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WHEN MANUFACTURERS HOLD INFORMATION BACK FROM STRONG SUPPLIERS

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Abstract. Supply chain coordination and collaboration in general requires dedicated investment by the members of the chain in order to decrease cost, increase capacity or mitigate risks. Usual assumptions in the literature include predefined contractual structures, common information on capacity, costs and added value generated. However, evidence suggests that supply chain collaboration is not as prevalent as theory would predict, indicating that true decision-makers may operate under different assumptions. In a supply chain model involving a dyad we prove the existence of equilibria under which information asymmetry between supplier and buyer is preferred: the buyer will keep information about relationship-specific investments private. We use a Stackelberg model for the single-period interaction between two parties when the buyer has to undertake a relationship-specific investment. Both parties have outside options and the upstream supplier has the leading role. We provide closed form results for general conditions and prove under mild conditions that a manufacturer may rationally seek to hide information about the quality and the relationship specific investment costs from the supplier so as to safeguard profits. A numerical instance illustrates the results.

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1. Introduction

The surge for intensified supply chain collaboration and the necessity to intensify information exchange within supply chains in order to implement more effective, efficient and timely cost-efficient value-added operations are well accepted empirical managerial priorities. Indeed, once a firm's processes have been optimized, further advances in profitability require coordinated efforts to maximize value and to minimize costs in the whole supply chain. To achieve coordination, firms exchange information about capacity, inventory, demand and allocation. Initiatives such as supply chain collaboration, *e.g.*, Collaborative Forecasting, Planning and Replenishment (CPFR), the extended enterprise [28] and, in general, supply chain coordination projects are described as "driving force[s]" [23] or "core capabilities" (idem) of firms. In practice, non-trivial application of supply chain collaboration involves some costly investments from concerned chain members, *e.g.*, in common information systems, platforms, routines, tools, fixtures or product design constraints. Once undertaken and coordinated, these investments facilitate the decision-making and implementation of common policies within the chain at minimum cost. The relationship specific investments for coordination frequently include internal resources, such as capital and human resources within the organization, as well as opportunity costs like declined orders for

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dedicated capacity that are non-verifiable costs in the contracting sense. Here, we wish to concern ourselves primarily with the investment costs and returns that accrue to the firm that made them.

In an empirical study of 500 UK industrial buyers in manufacturing, [29] consider the performance of buyer-supplier exchanges. Their findings separate financial from non-financial factors. Non-financial factors impacting negatively performance were: "value destroyed in the relationship but difficult to quantify", confidence abuse, price increases and information-sharing risk. When the buying firms are too small and the economic prospects in their respective sectors are poor or uncertain, they do not invest in relationship-specific assets. However, even for larger manufacturing organizations in growth sectors such as electronics and telecommunications industry, [29] finds that agency problems limit the realized investment on the buyer's part and hence impact the performance of the relationships and the supply chains.

Although the issue is related to the classical question of relationship specific assets (RSA) and strategic incentives to invest in such assets, our research angle is different and partially contradicting conventional wisdom. In most previous work, the downstream buyer is exploiting upstream investment in specific assets by undermining margins (Stackelberg leadership) or opportunistically renegotiating the contract once it has been signed (hold-up). These models intuitively assume that bargaining power resides at the buyer's side, supply markets are competitive and the investments are undertaken upstream. The empirical evidence for such findings are found in fast moving consumer goods (FMCG) sold through consolidated retailers. The findings suggest requiring contractual commitments over longer periods, relational effects through reputation and trust-building through joint ventures and cost-sharing.

However, these suggested solutions do not readily extend to all situations. Contrary to the conventional scenario, we consider the case of a strong supplier collaborating with weaker manufacturers. An illustrative example of our problem is found in the computer industry, where the upstream suppliers frequently are stronger than the manufacturers (OEMs). A number of manufacturers offer laptops and notebooks sold under OEM or ODM brand names, such as ASUS, Lenovo, Dell, *etc.* Facing highly competitive markets with a high rate of product innovation and resulting costs of inventory and distribution management, the low-profile manufacturers rely on a limited number of components suppliers (*e.g.*, Intel, AMD for processors) for their key parts. The assembly and integration of these components require specific investments in testing software and hardware, tooling as well as adaptations of planning systems in order to adjust production plans to arrival patterns of critical parts. An anecdotal visible effect of this strong supplier position is the end-user notification of the parts, *e.g.*, "Intel inside" on no-brand computers to signal their build quality. The situation here matches the empirical evidence above and constitutes the inverse of the "classical" setting: a strong seller-supplier does not manage to incite a weak buyer-manufacturer in engaging in a mutually beneficial supply chain collaboration.

