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A three-stage supply chain investment model  
under asymmetric information

Per J. Agrell and Peter Bogetoft

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DISCUSSION PAPER

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Voie du Roman Pays, 34  
B-1348 Louvain-la-Neuve  
Belgium

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**A three-stage supply chain investment model  
under asymmetric information**

Per J. AGRELL<sup>1</sup> and Peter BOGETOFT<sup>2</sup>

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**Abstract**

Specific supply-chain investments are vital in achieving faster lead-time performance and more competitive costs. In practice, such as in the highly leveraged telecom sector, the coordinating original equipment manufacturers (OEM) often delegate the upstream coordination of suppliers to contract manufacturers. This can be justified by informational advantages or economies of scale. However, the rationale of such schemes has also been challenged by analytical work on three-stage chains, leading to open questions. In this paper, we study the organizational and contractual choice of a supply chain coordinator (say an OEM) to either control or delegate the investment decision of some shared resource (say dedicated machines, information or product standards, etc) to a contract manufacturer (CM) or to an upstream supplier in a three-stage supply chain. The analysis derives closed-form results for the economic performance of three scenarios under asymmetric information on investment cost: direct contracting with an integrated CM-supplier, decentralized contracting to tier-1 suppliers and centralized contracting to tier-1 and tier-2 suppliers. The results show that the observed practice to delegate investments to tier-1 and possibly tier-2 suppliers leads to relatively poor performance due to under-investments. The superior arrangement is the centralized conditional model, where the OEM forces coordination among upstream suppliers by offering conditional financing. We close the paper with an analogy to the Boeing 787 supply chain and some discussion about the assumptions and applicability of the model.

**Keywords:** supply chain, coordination, investments, contracts, organization.

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<sup>1</sup> Université catholique de Louvain, CORE and Louvain School of Management, B-1348 Louvain-la-Neuve, Belgium. E-mail: per.agrell@uclouvain.be. This author is also member of ECORE, the association between CORE and ECARES.

<sup>2</sup> Department of Economics, Copenhagen Business School, DK-2000 Frederiksberg, Denmark.

## 1. Introduction

A theme of increasing academic and applied interest under the heading "supply chain management" (SCM) is the effectiveness of partnership policies among interfacing enterprises to achieve sustainable competitive advantages. Indeed, there is some consensus in the management literature that SCM is dependent upon a series of close relationships with which the focal enterprise builds and maintains long-term relations (Ellram and Cooper (1990); Cooper et al. (1997)). To achieve greater economic benefits, the supply chain may pursue strategies of collaboration and coordination among all or a subset of the supply chain partners. Beyond arm-length transactions of orders and deliveries, the collaborative supply chain encompasses some of three distinguishing dimensions (Nyaga et al., 2010) (i) information sharing, (ii) joint relationship effort and (iii) relationship specific investments. The coordinated supply chain is normally interpreted as involving some kind of delegated decision making or joint arbitration function in order to implement plans that maximize some jointly defined surplus function, e.g. vendor managed inventory (VMI).

By information sharing is meant all organized dissemination of information related to nominal and utilized capacity, actual and forecast demand, production, sales, orders, inventory levels, product design, costs, revenues, or subsets of those information sets. The sharing of information has been proven to prevent distortions in supply chain ordering patterns (Lee et al., 1997) and to lead to higher supply chain surplus under some conditions (Lee and Whang, 2000).

Joint relationship effort translates to the non-contractual work devoted to planning, coordination, monitoring and problem solving between supply chain partners (Min et al., 2005).

Relationship specific investments, or "dedicated investments" Williamson (1983); Heide and John (1988, 1990) are non-redeployable investments in capital or human resources tailored to a specific client or supplier. The dedicated investments are common in supply chains, ranging from common equipment, tools, operating systems and procedures, quality standards, training, administrative and information standards and transportation carriers and platforms. (Ojala and Hallikas, 2006) describe the structure of the investment decision-making jointly between OEMs and suppliers, including an analysis of the different risks involved. The dedicated investments may enable higher returns and sustainable competitive advantage, if embedded in interfirm routines and processes (Anderson and Weitz, 1992; Ganesan, 1994; Dyer and Singh, 1998; Rokkan et al., 2003). The existence of dedicated investments can be seen as a commitment device (Ganesan, 1994) and it is also empirically perceived as such by both parties (Anderson and Weitz, 1992; Jap and Ganesan, 2000; Nyaga et al., 2010).

(Rinehart et al., 2004) note lower levels of trust in shared investments than in purely contractual relationships in a field study among managers and executives. Indeed, the investment may be interpreted as a sign of initial low trust, securing commitment. The

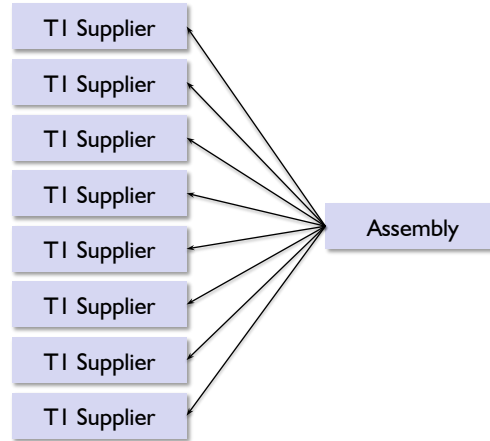


Figure 1: Classical 1-tier supply chain organization (e.g. automotive).

model in (Agrell et al., 2004) provides some intuition for this finding, as the investment incentives under asymmetric information and stochastic demand are severely diluted by double moral hazard in typical supplier-contract manufacturer-OEM supply chains.

