

THE IMPACT OF INFORMATION AND COORDINATION ON TRANSPORT PROCUREMENT

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ABSTRACT. Transport cost is second in importance after production cost in industry. It is the purpose of the present paper to study the impact of information sharing and contractual instruments between a supply chain and its transport suppliers. After reviewing the literature, we propose a model to measure the benefits in terms of transport cost and standard deviation of transport cost. We evaluate three scenarios over one period reiterated for a shipper carrier two-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. We evaluate the transfer in rent between carrier and shipper according to the information known and give some insights on optimal contract parameters.¹

Keywords:

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

1. INTRODUCTION

The transport sector is a key service provider of all industrial supply chains. Transport intervenes at all nodes of the industrial supply chain: from the primary raw material to the final delivery of the finished product at the end-customer's premises. Transport cost is the second in importance after the production cost in industry. In the USA transport costs represent almost 6% of GDP (8.6% in the EU) of which road freight represents around 75%. If one remembers that the service sector now represents about 60% of the GDP in the USA, transport looms even more as a component of the costs of the industrial sector. From the supply chain management vantage point, the impact of its costs and distinguishing properties on the overall performance of the supply chain merit to be looked at in a unifying and distinctive way. As opposed to other suppliers, all forms of transport are homogeneous in their characteristics: pure service, non-stockable products to meet demand and no production facilities (consumption-value only good as in Routledge 2000). However, transport services require highly specific long-life assets and its fixed costs represent an important share of total costs. 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 provided by third parties, independent from users of transport. The terminology in use distinguishes between the "shipper", the client, from the "carrier", provider of transport services. In this paper, we further distinguish carriers by the contractual nature of the relationships that link them to shippers: we distinguish the "usual" carriers from the "sporadic", governed by different contractual obligations, prices and time horizons. In this paper, the transport industry is considered in its broadest range but excluding transport of persons: from belt conveyors to express deliveries, trucks, planes, electric power lines, pipelines and so on.

Usually a shipper draws up long term contracts with several carriers for periodical quantity stationary commitments, limited flexibility (the shipper can exceed contracted capacity per period by paying progressively higher prices), rolling horizon flexibility (Anupindi 1998) as to volume,

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frequencies, prices, quality of service and eventual penalty or compensatory clauses. To the shipper, these carriers represent the core of her pool of transport service providers.

Each carrier also links himself to several shippers at the same time by contractual ties for the core of his capacity. Besides selling his capacity to shippers on contract, the carrier uses the spot market to sell his excess capacity on a “per job” basis. The contractual characteristics are: short term, short lead times, no pre-contractual price specifications, no obligation to deliver on the part of the carrier. To the shipper, these represent the next tier of transport service providers; their services have been used in the past and have been rated. They are necessary for special tasks or for meeting peaks in demand. The prices of such transactions are pegged to a “spot” market where available capacity meets an uncertain demand. A word is necessary here about the spot market. Unlike other markets for commodities, transport spot market is composed in fact of two markets: one for the one-leg trips where the shipper pays for just one side of the trip (this, of course, is valid only for transport using mobile units, not pipelines or electric lines), and the other, where the shipper facing the possibility that his cargo might not be shipped in time, accepts to pay both sides, including empty backhaul. This spot market is characterized by different lead times: if the shipper wants to pay just one way, he will have to wait for the carrier to find some cargo to bring back on the backhaul. If the shipment cannot wait, then the price is the full two way price.

Backed by easy financing, E-marketplaces in transport launched in 2000 made the mistake, borne from insufficient knowledge, that enormous transport capacity could be made available online to shippers on a “spot” basis and that transactions would ensue. Grieger (2003) shows, building on Wise and Morrison (2000), that suppliers do not want to be anonymous contestants in a ruthless bidding war, they prefer to belong to a hierarchical co-ordination of the supply chain, involved in hierarchical transactions. In this line of thought: “co-operative supply chains aim to reduce the number of suppliers and form long-term strategic alliances that ‘lock in’ suppliers and ‘lock out’ competition” (Grieger, 2003). The transport industry falls neatly into this category, proportionately little cargo can be moved by taking advantage of excess capacity (usually the backhaul leg of a truck’s trip coming back empty) because the shipper has to respect strict delivery times and cannot just wait for the possibility of a truck becoming available for just that trip, that day and that cargo.

Our purpose here is not to try and solve all the problems faced in a carrier – shipper relationship but rather to bring to light some particularities and bring attention to some mechanisms and behaviours that alter supply chain efficiency.

This paper is organized as follows. After reviewing the literature in the second section, the third section describes a model involving one single tier in the supply chain: the contractual relationship between one shipper as client and one carrier as transport supplier. The interest of studying this particular type of node in the supply chain is that all along a chain where real products are delivered (i.e. not services) transport is necessary at each step, from raw material producer to end-customer distribution. In this third section, we describe and characterize the nature and specificities of the contract linking the carrier to the shipper. In the fourth section, we describe three scenarios of behaviour for them: in the first, base scenario, the information is common to both, decisions are centrally coordinated. In the second scenario, we consider that the carrier retains a certain measure of 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. We sum the cost of operation and efficient fill rate for shipper and carrier. In the light of the comparison of the results we draw conclusions as to the importance and impact of both information and contractual arrangements between shipper and carrier. Finally, as a sixth section, we conclude and point to further avenues of exploration.

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 Fangruo Chen remarked in Chen (2002). In the supply chain management literature, transport service providers as suppliers are not usually individualized as such. In one line of literature, the transport industry is seen as a cost-centre in its own right. This approach leads research on efficient planning of routes, networks, warehouse location etc. Hosts of software packages have been developed to address the

necessary calculations to optimize on a daily or on a strategic basis the deliveries and transport of cargo. In the other line of literature, the transport industry is bundled with the other suppliers to the supply chain and, as such, its efficiency can be increased by coordination, truth-inducing mechanisms, contractual engineering and information sharing (see Chen's review of 2002 and 1998, 2001a, 2001b, Chen & Yu 2001a, Chen – Yu 2001b, Anupindi 1998, Porteus and Whang 1991, Lee and Whang 1999, Cachon et al. 1999, Zhao 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) bridges both lines of thought: a single model integrates production and transportation planning, taking into account transport costs and schedules. This approach does not take into account the impact of imperfect information and decentralized decisions. Neither does it take into consideration the eventual over or under utilization of the transport capacity involved. The integer program setup optimizes transport costs, routing, scheduling by integrating distances, transport time, time-windows and full or partial truck loads costs to the production planning.