This paper offers one explanation for this situation by modeling the contracting problem so as to focus on a key dimension, *i.e.*, the incentives for information sharing in the chain. Our conjecture is that all the previously cited collaborative initiatives are enabled or more effective with higher information precision and vice versa. However, as we will show, in settings where the product development cycle (the "clock-speed" of [18]) is short, such as in high-tech, telecommunications or fast fashion sectors, the shift in bargaining power balance does not lead to more supply chain collaboration. Quite to the contrary, weakened manufacturers may rationally respond by offering less, not more, information sharing.

We provide two contributions: one to the contracting literature, by reversing the order of the roles of information sharing and RSA, and another to the sourcing literature by offering empirically testable hypotheses. The outline of the paper is as follows: in the following section, we give some elements of related literature on the subject. The third section describes the model. A numeric example presents an illustration in Section 4. We conclude in Section 5.

2. Literature review

In the literature, the relationship-specific investments by partners in a supply chain in general are often addressed using either Transaction Cost theory [13,40] or relational exchange theory [2]. When those investments are subject of contracts [7,38], game [10,17,26], bargaining [33,35] and contract theories [9] are often used to explain the interactions [8]. In the particular case of freight transport, Knemeyer *et al.* [22] has surveyed the outsourcing practice and shown that it involves investments in specific assets and non-retrievable commitments of resources from both partners. Tsai *et al.* [37] demonstrate the risks involved in logistics outsourcing when relationship specific assets are involved.

The setting we present here is a single-period game version of the sequential bargaining or renegotiation of rental price with one buyer under asymmetric information about his willingness-to-pay presented in [19]. Fudenberg and Tirole [19] characterize the bargaining games equilibria when buyer and seller both suffer from incomplete information, when the seller makes the offers and when the players alternate making offers. The single-buyer interpretation of this problem when the buyer is willing to trade and profitable mutual interaction is given has been looked into by [20] which demonstrates that a perfect Bayesian equilibrium exists and by [5] which demonstrates that, under assumption that the belief distribution has an increasing failure rate, there exist just one optimal price. A single buyer-multiple seller model with quantity and wholesale price is studied in [15]. The buyer-seller model when the seller wishes to obtain information about the buyer's cost structure is dealt with in [11]. Models dealing with various settings of asymmetric information are presented in [16]. A multi-period model with similar traits is presented in [3] in which information is common and the contract can be renegotiated. In the present model, the contract is binding for the lifetime of the product generation and cannot be reneged.

Tirole [36], Edlin and Reichelstein [14], and Zhu [40] deal with investment in cost reduction by the seller which results in an advantage over the uninformed buyer. When the buyer gains information about the size of the seller's relationship specific investment, the holdup problem first discussed in [39], provides an advantage to the buyer. In the present model, it is the buyer who invests and the seller who is not informed of the size of the investment (the seller observes the incidence of investment ex post if a transaction is made). In [36], the seller obtains an information rent whereas in our model the buyer hides the information regarding the investment from the seller so as to increase his margins.

We consider that the supplier is a Bayesian rational player in the sense that she separates her beliefs from her preferences so that she quantifies the former with a subjective probability measure and the latter with a utility function. She seeks to maximize her expected utility [34]. The starting point for the modeling exercise is the standard contracting model with complete but unverifiable information in a single-period framework [24, 25].

In the case of small- and medium-sized enterprises (SME), it appears that they lack the know-how and capacity to invest in effective purchasing practice which might enable them to complement their own limited resources [12, 21]. Other studies [27, 32] have concluded that purchasing by SME is afforded low status in the UK in general, attributed to a lack of resources. However, this is not the case in SMEs offering high-tech products and operating in markets where competition is based on product characteristics [31]. For these firms, purchasing involves investing in relationship-specific assets. The importance of strategic purchasing, particularly in its advanced stages, has been shown through an empirical study in [30] to increase supply chain integration and performance. Strategic purchasing involves both integrating managerial processes as well as extending over time the relationship with the supplier. A fair share of the costs and investments incurred to engage in close collaborations are "soft" in the sense of verifiability. We can include change management, elaborating new processes, staff training, internal resources redeployment, as well as turning down other work due to the lack of time and resources involved. Contrary to the "custom mold" textbook scenario that is fully relationship-specific, yet conveniently observable, our RSA are less specific and highly intangible.

3. Model

Consider a supplier (seller) offering a critical component to a manufacturer (buyer), serving a given downstream demand. The product life is limited to one period (generation[2]) and the integration of the component requires a specific investment on the manufacturer's side to be effective.

[2] In consumer electronics or computer systems, the generation length can be as short as three to six months.

