How information influences the cost of transport in a supply chain, a monte carlo simulation

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Abstract

The present paper studies the impact of information sharing and contractual instruments on a shipper and her transport suppliers through a monte carlo simulation. After reviewing the literature, we propose a model to measure the benefits in terms of expected transport cost and variance of this cost. We evaluate three scenarios over a reiterated-single period setting in a shipper carrier single-echelon model with a mix of long-term and short-term procurement strategies: perfect information, asymmetric information and private information at one level of the supply chain. After spelling out the optimal parameters for the procurement policy, we evaluate the rent transfer between carrier and shipper in a numeric example using the monte-carlo method.

Keywords: Supply chain management; contracts; transport; information sharing; coordination.

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1 Introduction

Transport is principally a capacity-constrained, fixed-cost service industry.

Because of its highly specific nature and ability to share costs and investments among several clients, transport is overwhelmingly outsourced. We investigate a case where, through the monte carlo method, the profits of private information is compared with the centralized coordinated case of common information using a binormal distribution. More than scientific evidence, this paper wishes to nourish an ongoing debate wihtin the ranks of practitioners and let researchers gauge the importance for the industry of the common practice of withholding information from the other party.

This paper is organized as follows. After reviewing the literature in the next section, the third section describes the model involving one shipper as client and one carrier as transport supplier. In the fourth section, we describe three scenarios of behaviour: in the first, base scenario, the information is common to both, decisions are centrally coordinated. In the second scenario, the carrier retains information from the shipper. In the third, both shipper and carrier hide information from each other. In the fifth section, the numerical study, we generate a sample of instances of demands and transport spot prices and run each scenario on that sample. Conclusions as to the importance and impact of both information and contractual arrangements between shipper and carrier are drawn in the final section.

2 Literature review

Supply chain performance depends critically on how its members coordinate their decisions. And it is hard to imagine coordination without some form of information sharing, as noted in Chen (2004). The transport industry's efficiency can be increased by coordination, truth-inducing mechanisms, contractual engineering and information sharing as shown in Chen (2004, 1998), Chen & Yu (2005), Porteus & Whang (1991), Lee & Whang (2000), Cachon & Lariviere (1999a), Zhao *et al.* (2002). However, since their supplier definition entails back-logging of orders and inventory management, not all results apply to carriers or shippers. Ertogral *et al.* (1998) integrates production and transportation planning, taking into account transport costs and schedules. This approach does not take into account the impact of asymmetric information and decentralized decisions. Neither does it take into consideration the eventual over or under utilization of the transport capacity involved.

The transport industry characterizes itself by the non-scalable capital intensive capacity investments needed and a high share of fixed costs within total costs. Capacity can be expanded only well in advance of capacity requirement. Full capacity utilization is thus one of the primary objectives. Supply chain management dedicates commendable space to capacity as a limiting factor; authors have modeled that constraint in several papers.

A paper that has modeled contracting arrangements for capital-intensive, capacity-constrained goods is Wu *et al.* (2002). The paper provides valuable insights on the optimal balance between selling capacity in the forward contract market versus selling on the spot market. The results give a structure where a buyer and a seller can derive guidance on the optimal strategy between optimal forward contracting and spot buying of capacity. This model applies aptly to energy and other bulk products that have standard quality, interchangeable buyers and sellers and that rely on relatively efficient spot markets. This is not exactly the case of transport: parties to a contract have to iron out several operational details as to execution, quality criteria, etc that make each contract unique and entails greater transaction costs.

Spinler & Huchzermeier (2005) propose a variation of the preceding model by using options in lieu of futures contracts and spot market to increase capacity utilization in the presence of state-contingent demand. The purpose is to effectively offset part of the risk posed by fluctuating demand by a strategy which combines buying options on capacity ahead of revelation of demand and complementing by spot transactions upon the period of requiring that capacity. They show that such a strategy effectively is Pareto improving for both the seller of the option (transport supplier) and the buyer (the shipper). Both reduce their risk and the volatility of their costs. To circumvent the liquidity problem of transport as a non-standardized service, the model assumes that options will be traded on electronic marketplaces where information and transaction costs are lesser. As Grieger (2003) reported, carriers and shippers may be wary to trade with partners of unknown quality and customer-satisfaction drive, jeopardizing the forecast efficiency and welfare. This issue does not arise for electricity, the other industry specifically addressed in Spinler & Huchzermeier (2005), because of the more standardized nature of the traded good.

We draw on the *capacity constrained with uncertain demand coordination mechanisms* stream of literature (Anupindi & Bassok, 1998, Tsay, 1999, Tsay & Lovejoy, 1999, Tsay *et al.* , 1999, Cachon, 2004), designed to align the behaviours of the supplier and retailer. In common with this literature, capacity has to be planned well in advance, hence the carrier has a strong incentive to encourage the buyer to forecast and plan honestly the cargo to be effectively transported (see the capacity allocation game in Cachon & Lariviere, 1999b). We model the incentive that the carrier has to include in the contract for that coordination to take place. The simplest mechanism is for the shipper to pay the carrier a penalty when realized demand comes in at a level inferior to contracted capacity. This mechanism has been studied in Cachon & Lariviere (2001): the manufacturer pays a cancelation fee per unit not purchased if he takes delivery of fewer than the agreed-upon number of units. Another would be for the carrier to extract from the shipper a commitment for a given capacity, whatever the realized demand.

Similarly, the shipper must obtain the maximum capacity at the least price given demand risk. In other words, he must angle for risk sharing with the carrier. Just settling for a given capacity at a set price is not enough for him to achieve low transport cost variance over a long time horizon. Thus some measure of flexibility in capacity has to be introduced. Two such mechanisms are implemented here. One is a menu of extra capacities at pre-arranged prices: if the demand effectively exceeds the base contractual capacity, the shipper calls up extra capacity to meet it using this clause to set the premium price. The other is a penalty clause for the carrier when he is unable to meet the capacity thus committed: whenever the carrier fails to meet the shipper's demand, he pays a penalty proportionate to the shortcoming. In Moinzadeh & Nahmias (2000) that same general problem is treated: Q, the minimum commitment per period is given and there are both fixed and proportional penalties for adjustments, over an infinite horizon. The authors contend, but do not formally prove, that a type of order-up-to policy (s,S) is optimal. In that model, the fixed delivery contract with penalties serves as a risk sharing mechanism.

Because the demand, when realized, directly results in a transport requirement, there can be no time-flexibility arrangements as those described in the literature (Li & Kouvelis, 1999).

It has to be mentioned that, in our approach, we have elected to consider that transport capacities are not freely substitutable, ruling out "overbooking" (Karaesmen & van Ryzin, 2002). In other words, a carrier cannot just overbook his fleet on a given time slot because cargo cannot just be shifted to the next available one and there are few cases of "no-shows".

Our market mechanism draws also on the model in Seifert *et al.* (2004) for simultaneous long-term and short-term (spot) buying of commodities by a client from one or various suppliers. They show that buying a "moderate" fraction of total needs on the spot market significantly improves profits over the contract-only behaviour.

Our general model follows a similar pattern to that adopted in Gavirneni *et al.* (1999). That study set up three scenarios that differ by the information level of the participants. In this case, the information is the distribution of the sales addressed to the retailer and whether or not the supplier can be aware of the law of that demand, and whether he can further benefit by receiving immediately sales data from the retailer. To study the impact of information on capacity and inventory, each scenario evaluates the level of information affecting the optimum capacity and inventory at the supplier level. Penalties for the supplier are included when demand addressed to him goes unsatisfied.

3 Transport Model

We assume that a shipper S requires some specific transport infrastructure. She contends with uncertainty on two fronts: the first is a stochastic demand. The second is a market for transport services where spot prices can vary, substantially affecting her costs (figure 2).

Because of uncertainty on these two fronts, the shipper S chooses to minimize at least one source of uncertainty by tendering for a long term contract. To complement this contract, S also has the ability to buy extra capacity from the rest of the market for a spot transport price (equivalent to short term contracts, see Seifert *et al.* (2004)).

Let C be the carrier who has signed the contract with S and who further serves the market for unused capacity at the going spot price. Every period, C first serves the demand from S than from the market. However, capacity is not binding for the shipper: whenever she cannot purchase the necessary capacity from C, she turns to the spot market for the remainder.

3.1 Motivation of shipper and carrier behaviour

3.1.1 Opportunistic behaviour

We include in the model the possibility that one or both parties will behave opportunistically during the lifetime of the contract. This can happen through hold up situations especially since both carrier and shipper have to invest in specific assets to be able to comply with the contract requirements: specific transport vehicles, specific quality-enhancing procedures, personnel training, warehouses, software, logistical equipment, etc. We make no assumption about relative power of each player. In our model, both shipper and carrier are risk averse: the shipper wishes to avert the transport price volatility inherent in the spot market, the carrier wishes to ensure steady and sufficient revenues to match his financial and commercial costs over the long term.

We have chosen for simplicity's sake to restrict our demonstration to just two forms of information amenable to modeling: information about the available capacity that the carrier can offer to the shipper and information on the exact demand addressed to the shipper. If information about available capacity is kept from the shipper she may not know that the carrier is in fact redeploying it for better profit elsewhere. On the other hand, if the carrier is not cognizant of the exact demand addressed to the shipper, he may not be able to observe that capacity has been bought from some competitor at a lower price.

Depending upon the spot price in the market and since the carrier's total capacity ex-post is non-verifiable and non-observable by the shipper, the carrier can engage in hidden action by refusing to comply with the demand from the shipper, pay the corresponding penalty θ_c and sell this excess capacity in the spot market. In this case, the shipper has no other recourse than to offer his cargo on the spot market. We have not modeled the loss of lead time that ensues, but it clearly has an impact to the shipper that could be evaluated and included in a future study.

The shipper S can also deviate when her realized demand is not observable by the carrier. When the spot price is lower than the menu of prices less the penalty, the shipper can deviate by refusing to purchase capacity in excess of q from the carrier and instead buy the necessary complement from the spot market. She can also deviate when the spot market price is less than the contractual price less the penalty for not complying with the basic volume in the contract.

3.1.2 Information scenarii

We will study both under different scenarios: under the base scenario, both information is common knowledge. The shipper S observes the exact available capacity at each period of carrier C and C observes the realized demand addressed to S. In the second scenario, S cannot observe the capacity of C, but C does observe S's realized demand (or S makes that information available to C). In our third scenario, S cannot observe C's capacity and C cannot observe S's realized demand. In effect, we assume that there is no common knowledge of payoffs, or at least that this knowledge comes at a price. We do not model or attempt to include in our model the cost of such information gathering.

By the construction of our model, the gains of one party are the losses of the other, meaning that globally, social welfare does not increase except perhaps by lowered transaction costs in the following contract (if there is one).

We have not modeled a fourth possible scenario in this paper: when the shipper knows the capacity of the carrier and the carrier is not aware of the exact demand received by the shipper. Examining this scenario would add neither to the demonstration nor purpose of this paper.

3.2 Contract characteristics

3.2.1 Contract

Both carrier and shipper have an interest in fixing for the longest possible period the price of the service to be delivered because of decreased volatility of earnings (for the carrier) or costs (for the shipper). The capacity contracted is the object of ex-ante verification by the shipper. Refusing to honour this basic capacity requirement is a motive to reopen the contract and eventually to terminate it, so it is considered here that neither shipper nor carrier will renege on that commitment.

3.2.2 Minimum purchase commitments

It is considered here as established by Cachon & Lariviere (2001), Cachon & Zipkin (1999) that the optimal minimum purchase commitment for both shipper and carrier under asymmetric information corresponds to the average demand that the shipper expects over each period of the life of the contract. A penalty for the unused contracted capacity is set by the carrier to encourage credible information as to expected demand from the shipper.

3.2.3 Additional menu of capacities

To allow for some flexibility in the demand that the shipper receives, a menu of prices that give some additional capacities so that the shipper can call upon under certain conditions of price is included. This menu of prices encourages the shipper to call upon the carrier for the unforeseen demand received[1]. This added flexibility is of *increasing* value to the buyer as market environment becomes more volatile, (Tsay *et al.* , 1999, Tsay & Lovejoy, 1999).

[1] The price is higher than the base capacity price because the marginal cost to the carrier of such capacity is higher because it constrains his overall capacity and ability to meet other commitments. Bear in mind that capacity is non-scalable unless notified well in advance.