Previous work has shown that collaborative supply chain investments will depend partly on the intrinsic incentives in the overall project, the technological and economic risks assigned to the parties, the trust induced in the chain and the information available to the decision makers at the time of the decision. The original conjecture in this paper is that organizational scheme in itself will introduce a bias in the investment behavior. To provide some intuition, consider the classical single-tier supply chain organization in Figure 1 below. The chain coordinator here centralizes the information, initiative and the contracting with all the tier-1 suppliers. The gain of control comes at a considerable cost of coordination and information, which could be prohibitive if the number of suppliers is large, dynamic or uncertain. As a consequence, supply chains in e.g. telecommunications, computers and automotive industry use a two-tier structure as depicted in Figure 2 below. In this organization, the direct interactions with the coordinator are reduced, control and contracting for tier-2 suppliers are delegated to the tier-1 suppliers (e.g. contract manufacturers in the telecommunication industry). Expectedly this leads to decreased direct downstream contracting costs, but it may also bring advantages in terms of cost and time if the tier-1 suppliers exercise leverage or economies of scale toward the tier-2 suppliers. However, as will be shown in our model, this organization may also lead to delayed, suboptimal or duplicated coordination investments.

This work is devoted to the question of incentive provision for dedicated investments in supply chains under the (Mentzer et al., 2001) definition (three or more independent entities directly involved in the upstream and downstream flow). In particular, we investigate a dimension that has received less attention in the supply chain coordination

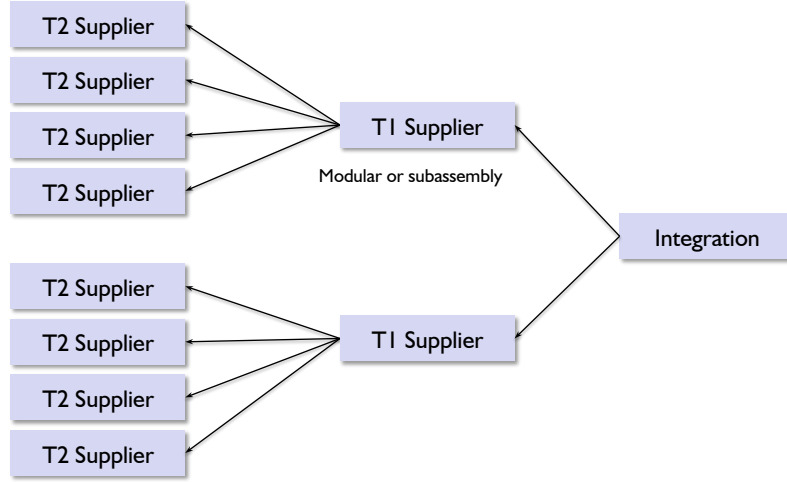


Figure 2: Structure of 2-tier supply chain organization (e.g. new Boeing 787, MCC Smart).

literature (cf. (Burgess et al., 2006)) namely the centralization or delegation of investment decisions in shared resources. The findings suggest that optimal coordination can be designed as a menu of contracts, which supports anecdotal evidence in the electronics industry that usually has been explained using arguments related to asymmetric information and mitigation of market power.

By a small investment decision model, we address a number of assumptions that have been voiced in the literature, albeit not systematically addressed: (i) asymmetric information on costs for dedicated investments, (ii) organizational design using delegation or centralization of investment provision, (iii) the arbitrage between incentive alignment and information sharing mechanisms for investment provision. The first assumption is relevant empirically and methodologically since joint investments or resources seem to be precursors (commitment signals) to information sharing (fruits of trust). Exposure to expropriation (rent extraction) through the revelation of private cost is indeed one of the risks perceived in supply chains. One of the conclusions in (Agrell et al., 2004) is indeed the commitment-inducing and information-gathering effect of direct investments upstream.

We study the organizational and contractual choices of a supply chain coordinator (say an OEM) that wants to induce investments in some shared resource, (say dedicated machines, information or product standards etc). The investment can take place either at a contract manufacturer (CM) or at an upstream supplier in a three-stage supply chain. However, the investment has substitute character, i.e. there is no value in having the two levels investing. Demand is considered deterministic and known by the coordinator in a single-period model. We present a formal model to investigate three prevalent scenarios; the full integration of the CM-supplier, a decentralized scenario where the

OEM provides an incentive scheme to the CM to invest on behalf of the chain, possibly with subsequent outsourcing of the investment to the supplier from the CM, and a centralized scenario with parallel contracting of both CM and supplier investments. For each scenario, we derive optimal investment policies for the CM and upstream supplier, and we determine resulting expected surplus for the OEM. The results show that the delegation of investments to tier-1 and possibly tier-2 suppliers leads to relatively poor performance due to under-investments. The superior arrangement is the centralized conditional model, where the OEM forces coordination among upstream suppliers by offering conditional financing. We close the paper with some discussion about the assumptions and applicability of the model.