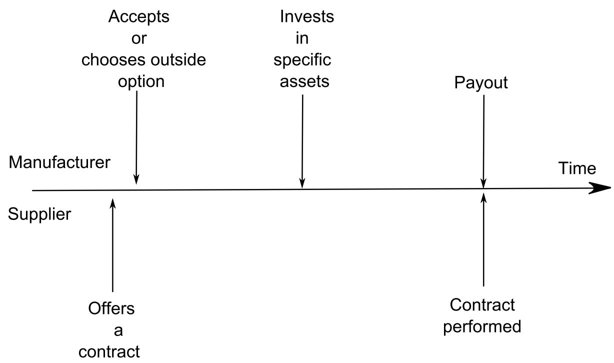

Figure 1. Timeline of events when manufacturer and supplier agree on a contract and to a new relationship. If the manufacturer does not agree to a contract, the timeline is stopped on this disagreement (not represented here).

Assuming away demand effects from the choice of components[3], the manufacturer is maximizing its expected profit Π_m for the product generation. The net revenue of a generation with the intended design is known as R[4]. The supply market is constituted by the supplier and an outside option, seen as a second-best option to use generic components. The manufacturer is required to make a specific investment of $A > 0$ to use the components from the supplier for maximum quality[5]. In the case when the contract with the supplier is rejected in favor of generic parts, the manufacturer incurs a quality cost of q for the production[6]. Both A and q are private information for the manufacturer and cannot be observed by the supplier.

The supplier is maximizing the expected profit contribution Π_s from the component production. The reservation profit for the supplier is defined as $\pi_0 > 0$ from selling the component at *e.g.*, spot-market prices.

The events in time take place in the following order: the supplier offers a contract to the manufacturer. If the latter finds the supplier's offer interesting, a contract is agreed upon and the manufacturer invests in the required specific assets (see Fig. 1). Demand is realized and revealed instantly to both. The manufacturer orders the corresponding amount of inputs to the supplier. Delivery and payout take place. If the manufacturer rejects the offer, both turn to outside options: the manufacturer buys generic parts and incurs a quality penalty, the supplier sells the parts on the spot market (this option is not represented in Fig. 1).

Denote the price at which the supplier sells the parts to the manufacturer by w. The corresponding price for generic parts, payable by the manufacturer, is labelled u.

The decision model is simple, the manufacturer makes a binary decision δ_m for the sourcing choice: 1 if he accepts the supplier's contract, 0 otherwise. We present all the notation in Table 1.

Manufacturer's problem:

$$\max_{\delta_m} \Pi_m = R - \delta_m(w)(A + w) - (1 - \delta_m(w))(u + q) \tag{3.1}$$

The profit-maximizing decision rule for the manufacturer becomes

$$\delta_m(w) = \begin{cases} 1 & \text{if } A + w \le u + q \\ 0 & \text{else} \end{cases} \tag{3.2}$$

[3] This excludes the situation eluded to in the introduction, "Intel inside" as well as any qualitative differences between the components offered.

[4] The net revenue R is the selling revenue net of all other direct costs beyond the component studied. We assume that the net revenues from the products are sufficiently high to always exceed the costs for this specific part.

[5] Due to frequent changes in technology and production processes, product-specific investments are without value at the end of a generation, essentially reducing the investment to a single-shot game. The model formulation takes this reality into account. The possibility that an investment may still be used after the end of the contract is not contemplated here.

[6] Using generic rather than customized components may require the redesign of other modules for integration, loss of intended functionality, loss of differentiation benefits or investment in specific equipment for assembly and/or testing.

TABLE 1. Table of notations.

Type	Notation	Definition
Manufacturer	A	specific asset investment by manufacturer
	q	quality cost incurred by manufacturer
	u	price available to manufacturer of generic input
	R	revenue generated from the sale of finished product
	$\Pi_m(.)$	manufacturer's profit function
	δ_m	binary decision variable, 1 when agreeing with supplier
	V	rent retained by the manufacturer from interaction
Supplier	w^1	price under full information
	w^2	price under complete uncertainty
	w^3	price under asymmetric information
	$\Pi_s(.)$	supplier's profit function
	π_0	supplier's reservation profit
	$f_Z(.), F_Z(.)$	pdf and cdf of belief about $z = u + q - A$, with μ as mean and σ as standard deviation

Supplier's problem:

$$\max_w \Pi_s = w\delta_m(w) + (1 - \delta_m(w))\pi_0, \tag{3.3}$$

with $\pi_0 \leq w$ or the supplier would not participate.