3.2.4 Time-line

The order in which the decisions take place are the following (see also figures 1 and 2):

- S observes expected demand and selects C
- S observes carrier capacity W, contract negotiated and signed.
- S first observes demand Q and spot market transport price P.
- S decides on the allocation of a share u of demand Q to C.
- C observes the spot market price and allocates capacity x to S and x_s to the spot market.
- After observing the allocation of capacity by C to her, S allocates the remaining demand $Q - x$ to the spot market.
- Transport is performed.
- Payout occurs.

There could be an interesting study to be done however in the case where a large number of clients face the same highly seasonal demand and the transporting providers' capacity is a bottleneck.

3.2.5 Notation

C and S have negotiated ex-ante and are bound by a contract extending over n periods with known and fixed parameters. S agrees to buy at each period capacity q at price c. The shipper has to pay a penalty θ_s for unused capacity up to q at each period. The contract includes a menu of prices p_a at quantities q_a that the carrier offers to the shipper S to help him meet demand in excess of the contracted capacity commitment q up till q_a (figure 2). The menu is a list of prices linear with the capacity offered. This seems counter intuitive: one would expect that the higher the capacity sought by the shipper, the lesser the marginal cost to the carrier, so that the carrier would be motivated to make a volume discount to capture the excess demand. We will revisit this matter when discussing the coordinating power of the contract. Each price in the menu is the going price for all the excess capacity required by the shipper. This menu is a list of options that the

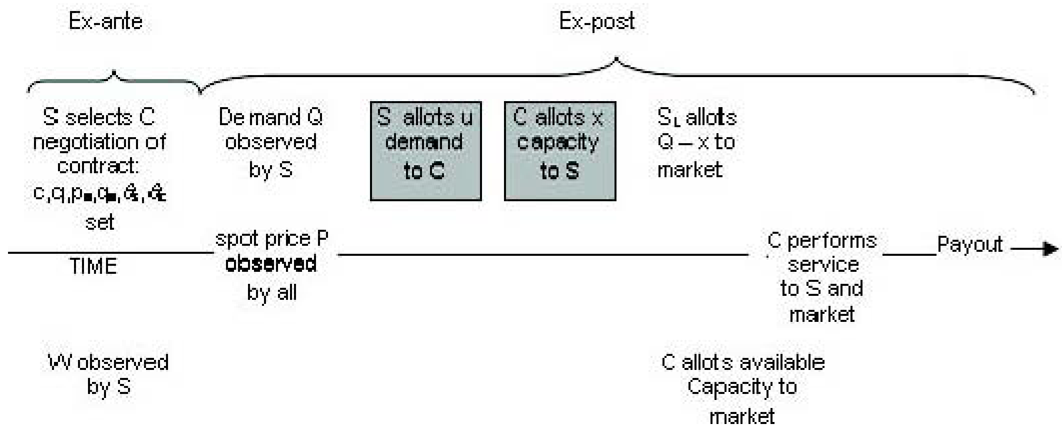

Figure 1: Chain of events: decisions by players in grey

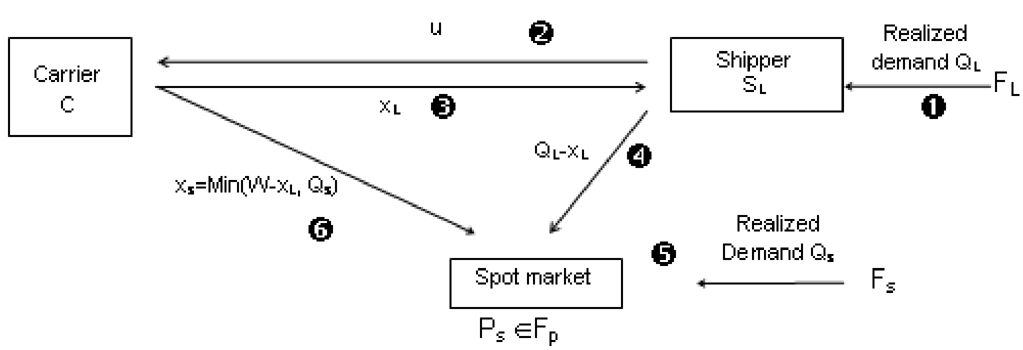

Figure 2: Capacity allocation

carrier presents on a "take it or leave it" basis to the shipper for the length of the contract and which the shipper can exercise at each period. The shipper will ask for more capacity if the demand addressed to him exceeds the committed capacity q, thus giving him added leeway to meet unforeseen demands that could not be predicted when drawing up contract specifications. This is not an option in the true sense since there is no premium to be paid but rather an option on a forward contract as the shipper is committed to taking the available capacity offered under the terms of the menu (quantity and price); even if the spot price is less than the price in the menu for that given additional capacity. To compensate the shipper, the carrier suffers a penalty θ_c if he cannot (or chooses no to) carry cargo above the contracted capacity q but within $q + q_a$.

State of nature is represented using three variables: P is the market price for immediate transport, Q the demand addressed to S and x_s the demand that the carrier can find on the spot market. The demand that the shipper observes is an exogenous, stochastic variable ζ_Q, the demand that the carrier can garner from the spot market is also an exogenous, stochastic variable ζ_S. We restrain our view of nature to $\Omega(P, Q)$ which is the probability space containing the possible realizations of the duples of transport spot price and of demand addressed to shipper S. $F_Q(.)$, (respectively $F_S(.)$) are the continuously differentiable, invertible and monotonous cumulative distribution functions of demand addressed to the shipper (received by the carrier from the spot market). $F_p(.)$ is the continuously differentiable, invertible and monotonous cumulative distribution function of the spot market price P and $f_p(.)$ its density function (mean μ_p and standard deviation σ_p). f_p has a cut-off at V_C (see infra for explanation). Let $f(.)$ be the density function of the **joint** continuously differentiable, invertible and monotonous cumulative distribution function $F(.)$ of **both** Q **and** P. Let $\rho \in [-1, 1]$ be the correlation factor between $F_Q(.)$ and $F_p(.)$. Often, $\rho \geq 0$ reflects the fact that the carriers have specialized transport capacity and serve one single industrial sector, leading to spot market prices rising in accordance with realized demands addressed to the shippers because of tightening capacity all around. This causes stronger constraints on the capacity of the carrier as well as higher variance of transport costs to the shipper.

The total capacity of C is W. C and the other carriers offering their capacity in the spot market have a common variable cost per unit transported V_C and a fixed cost F_C which is a function of the total capacity W.

In figure 1, u is the demand that S chooses to allocate to C, x_L is the capacity that C chooses to allocate to S, $Min(W - x_L, x_s)$ is the capacity allocated to the spot market by C. Satisfying the spot market does not represent an independent decision by the carrier and will not be contemplated as such in the remainder of this paper. It is apparent that the allocation of capacity of C to S is dependant upon the demand that S allocates to C in the first place.

3.3 Objective functions

3.3.1 Regionalizing the probability space

We divide the probability space Ω into two-dimensioned regions according to the decisions by both S and C (figure 3):

$$\begin{array}{l}
\Omega 1\,(Q,P)=\{Q:0\leq Q\leq q;V_C\leq P\}\\
\Omega 2\,(Q,P)=\{Q:q<Q;P:V_C\leq P\leq p_a-\theta_s\}\\
\Omega 3\,(Q,P)=\{Q:q<Q\leq q+q_a;P:p_a-\theta_s<P\leq p_a+\theta_c\}\\
\Omega 4\,(Q,P)=\{Q:q<Q\leq q+q_a;P:p_a+\theta_c<P\}\\
\Omega 5\,(Q,P)=\{Q:q+q_a<Q\leq W;V_C\leq P\leq p_a-\theta_s\}\\
\Omega 6\,(Q,P)=\{Q:q+q_a<Q\leq W;p_a-\theta_s<P\leq p_a+\theta_c\}\\
\Omega 7\,(Q,P)=\{Q:q+q_a<Q\leq W;p_a+\theta_c<P\}\\
\Omega 8\,(Q,P)=\{Q:W<Q;V_C\leq P\}\\
\Omega 9\,(Q,P)=\{Q:W<Q;p_a-\theta_s<P\leq p_a+\theta_c\}\\
\Omega 10\,(Q,P)=\{Q:W<Q;p_a+\theta_c<P\}
\end{array} \tag{1}$$

3.3.2 Carrier objective function

In our setting, carrier C has just two customers: S and the spot market (figure 1). The spot market receives attention insofar as $P > V_C$, in the other case, as it would uneconomical for any carrier to derive any capacity to it, the demand from the spot would go unfulfilled and hence is considered as non existent. We could have included in our model the possibility by the carrier to sell all his excess capacity on the spot market. We felt, however, that this would have been a too great departure from real practice as the lead time to be able to sell all excess capacity depends upon the knowledge of all market demand. This knowledge requires the assumption that the carrier C has an extensive commercial network or that information gathering is costless. As the experience of the freight matching exchanges show, this is not true. So we have assumed that this knowledge is not given. If the summed demands from these two do not reach total capacity, the excess capacity is lost for all intents and purposes: carrier C cannot sell all his excess capacity,

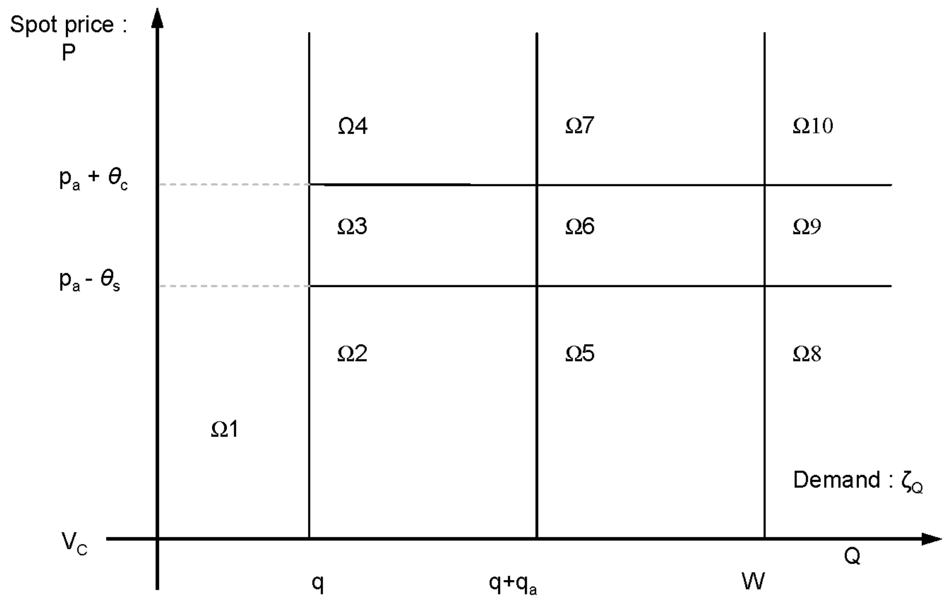

Figure 3: Probability spaces for spot price and demand addressed to S

reflecting true market reality. This unused capacity impacts the carrier's profitability and ability to support the long-term investments that he must incur to face the demands at least from S. We have not included it as a separate objective to carrier C as all components are already present in the objective function.

The carrier's decision variable is the capacity he allots to the shipper: x_L is the allotted capacity to S and $min(W - x_L, x_s)|P > V_C$ to the spot market. $W - x_L - x_s$is the wasted capacity. We consider that the fixed costs of supporting the necessary assets are specific, sunk and that the carrier does not have the choice to withdraw from the allocation game with S. We therefore neglect all considerations as to fixed costs of C. His profit function can thus be written by using the terms of the contract.

$$\begin{array}{l} W \geq x_L + x_s \\ 0 < q + q_a \leq W \\ 0 \leq \theta_s < c, \qquad 0 \leq \theta_c < c \\ 0 \leq q_a < q, \qquad c \leq p_a \\ 0 \leq u, 0 \leq x_L, \qquad 0 \leq x_s, \quad V_C < P, \quad x_L \leq u \end{array} \tag{2}$$

The profit function is conditional upon the allocation by S and the spot market price:

$$\pi\left(x_L|u,\Omega_i\right) = R_i\left(x_L|\Omega i\right) + Px_s - V_C\left(x_L + x_s\right) \tag{3}$$

Where V_C is the unit variable cost and where R_i is a revenue function, conditional upon the demand u addressed by S and the spot market price, of the form:

$$R_i\left(x_L|u,\Omega i\right) = \begin{cases} x_L c - (min(u,q) - x_L)\theta_c + (q-u)\theta_s & \text{when } 0 \leq x_L < q \\ qc + \left(x_L - q\right)p_a & \text{when } q \leq x_L \leq q + q_a \\ qc + \left(x_L - q\right)p_a + \left(x_L - q - q_a\right)P & \text{when } q + q_a < x_L \leq W \end{cases} . \tag{4}$$

q, q_a, c, p_a and θ_c, θ_s are the parameters defined by the contract. P is the spot market price (figure 4).