## 2. The Boeing 787 Case Revisited

To illustrate the findings in an alternative setting to the telecommunication sector, we will use the Boeing 787 Case (cf. (Tang et al., 2009)). As customary in the aerospace sector, Boeing operated a classical single-tier supply chain with thousands of suppliers coordinated by the central assembly as in Figure 1. For the 787 Dreamliner, Boeing implements a 2-tier system with 50 "strategic partners" responsible for the modular subassemblies of their respective modules corresponding to Figure 2. The new decentralized system, inspired by the supply chain and contracting structure of certain automotive manufacturers such as MCC Smart (cf. (Stephan et al., 2008)), was motivated by planned savings in development cost and time through higher outsourcing. In terms of our problem setting, the Boeing case offers several interesting observations. First, the increased delegation of contracting and coordination to tier-1 suppliers initially decreased development costs and [OEM] investments, but at the expense of specific investments in coordination procedures and software systems ("Exostar", (Tang et al., 2009)). Due to various problems in the supply chain organization, some tier-2 and tier-3 suppliers did not implement these systems or did not provide accurate information for the coordination. Moreover, the decentralized 787 Dreamliner production, as opposed to the earlier centralized 737 production, was characterized by long delays, threatening the confidence and future orders of the current customers. Facing these delays and technical coordination problems, Boeing eventually resorted to direct involvement [investments] at tier-1, tier-2 and tier-3 suppliers to address problems and to improve leadtime performance. This example may serve as backdrop for the stylized model with the roles "OEM", "CM" and [Tier-2] "Supplier" adequately assigned to "Boeing", the "system partners" and the "tier-2 suppliers", respectively.

## 3. Model

We present a formal model to investigate three prevalent scenarios; the full CM-Supplier integration, a decentralized CM scenario and centralized scenario with parallel

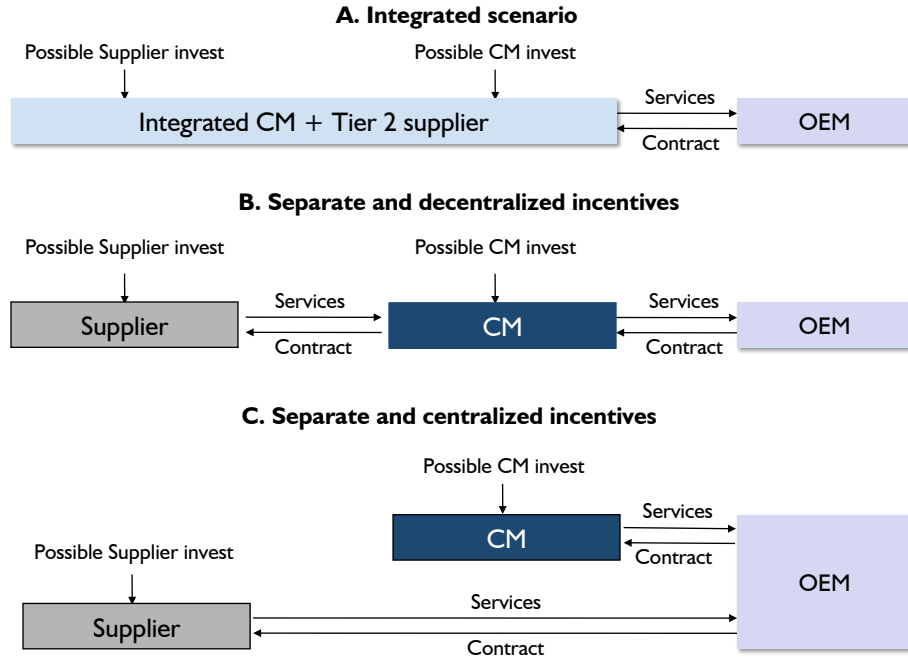


Figure 3: Investors at tier 1 (contract manufacturer, CM) and tier 2 (supplier), OEM and contractual organization and delegation.

contracting of both CM and Supplier investments (cf. Fig 3). For each scenario, we determine optimal investment policies for the CM and Supplier under supply chain coordination from an OEM.

In the first scenario, where CM and Supplier are integrated, the CM-Supplier internalizes the investment and the loss of investment is due to rationing by the coordinator in response to information problems.

The second scenario simplifies the agency problem by delegating to the CM to handle Supplier issues, but the results are characterized by lower investments and some distortions in the providership. Hence, the contractual simplicity comes at a cost in this sense<sup>1</sup>.

The third scenario provides the coordinator with the added opportunity to contract separately with both the CM and the Supplier. This arrangement brings several advantages for the investment incentives to limit costs, but it is shown that the relative

<sup>1</sup>We do not explicitly differentiate the direct contracting transactional costs (administration, tendering etc) from the organization of the investment. This assumption is valid as far as these cost are constant, independent, observable or verifiable by the OEM and/or CM.

profitability of investments at the two levels will crucially depend on the structure of this contracting organization, e.g. the role of the Supplier ‘bid’ for the contracting and the CM’s right to initiate investments.

### 3.1. *Investment decision*

The CM and the Supplier can both achieve the effects of the investment, the costs of which are private information to the CM and Supplier respectively. The investments are strict substitutes. We shall now formalize the setting in the simplest possible way without losing key properties of the situations or the solution.

