Consider n suppliers with identical reserve fund levels. Then, if CPNE contains m coalitions, the size of each coalition should be equal to either $\lceil n/m \rceil$ or $\lfloor n/m \rfloor$.*

Example 1. Suppose there are $n = 5$ suppliers. Let I_k represent a set of k identical suppliers. Then, Proposition 2 states that the possible stable coalition structures among the suppliers can only be one of the following forms: $\{I_5\}$, $\{I_2, I_3\}$, $\{I_1, I_2, I_2\}$, $\{I_1, I_1, I_1, I_2\}$, or $\{I_1, I_1, I_1, I_1, I_1\}$.

To determine which one of the above structures will be stable, we need to verify the following conditions characterized by $U(m)$, where $U(m)$ is the ratio of ex post payoff for a coalition of m suppliers versus a coalition of $m+1$ suppliers. (See Table A4 in the online appendix for detailed $U(m)$ expressions.)

Theorem 1 (CPNE with n Identical Suppliers). *For n suppliers with identical reserve fund levels F, there exists a unique CPNE with m^* coalitions. In particular, the suppliers*

(i) *will form a grand coalition ($m^* = 1$) if $U(1) \geq V_1(F)/V_n(nF)$;*

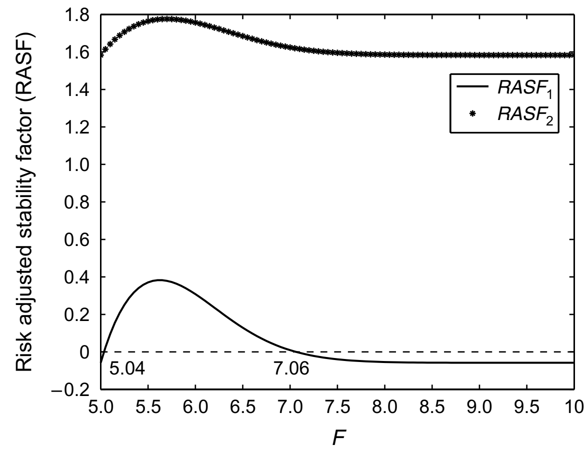
(ii) *will act independently ($m^* = n$) if $U(m) < V_1(F)/V_{\lceil n/m \rceil}(\lceil n/m \rceil F)$ for any $1 \leq m \leq n-1$;*

(iii) *will form m^* coalitions if $U(m) < V_1(F)/V_{\lceil n/m \rceil}(\lceil n/m \rceil F)$ for all $1 \leq m \leq m^* - 1$, and $U(m^*) \geq V_1(F)/V_{\lceil n/m^* \rceil}(\lceil n/m^* \rceil F)$, where $1 < m^* < n$.*

Theorem 1 suggests an algorithm to find the number of stable coalitions among n suppliers. Specifically, the number of stable coalitions among n suppliers is determined by the smallest m (where m is between 1 and $n - 1$) at which $U(m)$ exceeds $V_1(F)/V_{\lceil n/m \rceil}(\lceil n/m \rceil F)$. Equivalently, we can define for each $m \in \{1, 2, \ldots, n-1\}$ a risk-adjusted stability factor ($RASF_m$) as follows:

$$RASF_m = U(m) - \frac{V_1(F)}{V_{\lceil n/m \rceil}(\lceil n/m \rceil F)}. \quad (5)$$

Figure 3 **Risk-Adjusted Stability Factor (RASF) in a Three-Supplier System with Isoelastic Demand**



Then we can characterize the number of stable coalitions by searching for the smallest m where $RASF_m$ becomes nonnegative. This algorithm is illustrated via the following example.

Example 2. Suppose that there are $n = 3$ complementary suppliers, each facing an independent and identically distributed (i.i.d.) risk $\xi_i \sim N(5, 1)$, and market demand is $D(p) = ap^{-b}$ with $b = 8$. By Table A4, this results in, $U(m) = (1 + 1/(7 - m))^7$. We can then plot $RASF_m$ as a function of F as shown in Figure 3.[2]

Clearly, for relatively low values of F (between 5.04 and 7.06), $m = 1$ is the smallest index that makes $RASF_m$ nonnegative. Therefore $m^* = 1$ and the grand coalition $\{I_3\}$ is uniquely stable. As F increases, e.g., $F > 7.06$ (more than 98.03% individual survival probability), $RASF_2$ becomes the first nonnegative RASF, hence $m^* = 2$ (i.e., two stable coalitions $\{I_1, I_2\}$). By similar argument, when F is extremely close to 5 ($F < 5.04$, i.e., 51.6% individual survival probability), two coalitions are formed, and $\{I_1, I_2\}$ is stable. Note that independent structure $\{I_1, I_1, I_1\}$ is never stable because $RASF_2$ is always nonnegative for all values of F.

Based on the above, it is clear that the coalition formation decision depends on $RASF_m$ in (5). The second component of $RASF_m$ is a function of the reserve fund

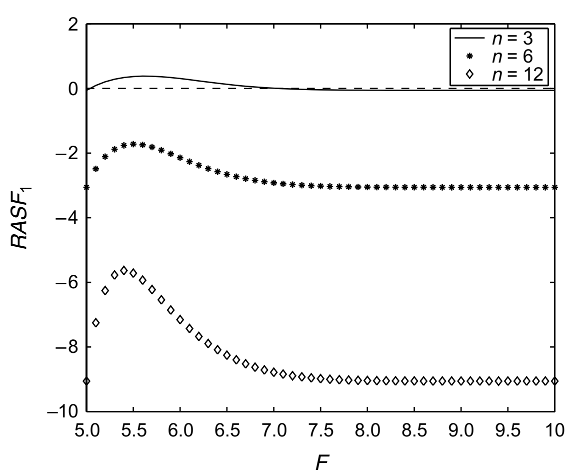
[2] As indicated before, the reserve fund amount F of an individual supplier corresponds directly to his survival probability (in this case, it is $\Phi(F - 5)$ for each supplier, where $\Phi(\cdot)$ is the CDF of the standard normal random variable) and inversely to his default risk. For all of our numerical values we report both F and the corresponding survival probabilities.

level F (or, equivalently, risk level) of the suppliers and the size of the supplier base n, and the type of supplier (i.e., complement or substitute) and the form of the demand function determine the first component $U(m)$ of RASF. We discuss below the detailed effects of the above four factors on the incentive to form coalitions.