The transport industry characterises itself by the non-scalable capital intensive production investments needed and a high share of fixed costs within total costs. Capacity can be expanded only well in advance of output 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 modelled that constraint in several papers. Gilbert and Cvsa (2000) model the behaviour of the client who under-invests in cost-reduction so as to escape being held up by the supplier. That model looked at the trade-off faced by a firm when its downstream channel partner has opportunities to invest in making relationship specific marginal cost reductions. The case of 7-Eleven and Frito Lay serves as illustration. Should 7-Eleven invest in reducing its variable costs in distributing certain Frito Lay products and see Frito Lay profit by it? The authors propose to construct a wholesale pricing contract that Frito Lay will extend to 7-Eleven to encourage investment in variable cost reduction in the presence of market uncertainty. By crafting this ex-ante pricing contract, the retailer's interests are aligned with the manufacturer's and eliminates or at least reduces supplier opportunistic behaviour.

A paper that has modelled contracting arrangements for capital-intensive, capacity-constrained goods is Wu et al (2002). In it, the authors have specifically targeted the energy sector but have tried to enlarge the results to other capacity-constrained sectors like hotels, airlines, plastics, chemicals and other dated/perishable capital-intensive service providers like transport. They have put in the limelight the "two-goods problem", the first of which is the availability of capacity itself, pre-committed to a specific buyer, and the second is the output actually delivered on the day to the buyer. This gives rise to the existence of two different markets where prices are formed: spot pricing where "on-the-day" demand meets offer and pre-arranged bilateral contracting. The paper provides valuable insights on the optimal balance between selling capacity in the forward contract market versus selling on the spot market. This paper provides an answer to industries where conditions of storability are not given. Their 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 (2003) propose a variation of the preceding model by using options in lieu of futures contracts and spot market to increase capacity utilisation 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 (Cf supra), 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, because of the more standardized nature of the traded good.

Agrell et al (2002) model a 3-stage, 2-period supply chain in the telecom sector. A supplier can decide to invest into certain new capacity and may share the economies by lowering his price. This model specifically excludes long-term partnerships that encourage parties to engage in activities

that are unfavourable in the short term but have substantial payoffs over time. The game between the shipper and carrier typically has to carry on for a long period (typically 2 to 5 years, coherent with the life-span of the specific asset) which practically eliminates the hit-and-run tactics that the authors might observe in their model due to asymmetric information.

We draw on the *quantity flexibility contract clause mechanism* under retailer uncertain demand (Tsay et al. 1999a, Tsay 1999, Tsay & Lovejoy 1999, Anupindi 1998, Tsay 2000, Cachon 2002), designed to align the behaviour of the supplier. “The Quantity Flexibility clause defines terms under which the quantity a buyer ultimately obtains may deviate from a previous planning estimate. The conditions can include limits on the range of allowable changes, pricing rules, or both.” (Tsay et al 1999a). As in our setting, capacity has to be planned well in advance, the carrier has a strong incentive to encourage the buyer to forecast and plan honestly the cargo to be effectively transported. We should therefore model the incentive that the carrier has to include in the contract for that coordination to take place. One of the simplest mechanisms 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 (1997): the manufacturer pays a cancellation 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. A third is for the carrier and shipper to agree to a given cumulative capacity K_n over a number N of periods: if in one period the realized demand is less than predicted, the shipper is committed to make it up to the carrier in future periods (as in Bassok & Anupindi 1997).

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. Several mechanisms can be implemented. One of these would be to set up 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. Another would be to set 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 1997 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 1997, Barnes & Schuster 1997).

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 et al., 2002). In other words, a carrier cannot just overbook his fleet on a given time slot because cargo available for that time slot cannot just be moved to the next available time slot and there are few cases of “no-shows”.

Our market mechanism draws also on the model in Seifert et al. (2003) for simultaneous long-term and short-term (spot) buying of commodities by a client from one or various suppliers. They study the impact of different buying strategies, involving different spot vs. contract buying proportions under various conditions of volatility of the spot price and also according to whether or not the client can eventually resell the commodity. They show that buying a “moderate” fraction of total needs on the spot market significantly improves profits over the contract-only behaviour. Their model contemplates both the possibility to buy and sell the commodity on the part of the buyer and also the “buy only” situation which is our case (it is not economically feasible for the shipper to resell unwanted transport capacity). We follow along the same path in modelling the behaviour of the shipper: he can simultaneously buy through long term contracts and through spot transactions the needed transport capacity to face the realized demand addressed to him, giving him added flexibility. Whereas previous research applies to commodities and thus takes into account stocks and inventory, we extend the results to the case of transport services after due modifications.

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. Similarly to Gavirneri (1999), the simulations in this work do consider different demand distributions and different standard deviations of demand faced by the shipper. However, the carrier cannot evaluate nor study sales data distribution laws because we suppose that the realized demand addressed to the shipper can be immediately satisfied by the carrier with no lead time and no inventory. The results of this paper and those of Gavirneri (1999) could be joined however in a further research into the advantages that could eventually be gained if the carrier could share with the shipper the inventory/sales data at the demand level. Take the case for example of the shampoo manufacturer having to deliver products to supermarkets; the carrier could benefit by knowing in advance the supermarket's ordering policy, inventory or sales.

In this paper, we show the importance and effects that both information sharing and coordination can have on the profitability of the carriers and the shippers. We have chosen to stick as closely to actual industrial practice so as to enable readers in transport procurement to easily apply the conclusions and calibrate better their bargaining with transport and logistic companies. 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.

3. TRANSPORT MARKET MODEL

Transport, as an industry, is at once very standardized in its service and very diverse in its physical infrastructure and this makes for difficult modelling. Standard features, at least across industrial sectors, are the basic measures of transport as a service as outlined by Morash (2001): fill rate, stockouts, cycle time, complete orders, on-time deliveries, backorders. Due to the geographic infrastructure in place, some physical aspects do have some very common traits: road, rail and water transport, among others, are divided among small units that often share common warehouse and handling infrastructures even though transported products can be very diverse. The interface between shipper and carrier is also very standardized across product types (same procurement procedures, same billing and payment norms, common cost structures, international terms of trade, common legal and regulatory framework). Our model tries to build upon the most general features and not depend upon special ones so as to enable possible empirical validation in the most various settings.

We assume that a shipper S_L require 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 (fig. 2).