### 3.2. *Coordinator Original Equipment Manufacturer: OEM*

The aim of the coordinator is to maximize his surplus. In a situation where a new supply-chain desirable investment is possible at the Supplier and CM levels, respectively, we may assume that the downstream value generated if these investments are undertaken is  $V > 0$ . This downstream value is known and verifiable, to abstract from the moral hazard problem of fulfilling investment obligations. If the OEM – as the chain coordinator – has to pay a total compensation  $T$  to the CM and/or the Supplier, e.g. by increasing the margin on products or services procured or through a lumpsum payment, the profit contribution for the OEM is

$$W = V - T$$

The objective of the coordinator is to maximize the expected value of  $W$ . Note that it follows from the postulated objective of the coordinator that he explicitly trades off the benefit derived from the costs of ensuring these. For sufficiently high values of  $V$ , however, this accommodates the objective of simply minimizing the expected costs of making the necessary CM and Supplier activities.

### 3.3. *Contract Manufacturer: CM*

The CM can make an investment at cost<sup>2</sup>  $x > 0$  that is private information to the CM. The Supplier and coordinator only knows that the CM’s cost – to make it simple - is independent from Supplier’s cost, and that it follows a probability distribution with density  $f(x)$  and cumulative probabilities  $F(x)$ . The aim of the riskneutral CM is to maximize expected revenue minus costs, i.e.

$$E [R - I(R, x)x|x]$$

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<sup>2</sup>Cost is here seen as the effective net real annuity of depreciation and capital cost in an efficient capital market as to avoid burdening the presentation with the consideration of the actual investment pattern, taxation and life cycle maintenance pattern.



where  $R$  is the compensation paid to the CM. It may depend on his investments as well as any other possible verifiable information, including the Supplier investment. (We shall investigate the effects of asymmetric information not only about investment cost but also about who actually performs it in the final discussion).  $I(R, x)$  is the (binary) investment decision of the CM, one when investment is undertaken and value zero otherwise. Lastly, we note that the expectation is a conditional one. It is the expected benefit given the private information about relevant investment cost.

### 3.4. Supplier

We model the Supplier in an analogous manner. The Supplier can invest at costs  $y > 0$ , private information for the Supplier. The investment cost  $y$  follows a probability distribution with density  $g(y)$  and cumulative probabilities  $G(y)$ , common knowledge to all players. The Supplier maximizes expected revenue less cost, i.e.

$$E [S - J(S, y) y | y]$$

where  $S$  is the revenue paid to the Supplier.

## 4. Solutions

To simplify the exposition and since we consider a service (e.g. quality screening) that can be provided at either the CM or the Supplier level, we will assume that the distributions of the costs  $x$  and  $y$  are independent but identically distributed. In the case of substitute investments, the chain surplus obtained is  $V$  unless none of the CM and Supplier invests, i.e.  $I = 0$  and  $J = 0$  then it is normalized to zero.

Since both the CM and the Supplier are rational, independent and profit maximizing, investment will only take place if it is incentive compatible for the agents. This means that the coordinator anticipates the usual incentive compatibility constraints for the CM and the Supplier, respectively:

$$I(R, x) = \arg \max_{\delta} \{E [R - \delta x | x]\} \quad (1)$$

$$J(S, y) = \arg \max_{\delta} \{E [S - \delta y | y]\} \quad (2)$$

Thus, both agents maximize their respective information rents with respect to the contractual mechanism imposed. In addition, individual rationality (IR) constraints must be fulfilled for each agent, since participation is voluntary. The reservation utility is normalized to zero.

$$E [R - I(R, x) x | x] \geq 0 \quad (3)$$

$$E [S - J(S, y) y | y] \geq 0 \quad (4)$$

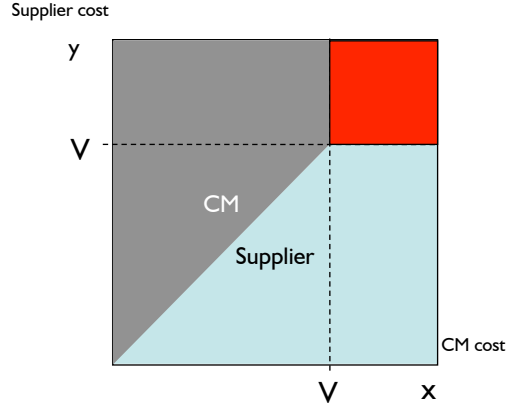


Figure 4: CM and Supplier investments, first-best solution for substitutes.

#### 4.1. First-best solution

Before investigating the possible solutions under asymmetric information, we observe as a benchmark the first-best solution. This is here defined as the solution when the coordinator has perfect information about the costs of the CM and Supplier. The optimal solution is clearly to invest iff

$$\min\{x, y\} \leq V$$

and in this case to implement the least costly investment level, i.e. if  $x = \min\{x, y\} \leq V$ , the CM invests,  $y = \min\{x, y\} \leq V$ , the Supplier invests (in cases of ties the solution can be picked arbitrary).

The first best solution is illustrated in Figure 4 below. We see that investment takes place at the least costly level and that we only forgo investments in the red are where no level can make the investments at costs below the value  $V$ .

We will now turn our attention to three scenarios regarding the organization of the supply chain; (i) integrated CM-Supplier and centralized contracting, (ii) independent CM and Supplier under centralized contracting, (iii) unbundled CM and Supplier under decentralized contracting.