Risk level of the suppliers (F). Example 2 illustrates that, when the suppliers themselves have access to a significant amount of funds to reduce their order default risks, they would prefer to form coalitions with a small number of other suppliers (i.e., large m^*). On the other hand, if the suppliers do not have such access, they would like to take advantage of resource sharing by forming large coalitions. The only exception is when the fund is quite limited (F extremely small, very close to μ) and suppliers cannot garner much risk-reduction benefit even by pooling their funds. In that case, the suppliers will opt for small coalitions (i.e., large m^*) to get better profit allocations.

Size of the supplier base (n). Larger coalitions are more achievable when the supplier base is smaller (lower n), i.e., when the intensity of direct competition among substitutable suppliers or indirect competition among complementary suppliers (Jiang and Wang 2010) is lower. This implies that, in assembly systems, low-modularization design, which would involve a small number of suppliers delivering these modules, facilitates cooperative decision making, whereas, in the substitutable case, cartels are more likely to be formed when there are fewer suppliers in the market. To illustrate this, consider Figure 4, which is based on Example 2. When $n = 3$, the grand coalition is achieved for $5.04 \le F \le 7.06$. When the number of suppliers increases to 6 or more, however, the grand coalition is never stable. The above two effects are summarized in Proposition 3 below.

Figure 4 **Risk-Adjusted Stability Factor with Index 1 ($RASF_1$) with Respect to the Size of the Supplier Base n**



Proposition 3. *In general, larger coalitions are more likely to be stable*

(i) *as the suppliers become riskier* (*or, equivalently, are endowed with a lower amount of reserve fund F*);

(ii) *when the number of suppliers in the supply base is relatively small* (*small n*).

As discussed before, the component type and the demand function shape coalition incentive through their effects on $U(m)$. To understand this better, for the rest of this section we restrict our attention to the three most commonly assumed demand functions in the related literature: isoelastic, linear-power (linear is a special case), and exponential (refer to Table A2 in the online appendix). Also, suppose that the pass-through rates of these functions, defined as the ratio of retail price change to the wholesale price change (dp/dW) (Tyagi 1999, Moorthy 2005), are greater than 50%. Note that this assumption implies that the consumers will shoulder more of the change in wholesale prices than will the retailer; this is natural in many industries (Besanko et al. 2005).

Structure of customer demand. Analysis of the demand functions suggests thata higher pass-through rate promotes the formation of larger coalitions. As illustrated in the online appendix, as the pass-through rate increases, the resource requirement for the grand coalition to be the stable equilibrium also increases. Recall that smaller coalitions will most likely lead to higher wholesale prices and consequently higher retail prices (Proposition 1), and the pass-through rate measures the ratio of change in retail price over the change in wholesale price. A higher pass-through rate then implies a more sensitive vertical structure in which inefficient upstream decisions (e.g., small alliances, high wholesale prices) will lead to higher downstream retail prices. Thus, the jeopardy of small alliances is amplified as the pass-through rate increases, and hence large-alliance structure becomes more rewarding and stable. Based on Table A2 in the online appendix, we can then conclude that isoelastic demands with lower levels of elasticity or linear-power demands that are more price sensitive are more conducive to larger coalitions.

Component/supplier type. It can also be shown that $U(m)$ for the substitutable case is smaller than for the complementary one, implying that large coalitions are more achievable among complementary than among substitutable suppliers. We illustrate this in the example below. This result is somewhat intuitive: since complementary suppliers are competing indirectly (rather than competing directly like substitutable suppliers), there is less reluctance on their part to enter into partnerships.

Example 3. Consider the same supplier set and market demand as in Example 2. For complementary suppliers, $U^C(m) = ((8-m)/(7-m))^7$. Theorem 1 shows that the grand coalition $\{I_3\}$ will be formed if $5.04 \le F \le 7.06$; otherwise, two coalitions $\{I_1, I_2\}$ will be formed. For substitutable suppliers, $U^S(m) = ((m+1)/m)^2((8-1/m)/(8-1/(m+1)))^7$. If $5.13 \le F \le 6.72$ (i.e., individual survival probability is between 55.17% and 95.82%), two coalitions $\{I_1, I_2\}$ will be formed; otherwise, independent coalitions $\{I_1, I_1, I_1\}$ will be formed. Note that, for any given F, substitutable suppliers yield smaller coalitions than complementary ones.

The above two effects are summarized in the proposition below.

Proposition 4. *In general, larger coalitions are more likely to be stable*
(i) *for supplier bases facing end customer demands with higher pass-through rates;*
(ii) *among complementary rather than substitutable suppliers.*

Risk reduction vs. competition reduction. Until now, we have focused on characterizing the conditions under which coalitions will be formed and whether the coalition will be large or small. A natural question that would arise is whether coalition formation is driven by suppliers' desire to reduce their risks or by the lure to reduce competition among themselves through cooperative decision making. Indeed, we can answer this question by characterizing the stable coalition structures in a riskless environment, as summarized specifically in the proposition below.

Proposition 5 (CPNE in Riskless Environment). *If the suppliers are effectively riskless (i.e., F is sufficiently large), they will form the maximum number of possible coalitions with the lowest possible sizes.*

In our model, coalitions can provide two kinds of benefits: risk mitigation and competition reduction. If the primary goal of coalition formation is competition reduction, suppliers should form a coalition even when they have a large amount of funds available for dealing with order defaults and are effectively riskless. However, the above proposition suggests quite the contrary. Indeed, the least cooperative structure will arise in this case, suggesting that the competition-reduction incentive alone does not lead to large coalitions.

When there are larger coalitions, the number of competing forces goes down and each coalition as a whole is able to obtain a higher profit from the downstream firm; so, one would expect that the suppliers would be better off with larger coalitions. However, this argument does not take into account the stability of such configurations. In particular, for larger coalitions to be stable, the benefit of adding one more supplier must be commensurate with the allocation that he will take away, and this might not be the case. Since suppliers individually decide on coalition formation in Stage 1 to maximize their own expected profits, very often the equilibrium structure does not reflect the optimum for the entire supply base (i.e., large coalitions). Therefore, it becomes more difficult to keep larger alliances stable in equilibrium under a riskless environment.