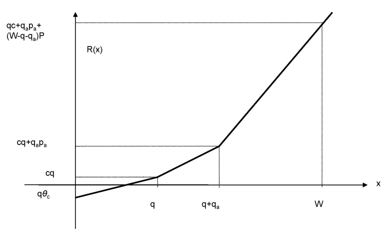

Figure 4: Behaviour of $R_i(x_L|\, u,\Omega_i)$

3.3.3 Shipper objective function

Shipper S produces and sells a product that requires transportation. To ensure that budget cost constraints are met and cost variance remains low, her best option is to negotiate beforehand a contract with a duly selected carrier whereby the average predicted level of demand that she has budgeted can be transported for a known and defined price. When that contract is in place, she must decide whether to allocate her necessity to her chosen contractual carrier or to the spot market. She plays the role of the Stackelberg leader in this game.

The decision variable u can take all values between 0 and total received demand Q and varies according to the different probability spaces where both P and Q can vary (figure 5). Whatever transport necessity is not being allocated to C shall be attributed to the spot market at the going spot price P. The function is

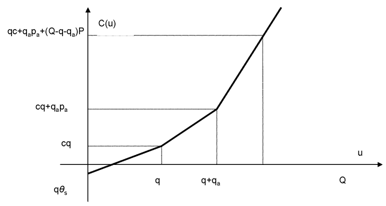

Figure 5: Behaviour of C(u)

conditional upon the response S receives from C which is represented by $x_L(u)$.

$$C_i\left(u|x_L, \Omega i\right) = \tag{5}$$

$$\begin{cases} cx_L(u) + [q-u]^+\theta_s + \left(\min\left(q,u\right) - x_L\left(u\right)\right)\theta_c + \left(Q - x_L\left(u\right)\right)P \\ \text{when } 0 \leq x_L\left(u\right) \leq q \\ cq + (x_L(u) - q)p_a - \left[u - x_L(u)\right]^+\theta_c + [Q-u]^+\theta_s + \left(Q - x_L\left(u\right)\right)P \\ \text{when } q < x\left(u\right) \leq q + q_a \\ cq + \min((x_L(u)-q), q_a)p_a - \min\left(\left[u - x_L(u)\right]^+, q_a\right)\theta_c \\ + \min\left(\left[Q-u\right]^+, q_a\right)\theta_s \qquad + \qquad \left(Q - x_L\left(u\right)\right)P \\ \text{when } q + q_a < x\left(u\right) \end{cases} \tag{6}$$

3.3.4 Defining optimal decisions according to demand and spot price

In each region of probability space, the optimal decisions by each player are different. Let us call R_Ω and C_Ω the revenue and cost functions over each separate domain identified by its number. Demand coming from the spot market that the carrier has identified is satisfied insofar as $P > V_C$. After satisfying the demand from the shipper, the carrier must still try to satisfy demand from the spot market, whenever the spot price is higher than his variable cost.

Table 1 recapitulates the results synthetically.

3.3.5 Expected cost and variance of transport cost

Given that we now have defined the costs to the shipper over all regions of the probability space, we can define her expected cost as a function of the received

i	u_i^*	x_{Li}^*	$\pi_{\Omega i}$	$C_{\Omega i}$
$\Omega 1$	Q	Q	$Qc+(q-Q)\,\theta_s+min\,(W-Q,Q_s)\,P-V_C\,(Q+Q_s)$	$Qc+(q-Q)\,\theta_s$
$\Omega 2$	q	q	$qc+(Q-q)\,(P+\theta_s)+min\,(W-Q,Q_s)\,P-V_C\,(Q+Q_s)$	$qc+(Q-q)\,(P+\theta_s)$
$\Omega 3$	Q	Q	$qc+(Q-q)\,p_a+min\,(W-Q,Q_s)\,P-V_C\,(Q+Q_s)$	$qc+(Q-q)\,p_a$
$\Omega 4$	Q	q	$qc+(Q-q)\,(P-\theta_c)+min\,(W-Q,Q_s)\,P-V_C\,(Q+Q_s)$	$qc+(Q-q)\,(P-\theta_c)$
$\Omega 5$	q	q	$qc+q_a\theta_s+(Q-q+min\,(W-Q,Q_s))\,P-V_C\,(Q+Q_s)$	$qc+q_a\theta_s+(Q-q)\,P$
$\Omega 6$	Q	Q	$qc+q_ap_a+(Q-q-q_a+\text{min}\,(W-Q,Q_s))\,P-V_C\,(Q+Q_s)$	$qc+q_ap_a+(Q-q-q_a)\,P$
$\Omega 7$	Q	q	$qc+q_a\theta_c+(Q-q+min\,(W-Q,Q_s))\,P-V_C\,(Q+Q_s)$	$qc+q_a\theta_c+(Q-q)\,P$
$\Omega 8$	q	q	$qc+q_a\theta_s+(W-q-q_a+min\,(W-Q,Q_s))\,P-V_C\,(Q+Q_s)$	$qc+q_a\theta_s+(Q-q)\,P$
$\Omega 9$	Q	Q	$qc+q_ap_a+(W-q-q_a+min\,(W-Q,Q_s))\,P-V_C\,(Q+Q_s)$	$qc+q_ap_a+(Q-q-q_a)\,P$
$\Omega 10$	Q	q	$qc+q_a\theta_c+(W-q+min\,(W-Q,Q_s))\,P-V_C\,(Q+Q_s)$	$qc+q_a\theta_c+(Q-q)\,P$

Table 1: Optimal decisions and profit or cost functions

demand Q and P.

$$E\left(C\left(u^{*},x_{L}^{*}\right)\right)=\int_{0}^{\infty}\int_{0}^{\infty}C\left(u^{*},x_{L}^{*}\right)f\left(Q,P\right)dQdP \tag{7}$$

3.4 Information Scenario analysis

We can now start modeling how each actor behaves according to the information he holds privately or that is common to both and see analytically the impact on their objective functions.

We put a superscript index for each scenario on the carrier profit, shipper cost and standard deviation functions ($\pi_C^1; C^1; \sigma^1; R^1$ for scenario 1 for example).

3.4.1 Scenario 1: Common information

The carrier and shipper share information truthfully, as if coordinated by a single centralized organization. This scenario generates the maximum total profit. According to the observed demands and spot price, shipper S decides to allocate the maximum of the realized demand to C and C allocates the maximum of his capacity to satisfy S.

$$u=Q,x_{L}=\min\left(W,Q\right) \tag{8}$$

The optimized *revenue function* R *for* C varies according to the different values of P and the sharing of capacity between S and the market:

$\pi_c^1(x_L^{1*},x_s^{1*},Q,x_s,P)-V_C(x_L^{1*},x_s^{1*})$	
$\forall\left(Q,P\right)\in\Omega1$	$Qc+\left(q-Q\right)\theta_s+\min\left(W-Q,x_s\right)P$
$\forall\left(Q,P\right)\in\Omega2\cup\Omega3\cup\Omega4$	$qc+\left(Q-q\right)p_a+\min\left(W-Q,x_s\right)P$
$\forall\left(Q,P\right)\in\Omega5\cup\Omega6\cup\Omega7$	$qc+q_ap_a+\left(\left(Q-q-q_a\right)+\min\left(W-Q,x_s\right)\right)P$
$\forall\left(Q,P\right)\in\Omega8\cup\Omega9\cup\Omega10$	$qc+q_ap_a+\left(W-q-q_a\right)P$

Table 2: Revenue function for the carrier in terms of the regions

The optimized *cost function of* S becomes:

In this scenario, the Stackelberg position of S does not influence the outcome since no deviation will occur.

$C^1(u^{1*}, \Omega 1 =$	
$\forall\,(Q,P) \in \Omega 1$	$Qc + (q-Q)\,\theta_s$
$\forall\,(Q,P) \in \Omega 2 \cup \Omega 3 \cup \Omega 4$	$qc + (Q-q)\,p_a$
$\forall\,(Q,P) \in \Omega 5 \cup \Omega 6 \cup \Omega 7$	$qc + q_a p_a + ((Q-q-q_a) + \min(W-Q, x_s))\,P$
$\forall\,(Q,P) \in \Omega 8 \cup \Omega 9 \cup \Omega 10$	$qc + q_a p_a + (Q-q-q_a)\,P$

Table 3: Revenue function for the shipper in terms of the regions

The conditional expected cost as a function of the received demand Q subject to P comes to:

$$\begin{aligned} E\left(C^1\left(u^{1*}, x_L^{1*}\right)\right) &= \int_{\Omega 1}\int_{\Omega 1}\left(Qc + (q-Q)\,\theta_s\right) f\,(Q,P)\,dQdP + \\ &\int_{V_C}^{\infty}\int_{q}^{q+q_a}\left(qc + (Q-q)\,p_a\right) f\,(Q,P)\,dQdP + \\ &\int_{V_C}^{\infty}\int_{q+q_a}^{\infty}\left(Qc + q_a p_a + (Q-q-q_a)\,P\right) f\,(Q,P)\,dQdP \end{aligned} \tag{9}$$

3.4.2 Scenario 2: Asymmetric information

C has private information on W, the transport capacity. Ex ante, S has verified that C has at his disposal sufficient capacity to comply with q. She did not or could not verify the existence or size of the additional capacity S has to invest in to meet the commitments of the menu of prices (possible sub-contractors to C, extension of capacity in future, changes in other client demand patterns, etc are all possible reasons for such lack of observation).

So C has an opportunity to deviate when P is higher than $p_a + \theta_c$. If C deviates, the demand in excess of q by S has to be offered to the spot market. So the cost increases for S. C has been modeled to take that same amount from the spot market at the spot price so as to make it easier to compare performance and rent transfer between both players in the conclusions. The exact demand Q of S is here assumed observable by both S and C. The cost function of S and the revenue function of C can be summarised in table 4:

3.4.3 Scenario 3: Private information

In this scenario, C has private information on W, S has private information on the demand Q: so both have an option to behave opportunistically according to the spot price P. Each sticks to q, basic capacity contracted for. In this last scenario,

Region	$C\left(x_L^{i*}, u^{i*} \vert \Omega i\right)$	$R\left(x_L^{i*}, u^{i*} \vert \Omega i\right)$
$\Omega 1$	$Qc + (q - Q)\,\theta_s$	$c + (q - Q)\,\theta_s$
$\Omega 2 \cup \Omega 3$	Id. as Scen 1	Id. as Scen 1
$\Omega 4$	$qc + (Q - q)\,(P - \theta_c)$	$qc + (Q - q)\,(P - \theta_c)$
$\Omega 5 \cup \Omega 6$	$qc + q_a p_a + (\min(W, Q) - q)\,P$	$qc + q_a p_a + (Q - q - q_a)\,P$
$\Omega 7$	$qc + q_a \theta_c + (Q - q)\,P$	$qc + q_a \theta_c + (Q - q)\,P$
$\Omega 8 \cup \Omega 9$	$qc + q_a p_a + (W - q - q_a)\,P$	$qc + q_a p_a + (Q - q - q_a)\,P$
$\Omega 10$	$qc + q_a \theta_c + (W - q)\,P$	$qc + q_a \theta_c + (Q - q)\,P$

Table 4: Cost and revenue functions when information is asymmetric (Scenario 2)

Region	$C\left(x_L^{i*}, u^{i*} \vert \Omega i\right)$	$R\left(x_L^{i*}, u^{i*} \vert \Omega i\right)$
$\Omega 1$	$Qc + (q - Q)\,\theta_s$	$c + (q - Q)\,\theta_s$
$\Omega 2$	$qc + (Q - q)\,P$	$qc + (Q - q)\,P$
$\Omega 3$	$qc + (Q - q)\,p_a$	$qc + (Q - q)\,p_a$
$\Omega 4$	$qc + (Q - q)\,P$	$qc + (Q - q)\,P$
$\Omega 5$	$qc + (Q - q)\,P$	$qc + (Q - q)\,P$
$\Omega 6$	$qc + q_a p_a + ((Q - q - q_a) + Q - W)\,P$	$qc + q_a p_a + (Q - q - q_a)$
$\Omega 7$	$qc + (Q - q)\,P$	$qc + (Q - q)\,P$
$\Omega 8$	$qc + q_a p_a + (W - q - q_a)\,P$	$qc + q_a p_a + (Q - q - q_a)\,P$
$\Omega 9$	$qc + q_a p_a + (W - q - q_a)\,P$	$qc + q_a p_a + (Q - q - q_a)\,P$
$\Omega 10$	$qc + (W - q)\,P$	$qc + (Q - q)\,P$

Table 5: Cost and revenue functions when information is private (Scenario 3)

the menu of prices is unenforceable. For any spot price either higher or lower than the menu price p_a according to the additional capacity necessary, either the shipper or the carrier decides to go to the spot market. The other party, for lack of knowledge of capacity or cargo, cannot ask for nor receive any compensation. The results are listed in table 5.