#### 4.2. Integrated solution

An integrated CM-Supplier will of course make the investment at the least costly level, i.e.

$$Z = \min\{X, Y\}$$

with cumulative distribution

$$H(z) = \text{Prob}\{Z \leq z\} = 1 - [1 - F(z)][1 - G(z)]$$

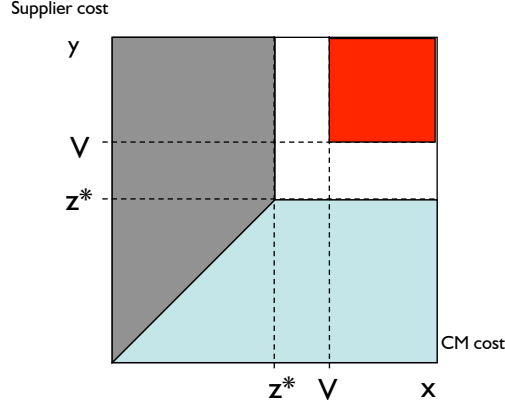


Figure 5: CM and Supplier investments, integrated case, substitutes.

Since the coordinator only knows  $H$ , not the specific  $z$ , his best strategy is to make a take-it or leave-it offer to the CM-Supplier "consortium", cf. (Tirole, 1988). This is a general result from mechanism design that has many applications, cf. e.g. (Antle et al., 1999).

Let  $z^*$  be coordinator's offer, the coordinator's expected value is

$$E(W) = [V - z^*]H(z^*)$$

Since the first factor is the net benefit when investment takes place and the provider, the CM-Supplier entity, is paid  $z^*$ , and the last factor is the probability that the CM-Supplier actually accepts and implements the investment.

**Proposition 1.** *The optimal contract for the integrated case is found as the solution  $z^*$  to*

$$z^* = V - [H(z^*)/h(z^*)]$$

The result (see Figure 5) for the integrated case is a rationing  $z^*$  with respect to  $V$ , reflecting the tradeoff between welfare and the information rents extracted by the CM-Supplier. By increasing  $z^*$ , the improvements are undertaken more often – but they are also more costly. We see that when investments do take place, they are implemented at the right level. The solution is attractive except that there are some coordination losses due to under-investments (white area). In general, the share of investments rationed away is decreasing in the chain surplus externality  $V$  (e.g the overall interest to improve time-to-market) and increasing with the uncertainty related to the investment cost, cf. (Antle et al., 1999).

This underinvestment is a direct consequence of the rationing mechanism used to lower the information rents that the CM-Supplier "consortium" can earn. We illustrate the rationing with two examples.

**Example 1.** Assuming that  $V = 1$  and that  $z$  follows a uniform distribution on  $[0, 1]$ , we get  $z^* = 1 - z^*/1$  or equivalently,  $z^* = 0.5$ . Hence, the coordinator deliberately forgoes half of the attractive investments in order to get the other investments at lower costs.

**Example 2.** As another example, let us assume that  $x$  and  $y$  are independent, uniformly distributed on  $[0, 1]$ . The cumulative distribution of  $z = \min\{x, y\}$  is therefore  $1 - (1 - z)^2$  with density  $2(1 - z)$ , such that the optimal  $z^*$  is given by

$$z^* = V - [1 - (1 - z^*)^2] / [2(1 - z^*)]$$

For  $V = 1$  we now obtain  $z^* = 0.354$  as investment threshold level.

In the analysis above, we have assumed that the coordinator cannot verify which of the two investments (the CM investment  $I$  or the Supplier side investment  $J$ ) the integrated entity undertakes - if any. If the investment type can be verified, e.g. concerning tangible assets or by access to open book procedures, the above solution can be improved. This situation is analyzed in details in (Antle et al., 1999). Here we show that an optimal solution involves the coordinator setting two cost thresholds,  $x^*$  and  $y^*$ , one for each of the two investments. Payment to the CM Supplier consortium will then depend on which investment is undertaken: It is  $x^*$  when  $(I, J) = (1, 0)$  and  $y^*$  when  $(I, J) = (0, 1)$  and 0 otherwise. The corresponding investment strategy of the integrated entity will be to pick  $I = 1$  if  $x^* - x \geq y^* - y$  and  $x^* - x \geq 0$  and  $J = 1$  if  $y^* - y > x^* - x$  and  $y^* - y \geq 0$ , i.e. the integrated entity picks the investment to maximize information rents (and breaks ties in favor of  $I$  here). This solution will lead to less rationing. However, it will involve a coordination inefficiency in the sense that the least-cost investment may not be implemented. What matter is cost compared to the thresholds. In such a “handicapping system” the coordinator would tend to favor investments about which he is better informed. If the expected values of  $x$  and  $y$  are the same but the spread of the former is larger than the spread of the latter, the coordinator would tend to set  $x^* < y^*$ .

#### 4.3. Decentralized contracting

The subsequent negotiation with the Supplier to achieve the coordination is here equivalent to a delegation of the subcontracting of the Supplier to the CM. I.e, the coordinator incentivizes the CM and the CM can then decide whether to make the necessary investments or to outsource it to the Tier-2 supplier.