Given the position of the supplier, we assume that she acts as a Stackelberg leader in the game-theoretic sense, maximizing her profit with respect to anticipated responses from the manufacturer. We limit the model to *one* final offer by the supplier that the manufacturer either accepts or rejects [33] can be seen that the asymmetric information rub2.

We evaluate the manufacturer's and supplier's expected profits under different scenarios of available information in three different information scenarios. In the first scenario, the supplier has full information on the costs and options of the manufacturer. In the second scenario, the supplier is not informed about the manufacturer's costs and available options. Given this asymmetry of information, we study how the manufacturer will attempt to "guide" the supplier in guessing the price of the generic input available to the manufacturer, the quality cost, and the specific investment that the manufacturer must make. We provide insights on the outcomes to be expected as a result. We also provide the results when the supplier is in complete ignorance of the manufacturer's private information. This last scenario can take place when the supplier is new to the industry she wishes to serve.

3.1. Sourcing under full information

As a benchmark, we consider the case where the supplier has full information on the costs and options for the manufacturer. In this case, the supplier may extract all interaction profit (information rent) from the manufacturer by exploiting the participation constraint (here the decision rule presented in (3.2)): the contractual price w^1 will be set as

$$w^1 = u + q - A \tag{3.4}$$

The contract w^1 will be proposed as long as the relationship meets the reservation profit π_0, $w^1 \geq \pi_0$.

The intuition even for a non-integrated supply chain is straight-forward: a fully informed supplier working in an integrated setting exercises a dominating position and prices his interaction at the quality-adjusted price of generic alternatives $(u + q)$ less the cost of the relationship specific investment A. The interaction leaves no dedicated profit contribution to the manufacturer. His profit is, in this case

$$\Pi_m = R - u - q, \tag{3.5}$$

with $w^1 \leq u + q - A$ since otherwise the manufacturer's decision rule (3.2) would be violated. In the following, we now consider the results taking into account the decentralized chain and the information asymmetry.

3.2. Sourcing under asymmetric information

In the case of asymmetric information on manufacturer's costs and outside options, the supplier must use an expected value approach to determine the contract. As seen from the benchmark contract presented in (3.4), all relevant parameters are private information. Hence, she assumes that the net manufacturer benefit of interaction, $z = u+q-A$ is a random variable from a probability distribution $F_Z(Z) = P(z \leq Z)$ with mean μ and standard deviation σ. She must estimate a value Z for the contract offer as to maximize the expected profit.

Remark 3.1. If the supplier ignores the distribution of z (complete uncertainty), the only rational option is to offer $w^2 = \pi_0$ since that is his indifference offer. For a given z, an accepted offer gives an expected rent transfer in favour of the manufacturer of $z - \pi_0$.

The estimated distribution of Z follows a probability density function $f_Z(.)$ and a cumulative density function $F_Z(.)$ over a domain $[\underline{Z}, \overline{Z}]$ which we shall assume to have an Increasing Failure Rate (IFR) [1][7]. The cumulative density functions which enjoy this IFR characteristic include a large variety of statistical distribution functions such as the continuous uniform, the gamma, the Weibull, the modified extreme value, the truncated normal and the log normal as characterized in [1]. We consider a domain $[\underline{Z}, \overline{Z}]$ such that $0 < \underline{Z} \leq \pi_0 \leq \overline{Z}$[8].

The contract is accepted when $w^3 = Z$ is $\delta_m(Z) = P(z \geq Z) = 1 - F_Z(Z)$. Let the complementary cumulative density function $1 - F_Z(Z) = \overline{F_Z}(Z)$.

The supplier now solves the following stochastic problem:

$$\max_Z E(\Pi_s(Z)) = Z\overline{F_Z}(Z) + \pi_0 F_Z(Z) = (Z - \pi_0)\overline{F_Z}(Z) + \pi_0 \tag{3.6}$$

As demonstrated in [5], if the supplier's belief distribution function is IFR, then there exist a unique contractual threshold value which maximizes his expected profit (3.6) from the offer she presents to the manufacturer.

The unique contract offer Z^* maximizing the supplier's profit is the solution to

$$Z^* - \frac{\overline{F_Z}(Z^*)}{f_Z(Z^*)} = \pi_0. \tag{3.7}$$

The supplier then offers a contract such that $w^3 = Z^*$. This contract is always higher than the outside option π_0 by definition of distribution functions. To be acceptable to the manufacturer, $Z^* \leq z$. Hence, the accepted contract is such that

$$\pi_0 \leq Z^* \leq u + q - A. \tag{3.8}$$

Compare the contract with the full information benchmark contract presented in (3.4) in terms of rent allocation. In the full information benchmark, the manufacturer has no expected rent. When information is private to the manufacturer, when the contract is accepted, the manufacturer keeps the rent

$$z - Z^*. \tag{3.9}$$

This rent V is positive or null for all Z^* which the manufacturer accepts.