Note that this result conforms with literature that studies coalition formation using different stability concepts than ours in a riskless environment. For example, Yin (2010) applies the NE stability concept and derives a similar insight for complementary suppliers. In analyzing the CPNE coalition structure, we are able to extend this insight to both complementary and substitutable suppliers. Specifically, in the context of substitutable suppliers, we can show that an independent structure is the stable equilibrium for high values of F as long as there are more than two suppliers in the supply base (refer to the online appendix). So, clearly, the incentive for coalition formation does not lie in competition reduction. Rather, it is the risk of order default and the impetus to mitigate that risk through resource sharing that holds the coalitions together.

5.4. Asymmetric Suppliers

In the previous section, we consider the case where all suppliers have identical amounts of risk-management funds F and so are equally risky. In this section, we extend our analysis to the case when suppliers face the same i.i.d. exogenous shocks but hold different levels of reserve funds to deal with order default risks. The survival probability therefore varies across the suppliers.

For the sake of analytical tractability, we assume that there are two possible reserve fund levels for the suppliers. Specifically, there are n_L suppliers with low levels of reserve funds L and $n_H = n - n_L$ suppliers with high levels of reserve funds $H(> L)$; i.e., there are n_L high-risk and n_H low-risk suppliers. We need the following definition to characterize stable coalition structures.

Definition 1. Supplier coalitions $\{S_1, \ldots, S_m\}$ are *V-similar* if $V_{|S_k|}(F_{S_k}) \ge V_{|S_{k'}|+1}(F_{S_{k'}} + F_s)$ $\forall k, k' \in \{1, 2, \ldots, m\}$ and $s \in S_k$.

Intuitively, the above definition states that the difference between the survival probabilities of any pair of coalitions S_k and $S_{k'}$ in a V-similar coalition structure $\mathscr{S}$ should not be very large. Using this definition, we first identify a condition for stable coalitions that is quite similar to the one with identical suppliers in the last section, except that there is an adjustment in the $RASF_m$ expression of (5) to account for the asymmetry. Specifically, in this case, $RASF_m = U(m) - T_m$, where $\{T_m\}_{m=1}^{n-1}$ depends on both the risk and demographic profiles of the supplier base (see below).

Theorem 2 (CPNE Among Asymmetric Suppliers). *There exists a unique CPNE with m^* coalitions. In particular, the suppliers*

(i) *will form a grand coalition* ($m^* = 1$) *if* $U(1) \geq T_1$,

(ii) *will act independently* ($m^* = n$) *if* $U(m) \leq T_m\ \forall m,\ 1 \leq m \leq n-1$;

(iii) *will form* m^* *coalitions if* $U(m) \leq T_m\ \forall m,\ 1 \leq m \leq m^*-1$, $U(m^*) \geq T_{m^*}$, *and* $1 < m^* < n$,

where $T_m = \min_{\mathscr{S}}\{\max_{1\leq k\leq m,\, s\in S_k}\{V_1(s)/V_{|S_k|}(F_{S_k})\}\colon \mathscr{S}$ *is a V-similar m-partition of the supply base N*$\}$ *and the CPNE is the structure $\mathscr{S}$ that yields* T_{m^*}.

As in the symmetric case, Theorem 2 also suggests an algorithm to find the stable coalitions by searching for the smallest m at which $U(m)$ exceeds T_m or, equivalently, $RASF_m$ becomes nonnegative. Unfortunately, $RASF_m$ is not straightforward to graph in the asymmetric case because of the difficulty in graphically expressing T_m, which involves two reserve fund levels. Therefore, we provide an example to illustrate Theorem 2.

Example 4. Consider the demand $D(p) = ap^{-7}$, which yields $U(m) = ((7-m)/(6-m))^6$ for complementary suppliers. Suppose that $\xi_i \sim \text{Exp}(1/2)$, $L = 3$ (approximately 77.69% individual survival probability), $H = 9$ (approximately 98.89% individual survival probability), $n_L = 2$, and $n_H = 3$. Thus, $F_N = 33$, where $F_N = n_L L + n_H H$ is the total fund level for the supplier base.

There is only one 1-partition of N, hence $T_1 = V_1(3)/V_5(33) \approx 8.54 > U(1) = 2.99$. Thus, a grand coalition is not stable. By Definition 1, the set of V-similar 2-partitions of 5 suppliers contains only $\{L_2H_1, H_2\}$, where L_xH_y denotes a set of x low-reserve suppliers and y high-reserve suppliers. By using the expression for T_m in Theorem 2, we can find $T_2 \approx 3.96 > U(2) = 3.81$. Hence, a two-coalition structure is not a CPNE either. Similarly, the set of V-similar 3-partitions contains only $\{L_1H_1, L_1H_1, H_1\}$. It can be calculated that $T_3 \approx 3.16 < U(3) = 5.62$. Therefore, the CPNE contains three coalitions $\{L_1H_1, L_1H_1, H_1\}$. □

Based on the expression of $RASF_m$ in the asymmetric case, it is evident that the effects of supplier type and customer demand on the coalition sizes noted in Proposition 4 for symmetric suppliers remain valid since these two factors affect only $U(m)$ and they affect it in the same way as before. In fact, even the effects of the size of the supplier base for identical suppliers also carry over to the asymmetric case. Beyond these, the main new insight we gain from this section pertains to the effects of two types of asymmetries (for large-enough H and L) as discussed below.

Risk-level Asymmetry. The degree of asymmetry between risk levels in the supplier base can be characterized by H/L. The following example illustrates how this ratio affects the coalition structure.

Example 5. In Example 4 above, $H/L = 3$. Keeping the total reserve fund at the same level, i.e., $F_N = 33$, we can reduce H/L by increasing L to 4.5 and decreasing H to 8, which approximately corresponds to 89.46% and 98.17% individual survival probabilities for L- and H-type suppliers, respectively. The ratio H/L is now approximately 1.78. In that case, $T_1 \approx 6.56 > U(1) = 2.99$, $T_2 \approx 3.41$ for coalitions $\{L_2H_1, H_2\}$, and $U(2) = 3.81 \geq T_2$. The CPNE now contains only 2 coalitions (compared to 3 for Example 4), and the stable structure can be identified as $\{L_2H_1, H_2\}$.