In this case, the coordinator can consider the CM as the single contracting partner. Much like in the case of integrated ownership, the CM can be characterized by its costs  $z$  of ensuring the new services with value  $V$ . In the present case, and given the separate ownership, however, the distribution of the CM’s direct or indirect cost  $z$  will reflect the internal incentive problem between the CM and the Supplier. The CM in its relation

with the Supplier faces the same problems as the coordinator does in its relation to the CM.

The CM can carry out the investment himself at a cost of  $x$ . Alternatively, he can try to outsource the investment to the Supplier level.

As before the optimal solution is found by backwards induction. Assume that the coordinator has offered  $z^*$ . Two situations can now be distinguished. In the first, the CM has costs  $x > z^*$  and must therefore rely on Supplier to do the investment. In the second, the CM has costs  $x \leq z^*$  and can therefore make a profit by doing the necessary investments itself. Still, it may reduce costs by outsourcing if the Supplier has even lower costs. We shall now analyze these cases.

The first situation where  $x > z^*$  is the simplest one. The CM has only one possibility, namely to outsource. It offers Supplier a payment  $y^*$  so as to solve

$$\max_y (z^* - y)G(y)$$

Or equivalently using the first order characterization

$$y^* = z^* - \frac{G(y^*)}{g(y^*)}$$

That is, the CM rations against the Supplier in same way as the coordinator rations against the CM or the integrated CM-Supplier above. Let  $y^*(z^*)$  be the solution to this problem.

The second situation where  $x \leq z^*$  is one in which investment is certainly going to take place, but where the CM can possibly improve its profit margin by the outsourcing.

Using  $y^{**}$  as a threshold towards the Supplier, the CM solves for a given threshold  $z^*$

$$\max_y (z^* - x)[1 - G(y)] + (z^* - y)[G(y)]$$

To see this, observe that with probability  $[1 - G(y^{**})]$  the Supplier will decline the investment opportunity and the CM will rely on its own investment. If, on the other hand, the Supplier undertakes an investment, which happens with probability  $G(y^{**})$ , the CM earns the margin between the coordinator's compensation  $z^*$  and its own compensation to the Supplier,  $y^{**}$ . Let  $y^{**}(x, z^*)$  be a solution to the above problem.

**Proposition 2.** *The optimal contract for the se CM under decentralized contracting is to offer the investment to the Supplier with the threshold  $y^{**}$  set as the solution to*

$$y^{**} = x - \frac{G(y^{**})}{g(y^{**})}$$

**Example 3.** *In the case of  $y$  uniformly distributed on  $[0, 1]$  and  $x \leq 2$ , we obtain  $y^{**} =$*

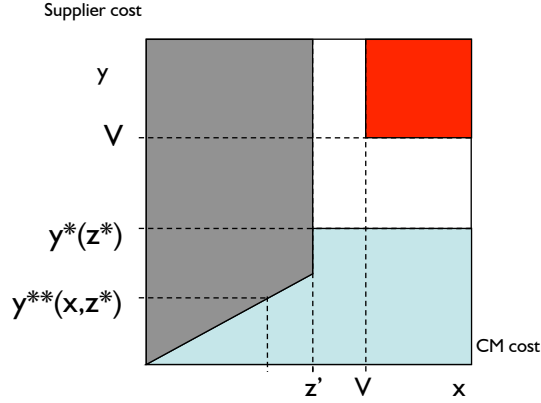


Figure 6: CM and Supplier investments, decentralized contracting with outsourcing, substitutes.

$x/2$ .

We can now summarize the CM's strategy. For  $x > z^*$  it outsources using  $y^*(z^*)$  and the Supplier invests with probability  $G(y^*(z^*))$ . For  $x \leq z^*$ , there is always going to be investment, either by the Supplier when  $y \leq y^{**}(x, z^*)$  or otherwise by the CM.

From the point of view of the OEM, this means that choosing  $z^*$  leads to CM or Supplier investment with probability  $F(z^*) + [1 - F(z^*)]G(y^*(z^*))$ .

The coordinator therefore chooses  $z^*$  to solve

$$\max_z (V - z)[F(z) + [1 - F(z)]G(y^*(z))]$$

The solution with decentralized contracting among vertical separated CM and Supplier activities is illustrated in Figure 6 below.

We see that there is a general underinvestment as represented by the white area. Also, we see that the CM tends to favour its internal investments compared to Supplier investments. Again, this is a consequence of the rationing – in this case the CM rations against possibly less costly Supplier solutions to save information rents awarded to the Supplier level. Again, this represents a coordination loss for the chain.

**Example 4.** Revisiting the previous example for uniformly distributed investment costs on  $[0, 1]$ , we get that  $y^*(z) = z/2$  and inserting this into the coordinator's problem, we see that she will maximize  $(V - z)[z + (1 - z)z/2]$ . For  $V = 1$ , the corresponding first order condition is a second degree polynomial, and choosing the correct root (the left one) we get  $z^* = (8 - \sqrt{28})/6 \simeq 0.4514$ . This means that the coordinator's trade-off

between the probability of investment and the price to pay is affected – it is now possible to lower the payment with less risk of forgoing investment.

The intuition is that since the CM has the possibility to outsource the investment, the probability distribution of the least cost alternative is having more mass on lower values than the uniform distribution. Indeed, if only the CM can provide the service, the probability of acceptance using  $z$  is  $F(z) = z$  while with the CM able to outsource also, the probability of acceptance is  $[F(z^*) + [1 - F(z^*)]G(y^*(z^*))] = z + (1 - z)\frac{z}{2}$  taking into account the optimal response of the CM in his outsourcing activities.