3.5 Comparing scenarii

3.5.1 Comparison between scenario 1 and 2

The differences between scenario 1 and scenario 2 can be calculated by using the partitions already created (see figure 3): we have a difference only when Q comes in between q and q+q_a and the spot price happens to be above $p_a + \theta_c$, which belongs to partition $\Omega 4 \cup \Omega 7 \cup \Omega 10$.

$$\forall (Q, P) \in \Omega 4 \cup \Omega 7 \cup \Omega 10$$

$$\pi^2 \left(x_L^{2*}, u^{2*}, Q, P\right) - \pi^1 \left(x_L^{1*}, u^{1*}, Q, P\right) = (Q - q)\left(P - \theta_c - p_a\right) \tag{10}$$

$$C^2 \left(u^{2*}, x_L^{2*}, Q, P\right) - C^1 \left(u^{1*}, x_L^{1*}, Q, P\right) = (Q - q)\left(P - \theta_c - p_a\right) \tag{11}$$

By definition of the contract parameters, we can write:

$$\forall (Q, P) \in \Omega 4 \cup \Omega 7 \cup \Omega 10$$

$$\begin{array}{c} \pi^2 \left(x_L^{2*}, u^{2*}, Q, P\right) - \pi^1 \left(x_L^{1*}, u^{1*}, Q, P\right) \geq 0 \\ C^2 \left(u^{2*}, x_L^{2*}, Q, P\right) - C^1 \left(u^{1*}, x_L^{1*}, Q, P\right) \geq 0 \end{array}$$

Both results are positive if there is but one instance of both the spot price higher than the menu of prices fixed in the contract plus the carrier penalty and existence of cargo to be taken in excess of base commitment q.

There is a transfer of resources from S to C when C can deviates from truthful behaviour by hiding the exact capacity he has at his disposal and withhold extra capacity from S to sell it to the spot market at a higher price.

The conditional expected cost of the difference in information is written:

$$\begin{array}{c} E\left(C^2\left(u^{2*}, x_L^{2*}, Q, P\right) - C^1\left(u^{1*}, x_L^{1*}, Q, P\right)\right) = \int\limits_{\{P,Q\} \in (\Omega 4 \cup \Omega 7 \cup \Omega 10)^2} \int\limits_{((Q-q)(P-p_a))f(Q,P)dQdP} \\ = E\left(\pi^2\left(x_L^{2*}, u^{2*}, Q, P\right) - \pi^1\left(x_L^{1*}, u^{1*}, Q, P\right)\right) \end{array} \tag{12}$$

The variance of the transport cost to S increases with the variances of the component laws: ζ_L and P affected by the values given to the contractual parameters.

3.5.2 Comparison between scenario 1 and 3

The differences occur in regions $\Omega 2$,$\Omega 4$,$\Omega 5$, $\Omega 7$, $\Omega 8$ and $\Omega 10$ when either the shipper or the carrier has an incentive to deviate. By investigation, these come to:

$$\forall (Q, P) \in \Omega 2$$

$$\pi^3 \left(x_L^{3*}, u^{3*}, Q, P\right) - \pi^1 \left(x_L^{1*}, u^{1*}, Q, P\right) = (Q - q)\left(p_a - P\right) \tag{13}$$

$$C^3 \left(x_L^{3*}, u^{3*}, Q, P\right) - C^1 \left(x_L^{1*}, u^{1*}, Q, P\right) = (Q - q)\left(p_a - P\right) \tag{14}$$

$$\forall (Q, P) \in \Omega 4$$

$$\pi^3\left(x_L^*, u^*, Q, P\right) - \pi^1\left(x_L^*, u^*, Q, P\right) = (Q - q)\left(P - p_a\right) \tag{15}$$

$$C^3\left(x_L^{3*}, u^{3*}, Q, P\right) - C^1\left(x_L^{1*}, u^{1*}, Q, P\right) = (Q - q)\left(P - p_a\right) \tag{16}$$

$$\forall (Q, P) \in \Omega 5 \cup \Omega 8$$

$$\pi^3\left(x_L^*, u^*, Q, P\right) - \pi^1\left(x_L^*, u^*, Q, P\right) = q_a\left(P - p_a\right) \tag{17}$$

$$\forall (Q, P) \in \Omega 7 \cup \Omega 10$$

$$\pi^3\left(x_L^*, u^*, Q, P\right) - \pi^1\left(x_L^*, u^*, Q, P\right) = q_a\left(P - p_a\right) \tag{18}$$

$$\forall (Q, P) \in \Omega 1 \cup \Omega 3 \cup \Omega 6 \cup \Omega 9$$

$$\pi^3\left(x_L^*, u^*, Q, P\right) - \pi^1\left(x_L^*, u^*, Q, P\right) = 0 \tag{19}$$

$$C^3\left(x_L^*, u^*, Q_L, P\right) - C^1\left(x_L^*, u^*, Q, P\right) = 0 \tag{20}$$

The conditional expectation of this difference subject to P and Q can be written as:

$$\begin{aligned} E\left(C^3\left(x_L^{3*}, u^{3*}\right) - C^1\left(x_L^{1*}, u^{1*}\right) | Q_L, P\right) = & \int\limits_{P\in\Omega 2}\int\limits_{Q\in\Omega 2} \left(\left(Q - q\right)\left(p_a - P\right)\right) f\left(Q, P\right) dQdP + \\ & \int\limits_{P\in\Omega 4}\int\limits_{Q\in\Omega 4} \left(\left(Q - q\right)\left(P - p_a\right)\right) f\left(Q, P\right) dQdP + \\ & \int\limits_{P\in\Omega 5\cup\Omega 8}\int\limits_{Q\in\Omega 5\cup\Omega 8} \left(q_a\left(P - p_a\right)\right) f\left(Q, P\right) dQdP + \\ & \int\limits_{P\in\Omega 7\cup\Omega 10}\int\limits_{Q\in\Omega 7\cup\Omega 10} \left(q_a\left(P - p_a\right)\right) f\left(Q, P\right) dQdP \end{aligned} \tag{21}$$

Following the same reasoning, we can write the conditional expectation of the difference, subject to P and Q, of the profit to the carrier as:

$$\begin{aligned} E\left(\pi^3\left(x_L^{3*}, u^{3*}\right) - \pi^1\left(x_L^{1*}, u^{1*}\right) | Q, P\right) = & \int\limits_{\Omega 2}\int\limits_{\Omega 2} \left(\left(Q - q\right)\left(p_a - P\right)\right) f\left(Q, P\right) dQdP + \\ & \int\limits_{\Omega 4}\int\limits_{\Omega 4} \left(\left(Q - q\right)\left(p_a - P\right)\right) f\left(Q, P\right) dQdP + \\ & \int\limits_{\Omega 5\cup\Omega 8}\int\limits_{\Omega 5\cup\Omega 8} \left(q_a\left(p_a - P\right)\right) f\left(Q, P\right) dQdP + \\ & \int\limits_{\Omega 7\cup\Omega 10}\int\limits_{\Omega 7\cup\Omega 10} \left(q_a\left(p_a - P\right)\right) f\left(Q, P\right) dQdP + \end{aligned} \tag{22}$$

These indications give guidance to the way the contractual parameters have to be negotiated by the shipper and the carrier so that if the information conditions are not given, at least the differences between both scenarios can be minimized. Such uncertainties and optimization of the contractual parameters will be the subject of another paper. For now, we have found that applying the preceding reasoning through a numerical study would give some indications as to the importance of the different parameters on behaviour by S and C.

4 Numerical study

4.1 Elaboration of the sample

In this section, we perform a numerical study to gain further insight into how the 3 scenarios affect the overall efficiency of the supply chain, revealing the impact that both contract characteristics and information sharing have on the overall profit and EFR of the supply chain.

We have taken the most general case for the demands addressed to the shippers and the price for spot transportation: exogenous stochastic variables with possibilities that they can be correlated. This study has been based upon a sample generated through the normal distribution random number generator of Microsoft Excel XP. The demand coming from the spot market is derived from the generated numbers for shipper S through the formula for bivariate normal distribution:

$$X = \mu_1 + \sigma_1 U$$
$$Y = \mu_2 + \sigma_2 \sqrt{1-\rho^2} V$$

Where X $\sim$ N(μ_1, σ_1), Y $\sim$ N(μ_2, σ_2), U and V are independent random variables, each with normal distributions, and ρ_D = 0.60 the correlation factor between X and Y.

The spot price distribution is also normal and correlated with the demand Q addressed to S by a factor of 0.20.

$Q \sim N(100, 25)$
$Q_s \sim N(100, 25)$
$P \sim N(5, 1.2)$

We have generated 1000 occurrences of triples (Q,Q_s,P) (see 7). When further analysis into a particular result which has an important bearing on the final conclusion of the reasoning, we have fixed the corresponding parameters for the contract and repeated the sample 250 times. We then compare the 250 averages and calculate their confidence intervals and corresponding p-values.

We first evaluate the base scenario given the costs and other parameters detailed in Table 1 for the shippers and the carrier. Later, we study the impact produced by the variation of different parameters and conclude as to the resulting supply chain efficiency.

4.2 Setting of other variables of the model

The other variables have been set as per table 6:

	Q	Q_s (Market demand)	P (spot price)
Mean	98.3	98.6	5
Standard deviation	24.7	25.9	1.03
Correlation factor		0.6	0.2

Table 6: Base demand distribution parameters for numerical study

The contract characteristics are recorded in table 7:

Capacity q	Contract price c	Shipper penalty θ_s	Carrier penalty θ_c	Additional capacity limit q_a
120	4	1	1	25

Table 7: Base parameters for numerical study

The menu of prices offered by the carrier C to the shipper S for demands exceeding contracted capacity are given in table 8.

For q_a in range	< 5	6 to 10	11 to 15	16 to 20	21 to 25
The price is p_a	4.25	4.50	4.75	5	5.25

Table 8: Base parameters for numerical study

THE CARRIER INTERNAL COST AND CAPACITY:

The total cost for the carrier if the total capacity is used is $400 + 2 * 200 = 800$. We consider that one unit of demand is carried at the transport price.

5 Impact of contract characteristics as coordination factors of the supply chain

In this section, we study the impact of the different contract characteristics on the principal elements of the objective functions of the carrier and shipper. We

Capacity W	Variable cost per unit Vc	Fixed cost $Fc(W)$
200	2	400

Table 9: Base parameters for numerical study

approach the influence of the same contract characteristics on the information scenarios only in the next section.

Three stages of coordination can be defined (table 10): the first is the case of the market: no contract, total dependence on the spot price. The second is the case of the shipper S in scenario 3: he can't have the penalties limiting deviation on both sides enforced, so only the basic commitment on capacity and price exist. The third is the case of S in scenario 1, when all necessary information is common knowledge. Using 250 samples of 1000 triplets to calculate the following results, we can show the following results:

p-value < 0.01	Average Transport Cost	Std Deviation
No contract	485.9 ($\pm$0.9)	181.1 ($\pm$0.7)
Contract no penalties	402.6 ($\pm$0.54)	106.0 ($\pm$0.4)
Contract & penalties	425.6 ($\pm$0.44)	87.1 ($\pm$0.4)

Table 10: Impact of coordination on two criteria with c=4, q=120, qa=25

5.1 Penalties

In the present case, incentive compatibility given by the contract is through the penalties that either the shipper or the carrier can suffer. We have quantified this impact by varying the size of both penalties at the same time.