Because of uncertainty on these two fronts, the shipper S_L chooses to minimize at least one source of uncertainty by tendering for a long term contract among several carriers he has been able to select by some order qualifying test. This feature is standard practice among all major industrial or otherwise B2B shippers. The ensuing contract is signed for a long period, proportionate to the life-span of the assets that both the carrier and the shipper will have to invest in to fill in their respective engagements. So S_L buys transport services through an *ex-ante long term contract*. To complement this contract, S_L also has the ability to buy extra capacity from the rest of the market for a spot transport price (equivalent to short term contracts, Seifert 2003). The motivation for S_L to buy on the spot market may be in fact that her necessities may vary in such a degree as to render *ex-ante* contracting of large capacities uneconomical.

Let C be the carrier who has signed the contract with S_L and who further serves the market for unused capacity at the going spot price. Every period, C first serves the demand from S_L 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 (see fig 4). Our interest is not in the allocation game. The shipper's objective function is a composite function of minimization of cost and maximization of client satisfaction.

3.1. *Motivation of shipper and carrier behaviour*

This model is set in the transaction cost economics (TCE) stream of economic literature. Therefore, the contract is an effort to craft order, thereby to mitigate conflict and realize mutual gains. Under this view, the contract cannot be more than an attempt at incompletely predicting future outcomes and present each partner with a set of pre-arranged guides to the other's behaviour. Building upon both past experience transport practice in industry and TCE theory, we include in the model the possibility that one or both parties will behave opportunistically during the lifetime of the contract. This can happen 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. These assets have low redeployable value and effectively contribute to strong inter-dependency and allow post-contractual opportunism. We have neglected to consider the asymmetry in dependency which comes from one party being "stronger" or having more bargaining power than the other (e.g. due to higher competitive pressure on the carrier, specific asset investment asymmetry, or shipper image integrity hostage to carrier among others). This is on the specific purpose of enabling further empirical study to apply to both cases where the shipper is the stronger and hence more likely to engage in opportunistic behaviour as to cases where the opposite is true.

Both theory and practice share the observation that "[p]arties to a transaction that are bilaterally dependent are "vulnerable", in that buyers cannot easily turn to alternative sources of supply, while suppliers can redeploy specialized assets to their next best use or user only at a loss of productive value" (Williamson 2002, p.176).

In view of the preceding comments, how can each party still engage in opportunistic behaviour?

First it has to be noted that 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. Both have as objective to reduce volatility when negotiating the ex-ante contract and reduce transport cost / increase revenue on a per period basis during the life of the contract.

As both practice and theory reveal, a common behaviour is to retain information from the other that could enable the other party to claim compensation or assume a retaliatory attitude. The range of information liable to this kind of claim is vast: early or timely information of future transport needs, subsequent changes in schedules, delays in delivery, type or quality of transport capacity available, prices etc. It would have been best to include the largest possible array of information gauges in our model, but effects of some kind of information on costs or profits are distinctly difficult to quantify. We have chosen for simplicity's sake to restrict our demonstration to just two forms of information amenable to modelling: 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.

At issue are not only the ex-ante bargaining and crafting of the contractual arrangements but also the ongoing contractual relations. We will study both under different scenarios: under the most favourable one, trust is comforted by observability of information. The shipper S_L observes the exact available capacity at each period of carrier C and C observes the realized demand addressed to S_L . This is our base scenario, consistent with the literature's definition of central control in the power of a single decision-maker with access to all available information as could be the case if both entities were part of the same corporation. In the second scenario, S_L cannot observe the capacity of C , but C does observe S_L 's realized demand (or S_L makes that information available to C). In our third scenario, S_L cannot observe C 's capacity and C cannot observe S_L '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.

We assume in this paper that both parties will be better off (and will recognize that such an attitude has long term pay-offs) if they commit to informing truthfully. We venture that given today's competitive pressures put on all industrial manufacturers, given the emphasis put on dependability, given the high density of the meshing binding supplier and client, neither a carrier nor a shipper will risk antagonizing the other by consciously retaining information. In today's markets, because of the sunk investments and specific assets involved, such an attitude entails risks of client loss, reputation

loss and other unquantifiable damage. We further venture to suggest that the contractual hazards increase inversely to technological development of the transport market (a testable empirical hypothesis would then be that less developed countries have higher relative transaction costs).

The model also takes into account diverse contractual arrangements because of their influence on the behaviour of both parties. No optimal contract design approach has been chosen. We have chosen some that are considered of importance by their impact on the behaviour of contracting parties. Behaviour is guided by profit in both the short *and* the long term so we concentrate on the three repetitive and constant attitudes described earlier during the lifetime of the contract. We further consider that if one party behaves opportunistically, he will never be caught, so that the renewal of the contract should be independent of the behaviour. However, it is obvious that both parties will draw conclusions as to the past benefits and effective service rates (both observable) during the life of the expired contract when renegotiating terms.

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).

3.2. *Contract characteristics*

The importance of contracts in co-ordinating a supply chain and improving system efficiencies have been highlighted in a number of papers: Seifert (2003), Gilbert et al (2000), Van Mieghem (2001), Tsay et al (1999a). We have used a contract as a coordination mechanism because of its popularity in the transport industry and because it is recognized that the information structure in the transport industry shows wide asymmetry and conflicting objectives between carrier and shipper.

The contract results in most cases from a tender offer set up by the shipper and where a limited number of carriers are invited to bid. This first set is selected because of their experience and/or ability in transporting goods for other shippers in the same industrial sector (or an adjacent one). In the first round, the shipper qualifies on technical grounds a group of carriers. Among the qualifying criteria used by the shipper, one of the most common is the capacity that the carrier will be able to allocate to the shipper in the course of the contract. In a second round, these qualified carriers will receive an invitation to bid according to a schedule of conditions or terms of reference. The shipper selects the best bid and signs a contract where a number of conditions about quality, quantity, penalties and duration of the contract are fixed. The unselected carriers that have qualified for the second round can, however, still hope to share in part of the shipper's business: they become the second tier carriers and will receive orders pegged to the spot market price in instances when the winning carrier cannot take all the cargo the shipper has to ship.

We must now engage in setting the aspects of the optimal contract given the current theoretical setup. We have chosen the taxonomy of contracts in Tsay et al (1999). According to this taxonomy, contracts are classified by contract clauses and we now discuss each one in turn.