The explanation which can be brought to explain the solution above is to consider the parameters of the belief distribution function as the *accuracy* and *precision* of the information available to the supplier. The mean of the distribution function that the supplier must build reflects the *accuracy* of this information. The *precision* is represented by the standard deviation. If the manufacturer conveys to the supplier a μ very different from the true z, the ensuing Z^* based upon the distribution function F_Z (built with μ) will also be very different from the Z^* based upon the true z. In the same way, the precision of the information is the standard deviation

[7] Note that in an IFR distribution $\overline{F_Z}(Z) \neq 0$ which leads to the notion that $F_Z(\overline{Z}) < 1$ but it can be defined such that it is arbitrarily close to 1.

[8] The case where $\pi_0 > \overline{Z}$ is trivial: the supplier enjoys a better profit from her alternative, there is no incentive to trade with the manufacturer. If $\pi_0 < \underline{Z}$, π_0 is replaced by $\underline{Z}$ in (3.7).

of the distribution of the belief Z. In this way, as information becomes perfect (*i.e.*, $\mu \to z$ and $\sigma \to 0$), Z^* tends to $u+q-A$ from below. To get a better grasp of this relationship, we refer the reader to the Figure 3 on page 562 in the numerical illustration in Section 4.3.

We now place ourselves in the position of the manufacturer to evaluate the rent he can retain by virtue of the information he withholds from the supplier. Along the timeline presented in Figure 1, this point is placed before the supplier's offer: he is in a position to influence the supplier's belief about z. He does not know the supplier's ensuing distribution f_Z nor his reservation profit π_0 from selling the component at *e.g.*, spot market prices, so, under strict logic, we should assume that the manufacturer forms a belief about the distribution of the supplier's belief and reservation profit. To "guide" the supplier, he informs her of a value μ with a precision σ for the distribution of z. In this way, he structures the construction by the supplier of f_Z. However, this is not enough for the manufacturer to determine the future offer w^3. He must in turn also form a Bayesian belief about π_0 supported by a distribution function G_π. This belief has μ_π as mean.

So as to simplify the model, we take F_Z as a proxy of the manufacturer's distribution of the supplier's belief about z. The manufacturer's information rent then can be stated as a function of the expected π_0 and the known information parameters μ and σ:

$$\begin{aligned} E[V(\mu,\sigma,\mu_\pi)] &= E[\mathit{\Pi}_m\left(w^3\right)] - \mathit{\Pi}_m\left(z\right) \\ &= R - Z^* - (R-z). \end{aligned}$$

Based upon this belief and the parameters μ and σ the manufacturer can now estimate the supplier's optimal threshold Z^* which will maximize the supplier's profit using the formula in (3.7) and replacing the supplier's profit from interacting with her outside option by the manufacturer's belief about this profit μ_π. By rearranging the terms, we obtain

$$E[V(\mu,\sigma,\mu_\pi)] = z - \mu_\pi - \frac{\overline{F_Z}(Z^*,\mu,\sigma)}{f_Z(Z^*,\mu,\sigma)}. \tag{3.10}$$

For an illustration of this result, the reader is referred to Figure 4 presented in the numerical illustration.

We can state the main result of the model.

Theorem 3.2. *The information rent V that the manufacturer can extract from his interaction with the supplier is a function of the accuracy μ and precision σ of the information provided to the supplier about his net benefit of interaction as the first and second moments of the belief distribution that the supplier has to make, as well as the manufacturer's estimate μ_π of the supplier's reservation profit π_0:*

$$E[V(\mu,\sigma,\mu_\pi)] = z - \mu_\pi - \frac{\overline{F_Z}(Z^*,\mu,\sigma)}{f_Z(Z^*,\mu,\sigma)}, \tag{3.11}$$

where μ_π is the mean of the distribution of G_π, and for Z^* solution to (3.7).

This rent depends on the manufacturer's guidance of the supplier's belief. For given values of z, the higher the mean of the distribution μ is respective to z, the lower the difference between z and Z^* will be (tending to 0). When $\mu > z$, the expected information rent for the manufacturer $V = 0$, *i.e.*, the manufacturer does not invest A, rejects the offer and turns to his outside option. If μ tends to z from below and if σ nears 0 (full information case), then $E[V(\mu,\sigma)]$ tends to 0. Finally, when $\mu \ll z$, Z^* tends to μ_π.