The takeaway from the above example is that, for large coalitions to be stable, the reserve fund levels (or, equivalently, order default risks) of the supplier base cannot be too different from each other. Indeed, we formalize the above by establishing the following proposition for a grand coalition.

Proposition 6. *In general, given a demographic profile* (n_H/n_L) *and a total reserve fund amount F_N of the supplier base, a grand coalition is more likely to be sustained by suppliers with similar reserve fund levels* (*i.e., H/L closer to* 1).

Demographic Asymmetry. This asymmetry comes from the number of suppliers in the low- and high-funded groups. Consider two sets of suppliers with the same total resource level F_N and risk-level asymmetry H/L, but with the demographic distribution in one set more skewed toward low-funded suppliers, e.g., $n_H/n_L > n'_H/n'_L$. The following example shows that larger alliances are more likely to be stable in the latter one.

Example 6. Consider Example 4 again with $F_N = 33$ and $H/L = 3$, but suppose now we have 3 low-funded and 2 high-funded suppliers. Specifically, $n_L = 3$, $n_H = 2$, $L = 11/3$, and $H = 11$. We can then show that the CPNE in this case contains two coalitions $\{L_3, H_2\}$ compared to $\{L_1H_1, L_1H_1, H_1\}$ in Example 4.

Again, we can formalize the above insight in the following proposition about grand coalitions.

Proposition 7. *In general, given a risk profile H/L and a total reserve fund amount F_N of the supplier base, a grand coalition is more likely to be sustained when the supply base has relatively more suppliers with low reserve fund levels* (*i.e., n_H/n_L closer to* 0).

In summary, the main conclusion of the analysis in this section is that homogeneity in terms of risk profile and an abundance of suppliers with a limited amount of funds available for risk mitigation in the case of an order default incentivize the formation of large coalitions, and vice versa.

6. Robustness Analysis

To focus on the core issues related to supplier coalitions, we made several assumptions in our analysis in §5. The major ones are that (i) the amount of reserve fund F is an exogenously given parameter; (ii) the profit allocation among the coalition partners is proportional to their shares in the pooled reserve fund; and (iii) in the case of an order default, the downstream firm can procure the component(s) without paying a premium. In this section, we briefly discuss the implications of relaxing the above assumptions and identify to what extent the insights of §5 are affected.

6.1. Endogenous Reserve Fund Investment Decision

Until now we have assumed that ex ante investments by the suppliers in their reserve funds for risk mitigation are exogenous. However, such investments can be expensive because of the cost of capital (e.g., marginal return of capital and loss of other investment opportunities). So, the suppliers need to counterbalance the costs and benefits of coalition formation (see §5.2) against the costs and benefits of this investment. Keeping this in mind, in this subsection, we address the issue of upstream suppliers making their investment decisions in reserve funds before the coalition formation decision in Figure 3 (say, Stage 0), thus endogenizing the risk levels of the suppliers. Suppliers make these decisions competitively, and we characterize the resulting Nash equilibrium (NE) investment levels.

Suppose that a supplier's cost of investing at level F is $c_f(F) = vF$, where $v \geq 0$. We prove in the following that there is a unique level F^I (symmetric equilibrium) in which each supplier would invest. The corresponding stable CPNE coalition structure can then be identified via Theorem 1, as $m^I = m^*(F^I)$.

Proposition 8. *Assume that* $V_1(\hat{F})/V_k(\hat{F}+(k-1)F)$ *decreases in* $\hat{F}$ *for any given* F. *For* n *suppliers each with investment cost rate* v, *there exists an* $F^I > 0$ *and* $1 \leq m^I \leq n$ *such that it is a Nash equilibrium (NE) for each supplier to ex ante invest at level* F^I *in their reserve funds andfor suppliers to form* m^I *coalitions of similar sizes. In particular,*

$$F^I = \max\left\{F\colon \frac{v}{\pi(m^*)} \leq g_{\lceil n/m^*\rceil}\left(\left\lceil\frac{n}{m^*}\right\rceil F\right)\frac{m^*}{n} + G_{\lceil n/m^*\rceil} \cdot \left(\left\lceil\frac{n}{m^*}\right\rceil F\right)\frac{n-m^*}{n}\right\}, \quad m^I = m^*(F^I), \tag{6}$$

where $m^*(\cdot)$ *follows Theorem 1.*

Note that for technical tractability we need to enforce some assumption as stated in the proposition. This assumption states that the survival probability per unit of funds when operating alone versus joining another alliance should be high (low) when the fund level is low (high), which holds for any exponential distribution.

In general, the equilibrium investment level F^I increases and the number of stable coalition m^I decreases with the production and the investment costs. As the production cost increases, the margin becomes slimmer, making the loss due to order default more significant, and hence collaboration more attractive. The investment cost v has a similar impact. An environment where getting credit is costly (high v) incentivizes suppliers toward more resource pooling, yielding lean investment levels and more cooperation in equilibrium. On the other hand, a lower cost of capital hinders the formation of coalitions. Indeed, in the extreme case when the cost of capital is negligible, there is no incentive for the suppliers to form a coalition. This again supports our previous assertion that risk reduction is the primary motive for coalition formation.

6.2. Generalization of the Profit Allocation Rule

Our results so far are based on profits being allocated among the coalition partners proportional to their shares in the pooled coalition reserve fund. The existing cooperative game literature the in supply chain management area mostly uses allocations based on Shapley values (i.e., equal allocation in the absence of default risk; see Nagarajan and Sošić 2007, Granot and Yin 2008). Our proportional allocation indeed turns out to be equivalent to Shapley allocations when suppliers are symmetric.

Now consider a generalization of our allocation scheme in which the profits are shared according to $\gamma_{i,S_k} = F_i^u/\sum_{j\in S_k} F_j^u$ for some $u \geq 0$. This family of allocation rules is quite general. In particular, through such mechanisms, the profit can be allocated proportionally ($u = 1$, as in the main analysis), in favor of high-reserve suppliers (when $u > 1$) or in favor of low-reserve suppliers (when $0 < u < 1$). Even in this case, we can characterize the condition for a grand coalition to be stable as shown below.