3.2.1. *Long versus short term*

To shadow more closely practical thought in transport industry, we have considered that any contract will extend over a large, finite number of sub-periods. This means that each party can and will take into consideration both the long and short term. So, they will behave so as to maximise profits in the short term (one sub-period) and also retain some possibility of achieving profits over the long term (length of the contract is one period and the possibility of being an insider when competition starts to renegotiate a contract upon renewal for the next period). Issues concerning appraisal and calculation of reputation effects, trust and other intangible benefits of a self binding behaviour have not been settled satisfactorily in the literature on contracts. We have chosen not to include in our model calculations of the impact over the long term of such behaviours, but just assume some degree of reputation preserving behaviour. As observed in Tsay et al (1999): "the lengthening of the time horizon may encourage parties to engage in activities that are unfavourable in the short term but have substantial payoffs over time." In effect, "stable partnerships can reduce transaction costs and allow for greater cooperation (e.g. information sharing and collaborative product and process improvement)". The present model is more of a single period (the contract), finite horizon structure.

3.2.2. *Decision rights*

In our setting, the decisions in each period are few: S_L can choose to solicit C for additional capacity under the terms of the menu of prices, as described later. The base transport price is set and S_L has no control over the demand that is being addressed to him. C has the obligation to comply with the capacity requirements and quality levels in accordance with contract specifications. The advantage of such restriction of decision rights is to enhance stability and visibility in costs and reduce on-going negotiations during the contract's life. Both parties are better off if they can plan far ahead with no haggling. Any extra capacity or cargo is off loaded onto the spot market or can be freely traded between shipper and carrier using the spot market price as reference.

3.2.3. Pricing

Pricing plays a role for both parties. To the carrier, it enables him to match his long term capacity and quality-enhancing investments plans with his workload and revenue projections. To the shipper, it sets a reference to guide his budgetary planning process over various periods. Both have an interest in fixing for the longest possible period the price of the service to be delivered. We have chosen to set a price per unit of cargo up to a fixed capacity over the life of the contract and for one leg of each trip (this simplification allows to include in our scope all types of transport including pipelines, power lines and such). The carrier is committed to taking the cargo the shipper has at each period for that price per unit (this implies both that the carrier already has the same frequency return cargo for long-haul freight and that this price covers the carrier's variable cost). The terms of the contract will specify the capacity that the carrier has to reserve for her use. This capacity 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. Some contracts specify a price for a given capacity whatever the real cargo effectively transported up to that capacity. This is called capacity reservation and applies to very specific activities where the cost of unused capacity bears no comparison to the cost of long lead time or inability to deliver the service to the shipper (case of a standby plane or helicopter for medical urgencies). Using a price per quantity transported also makes it a variable cost to the shipper.

The case of the two-part tariff, so dear to most authors in supply chain literature, would be awkward in this setting for the shipper because he would not be able to make the cost totally variable. Further, it would displace some of the risk of demand variance onto him, instead of shifting it to the carrier. We argue that the shipper enjoys sufficient power over the carrier (and eventual competitors) to force the carrier to accept a totally variable cost. There is, however, a compensation to the carrier which we cover later in the form of a penalty for overestimating the realised demand that the shipper pays to the carrier.

Periodic reviews as well as other forms of indexation of this base price are covered in our model, because such automatic price changes are not subject to haggling and are fixed and known within each period, not affecting either party.

3.2.4. Minimum purchase commitments

The minimum purchase commitment clause included in most contracts takes the form here of a target of cargo to be transported at each period. It is for this capacity that the shipper pays a set unit price, basic object of the contract. The capacity corresponds to the average demand that the shipper hopes to receive over the life of the contract. It can be seasonal or take any other form of evolution, according to the shipper's forecast. The shipper would be tempted to overestimate the real capacity needed if that might help him garner a lower price from the carrier. To encourage credible information as to expected demand from the shipper (who is privately informed of his demand when negotiating the contract), we have taken into account the results from Cachon & Lariviere (1997) and Cachon & Zipkin (1999), where penalties are imposed to achieve Nash equilibria. The adjustment mechanism we have chosen for its simplicity and because it relies on observable information on each part is a penalty imposed on the shipper for the unused contracted capacity in each period. With such a penalty in place, the carrier can hope to obtain the necessary information as to the average demand expected by the shipper.

This penalty alone will not suffice in guaranteeing his necessary capacity investments that are required to meet the capacity commitments. Only part of the risk arising from demand variance is mitigated. The level of such a penalty, relative to the base price per unit is the subject of negotiation between the shipper and carrier and reflects their power leverage.

We are conscious that this is a somewhat artificial coordinating mechanism so we have included in the numerical study the case where the penalties are set to zero.

3.2.5. Quantity flexibility

The quantity flexibility (QF) described in the taxonomy of Tsay et al (1999) describes the benefit the buyer receives under such a clause as being the advantage of deviate from previously planned estimate thus allowing for a degree of liberty where previously there was none. They describe the clause as a way for the buyer to forecast and plan more deliberately and honestly. The seller gives the buyer a price break to give the buyer an incentive to participate. To Tsay et al, the “QF clause has risk-sharing intent, and the hope is that the agreement can make both parties better off”. Tsay (1999) models the behaviour of a client and supplier who would each have an incentive to overstate intended purchases and underestimate necessary capacity but whose conduct is effectively coordinated by penalties imposed both ways: on over-forecasting and on under-producing, leading to a system-wide optimal outcome. Following along the same tracks, to allow for some flexibility in the demand that the shipper receives, we have included a menu of prices that give some additional capacities that the shipper can call upon under certain conditions of price. This menu of prices encourages the shipper to call upon the carrier for the unforeseen demand received². This added flexibility is of increasing value to the buyer as market environment becomes more volatile, according to the description in Tsay et al (1999) of Tsay & Lovejoy (1998).

3.2.6. *Buyback or return policies*

This type of clause does not apply in our context: transport is not a stockable product.

3.2.7. *Allocation rules*

We have modelled a priority rule whereby the carrier first serves shipper S_L . We presume that the existence of a long term contract and penalties generate sufficient incentives for this behaviour. Reciprocally, the shipper S_L also first allocates his realized demand to C before turning to the spot market. His interest is not only to financially help his supplier, but also to reduce the slightly higher transaction costs that any transaction on the spot market has versus using the contractual supplier. No contractual clause to foster this behaviour has been allowed for in our model. The order in which the decisions take place are the following (see also fig 1 and fig. 2):

- S observes carrier capacity W , contract signed.
- S_L first observes demand Q_L addressed to her and spot market transport price P_s .
- S_L decides on the allocation of a share u of demand Q_L to C.
- C observes the spot market price and allocates capacity x_L to her and x_s to the spot market.
- After observing the allocation of capacity by C to her, S_L allocates the remaining demand Q_L 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.

² The price is higher than the base capacity price because the marginal cost to the carrier of such capacity is higher than the average and constrains his overall capacity and ability to meet other commitments. Remember that the capacity is non-scalable unless notified well in advance.