In the scenario of complete information, as both the contract capacity price c and penalties θ_s and θ_c go down, the standard deviation of the cost to shipper S goes up which is intuitive. At a given contract price c, standard deviation of cost increases inversely to the penalties (figure 6 has p-values of 0.01, no thicker than the width of the lines). As can be expected, the average cost of transport follows the evolution of penalties.

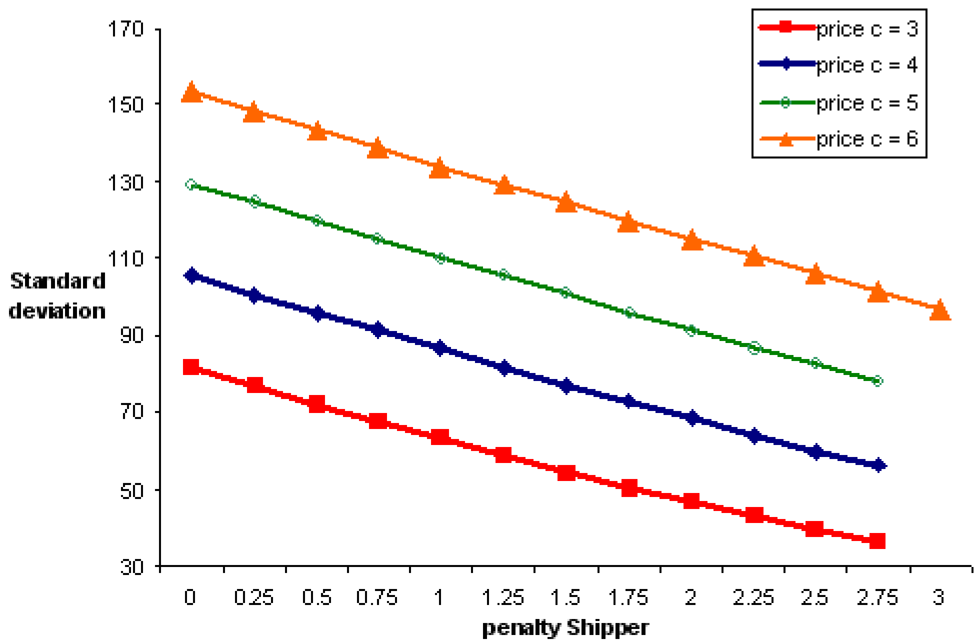

Figure 6: Impact of penalties on the standard deviation of transport cost for S at given c

5.2 Contract price

As another coordinating lever, what influence does the contract price have on the average cost and the variance of the transport cost to the shipper? Would a higher price offered to the carrier suffice to induce better incentive compatibility?

Let us consider first the variance of transport costs (table 10). Thanks to the contract in place, S has a transport cost variance of 87.1 vs 181.1 for the spot market, about half. She also enjoys lower overall average cost for her transport.

p-value<0.01	Contract price			
	3.5	4	4.5	5
Average cost	375.8	425.6	475.4	525.2
Std Deviation	74.4	87.05	98.8	110.7
kurtosis	19.8%	20.4%	20.8%	21.1%

Table 11: Shipper S statistics with long-term contract in place scenario 1

In table 11 we see that ceteris paribus a higher contract price does not warrant lower relative cost variance.

5.3 Contract capacity and additional capacity

The average transport cost (which reflects the added penalty cost to the shipper) grows both when capacity and additional capacity contracted grow, which is intuitive since this reflects the latitude that the shipper has in asking for more capacity and lessening the impact of the penalty. Almost as intuitive is the result that the variance of the cost diminishes as capacity and additional capacity increase. All these parameters should lead the shipper to try to negotiate a "sweet spot" of compromise between cost and variance. In our numerical example, this sweet spot would be in the region of a contract capacity of 120 with an additional capacity of 10 (Figure 7) where the average cost plus one standard deviation is at its lowest:

But this result does not take into account the cost of this capacity. To include this parameter, we have devised an "efficiency ratio" defined by the formula:

$$Efficiency = \frac{(\mu_{\cos t} + \sigma_{\cos t})}{Min\,(\mu_{\cos t} + \sigma_{\cos t})}$$

Where μ_{cost} is the average cost of transport for each duple (capacity, additional capacity) and σ_{cost} is the standard deviation of the average cost of transport

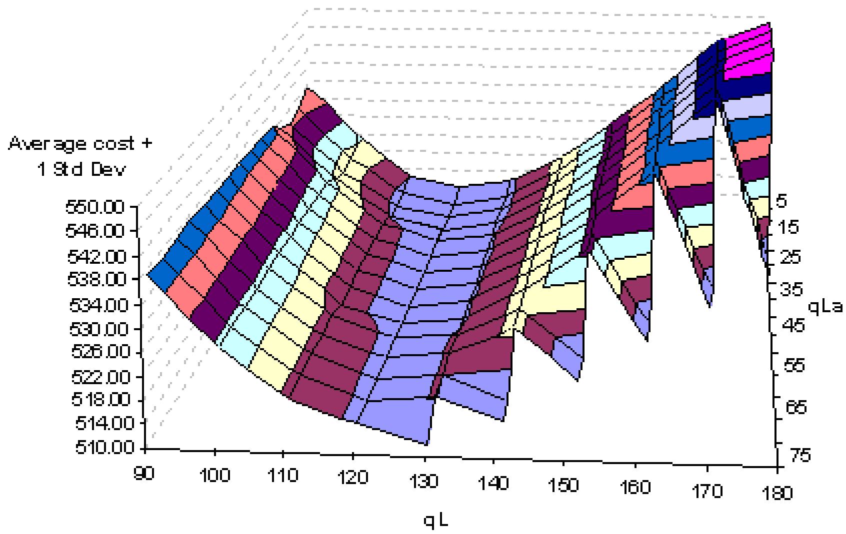

Figure 7: Average cost + 1 standard deviation according to capacity and additional capacity

for each duple (capacity, additional capacity); Min($\mu_{cost} + \sigma_{cost}$) is the minimum observed of the average costs for all combinations of capacity and additional capacity.

According to the graph of these efficiency ratios (figure 8), the optimum contract for the shipper has the following characteristics:

$q = 120$
$q_a = 10$
penalty θ_s= 1
penalty θ_c = 1
contract price $c = 4$
menu of prices p_a: from 4 to 5 in steps of 0.25

5.4 Menu of prices hierarchy

The menu offered to the shipper in our central numerical example is the following (table 12):

The prices increase with the demand from the shipper: if the shipper observes a demand Q of 144, he can get from shipper S a contract capacity of:

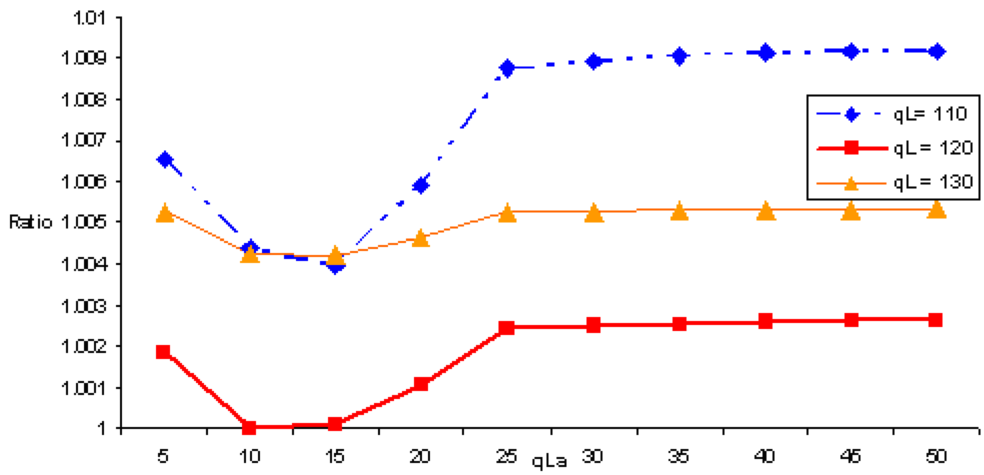

Figure 8: Graph of efficiency ratio for 3 capacities and all additional capacities, p-values <0.01

q_a	p_a
0 - 4	4
5 - 9	4.25
10 - 14	4.50
15 - 19	4.75
20 - 24	5.00
25	5.25

Table 12: Menu of prices in contract

$$q = 120$$

and additional capacity:

$$Q - q_a = 24$$

For that capacity, the menu price is:

$$p_a = 5.00.$$

Why doesn't the carrier offer some kind of volume rebate as an inducement? One must remember that transport is a non-scalable capital-intensive production facility. If one admits that the available capacity is divided into discrete facilities (whether trucks, vessels, conveyor belts, rail carriages, pipelines) with different cost structures and usable lives, then of course the lowest cost facilities are used first and progressively higher cost facilities are brought into use as demand increases. Hence, marginal costs increase with demand. On the other side of the equation, giving additional flexibility to the client has been established to increase his "willingness-to-pay" by Tsay (1999). On average, the shipper is marginally better off accepting the offered menu price rather than buying the needed capacity from the spot market (not so much because he thus lowers his average cost as because he reduces the standard deviation of such cost from 87.86 (scenario 3) to 86.56 (see table 6) and reduces the transaction involved in buying from the spot market instead of from the contracted carrier. So he will accept *ex ante* the menu in the contract. Of course, the carrier is also worse off offering the menu, but less than if he were to offer volume discounts! In effect, the carrier might not offer any menu at all (his revenues would increase slightly). The menu is in fact another way to coax the shipper S into allocating him extra work, enabling him to increase his capacity utilisation over the whole life of the contract. A situation which is always better than having to look for cargo in the spot market. The forfeited revenue can be more than compensated by added transaction costs and lack of transparency in the spot market.

5.4.1 Carrier's point of view

The interest of a contract to the carrier is clear as he has to commit capital over the long term in new capacity to satisfy the shipper's demand. The transport market being illiquid and commercial relationships being very tradition-bound, the carrier probably would not have invested in additional capacity just to satisfy the spot market.

He turns a profit because he can further leverage the available capacity to win more business from the spot market in the cases when S does not receive enough demand. Considering that his total assets have a capacity of 200, that he has a fixed cost of 400, it can be said that the total cost "allocated" to the contract is:

$$\begin{aligned} \text{Fixed cost in contract } &= \tfrac{400}{200}.125 = 250 \\ \text{Variable cost in contract } &= 125.2 = 250 \\ \text{Total cost per unit } &= \tfrac{250+250}{125} = 4 \end{aligned}$$

When $c = 4$, the carrier makes a tidy profit of 135.71. He even makes a profit when $c = 3.75$ ceteris paribus, as shown below (table 14), because he can "subsidize" the contract by selling excess capacity onto the spot market at a much higher mean price. So his real profit lies in his ability to build upon the sunk capacity to look for other commercial opportunities outside the relationship to shipper S. He can allow the contract price to be less than the "allocated" total cost because of the reduced variance of his revenues as can be concluded by the following table where we have calculated the variance of the carrier's revenues in the case he works with a contract with S and in the case where he sells his total capacity on the spot market (no contract) (table 13). His revenues are lower but he has the security of a substantially longer term view over a period designed to last the life of the specific assets acquired.

$p < 0.01$	contract		no contract	
	Mean	Confid. Interval	Mean	Confid. Interval
Average revenue	812.4	0.7	918.4	1.2
Standard Deviation	132.5	0.5	241.6	0.8
Profit	47.6	0.5	49.7	0.5

Table 13: Impact of contract on carrier performance under full information $c = 3.75, \theta_s = \theta_c = 1, q_L = 120$

Overall, he is much better off ensuring a stable and reliable stream of revenues by linking the investment to the contract with the shipper.

5.5 Conclusion on contractual coordination

We observe that to the shipper, average transport cost, variance of transport cost can be noticeably improved by replacing a pure spot buying of transport capacity by a suitable mix of two procurement strategies: one taking a long-term approach by a designed contract between the carrier and the shipper, another by complementing this long-term approach by a short-term one that consists of spot-market buying for a fraction of every period's transportation needs (table 14). A similar conclusion has been reported in Seifert *et al.* (2004).