In the analysis above, we have assumed that the coordinator cannot monitor if the investment takes place at the CM site or at the Supplier site. This naturally depends on the level of observability of the investment (tangible or not tangible). If the investment type can be observed, and if we relax the limited liability constraint into one of expected non-negative profits, it may be possible to improve the solution as demonstrated in (Mookherjee, 2006).

#### 4.4. Open centralized contracting

We now turn to an organization where the coordinator centralizes the contracting to both the CM and the Supplier. There are two possible interpretations of this setting. In the first, the coordinator uses unconditional control in the sense that his contracting of the CM is independent on the reaction that his contracting has on the Supplier and vice versa. This is the most obvious and probably the most natural contracting in a practical setting. It sends clear signals to the CM and the Supplier, but at the risk of double investments.

The second interpretation involves conditional strategies. The coordinator may use one of the parties as the default provider and the other as an optional provider. Thus, for example, the coordinator could first invite the Supplier to do the investment and if it declines, it could turn to the CM for possible investments, as a backup. Clearly, the latter solution has some resemblances with the decentralized solution above. Still, it will be different as we shall see since the coordinator does not have the information about the CM cost that the decentralized strategies made use of.

The unconditional centralized solution requires the coordinator to choose costs targets  $x^*$  and  $y^*$  that the CM and Supplier, respectively, will get covered if they invest. The cost targets are set by the coordinator by solving

$$\max_{x,y} (V - x)F(x) + (V - y)G(y) - V[F(x)G(y)]$$

To see this, observe that the coordinator expected net benefit is the value  $V$  net of payment to the CM if the CM invests plus the net benefit from the Supplier's investments minus the value if they both invest (to balance out the double counting of values from the first two terms).

This problem leads to first order conditions

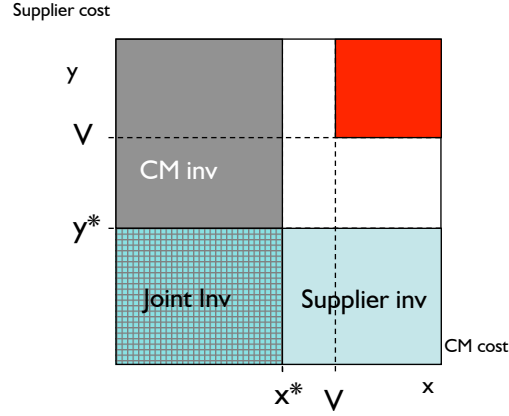


Figure 7: CM and Supplier investments, centralized individual contracting, substitutes.

$$x^* = V[1 - G(y^*)] - [F(x^*)/f(x^*)]$$

$$y^* = V[1 - F(x^*)] - [G(y^*)/g(y^*)]$$

We see that the first-order conditions have the same general structure as earlier. The coordinator offers less than the possible value of the investment, i.e. he rations, to save information rents. In the present setting, the starting point is moreover not the value  $V$  but rather the discounted values  $V[1 - G(y^*)]$  and  $V[1 - F(x^*)]$  respectively, i.e. it is only the value  $V$  multiplied by the probability that the other level do not invest that counts. This reflects that the attainable value in this case is the value that is not already extracted by the other level. This leads to a more severe under-investment to lower the costs of double investments at low costs at both levels.

The solution is illustrated in Figure 7

**Example 5.** In the case of  $V = 1$  and uniform costs on  $[0, 1]$ , for example, we get  $x^* = y^* = 1/3$ . Hence, the coordinator rations more harshly against the CM and Supplier (using  $1/3$  as opposed to  $1/2$  in the case of possible investment in one level only) to lower the cost of double investments. More generally, in the case of uniform costs on  $[0, 1]$  and value  $V$ , the symmetric solution is

$$x^* = y^* = \frac{V}{2 + V}$$

The coordinator will always choose to ration - if only slightly for large values of  $V$ . This happens for the following reason: when the cost targets are getting closer to the upper limit 1, the marginal cost of rationing is declining since the forgone investments



are most likely picked up by the other level. Also, the marginal benefits from rationing are increasing since the double investment problem is high when the cost targets are high and therefore the marginal saving in double investment costs is increasing for larger value of the targets.

#### 4.5. Conditional centralized contracting

Consider next the conditional centralized solution. Let us assume that the Supplier is the primary provider and that the CM may be called upon to invest if the Supplier declines. The alternative situation with the CM being the primary and the Supplier the secondary provider is similar. The conditional centralized solution requires the coordinator to choose a cost target  $y^*$  that is offered to the Supplier and cost target  $x^*$  that is offered to the CM if the Supplier has declined  $y^*$ .

These targets are set to solve

$$\max_{x,y} (V - y)G(y) + (V - x)F(x)[1 - G(y)]$$

To see this, observe that the coordinator expected net benefit is composed by two terms. The first is the value  $V$  net of payment to the Supplier  $y^*$  if the Supplier invests. This happens with probability  $G(y^*)$ . The second term is the net benefit if the Supplier declines and the CM accepts. This happens with probability  $[1 - G(y^*)]F(x^*)$ .