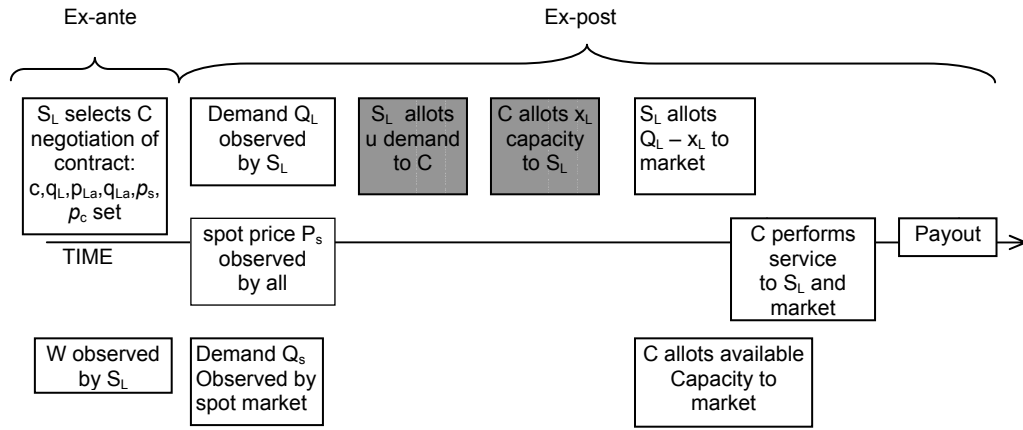


Fig. 1: Chain of events: decisions by players in grey

3.2.8. Lead time and quality

In our model lead time is not an issue since revelation of demand to shipper S_L is immediately followed by his order of capacity to carrier C . In the same “simultaneous” moment, C knows how much of his capacity is left and he can serve the market own demand at spot market price. This is of course a simplification of reality: orders for capacity from S_L to C may arrive at 15h00 of one day for service on the next and S_L may require by 17h00 an answer for his request for capacity. By 18h00, all available spot capacity in the market must be allotted. Any slip-up in this tight schedule may cause costly delays and juggling of orders. Advance knowledge of capacity demand becomes a highly desirable/valued feature to a carrier. This lead time scheduling and capacity allotment, distinct from yield management already the subject of numerous studies, should be investigated further.

As to quality, we have considered in our model, perhaps too simply, that carrier C has been elected among a set of carriers comparable in quality levels and qualified on all required quality yardsticks that S_L may impose.

3.2.9. Notation

C and S_L have negotiated ex-ante and are bound by a contract extending over one period of n sub periods with known and fixed parameters. S_L agrees to buy at each sub-period capacity q_L at price c . The shipper has to pay a penalty θ_s for unused capacity up to q_L at each period. The carrier suffers a penalty θ_c if he cannot (or chooses no to) carry the contracted capacity q_L at each period for non-performance of contracted service. The contract includes a menu of prices $p_{L,a}$ at quantities $q_{L,a}$ that the carrier offers to the shipper S_L to help him meet demand in excess of the contracted capacity commitment q_L up till $q_{L,a}$ (fig.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 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_L , 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.

3.3. Opportunistic behaviour

Opportunistic behaviour occurs in our case when either the shipper S_L or the carrier can escape from their contractual engagements without incurring retaliation from the other party. Retaliation can happen in one of two ways: either the party victim of the moral hazard has the possibility to obtain compensation through some previously agreed upon compensation or he does not and his recourse can be either to bring his case to some court of justice (often specified in the contract) or not to

renew the contract when it comes up for renewal. In any case, if truthfulness is a priori reigning in the relationship, all retaliation depends upon verifying opportunistic behaviour. The party wishing that verification incurs a cost to perform this information collecting process. This cost can be large in the case of two arms-length entities like the ones in our case. We will focus in this paper on certain pieces of information which can be hard to come by and which can make a significant impact on the cost functions of either party. There are a number of other items of information which can be verifiable only at a cost and that can result from moral hazard (precise delivery date and time for example).

The **first piece of information** belongs to the carrier and is the size of the transport capacity he owns or otherwise controls. Ex-ante the shipper does verify the available capacity of the carrier and the carrier must convey all necessary information so that the shipper can be assured that the required capacity exists. This is included in the due-diligence that the shipper does to qualify the carrier for the second round of the tender. Thereafter, no further control is undertaken by the shipper in the course of the contract. So, in the course of the life of the contract, this information is no longer observable and the shipper would incur a cost in verifying it. In some circumstances, the capacity under the carrier's control can extend to sub-contractors which are not linked to the carrier in a formal way but by affinity or other commercial links (this is the case of owner-operated trucks that can take spot engagements for other larger carriers on an ad hoc basis). The shipper cannot easily verify that the carrier has more than the basic contracted capacity to ensure correct execution of his contracted commitments. It is not even verifiable ex-post without the explicit cooperation of the carrier. Only when the contract comes up for renewal can the shipper use records of past shipments to assess the capacity of the carrier. In a way, this is the only possible recourse the shipper has: not to renew the contract with this carrier.

The **second piece of information** involves the size of the available transport requirements of the shipper: the carrier may not be able to verify period after period that the orders handed him by the shipper represent his entire necessity. This information is also neither observable directly nor verifiable without cost to the carrier. The shipper may contract added capacity with other carriers whenever it suits him financially.

Depending upon the spot price in the market and since the carrier's total capacity 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 modelled 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_L 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 from standard contractual behaviour by refusing to purchase capacity in excess of q_L 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.

We have modelled all three deviations in our scenarios. We have not modelled the fourth possible scenario in this preliminary paper: when the shipper knows the capacity of the carrier and the carrier is not aware of the exact demand received by the shipper. We intend to address this scenario in a later extension of this paper.

3.4. Demand and capacity characteristics

State of nature is represented using three variables: P_s is the market price for immediate transport. The demands that the shippers meet individually and non-competitively are two exogenous, stochastic variables ζ_L ζ_s . $\Omega(P_s, Q_L, Q_s)$ is the probability space containing the possible realizations of the triplets of transport spot price, and of demands addressed to shipper S_L and the market. $F_L(\cdot)$ and $F_s(\cdot)$ are the continuously differentiable, invertible and monotonous cumulative distribution function of demand addressed to, respectively, S_L and the market. $f_L(\cdot)$ and $f_s(\cdot)$ are the density functions of $F_L(\cdot)$ and $F_s(\cdot)$. $F_p(\cdot)$ is the continuously differentiable, invertible and monotonous cumulative distribution function of the spot market price P_s and $f_p(\cdot)$ its density function (mean μ_p and standard deviation σ_p). Let $f(\cdot)$ be the density function of the **joint** continuously differentiable, invertible and monotonous cumulative distribution function $F(\cdot)$ of **both Q_L and P_s** . Let $\rho_D \in [-1, 1]$ be the

correlation factor between $F_L(\cdot)$ and $F_s(\cdot)$ and let $\rho_p \in [-1,1]$ be the correlation factor between $F_L(\cdot)$ and $F_p(\cdot)$. Often, ρ_D and $\rho_p \geq 0$ reflect 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 shippers. Each shipper knows ex-ante the mean μ and standard deviation σ (μ_L, σ_L for S_L and μ_s, σ_s for demand originating from spot market) of the cumulative distribution function of their demand. The demands have to be satisfied in full at each period; meaning that there is no backlogging: any unsatisfied demand is lost.