Another aspect we haven't touched on heretofore is the fact that a shipper will not even evaluate carriers who do not meet order-qualifying minimum acceptable levels in four performance dimensions: logistical cost, logistical productivity, customer service and quality. Morash (2001) in his field study of north American and Canadian Council of Logistics Management Association (CLM in the US and CALM in Canada) has ranked seven major types of supply chain capabilities according to their importance, once minimum levels have been met. Customer service, quality and information systems support came top, ahead of logistics cost and productivity. These quality or reliability of service clauses are of paramount importance to the shipper and override cost considerations.

No attempt has been made to quantify the impact of variations of the spot market price volatility here. Further study should be put in measuring the difference in efficiency between the pure spot strategy and the contract/spot one by changing transport price volatility.

p-value < 0.01	Pure spot buying (no coordination)		Mix contract + spot (coordination)	
	Std Dev of cost/Rev	Average Cost /Reve	Std Dev of cost/Rev	Average Cost /Reve
Shipper	181.1 ($\pm$0.7)	485.9($\pm$0.9)	86.6 ($\pm$0.4)	425.1($\pm$0.4)
Carrier	241.3 ($\pm$0.8)	918.4($\pm$1.2)	135.7($\pm$0.5)	837.4($\pm$0.7)

Table 14: Comparative of contractual coordination vs no coordination

We now have established how a carefully crafted contract and appropriate spot buying can enhance the overall efficiency of the supply chain, we proceed to demonstrate how sharing information between carrier and shipper S impacts their profitability and variance of results or costs.

5.6 Impact of information sharing on shipper and carrier

We come around to the study of the combined influence of the coordination factors across the information scenarios defined earlier.

Our model has been limited to studying the impact of only three parameters of information on the performance and efficiency of the supply chain:

- W : total transport capacity of C
- Q: realized demand of S
- P: spot price.

The study concentrates on the interactions between S and C and on the influence of sharing the above three types of information. To give an idea of the order of the differences involved, we first begin with the central numbers in all three scenarios (table 15). The σ/μ ratio is a measure of the kurtosis of the distribution: we have divided the transport cost standard deviation by the average transport cost. The higher the ratio, the flatter the distribution curve of the means and thus the thicker the tails of the distribution. Throughout the three scenarios, the carrier's average revenue and standard deviation of revenues remain relatively constant with a correspondingly constant kurtosis.

p-value<0.01	Shipper S			Carrier C		
	Mean cost	Std Dev	σ/μ	Mean rev	Std Dev	$\sigma\mu$
Scenario1	425.45 (±0.44)	86.56 (±0.38)	20.35%	837.35 (±0.68)	135.76 (±0.56)	16.21%
Scenario2	425.18 (±0.44)	86.44 (±0.38)	20.33%	838.79 (±0.68)	137.33 (±0.56)	16.37%
Scenario3	426.05 (±0.44)	87.86 (±0.40)	20.62%	837.35 (±0.69)	135.71 (±0.54)	16.21%

Table 15: Results of 3 scenarios with parameters fixed in central case $C = 4, q = 100, q_a = 20, \theta_c = \theta_s = 1$

It is immediate with contractual parameters having been fixed as they are that the influence of information overall is much less than the coordination induced by the carefully crafted contract mentioned earlier. However, these ex-ante adjustments may not be standard practice in industry. To get a better appreciation of the influence of these contracting parameters on the overall efficiency of the supply chain and the interactions with information, we will now proceed to twiddle the parameters two by two and see their effect across the information scenarios.

We hope that the results should help practitioners in assessing how a given contract will influence their overall transport cost (or revenue) and what results they should look for during initial bargaining given the known information scenario they might encounter during the contract's life.

This section is divided into three subsections. In the first one, we vary capacity and additional capacity and fix all other contract parameters and study standard deviation of transport cost among the three scenarios. In the second subsection, we vary the contract price and penalties to see how their combined effects change with access to information. In the third, we vary the contract price and capacities and see the effects across the scenarios.

5.6.1 Influence of capacity and additional capacity

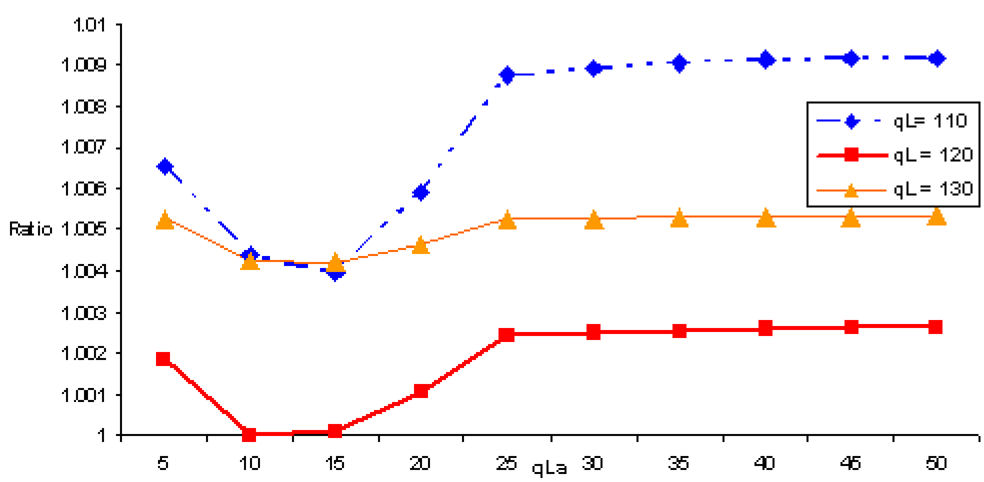

Figure 9: Transport cost standard deviation as a function of capacity and additional capacity, comparison scenario 3 – scenario 2

We see in one sample of 1000 triplets (figure 9) that under tight capacity, the second scenario increases transport cost variance to shipper S. On the contrary, we observe that the higher the contracted capacity q, standard deviation of transport cost is indifferent to whether or not the carrier deviates from coordinated behaviour. There is a maximum difference at a contract capacity of 90 and additional capacity of 75: scenario 2 generates high variance relative to the common knowledge scenario. This gives an incentive to S to correctly assess initial forecast average demand that she will face because the additional capacity that she might think would bring constancy in cost is undermined if the carrier withholds capacity from her.

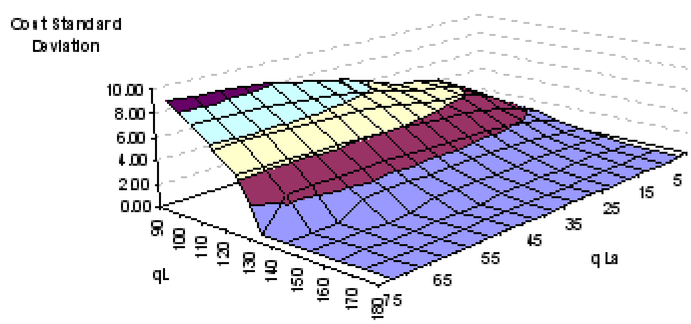

Figure 10: Transport cost standard deviation as a function of capacity and additional capacity, comparison scenario 3 – scenario 2

The third scenario shows the same pattern of degradation of transport cost variance at all levels against scenario 2, and consequently against scenario 1 (figure 10).

In effect, this means that S must counterbalance the negative effects of lack of common knowledge by carefully tuning the capacity she contracts and the additional capacity she includes in the ex-ante contract.

5.6.2 Influence of contract price and penalties

We now give the results of the standard deviation of transport cost in function of the contract price c and the penalties θ_s and θ_c.

5.6.3 Average transport cost and standard deviation of cost

The transport cost is higher in the second scenario versus the first when the penalties and contract price are too low to induce coordination. Past a certain level, higher contract price or penalties cannot beat common knowledge in average cost.

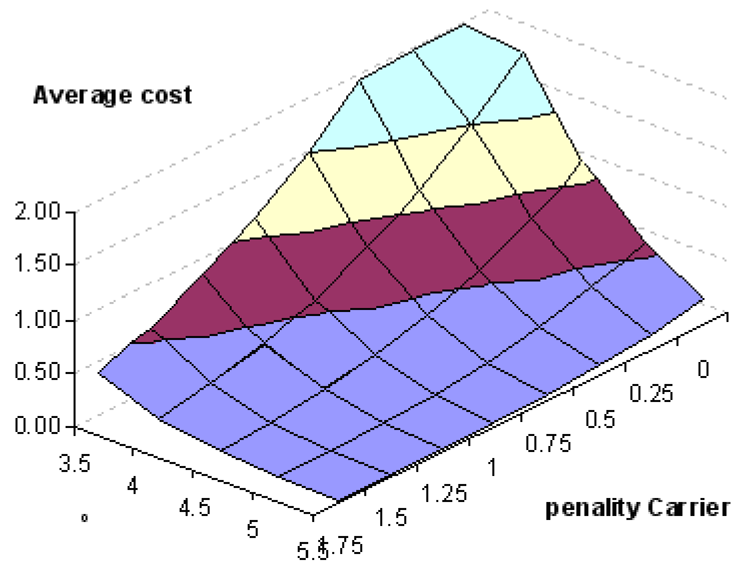

Figure 11: Influence of contract price and penalties on average transport cost: scenario 2- scenario 1

The same result applies to the standard deviation of the transport cost. Basically, at a penalty of 1 and contract price of 4 differences are ironed out whether or not the carrier deviates. (figures 11 and 12).

As for the third scenario against the first, the results are also very similar and warrant the same conclusion.

There is therefore no need to set up high penalties or high contract prices to ensure coordination or compensate for lack of information.

The standard deviation of the transport cost reacts much sooner to increases in contract price. To enhance the readability of the results, we have divided the standard deviation thus obtained by the average transport price. We have a better notion of the kurtosis of the distribution of the transport costs (figure 13).

The first important comment is that the ratios all come in a very small range: the kurtosis of distribution does not change a lot whether information is being shared or not. Even when the contract price is higher, the standard deviation of the transport cost increases even more, lifting the overall ratio in both the first

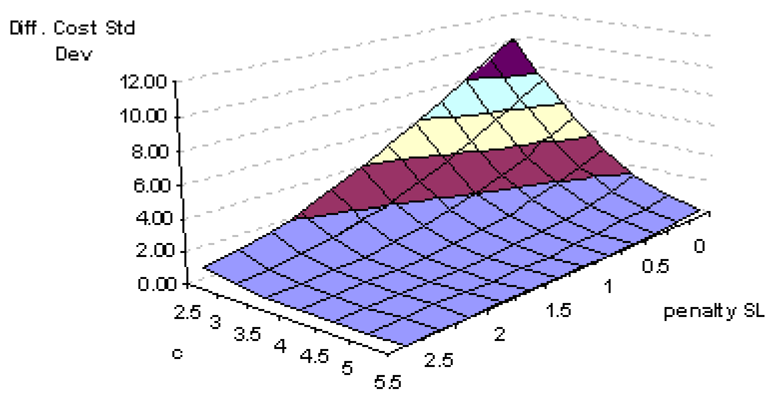

Figure 12: Influence of contract price and penalties on the standard deviation of transport cost: difference between scenario 2 and 1 (p-value<0.01)

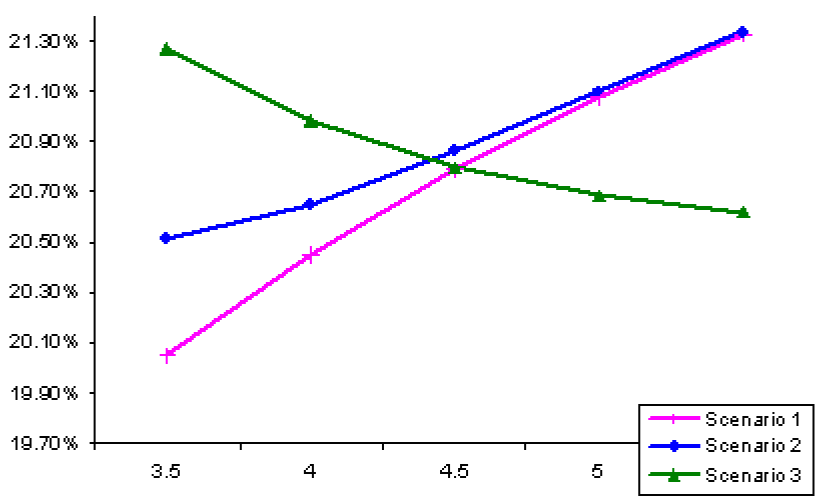

Figure 13: Kurtosis of transport cost distribution: three scenarios (θ_s=θ_c=1, p-value $<$ 0.01)

and second scenarios. Only in the third case does the increased price bring higher coordination and lower variance of cost to S.