So the manufacturer's dominant strategy is to signal $\mu = 0$ and $\sigma = 0$ influencing the supplier into building a belief distribution F_Z such that $\underline{Z} = \mu_0$, $\mu = \mu_0$ and $\sigma = 0$. In which case, $Z^* = \mu_0$[9]. This result is equivalent to the complete uncertainty scenario seen above. It yields the maximum information rent and maximum overall profit to the manufacturer.

The intuition of the theorem is strong: the weak manufacturer can expect to extract a rent by guiding the strong manufacturer into believing that he does not make more than an economic profit by using her products

[9] Using the values given in the numerical illustration, we obtain $Z^* = 25.0376$ for $\mu = 25$ and $\sigma = 0.05$.

TABLE 2. Resulting contracts and supplier participation constraints per information set.

Information set	Contract	Supplier participation constraints
Full information	$w^1 = u + q - A$	$\pi_0 \leq u + q - A$
No information	$w^2 = \pi_0$	
Asymmetric information	$w^3 = \pi_0 + \frac{\overline{F_Z}(Z^*)}{f_Z(Z^*)}$	$\pi_0 \leq Z^*$

given the size of the investment A to be made. Contrary to previous results reported in literature, the collaboration in the supply chain is thus wilfully weakened by a manufacturer obfuscating his technological capacity and investments. The asymmetry of information can be assured by multiple means: through the organization of the supply chain, the modularity of the product and the standards used. Indeed, part of the returns from product innovation and development from otherwise weak manufacturers lies in the leverage it offers in terms of bargaining position towards the suppliers. However, as in the example here, note that this rent provision is costly to the chain, in $F_Z(Z^*)$ % of the cases the proposed contract is rejected and the manufacturer resorts to a second-best solution. The challenge for managers in sourcing and supply chain management is then to create contractual commitment beyond the single-generation setting so as to distribute rents through repeated win-win agreements.

To recapitulate, we find that the supplier offers different contracts according to the information in her possession (*cf.* Tab. 2). To extract a higher rent from the interaction, the manufacturer will provide incorrect information by, *e.g.*, implying a high cost for A, inducing the supplier into contracts which, for the overall efficiency of the supply chain, are less than optimal.

Under opportunistic behaviour on the manufacturer's part, this rent is not null and increases with his ability to influence the *a priori* beliefs of the supplier. In the computer industry, two suppliers stand out for their power: Microsoft and Intel. Between 2004 and 2009, Intel managed to improve its market power over PC assemblers by promoting its processing units heavily. Intel set the obligation for the OEM to attach their logo on their products. The OEMs (ACER, Asus, Lenovo), still not well known to European or American markets, were the weak manufacturers. This type of behaviour is noticeable in negotiations between buyers and suppliers in very different business to business settings.

Take for example the case of a company wishing to install a new information system to connect their operations with those of the supplier. Given the required changes to managerial processes, this specific investment includes a substantial human resources cost. The downstream partner will tend to exaggerate this cost to the supplier so as to obtain a better deal. Symmetrically, the supplier will attempt to gauge the effort, cost and investment made by the client. When the supplier is a major information technology provider such as IBM, the knowledge gained from similar transactions with other clients in similar industries helps it to price more finely the package and discount the exaggerated costs presented by the customer.

In the least, the true costs will not be revealed so that, in the next generation, when negotiation occurs, renewed opportunistic behaviour can yield information rents to the downstream partner. It is the authors' experience that even after working together many years, this type of information withholding behaviour over coordinating investments will still take place. This type of behaviour has not been addressed in the modeling literature and does not seat easily with the truthfulness and collaboration paradigms.

Such behavior on the part of the manufacturer will probably disappear if he trusts the supplier sufficiently to expect that the latter will not try to take advantage of the information disclosed. In absence of such trust, the manufacturer might aim to obtain further assistance or other benefit after the start of the life of the relationship. To support such expectation, it might be of interest to the supplier to promise some incentive within the framework of the contract, once the investments have been made and the contract is in place. How and under what form this incentive might be presented by the supplier as well as its effect on the manufacturer escape the scope of this paper.

To get a better grasp of the link between the estimate of the unknown quantities and the rent that the manufacturer keeps, we present a numerical illustration.

TABLE 3. Thresholds Z^* when the mean of the distribution of the belief about z ranges between 50 and 210 and $\sigma = 20$.