All other production costs of S_L are ignored.

The total capacity of C is W . C has a variable cost per unit transported V_c and a fixed cost F_c . No assumption is made regarding W . F_c is a function of this capacity W .

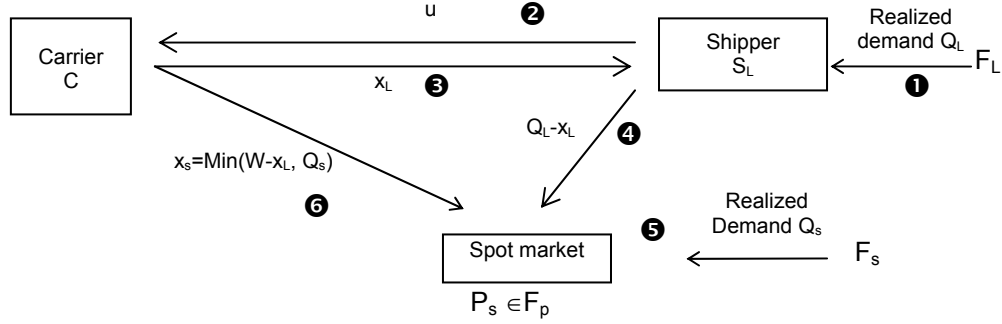


Fig. 2: Capacity allocation

In figure 1, u is the demand that S_L chooses to allocate to C , x_L is the capacity that C chooses to allocate to S_L , x_s is the capacity allocated to the spot market by C . It is apparent that the allocation of capacity of C to S_L is dependant upon the demand that S_L allocates to C in the first place.

3.5. Objective functions

3.5.1. Regionalizing the probability space

We divide the probability space Ω into regions which facilitates the discussion as to the best decision by both S_L and C (fig. 3):

$$\begin{aligned}
 \Omega 1(Q_L, P_s) &= \{Q_L : 0 \leq Q_L \leq q_L; 0 \leq P_s\} \\
 \Omega 2(Q_L, P_s) &= \{Q_L : q_L < Q_L; P_s : 0 \leq P_s \leq p_{La} - \theta_s\} \\
 \Omega 3(Q_L, P_s) &= \{Q_L : q_L < Q_L \leq q_L + q_{La}; P_s : p_{La} - \theta_s < P_s \leq p_{La} + \theta_c\} \\
 \Omega 4(Q_L, P_s) &= \{Q_L : q_L < Q_L \leq q_L + q_{La}; P_s : p_{La} + \theta_c < P_s\} \\
 \Omega 5(Q_L, P_s) &= \{Q_L : q_L + q_{La} < Q_L \leq W; 0 \leq P_s \leq p_{La} - \theta_s\} \\
 \Omega 6(Q_L, P_s) &= \{Q_L : q_L + q_{La} < Q_L \leq W; p_{La} - \theta_s < P_s \leq p_{La} + \theta_c\} \\
 \Omega 7(Q_L, P_s) &= \{Q_L : q_L + q_{La} < Q_L \leq W; p_{La} + \theta_c < P_s\} \\
 \Omega 8(Q_L, P_s) &= \{Q_L : W < Q_L; 0 \leq P_s\} \\
 \Omega 9(Q_L, P_s) &= \{Q_L : W < Q_L; p_{La} - \theta_s < P_s \leq p_{La} + \theta_c\} \\
 \Omega 10(Q_L, P_s) &= \{Q_L : W < Q_L; p_{La} + \theta_c < P_s\}
 \end{aligned} \tag{3}$$

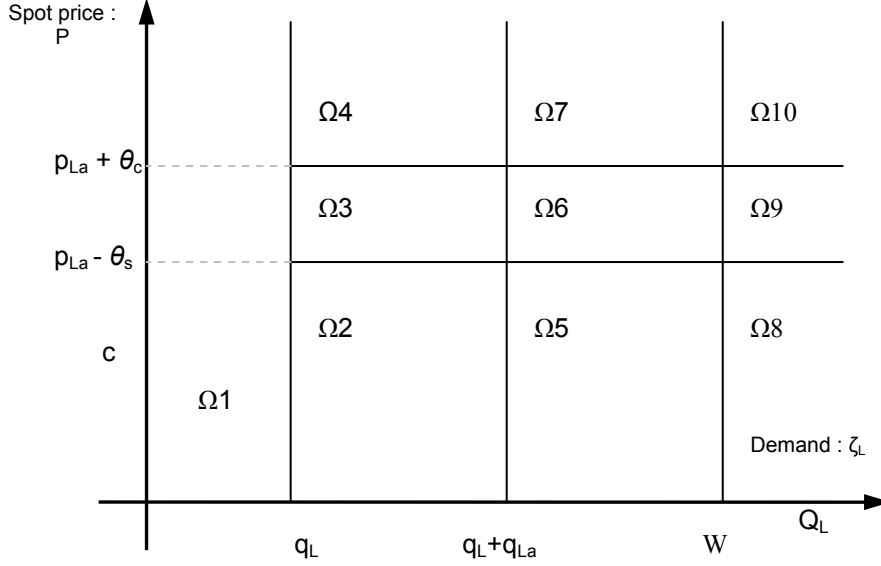


Fig. 3: Probability spaces for spot price and demand addressed to S_L

3.5.2. Carrier objective function

In our setting, carrier C has just two customers: S_L and the spot market (fig. 1). 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 standard. 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. This is not a peculiar quirk of our model but the reflection of 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_L . We have not included it as a separate objective to carrier C as all components are already present in the above objective function.

The objective function of the carrier is to increase revenue and reduce standard deviation of revenues over all periods. His best efforts should therefore be to focus the search of long term clients and assure constant volume of business so as to mitigate the risk he assumes by investing in new capacity. To that end, signing a contract with a shipper that guarantees periodic volumes at fixed prices covering both fixed and variable cost is the best strategy. His decision variables are the capacity he allots to each source of demand: x_L is the allotted capacity to S_L and x_s 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_L . 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.