This problem leads to first order conditions

$$x^* = V - [F(x^*)/f(x^*)]$$

$$y^* = V - (V - x^*)F(x^*) - [G(y^*)/g(y^*)]$$

We see that the first order conditions have a structure quite similar to the previous problems. Indeed, the optimal cost threshold for the CM,  $x^*$ , is exactly as it would be if the CM were the only possible provider. This is not surprising since the CM in our setup is the secondary provider, i.e.  $x^*$  is used when Supplier has already declined to do the investments. In setting  $x^*$ , the coordinator therefore faces the usual trade-off of lowering the price when investment takes place and at the same time running the risk of no investments. The second first order condition is also of the usual form, except that the value to be gained is lowered by the expected gains forgone by not using the CM as the provider. That is, the value from having Supplier do the investment is reduced by the value of the option of using the CM as the provider.

The solution is illustrated in Figure 8 below.

**Example 6.** In the case of cost uniformly distributed on  $[0, 1]$  and value  $V$  (at the most 2), the optimal solutions are  $x^* = V/2$  and  $y^* = (3/8)V$ .

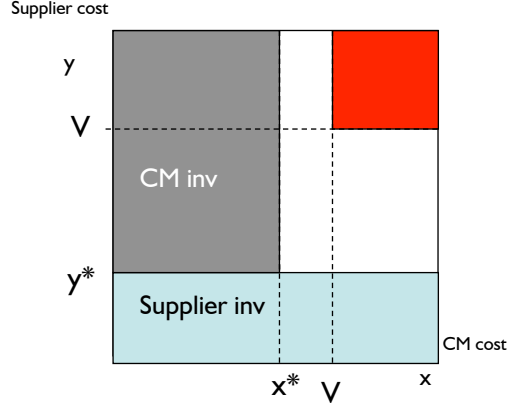


Figure 8: CM and Supplier investments, centralized conditional contracting, substitutes.

It may seem counter-intuitive that we are willing to pay more for the CM investment than for the identical Supplier investment. However, this is a consequence of the rent-saving exercise. If the same opportunity is offered to both providers, the only role of the secondary provider would be to increase the investment probability. In the optimal solution, the secondary provider is also used as a competitor against the primary provider.

**Proposition 3.** *The conditional solution is always weakly superior to the unconditional solution.*

The intuition behind the Proposition is clear: simply observe that the unconditional solution is also feasible in the conditional case – it is just not optimal. The disadvantage of the conditional approach from a practical perspective, however, is that it takes more time using a sequential two-stage approach rather than a simple single-stage approach. Also, this would make investment planning in the CM more difficult since it cannot plan an investment based on its own cost alone – it must await the response of the Supplier.

The conditional approach can be refined into a series of conditional offer: First, Supplier gets an offer of a relatively low cost target. If the Supplier declines, the CM gets an offer at a slightly higher level. If the CM declines, a new and higher offer is made to the Supplier and so on. Such sequential or parallel bargaining can lower the rents to the Supplier and CM levels, but it would run into more serious practical problems of time needed and investment planning as discussed above. For this reason, we shall not expand on it.

## 5. Conclusion

To summarize the findings, we table the outcome for the case of uniform costs  $[0, 1]$  and welfare  $V = 1$  in Table 1.

Table 1: Outcomes, uniform example

Contracting	$x^*$	$P(I, J)$	$E(W)$	Rationing	Misallocation	Double invest
First-best	—	1.000	0.667	No	No	No
Integrated	0.354	0.583	0.376	Yes	No	No
Centralized cond	0.500	0.750	0.417	Yes	No	No
Decentralized	0.451	0.575	0.316	Yes	Yes	No
Centralized open	0.333	0.556	0.333	Yes	No	Yes

The centralized conditional solution is the preferred option for substitute investments as it avoids misallocations (i.e., lowest cost investment is implemented) and does not involve useless duplicated investments. There are still losses associated with the outcome. The losses are due to rationing. To save information rents paid to upstream agents, the OEM foregoes investments for some costs levels that are less than the values generated by the investment.

More generally, our results point at the importance of controlling investments in supply chains, and our analysis serves to pinpoint important issues to be dealt with, viz. the limitation of information, the coordination of investments and the implementation of all wealth-enhancing investments. Returning to the illustrative example of the Boeing 787 supply chain, we see that the manufacturer tried decentralized contracting after incurring to high fixed costs with centralized contracting. However, the resulting underinvestment in the second stage lead to cost reductions, but also failing leadtime performance. Qualitatively, these results confirm our findings. Eventually, the hybrid centralized-decentralized approach resulting from the Boeing experimentation might have been improved with the suggested centralized conditional contracting, forcing the tier-1 and tier-2 suppliers to openly agree on the coordination investments made and their costs.

Of course, in reality, further complications will matter and it would be relevant to extend our analysis to account for some of these.

One relevant extension would be to combine the investment analysis with analysis of operational incentives after the incentives. In practice, the investment decision may impact the possibilities to monitor and incentivize the upstream suppliers and this may alter relative value of investing in the two tiers.

Another extension could be to introduce imperfect monitoring of the investments. If the investment levels cannot be perfectly monitored, we would have to rely on imperfect contracts and again the relative attractiveness of investments in the two tiers may be affected. A simple one-tier model with imperfect monitoring of investment effort is (Bogetoft and Olesen, 2003).

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