Proposition 9 (Grand Coalition Among Asymmetric Suppliers Under General Allocations). *For a set of* n_L *suppliers with reserve levels* L *and* n_H *suppliers with reserve levels* H, *where* $n_L + n_H = n$, $H > L$ *and* $F_N = n_L L + n_H H$,

(i) *a grand coalition is a CPNE if and only if* $U(1) \geq \max\{G_1(L)/L^u, G_1(H)/H^u\}((n_L L^u + n_H H^u)/G_n(F_N))$;

(ii) *a grand coalition is more likely to be stable when* u *is closer to* $u_f = (\ln G_1(L)/G_1(H))/\ln(L/H)$.

Clearly, the grand coalition characterization is similar to that for the proportional allocation rule (Theorem 1) with adjustments to account for varying u.

The most interesting new insight is that a grand coalition will most likely be induced by a "fair" allocation $u_f = ((\ln G_1(L)/G_1(H))/\ln(L/H)) \in [0,1]$, where u_f incorporates the degree of heterogeneity in survival probabilities as well as reserve funds among the supply base. Moreover, even when the allocation rule is not fair, a grand coalition can still be stable provided that suitable values of u make allocations relatively fairer; i.e., make u close to u_f. Since the fair allocation u_f is always smaller than 1, it implies that, to induce grand coalition, the allocation scheme needs to properly favor the riskier suppliers in the supply base (i.e., the suppliers with lower levels of reserve funds).

Last, note that as the suppliers become more homogeneous, i.e., $L/H \to 1$, the fair allocation approaches the proportional rule used in the main analysis, i.e., $u_f \to 1$. Under the assumption that the partners in the shipping pool are relatively homogeneous, this suggests that the proportional profit allocation system used in that industry (as indicated in Haralambides 1996) might indeed be appropriate since such a system makes it more likely that a large coalition would be stable.

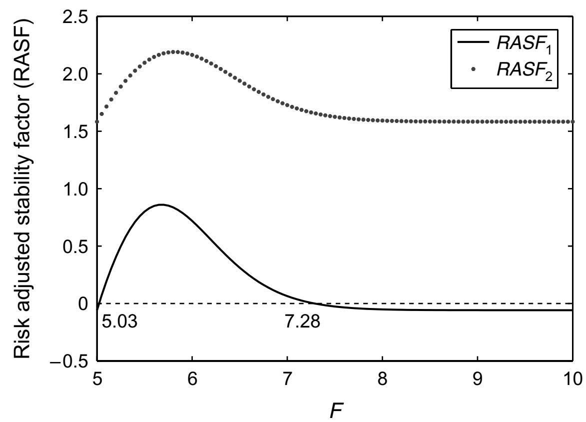
6.3. Positive Default Premium on Wholesale Prices

In analyzing the key trade-off of joining small versus large alliances, we assumed that in the case of an order default, the component can be procured from an alternate source in a frictionless manner (i.e., $\delta = 0$). Although such an assumption may be realistic under certain scenarios, in this section we allow $\delta > 0$ and investigate how it may affect coalition structures. That is, the downstream firm will take into account the possibility that each coalition might default with certain probability, in which case she would have to pay a premium δ_{S_k} to ensure supply, where $\delta_{S_k} = |S_k|\,\delta$ for complementary components and $\delta_{S_k} = \delta$ for substitutable ones.

In the online appendix we show that for symmetric suppliers the alliance structure in §5.2 remains valid as long as the premium δ is not too large. Specifically, we can use a set of refined RASFs which now depend also on δ, to identify the stable coalition structures. Rather than going into the details, we illustrate it with the following example.

Example 7. Consider the same scenario as in Example 2, i.e., an assembly system with $D(p) = ap^{-8}$, $C = 1$, and $n = 3$. According to Lemma A9 in the online appendix, in general, the structure in Theorem 1 will hold as long as $\delta \le 3.18$. Suppose that $\delta = 0.1$. Based on Figure 5, we can then deduce if the reserve fund level $F \in [5.03, 7.28]$, i.e., individual survival probability, is between 51.2% and 98.87%, respectively, then the grand coalition is uniquely stable. If $F < 5.03$ or $F > 7.28$, then a two-coalition structure $\{I_1, I_2\}$ is stable. An independent structure is never stable.[3]

Figure 5 **Risk Adjusted Stability Factor Among Complementary Suppliers with $D = ap^{-8}$, $n = 3$, $C = 1$, and $\delta = 0.1$**

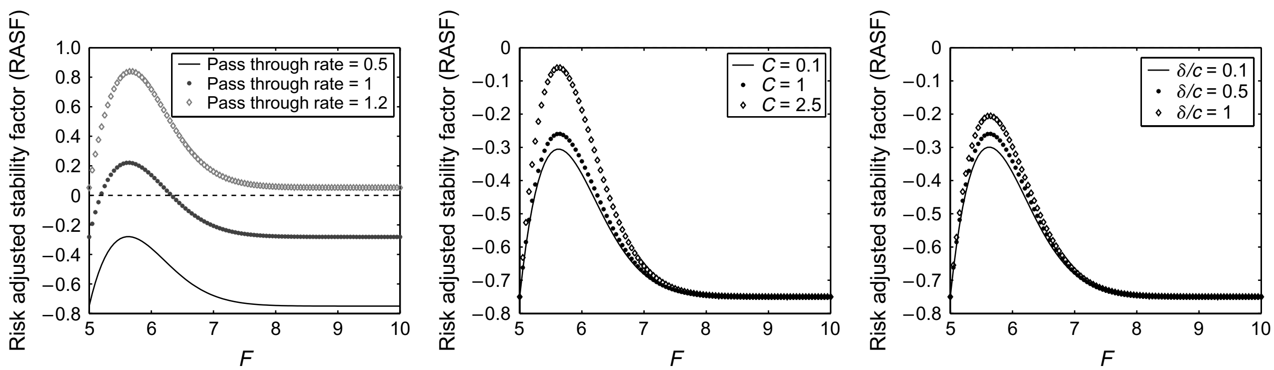


The coalition structures in the above example with $\delta > 0$ are quite similar to Example 2 with $\delta = 0$, except for the threshold reserve fund levels. Although the applicability of Theorem 1 requires the default premium δ to be below a threshold value, our numerical values have shown this condition to be not at all restrictive. For instance, in the above example with threshold $\delta = 3.18$, the equilibrium wholesale prices are between 0.53 and 1.48. These values are significantly less than the threshold default premium.