We restate here all the contract characteristics as defined above:

$$\begin{aligned}
 W &\geq x_L + x_s \\
 0 &< q_L + q_{La} \leq W \\
 0 &\leq \theta_s < c, & 0 &\leq \theta_c < c \\
 0 &\leq q_{La} < q_L, & c &\leq p_{La} \\
 0 &\leq u, & 0 &\leq x_L, & 0 &\leq x_s, & 0 &\leq P_s, & x_L &\leq u
 \end{aligned}$$

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

$$\pi(x_L | u, \Omega_i) = R_i(x_L | \Omega_i) + P_s x_s - VC(x_L + x_s) \quad (1)$$

Where $VC(x_L, x_s)$ is the variable cost as a function of the allocation of capacity to S_L and the market and where R_i is a revenue function, conditional upon the demand u addressed by S_L and the spot market price, of the form:

$$R_i(x_L | u, \Omega_i) = \begin{cases} x_L c - (\min(u, q_L) - x_L) \theta_c + (q_L - u) \theta_s & : 0 \leq x_L < q_L \\ q_L c + (x_L - q_L) p_{La} & : q_L \leq x_L \leq q_L + q_{La} \\ q_L c + (x_L - q_L) p_{La} + (x_L - q_L - q_{La}) P_s & : q_L + q_{La} < x_L \leq W \end{cases} \quad (2)$$

q_L , q_{La} , c , p_{La} and θ_c, θ_s are the parameters defined by the contract. P_s is the spot market price (fig.4).

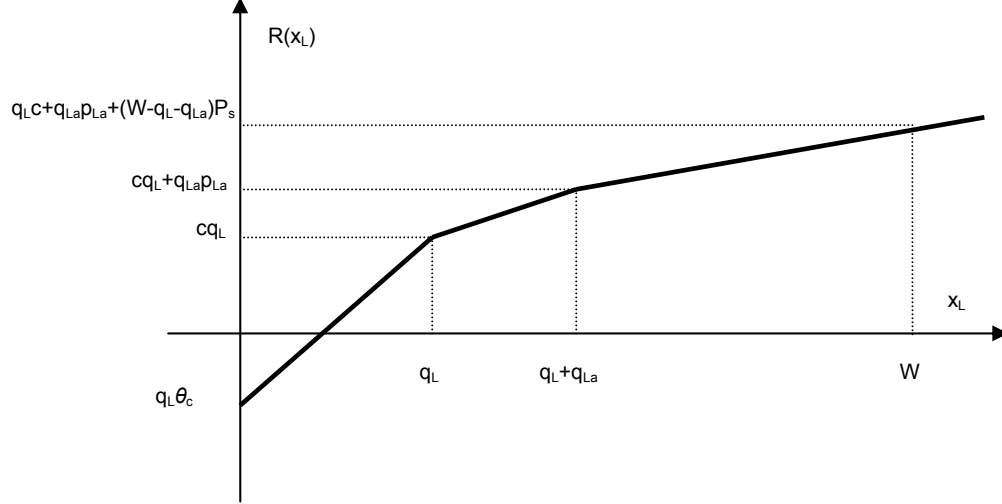


Fig 4: Behaviour of $f(x_L)$ where $u=W$

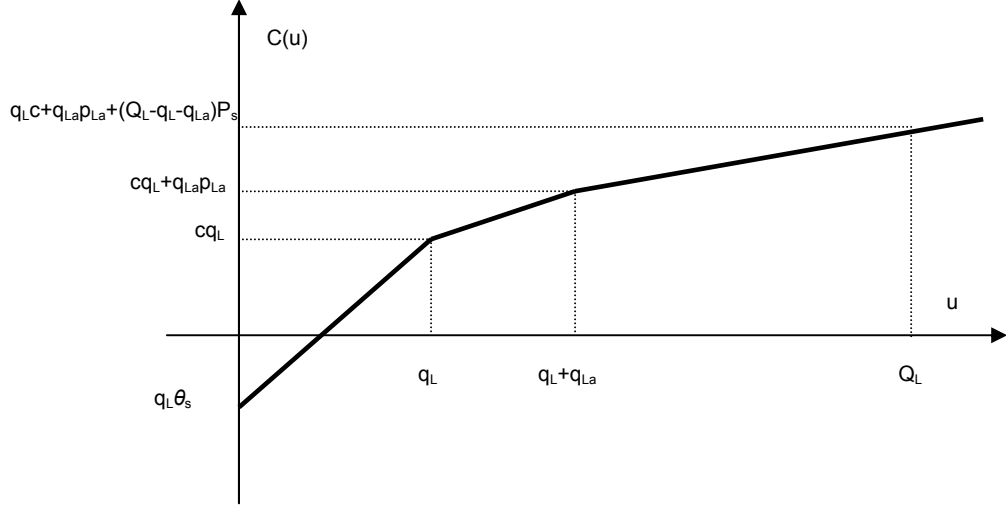
The overall profit depends on the allocation of capacity between the demands received from S_L and from the market, but also on the spot price as the optimal allocation of capacity by C to S_L will vary according to how much revenue can be had by diverting that same capacity to the spot market. By investigation, we see also that S_L has an opportunity to reduce transport cost by diverting cargo to the spot market when conditions of the spot price relative to the contract parameters warrant it.

3.5.3. Shipper objective function

Shipper S_L faces the following situation: she produces and sells a product that requires transportation, either in the internal supply chain process or in the relationship with his clients. For obvious budgetary reasons, she has to ensure that transport costs remain as constant and predictable as possible. 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 at the ex-ante contractual price or to the spot market at the going spot market price. 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_L . This necessity can be distributed among the different probability spaces described below according to both P_s and Q_L (see fig. 5). Whatever transport necessity is not being allocated to C will be offered to the spot market at the going spot price P_s . The function is conditional upon the response S_L receives from C which is represented by $x_L(u)$.

$$(3) \quad C_i(u | x_L, \Omega) = \begin{cases} cx_L(u) + [q_L - u]^+ \theta_s + (\min(q_L, u) - x_L(u)) \theta_c + (Q_L - x_L(u)) P_s & : 0 \leq x_L(u) \leq q_L \\ cq_L + (x_L(u) - q_L) p_{La} - [u - x_L(u)]^+ \theta_c + [Q_L - u]^+ \theta_s + (Q_L - x_L(u)) P_s & : q_L < x(u) \leq q_L + q_{La} \\ cq_L + \min((x_L(u) - q_L), q_{La}) p_{La} - \min([u - x_L(u)]^+, q_{La}) \theta_c + \min([Q_L - u]^+, q_{La}) \theta_s \\ + (Q_L - x_L(u)) P_s & : q_L + q_{La} < x(u) \end{cases}$$

Fig.5: Behaviour of $C(u)$

3.5.4. 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 discuss how the carrier C can optimize his revenue according to spot and demand. By symmetry, the same optimal decision by S_L will minimize the cost for her, so the revenue function is symmetrically reflected in the cost function for each region of probability space. Let us call R_Ω and C_Ω the revenue and cost functions over each separate domain identified by its number.