5.6.4 Influence of contract price and capacity

Moving on to influence of contract price and capacity with information scenarios, we start by showing the difference between scenario 2 and 1 of the average cost of transport. Common information brings singularly high advantages when a contract price is low and coupled with a low contracted capacity (figure 14). On the contrary, when S has underestimated her needs when negotiating capacity levels in the contract, but negotiated a c nearer to the average spot price, her average transport cost is much nearer the cost supported in a scenario where C hides his exact capacity from S and sells in the spot market.

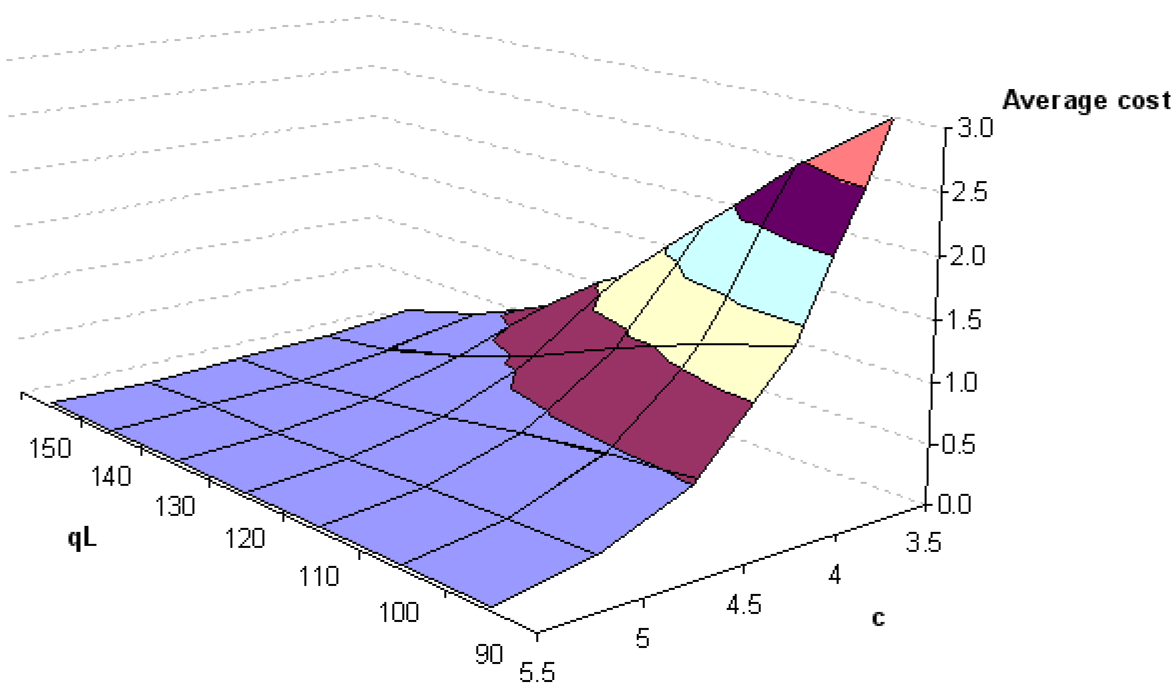

Figure 14: Average cost of transport to Sas a function of capacity and contract price, difference between scenario 2 and 1

When both carrier and shipper can deviate, the price specified in the contract for the base capacity becomes important in the overall cost if this capacity has been underestimated. If the shipper and carrier intend to deviate, average cost will change significantly according to the contract price (figure 15).

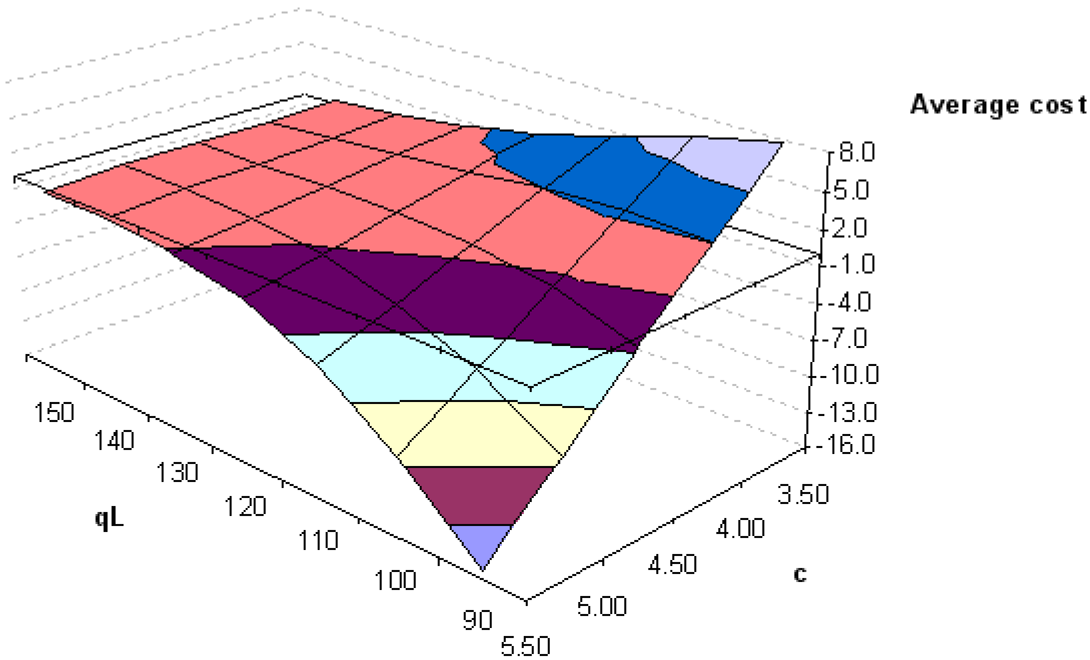

Figure 15: Average cost of transport to S as a function of capacity and contract price, difference between scenario 3 and 1

The first scenario (figure 16) dominates the second scenario at all points and especially when both capacity is tight and contract price is low.

In the comparison between the third and first scenario of the standard deviation of transport cost, much the same observations can be made as when looking at average cost (figure 17). Once again, we conclude that the information asymmetry can almost be bridged by coherent contractual ex ante arrangements.

5.7 Conclusion to numerical study

This study has been done with particular hypotheses that must be put into perspective. For example, we have taken normal distribution for both the demands received and the spot price of transport. Even if this choice may be considered as

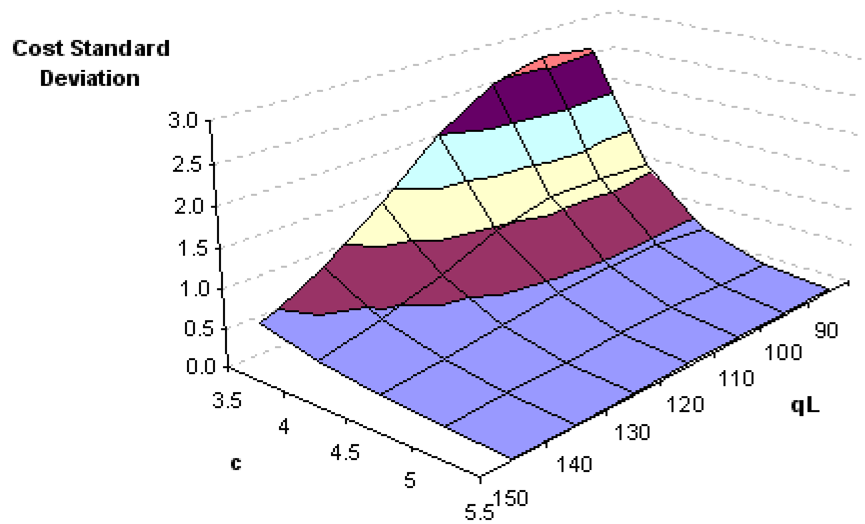

Figure 16: Difference between scenario 2 and 1 of Standard Deviation of transport cost for S

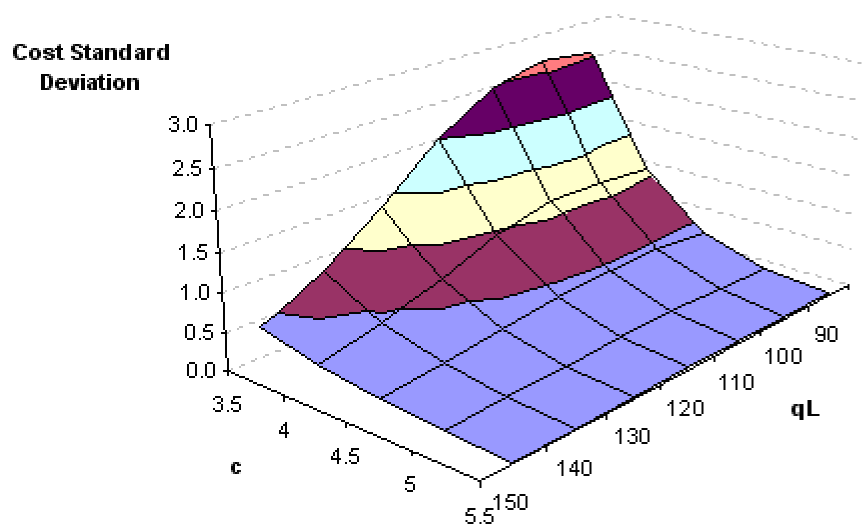

Figure 17: Difference between scenario 3 and 1 of Standard Deviation of transport cost for S

restrictive, results from the interaction with contractual parameters and information scenarios would be similar in other symmetric distribution laws.

The choice of the parameters to be studied has much stronger influence on the overall results than whichever choice of distribution laws, price and demand volatilities are chosen.

The scenario of full information or common knowledge is always superior even if in a minor way. However, as common knowledge may not be given between a carrier and a shipper when negotiating their first contract, each must then recur to fine tuning the contract parameters to regain most of the advantages to be had as result of a trust or central coordination scenario.

In table 16 are recorded the ideal contract that both the carrier and the shipper should strive to sign when common knowledge or observability are not given.

p-value<0.01	Scenario 1	Scenario 2	Scenario 3
c	4		
q	120		
q_a	10		
$\theta_c = \theta_s$	1		
Average cost	425.5(±0.4)	426.0(±0.4)	427.0(±0.5)
Stand Deviation	86.90(±0.4)	88.07(±0.4)	89.6(±0.4)
Market characteristics			
	Q	Q_s	P
Average	98.4	98.6	4.98
Standard Deviation	24.8	25.0	1.03

Table 16: Contract parameters that optimize costs for the shipper among diverse information scenarios

These results must be related to the environment in which both carrier and shipper negotiate. The best way is to relate the contract characteristics to the spot price and to the demand addressed to the shipper. The shipper must settle for a contract price c that is one standard deviation less than the average price of spot capacity observed in the market. He must also contract approximately his forecast average necessity plus one standard deviation and an additional capacity equal to around half a standard deviation of the forecast demand he will receive. Penalties should represent 25% of the contract price for the base capacity commitment. All those objectives should be achieved together in the contract for best results.

6 Conclusion and possible evolution

In this paper, we show the importance and effects that information sharing can have on the profitability of carriers and shippers. This example sticks to actual industrial conditions so as to enable readers in transport procurement to easily apply the conclusions to their own situations. The relative importance of information is clearly marked out so as to give information sharing and trust building the share they should have in a well thought out strategy. Given the variety of information which must be shared in a normal shipper-carrier relationship, the opportunities to enhance efficiency in the supply chain abound. This area is probably the one where the most progress will be made in the years to come bringing to the firms who will master it valuable nuggets of efficiency as well as increased responsiveness.

In this paper, we present transport as an individualized supply chain member and supplier to the chain. We have modelled the impact and influence that information sharing and coordination with transport suppliers has on the efficiency of the supply chain. The present model only studies the influence of three information factors and six coordination factors on the cost, standard deviation of such cost of the transport supplier to the supply chain. We have not considered agglomerating these three gauges into one sole efficiency index as we believe that this would entail a loss of information from the point of view of application to practice.

Given limitations due to a special case of binormal distribution, however, the conclusions we arrive at are interesting in advancing the debate about the influence of information asymmetry and contractual coordination in the supply chain for transport.