Also, the range of F that induces a grand coalition is wider for $\delta > 0$, implying that suppliers will be more incentivized to join larger coalitions, and, therefore, a smaller number of coalitions should be observed in equilibrium for a positive default premium. Our numerical values suggest this insight to be quite robust. They also suggest that the curvature of RASF with $\delta > 0$ is robust to problem parameters. Figure 6 shows the change of $RASF_1$ with respect to the pass-through rate, the total production cost ($C = nc$), and the default premium-to-component cost ratio δ/c. In general, the curves shift rightward/upward as these factors become more significant, indicating that stable large alliances are more achievable when the downstream firm is more sensitive to upstream price changes, when the raw material/labor is more costly, and when the default penalty is more severe. We again wish to point out that the threshold δ for our results to be valid is not too restrictive, indicating the generality of our results. For the examples shown in Figure 6,

[3] When the default premium is above a threshold value, e.g., $\delta > 3.18$ for Example 7, we cannot analytically guarantee that the structure in Theorem 1 will still hold. However, the CPNE can still be verified numerically for small numbers of suppliers. For Example 7, when $\delta = 4$, a grand coalition will be formed among three suppliers when $F \in [5, 8.25]$; otherwise, if $F > 8.25$, the two-coalition structure $\{I_1, I_2\}$ is uniquely stable.

Figure 6 $RASF_1$ for Complementary Suppliers with Variation in (i) Pass Through Rates, (ii) Total Production Costs, (iii) Default Premium/Component Cost Ratios



the maximum δ goes beyond the total production cost $C = cn = 1$.

Last, we comment that we assume a per unit premium δ in our analysis. An alternative assumption is a lump sum payment, reflecting the fixed searching/expediting fees of emergency sourcing. That is, if a coalition S_k defaults, the downstream firm can still procure at the preannounced wholesale price w_{S_k}, yet it costs her Δ_{S_k} to seek new suppliers. All results in §§4 and 5 hold unconditionally for this alternative assumption.

7. Concluding Remarks

Forming cooperative alliances/coalitions with other firms is an important lever that an organization may seek beyond its internal measures to deal with business risks. Such an arrangement equips its members with better resources and opportunities and also changes the way they operate and envision themselves. This phenomenon is observed in a number of industries including agriculture, marine transportation, and manufacturing. Alliances can be especially effective in dealing with external risks that a firm might be facing. However, given the individual and collective profit motives that an alliance must satisfy, the incentives to form them and their stability are issues of research interest. So far, supply chain management literature has studied alliance formation focusing primarily on demand-side risks. However, one of the salient features of the recent business environment has been a significant increase in the supply-side risk. The objective of this paper is to understand what types of stable supplier alliances will develop in the presence of the risk of supply (order) default, and how alliance formation incentives are shaped by the business environment.

To achieve our objective, we use a channel framework consisting of n upstream suppliers and one downstream firm where the suppliers face the risk of completely defaulting in fulfilling their orders and can form alliances to counteract such risk. Our framework is applicable for both complementary and substitutable suppliers and has a number of other characteristics that distinguishes it from the existing literature. Specifically, each supplier faces an exogenous random shock that creates the default risk. Each of them also incurs an operating cost to maintain a fund that has been reserved to deal with the shock, provided that the fund amount is large enough. Since the funds are generic and shareable, entering into alliances can further reduce the default risk through fund sharing among partners, although the risk-mitigating benefit of such funds exhibits diminishing returns. Also, the profit allocation mechanism among the partners in an alliance is proportional to their shares in the pooled fund (equivalent to Shapley value-based allocation for symmetric suppliers). The above enables us to deal with an important trade-off that a supplier faces while deciding whether to join an alliance not captured before in the literature—doing so decreases a supplier's default risk but also might have adverse implications in terms of his profit share.

We first focus on the scenario where all suppliers are symmetric in terms of fund (or risk) levels and fully characterize the stable alliances that will develop among them in equilibrium. It turns out that the sizes and numbers of stable alliances depend primarily on a measure, termed the "risk-adjusted stability factor" (RASF), that succinctly captures the business environment of the suppliers. Further analysis of this measure reveals that larger alliances are stable when (i) the suppliers are riskier (i.e., their fund levels are lower), (ii) the supplier base is smaller, (iii) the suppliers are complements (rather than substitutes), and (iv) the pass-through rate of the customer demand is higher. On the other hand, the converse business conditions result in smaller alliances. One of our most important insights is that it is the need to reduce the risk of order default through resource sharing, rather than to reduce competition, that encourages and provides stability to large alliances. Consequently, if suppliers are risk free, they tend to shy away from forming alliances and mostly operate independently, and when they are very risky, they tend to form grand coalitions. We also characterize the exact composition of stable alliances that develops even when the suppliers are asymmetric in terms of their fund levels. Most of the above insights continue to hold, except when the supplier base is diverse in terms of their reserve fund levels or contains too many suppliers with high amounts of reserve funds.

Traditionally, the stability of grand coalitions has been important to antitrust authorities because of its implications for monopoly power (although many industries are exempted from such laws under a variety of instances as exemplified in Government of Canada 2002). Our context brings another aspect of such large alliances to light; they are less prone to order default. So, conditions for stable large alliances result in less risky supply chains. Given the importance of reliable supply chains in world commerce, antitrust authorities need to keep this impact in mind while evaluating them (especially in industries where supply risks are of concern). For example, the stability of alliances discussed in this paper, like TI and FPOs, has far-reaching implications. Any disruption in marine oil supply, which accounts for the majority of oil transportation, can be devastating for the world economy (*The Economist* 2012), whereas disruption in the food supply in countries like India has major food security ramifications (Economist Intelligence Unit 2012). Moreover, our analysis also suggests a certain rationale as to why we see more alliances in industries like automobile (International Labor Organization 2005) and agriculture (Bright et al. 2010). The former may be attributed to the complementary nature of the components, and the latter may arise from the fact that most of the members of organizations like FPOs in India are small farmers who face significant amounts of risk and have low amounts of reserve funds accessible to them.