μ	50	70	90	110	130	150	170	190	210
Z^*	50.0	61.5	75.4	90.9	107.4	124.7	142.6	160.7	179.2

4. Numerical illustration

We illustrate the findings from the model with a simple numerical case. A manufacturer and a supplier wish to work on a specific design to be included in a new product. We use the following values for the parameters:

$$\begin{aligned} q &= 60 \qquad & A &= 50, \qquad & u &= 100, \\ \pi_0 &= 25 \qquad & R &= 200. \end{aligned} \tag{4.1}$$

4.1. Scenario for the benchmark full information

Here, the manufacturer's investment A and the price for generic parts u as well as the quality difference, $q = 60$ are common information. The supplier proposes the contract in equation (3.4),

$$w^1 = u + q - A = 100 + 60 - 50 = 110.$$

This contract is accepted and results in a cost for him of $w^1 + A = 160$, making him indifferent to using generic parts. The manufacturer's profit is $\Pi_m\left(w^1\right) = R - w^1 - A = 40$. The supplier's profit is $\Pi_s\left(w^1\right) = 110$, better than her reservation profit $\pi_0 = 25$. However, the relevant bound here is naturally the joint profit contribution from the interaction, $\Pi_m + \Pi_s = 150$. The results are presented together in Table 4.

4.2. Complete ignorance

When the supplier is totally uninformed about the relevant information for the manufacturer, she can only offer $w^2 = \pi_0 = 25$. The profits are $\Pi_m\left(w^2\right) = R - w^2 - A = 125$. The supplier's profit is $\Pi_s\left(w^1\right) = 25$.

The difference between both offers represents the price of information to the supplier.

4.3. Asymmetric information

Now consider that the manufacturer has private information about his costs. Assume that the net benefit of interaction is normally distributed $\mathcal{N}(\mu, \sigma)$ truncated at 0. Using the result in equation (3.7), the supplier calculates an optimal contract w^3 such that

$$w^3 - \frac{\overline{F_Z}(w^3)}{f_Z(w^3)} = \pi_0. \tag{4.2}$$

Numerically, we obtain $w^3 = 90.9$ for the instance when $\mu = 110$ and $\sigma = 20$.

Thus, for the outcome given above (the mean of the distribution), the profits are

$$\Pi_m\left(w^3\right) = R - \left(w^3 + A\right) = 200 - (90.9 + 50) = 59.1 > \Pi_m\left(w^1\right) = 40,$$

whereas

$$\Pi_s\left(w^3\right) = w^3 = 90.9 < \Pi_s\left(w^1\right) = 110.$$

We observe an increase of almost 48% in profit level for the manufacturer through the asymmetric information. The manufacturer accepts the offer and the supplier still comes out ahead as compared to turning to his outside option.

The optimal contracts Z^* vary according to μ, the mean of the distribution of Z, from which the given parameters above are just one of possible outcomes. Table 3 presents some of the results when μ ranges between

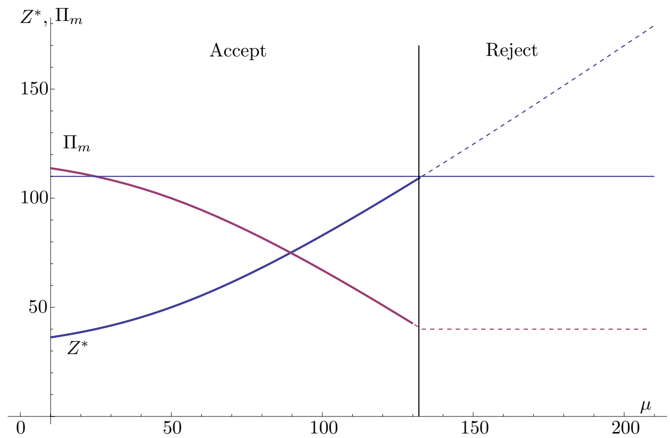

FIGURE 2. Evolution of $w^3 = Z^*$ and of Π_m when the mean of the distribution Z μ increases from 10 to 210 and $\sigma = 20$. The manufacturer rejects the offer and turns to his second-best option when $\mu > 132$: his profit is reduced.

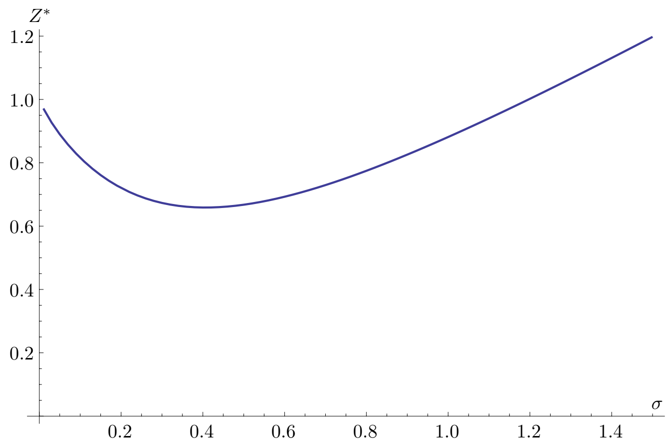

FIGURE 3. Evolution of Z^* when standard deviation of the distribution of the belief about the manufacturer's z increases from 0 to 30 and $\mu = 110$.