1. First, as in Seifert *et al.* (2004), we confirm that adopting a procurement policy where spot buying complements contract buying is a superior policy to the one consisting of pure spot buying. In particular, standard deviation of the transport cost in a mixed contract and spot buying strategy is half the one in pure spot buying.

2. The contract in the mixed strategy must include a fixed capacity commitment and some additional flexibility in capacity (QF clause).

3. Penalties should be included: the carrier is penalised when he cannot comply with his contractual capacity engagements; the shipper is penalised

when he cannot fulfil his buying engagements. We have shown that this ensures coordination.

4. We show that the carrier, even if his revenues are not as high when linked to a shipper by a contract, still has ample motivation to elect such a choice as opposed to selling his capacity in the spot market.

5. The numerical study clearly shows that some contractual arrangements existing ex-ante have singular power to iron out information asymmetry between carrier and shipper. Overall, contractual arrangements do not dominate the results of central coordination or costless information. To reach this level of central coordination, we argue that the best way is for both shipper and carrier to trust each other. This truthfulness should enable each party to build a trust relationship and his or her reputation in the sense of Williamson (1996) ("a farsighted approach to contracting (in which credible commitments, or lack thereof, play a key role)").

6. We have proved that if the committed contract capacity fixed in the contract is too low (less than the estimated average of demand plus one standard deviation) and when the contract price is set too low compared to the current average spot price observed, the carrier has a strong incentive to behave opportunistically and fail the shipper, causing increase in average transport cost and standard deviation of cost. In this case, whatever their level, penalties bear only incidental influence.

7. The information imbalances induced by keeping private information as to the real transport capacity by the carrier, the real demand received by the shipper is detrimental to the overall efficiency of the supply chain, when the ex-ante contractual coordination mechanism has been poorly designed, because it encourages deviant attitudes both from the carrier and the shipper. We have proved that these imbalances are a direct function of the contract parameters negotiated.

8. Carefully crafted ex-ante contractual arrangements can substantially correct this information asymmetry but increases the overall transport cost to the shipper. The most influential factors in the contract are the committed capacity, the contract price for this committed capacity and, to a lesser degree, the additional capacity with an increasing menu of prices offered by the carrier.

One prolongation of the present paper will deal with solving the mathematical model for the optimal contract parameters both in terms of information as well as coordination as expressed in terms of cost and standard deviation.

The aim of the supply chain manager should be to reduce variance in costs because, in a multi-period game, it increases the notorious double margining phenomenon. The shipper increases his budgeted costs because he cannot ensure regularity of his cost and hence must protect himself by padding his transport budget; the carrier because he has to contend with fixed cost non-scalable capacity and so must also preserve his financial health by higher than warranted profit margins.

Another avenue to be explored is the study of how standard deviation of transport cost is affected by different levels of the variance of both the spot price P and the demand Q (along the lines of Seifert *et al.* , 2004, Gavirneni *et al.* , 1999).

In all cases, the most interesting point to study is to allow the carrier to increase capacity utilization and reduce revenue volatility and thus share with the supply chain the economies. The net effect to the supply chain would be to reduce the total investment cost of the transport capacity contracted and hence the total transport cost component. In fact, the logistics industry as a whole is investing and developing tools to enhance the circulation of information among the interested parties as has been shown in the survey in Peters (2002).

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7 Appendix A – Characteristics of the numerical example of the study

For most of the graphs in the paper, we have generated a sample of 1000 triplets (Q, Q_s, P).

This sample is generated through the Microsoft Excel worksheet function random number generator for normal distribution. Q has an average of 100 and a standard deviation of 25. Q_s is built according to the bivariate normal distribution with a correlation factor to Q of $\rho = 0.6$. Ps is also generated along a same bivariate normal distribution with a correlation factor to Q of $\rho = 0.20$.

When more robust results were called for, we have generated 250 samples of 1000 triplets and averaged them using the Central Limit Theorem. Wherever that has been the case, we give the confidence interval with a p-value $<$0.01.

This is one graph of the distribution of Q_s vs $Q$for one sample of 1000 triplets (18):

We have grouped the demands in categories of 6 from less than 22 to more than 172 20:

These samples have the following statistics:

$Q : \mu_L = 98.4, \sigma_L = 24.75$

$Q_s : \mu_S = 98.6\ \sigma_S = 25.96$

$P : \mu_p = 4.98\ \sigma_p = 1.03$

Due to an identified and documented bias in the Microsoft Excel worksheet number generator, the left hand side distribution tail is slightly too thick compared to the normal one, but the result is not affected and we could even argue that this skewness is more life-like 21.

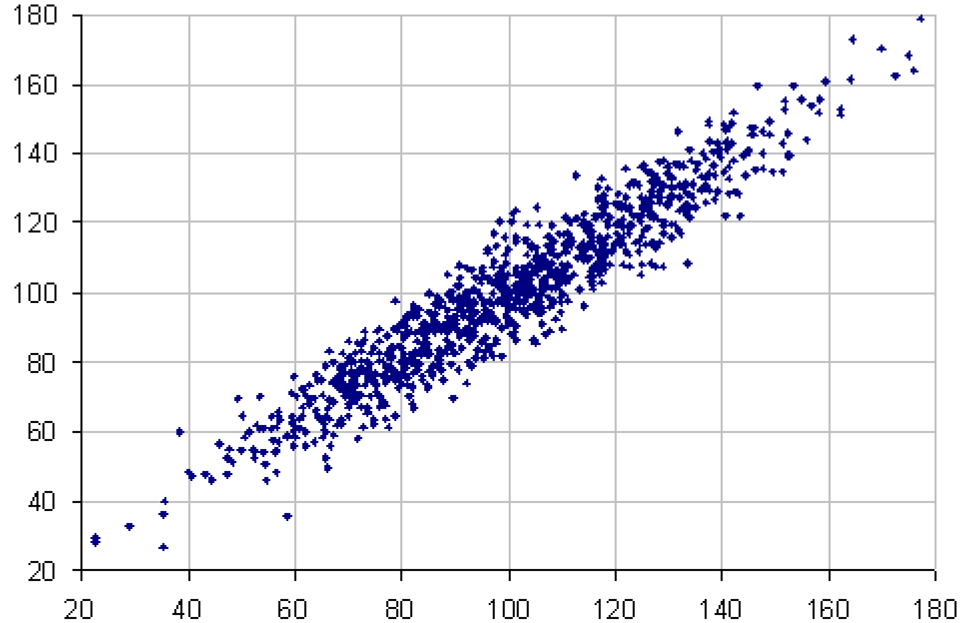

Figure 18: QQ plot of Q_s over Q

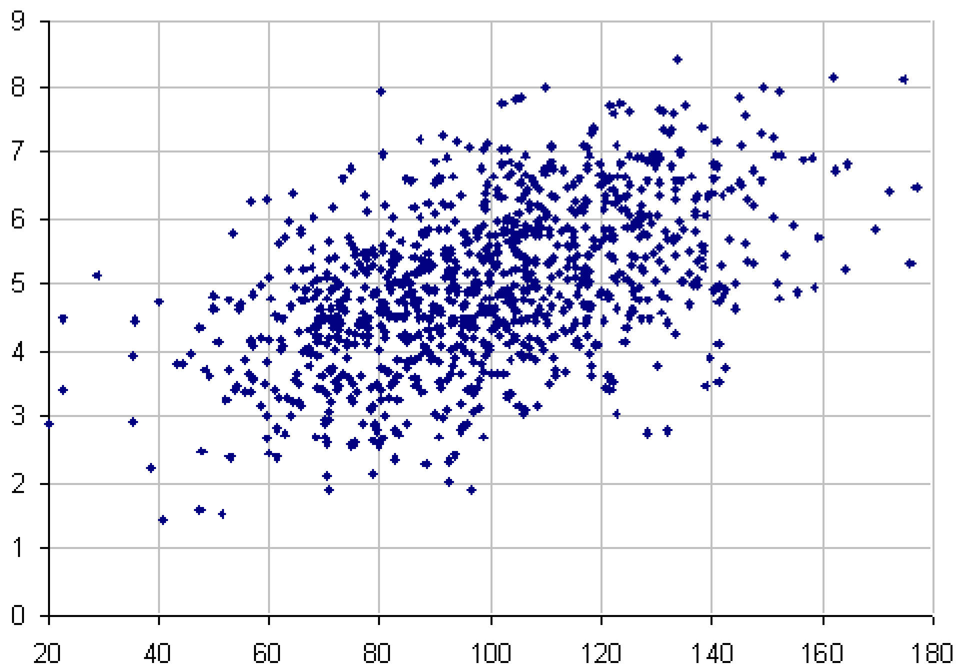

Figure 19: QQ plot of P over Q

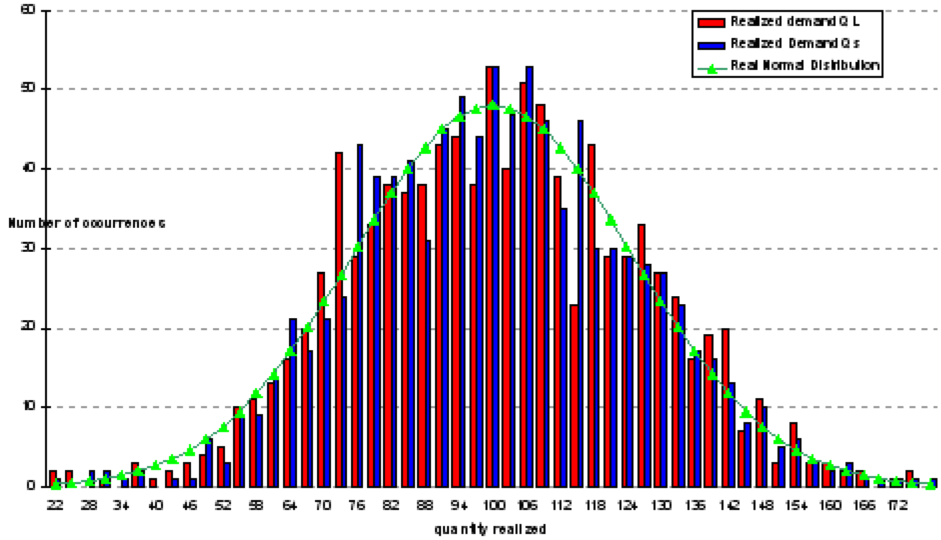

Figure 20: Graph of the distribution of the 1000 occurrences of Q and Q_s

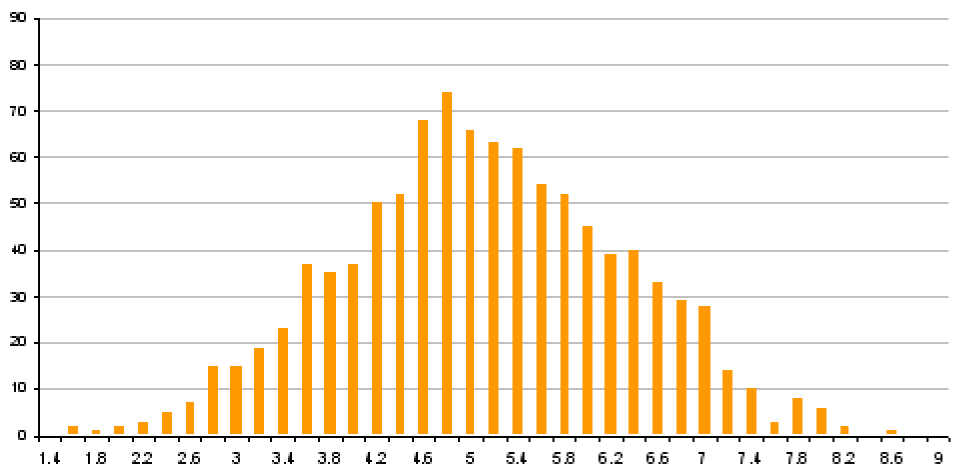

Figure 21: Graph of the spot transport price distribution

The volatility level that has been chosen for this numerical study has entailed a range of prices from a low of 1.43 and a maximum of 8.41. We have been exposed through industrial practice to other examples of spot market volatility in the transport industry. Though our choice is not borne out by statistical evidence, the one we have simulated seems to have only slightly exaggerated tails and is probably too “flat” compared to reality. This is both a product of design to enhance visibility of results. We hope that the reader will agree with us that this choice but does not impair the validity neither of the reasoning nor of the conclusions.