We also consider the case where the suppliers first decide how much they want to invest in their costly risk-management reserve funds before their alliance formation strategy. It turns out that, if the investment cost is relatively low (e.g., in the present interest rate environment), they will invest significantly and not form alliances so as not to share the profits. On the other hand, if resource investment is costly, each of them will not invest much and depend on resource sharing in large alliances to reduce their risks. Interestingly, the results of this paper are quite robust. For example, they hold true irrespective of whether or not a default premium is to be paid in addition to the wholesale price in the case of a supply default, as long as the premium is not too high. The primary effect of a positive default premium is that it increases the sizes of the alliances and reduces their number. We also generalize our analysis by considering nonproportional profit allocations. Specifically, we demonstrate what form of fair allocations (maybe nonproportional) can provide stability to alliances by showing disproportionate favoritism toward risky suppliers.

Although this paper tackles how order default risk would affect alliance/coalition formation and how suppliers trade off the pros and cons of such a strategy, there are certainly many ways to extend this line of work. A more in-depth study would call for further differentiation among the suppliers—more than the two levels considered in this paper, with more refined characterization of the risks they are exposed to. Extending the analysis to more general supply chain networks and partial order default settings would also be interesting. One could also consider other types of supply-side risks, including random yield and fluctuating raw material costs, possibly bringing risk correlation into the picture. Another possible avenue for future research is to focus on resources that are product- or relation-specific, e.g., inventory or capacity, and hence can only be shared under certain circumstances. This will possibly require separate analysis for complementary and substitutable cases. Last but not least, this paper focuses on understanding the interplay between two driving forces of forming alliances: supply risk mitigation and competition reduction. Factors such as demand risk and negotiation power are left outside the scope of the study. One possibility is to extend the model to incorporate some other potential drivers of alliance formation such as demand risk mitigation, benefits due to better access to markets, higher bargaining power, and economies of scale. This would require significantly different modelling and analysis frameworks. However, our conjecture is that some of these factors would result in further adjustments in RASFs developed in this paper that in turn would affect the incentives for alliance formation. Another possibility is to find proxies for these drivers and empirically test and evaluate their relative importances in alliance decisions.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/mnsc.2015.2175.

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References

Babich V (2010) Independence of capacity ordering and financial subsidies to risky suppliers. *Manufacturing Service Oper. Management* 12(4):583–607.

Babich V, Burnetas AN, Ritchken PH (2007) Competition and diversification effects in supply chains with supplier default risk. *Manufacturing Service Oper. Management* 9(2):123–146.

Bernheim BD, Whinston MD (1987) Coalition-proof Nash equilibria ii. applications. *J. Econom. Theory* 42(1):13–29.

Bernheim BD, Peleg B, Whinston MD (1987) Coalition-proof Nash equilibria i. concepts. *J. Econom. Theory* 42(1):1–12.

Bernstein F, Federgruen A (2005) Decentralized supply chains with competing retailers under demand uncertainty. *Management Sci.* 51(1):18–29.

Besanko D, Dubé J-P, Gupta S (2005) Own-brand and cross-brand retail pass-through. *Marketing Sci.* 24(1):123–137.

Bright D, Seville D, Borkenhagen L, Vorley B, Boyle G, Lundy M, Fowler P (2010) *Think Big Go Small: Adapting Business Models to Incorporate Smallholders into Supply Chains*, Briefings for Business (Oxfam International, Oxford, UK), https://www.oxfam.org/sites/www.oxfam.org/files/b4b-think-big-go-small.pdf.

Chaturvedi A, Martínez-de Albéniz V (2011) Optimal procurement design in the presence of supply risk. *Manufacturing Service Oper. Management* 13(2):227–243.

Cho S-H (2014) Horizontal mergers in multi-tier decentralized supply chains. *Management Sci.* 60(2):356–379.

Chopra S, Reinhardt G, Mohan U (2007) The importance of decoupling recurrent and disruption risks in a supply chain. *Naval Res. Logist.* 54(5):544–555.

Dong L, Tomlin B (2012) Managing disruption risk: The interplay between operations and insurance. *Management Sci.* 58(10):1898–1915.

Economist Intelligence Unit (2012) Global food security index 2012: An assessment of food affordability, availability and quality. Last accessed September 1, 2015, http://pages.eiu.com/rs/eiu2/images/EIU_DUPONT_Food_Index_July_2012.pdf.

Economist, The (2012) The new grease? How to assess the risks of a 2012 oil shock. (March 10), http://www.economist.com/node/21549949.

Garella PG, Peitz M (2007) Alliances between competitors and consumer information. *J. Eur. Econom. Assoc.* 5(4):823–845.

Genicot G, Ray D (2003) Group formation in risk-sharing arrangement. *Rev. Econom. Stud.* 70(1):87–113.

Girotra K, Netessine S (2014) *The Risk-Driven Business Model: Four Questions That will Define Your Company* (Harvard Business Press, Cambridge, MA).

Government of Canada (2002) Government response to the report of the House of Commons Standing Committee on Industry, Science and Technology "A plan to modernize Canada's competition regime." Accessed September 1, 2015, https://www.ic.gc.ca/eic/site/icgc.nsf/vwapj/GovtResponse.pdf/$file/GovtResponse.pdf.

Granot D, Yin S (2008) Competition and cooperation in decentralized push and pull assembly systems. *Management Sci.* 54(4):733–747.

Gulati R, Singh H (2008) The architecture of cooperation: Managing coordination costs and appropriation concerns in strategic alliances. *Admin. Sci. Quart.* 43(4):781–814.

Gümüs M, Ray S, Gurnani H (2012) Supply-side story: Risks, guarantees, competition, and information asymmetry. *Management Sci.* 58(9):1694–1714.

Gurnani H, Gümüs M, Ray S, Ray T (2012) Optimal procurement strategy under supply risk. *Asia-Pacific J. Oper. Res.* 29(1):1240006.

Hamel G (1991) Competition for competence and inter-partner learning within international strategic alliances. *Strategic Management J.* 12(1):83–103.

Haralambides H (1996) The economics of bulk shipping pools. *Maritime Policy Management* 23(3):221–237.

International Labor Organization (2005) *Automotive Industry Trends Affecting Component Suppliers: Report for Discussion at the Tripartite Meeting on Employment, Social Dialogue, Rights at Work and Industrial Relations in Transport Equipment Manufacturing* (International Labor Organization, Geneva).

Jiang L, Wang Y (2010) Supplier competition in decentralized assembly systems with price-sensitive and uncertain demand. *Manufacturing Service Oper. Management* 12(1):93–101.