TABLE 4. Profits from the different information scenarios in the numerical illustration. The $\Delta\%$ line presents the difference percentage-wise with the benchmark common information scenario.

Scenario	Manufacturer		Supplier	
	Min	Max	Min	Max
Common Info	40		110	
Asymmetric Info	100.0	155.4	50	95.4
$\Delta\%$	−37.5	−2.88	−54.5	−13.3
Outside option/No information	125		25	

50 and 210. For $\mu > 132$, the manufacturer would reject the contract since he would be better off by turning to his outside option (see Fig. 2).

Thus, an overestimate of the manufacturer's investment and outside option cost can lead to the supplier being turned down. An underestimate reduces the supplier's profit (*cf.* Tab. 4).

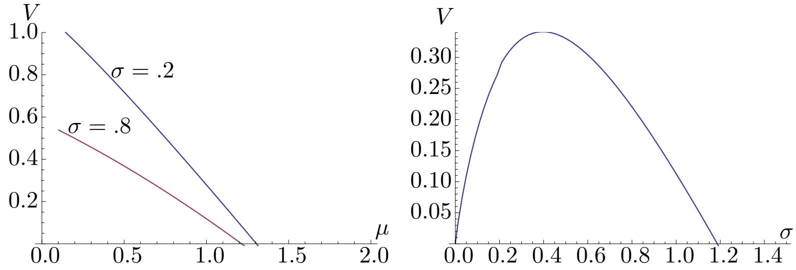

FIGURE 4. Evolution of the manufacturer's expected rent V when μ evolves between 25 and 200 for $\sigma = 1$ and $\sigma = 5$, and when σ evolves from 0 to 68 but $\mu = 110$ (right hand graph).

We now evaluate the impact of the precision of the information held by the supplier on the contract that he will offer.

To do so, we vary the degree of information precision available to the supplier represented as the standard deviation of the distribution function σ that the supplier builds to embody his belief. When $\sigma = 0$, the supplier has a high precision notion of μ (which does not guarantee that she knows z, merely that the μ which she has been given is precise). We present in Figure 3 the change of Z^* in terms of σ. As can be seen, when it goes from 23 to 0, Z^* approaches $z = u + q - A$ from below.

The comparison between the different scenarios are summarized in Table 4. the cost or profit varies according to the initial estimate formulated by the supplier. It can be seen that the manufacturer gets to keep part of the profit in the asymmetric information scenario.

To illustrate Theorem 3.2, we present in Figure 4 the evolution of the difference in rent which the manufacturer keeps according to the mean of the supplier's distribution of belief and for two different levels of standard deviation (left hand graph) and when the standard deviation varies. A low standard deviation ($\sigma = 1$) yields a null rent when the supplier also has $\mu = z$. Clearly, the manufacturer must try to guide the supplier towards low estimates of z and fudge the information in such a way that the supplier will have a vague idea of the true z (tantamount to influencing her into increasing σ).

5. Conclusion

Supply chain integration resulting from extensive information sharing may lead to increased joint supply chain surplus, in particular through the implementation of collaborative investments in product, process and service development. However, empirical experiences show that the options for potential collaborations are far from exhausted for various reasons. One conventional wisdom has been to blame the lack of collaborative effort in supply chains on strong downstream bargaining power, leading to hold-up of upstream investors in relationship specific investments. This paper complements this viewpoint by showing that rational decision making among manufacturers and suppliers in the supply chains where the supplier dominates may suffer from similar problems.

In particular, our findings explain how weak downstream manufacturers may choose to stay outside of collaborative arrangements with strong component suppliers, under-investing in supply chain collaboration, in order to safeguard profit contributions from key products. Our results extend research in supply chain management collaboration and coordination in situations preceding the signing of a contract. Such results can confirm the impact of non-financial factors which, according to [29], impact the buyer-supplier dyad performance and so justify the lack of openness in downstream firms, especially as regards the exact extent of relationship-specific investments in connection with their upstream partners. Our results also validate those presented in [6] which study a multi-period scenario where the buyer also wishes to obtain an advantage over the supplier by withholding information. They extend results presented in the particular case of transport in [4].

Further avenues of research are available to explain how the current findings compare in multi-sourcing scenarios, *e.g.*, when a manufacturer invests in designs flexible enough to accommodate multiple components in the assembly.

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