Kazaz B, Webster S (2011) The impact of yield-dependent trading costs on pricing and production planning under supply uncertainty. *Manufacturing Service Oper. Management* 13(3):404–417.

Kim S-H, Netessine S (2013) Collaborative cost reduction and component procurement under information asymmetry. *Management Sci.* 59(1):189–206.

Kleindorfer PR, Saad GH (2013) Managing disruption risks in supply chains. *Production Oper. Management* 14(1):53–68.

Li J, Netessine S (2011) Partnering with competitors—An empirical analysis of airline alliances and multimarket competition. Working paper 2011/114/ACGRE/TOM, INSEAD, Fontainebleau, France.

Lohr S (2011) Stress test for the global supply chain. *New York Times* (March 19), http://www.nytimes.com/2011/03/20/business/20supply.html?pagewanted=all&_r=0.

Lynch GS (2011) Supply chain risk management. Gurnani H, Mehrotra A, Ray S, eds. *Supply Chain Disruption: Theory and Practice of Managing Risk* (Springer, New York), 319–336.

MacLeod C, Wiseman P (2008) Economy rocks China factories. *USA Today* (October 22), http://usatoday30.usatoday.com/money/world/2008-10-21-red-dragon-china-factories-economy_N.htm.

Ministry of Agriculture (2013) Policy and process guidelines for farmer producer organisations, Report, Department of Agriculture and Cooperation, Ministry of Agriculture, Indian Government, New Delhi.

Moorthy S (2005) A general theory of pass-through in channels with category management and retail competition. *Marketing Sci.* 24(1):110–122.

Mowery DC, Oxley JE, Silverman BS (1996) Strategic alliances and interfirm knowledge transfer. *Strategic Management J.* 17(S2):77–91.

Nagarajan M, Bassok Y (2008) A bargaining framework in supply chains: The assembly problem. *Management Sci.* 54(8):1482–1496.

Nagarajan M, Sošić G (2007) Stable farsighted coalitions in competitive markets. *Management Sci.* 53(1):29–45.

Nagarajan M, Sošić G (2009) Coalition stability in assembly models. *Oper. Res.* 57(1):131–145.

Netessine S, Zhang F (2005) Positive vs. negative externalities in inventory management: Implications for supply chain design. *Manufacturing Service Oper. Management* 7(1):58–73.

Packard WV (1989) *Shipping Pools* (Lloyd's of London Press, London).

Paulraj A, Lado AA, Chen IJ (2008) Inter-organizational communication as a relational competency: Antecedents and performance outcomes in collaborative buyer–supplier relationships. *J. Oper. Management* 26(1):45–64.

Rimal A, Schmitz A (1999) Freeze risk and adoption of technology by orange producers. *J. Agribusiness* 17(2):93–103.

Saghafian S, Van Oyen MP (2012) The value of flexible backup suppliers and disruption risk information: Newsvendor analysis with recourse. *IIE Trans.* 44(10):834–867.
SCDigest (2012) Global supply chain news: Toyota taking massive effort to reduce its supply chain risk in Japan. *Supply Chain Digest* (March 7), http://www.scdigest.com/ontarget/12-03-07-2.php?cid=5576.
Singh K, Mitchell W (2005) Growth dynamics: The bidirectional relationship between interfirm collaboration and business sales in entrant and incumbent alliances. *Strategic Management J.* 26(6):497–521.
Sodhi MS, Son B-G, Tang CS (2011) Researchers' perspectives on supply chain risk management. *Production Oper. Management* 21(1):1–13.
Song Y, Ray S, Li S (2007) Structural properties of buyback contracts for price-setting newsvendors. *Manufacturing Service Oper. Management* 10(1):1–18.
Sošić G (2011) Impact of demand uncertainty on stability of supplier alliances in assembly models. *Production Oper. Management* 20(6):905–920.
Stuart TE (2000) Interorganizational alliances and the performance of firms: A study of growth and innovation rates in a high-technology industry. *Strategic Management J.* 21(8):791–811.
Swinney R, Netessine S (2009) Long-term contracts under the threat of supplier default. *Manufacturing Service Oper. Management* 11(1):109–127.
Tomlin B (2006) On the value of mitigation and contingency strategies for managing supply chain disruption risks. *Management Sci.* 52(5):639–657.
Tomlin B (2009) Impact of supply learning when suppliers are unreliable. *Manufacturing Service Oper. Management* 11(2):192–209.
Tyagi RK (1999) A characterization of retailer response to manufacturer trade deals. *J. Marketing Res.* 36(4):510–516.
Varadarajan P, Cunningham MH (1995) Strategic alliances: A synthesis of conceptual foundations. *J. Acad. Marketing Sci.* 23(4):282–296.
Wadecki A, Babich V, Wu O (2012) Supply chain disruptions: Theory and practice of managing risk. Gurnani H, Mehrotra A, Ray S, eds. *Manufacturers' Competition and Subsidies to Suppliers* (Springer, London), 141–163.
Wang Y (2006) Joint pricing-production decisions in supply chains of complementary products with uncertain demand. *Oper. Res.* 54(6):1110–1127.
Wang Y, Gerchak Y (2003) Capacity games in assembly systems with uncertain demand. *Manufacturing Service Oper. Management* 5(3):252–267.
Wang Y, Gilland W, Tomlin B (2010) Mitigating supply risk: Dual sourcing or process improvement? *Manufacturing Service Oper. Management* 12(3):489–510.
Wei MM, Yao T, Jiang B, Young ST (2013) Profit seeking vs. survival seeking: An analytical study of supplier's behavior and buyer's subsidy strategy. *Production Oper. Management* 22(2):269–282.
Yang Z, Aydin G, Babich V, Beil DR (2009) Supply disruptions, asymmetric information, and a backup production option. *Management Sci.* 55(2):192–209.
Yang Z, Aydin G, Babich V, Beil DR (2012) Using a dual-sourcing option in the presence of asymmetric information about supplier reliability: Competition vs. diversification. *Manufacturing Service Oper. Management* 14(2):202–217.
Yin S (2010) Alliance formation among perfectly complementary suppliers in a price-sensitive assembly system. *Manufacturing Service Oper. Management* 12(3):527–544.
Yoshino MY, Fagan PL (2003) The Renault–Nissan alliance. HBS Case 303-023, Harvard Business School, Boston.