○ Case 1: $\Omega 1$

Realized demand received by S_L is less than contracted, whatever the spot price, the shipper and carrier honour the contract. Because the minimum capacity included in the contract is higher, S_L pays a penalty in proportion to the unused capacity. Neither have any liberty of choice in this space. C has no choice but to allocate $x_L = u$ capacity to S_L as otherwise, he runs the risk of having the contract reopened, a risk he does not want to run as we have seen above (Cf. 3.2.2 Decision rights).

The equation for this small segment of realized demand and spot price can be written as:

$$\begin{aligned} R_{\Omega 1}(x_L | u, \Omega 1) &= x_L(u)c + (q_L - x_L(u))\theta_s \\ R_{\Omega 1}(x_{L1}^* | u, \Omega 1) &= uc + (q_L - x_L(u))\theta_s \end{aligned} \quad (4)$$

By symmetry, we have:

$$C_{\Omega 1}(u | x_L, \Omega 1) = uc + (q_L - x_L(u))\theta_s \quad (5)$$

This gives the optimal allocation for S_L : $u_1^* = Q_L$

$$C_{\Omega 1}\left(u_1^* \mid x_L, \Omega 1\right)=Q_L c+\left(q_L-Q_L\right) \theta_s \quad (6)$$

which minimizes the penalty to be paid to C. Giving in turn: $x_{L 1}^*=Q_L$

$$R_{\Omega 1}\left(x_{L 1}^*, u_1^* \mid \Omega 1\right)=Q_L c+\left(q_L-Q_L\right) \theta_s \quad (7)$$

○ Case 2: $\Omega 2$

Realized demand addressed to S_L is between q_L and $q_{L a}$. Here, each has the possibility to choose how to allocate capacity above the minimum contractual obligations. S_L can choose to allocate all demand in excess of q_L either to the spot market, to C but at spot price or to C using the menu of prices included in the contract. C also can choose to refuse the extra capacity. The optimal behaviour here is for S_L to call on C for extra capacity but at the spot price, since the spot price is lower than the menu price $p_{L a}$ less the penalty for not using carrier C's capacity, and pays to C the penalty θ_s as built into the contract. This reduces S_L 's transport cost.

The equation for this segment of realized demand and price is:

$$\begin{aligned} R_{\Omega 2}\left(x_L \mid u, \Omega 2\right) &=q_L c+\left(x_L(u)-q_L\right) p_{L a}-\left(u-x_L(u)\right) \theta_c+\left(Q_L-u\right) \theta_s+\left(Q_L-x_L(u)\right) P_s \\ C_{\Omega 2}\left(u \mid x_L, \Omega 2\right) &=q_L c+\left(x_L(u)-q_L\right) p_{L a}-\left(u-x_L(u)\right) \theta_c+\left(Q_L-u\right) \theta_s+\left(Q_L-x_L(u)\right) P_s \end{aligned}$$

The optimal allocation for each is achieved when $u_2^*=q_L=x_{L 2}^*$ and gives:

$$\begin{aligned} R_{\Omega 2}\left(x_{L 2}^*, u_2^* \mid \Omega 2\right) &=q_L c+\left(Q_L-q_L\right)\left(P_s+\theta_s\right) \\ C_{\Omega 2}\left(u_2^*, x_{L 2}^* \mid \Omega 2\right) &=q_L c+\left(Q_L-q_L\right)\left(P_s+\theta_s\right) \end{aligned} \quad (8)$$

○ Case 3: $\Omega 3$

Here demand addressed to S_L is still between q_L and $q_{L a}$ but the spot price is between $p_{L a}-\theta_s$ and $p_{L a}+\theta_c$. The optimal allocation, is for S_L to use the additional capacity $q_{L a}$ at the additional price $p_{L a}$. The optimal behaviour for is to C provide the necessary capacity. Transport is performed. No penalties are due.

The equation is thus:

$$\begin{aligned} R_{\Omega 3}\left(x_L \mid u, \Omega 3\right) &=q_L c+\left(x_L(u)-q_L\right) p_{L a}-\left(u-x_L(u)\right) \theta_c+\left(Q_L-u\right) \theta_s+\left(Q_L-x_L(u)\right) P_s \\ C_{\Omega 3}\left(u \mid x_L, \Omega 3\right) &=q_L c+\left(x_L(u)-q_L\right) p_{L a}-\left(u-x_L(u)\right) \theta_c+\left(Q_L-u\right) \theta_s+\left(Q_L-x_L(u)\right) P_s \end{aligned}$$

The optimal is $u_3^*=Q_L=x_{L 3}^*$ and the functions become:

$$\begin{aligned} R_{\Omega 3}\left(x_{L 3}^*, u_3^* \mid \Omega 3\right) &=q_L c+\left(Q_L-q_L\right) p_{L a} \\ C_{\Omega 3}\left(u_3^*, x_{L 3}^* \mid \Omega 3\right) &=q_L c+\left(Q_L-q_L\right) p_{L a} \end{aligned} \quad (9)$$

○ Case 4: $\Omega 4$

Realized demand comes in between q_L and $q_{L a}$ but the spot price is over $p_{L a}+\theta_c$. In this case, the carrier will pay S_L a penalty for refusing to carry the additional cargo as per the QF clause. Cargo will still be carried by C but at the spot price: P_s , giving an additional profit to C.

The revenue equation can still be written as in case 3:

$$\begin{aligned} R_{\Omega 4}\left(x_L \mid u, \Omega 4\right) &=q_L c+\left(x_L(u)-q_L\right) p_{L a}-\left(u-x_L(u)\right) \theta_c+\left(Q_L-u\right) \theta_s+\left(Q_L-x_L(u)\right) P_s \\ C_{\Omega 4}\left(u \mid x_L, \Omega 4\right) &=q_L c+\left(x_L(u)-q_L\right) p_{L a}-\left(u-x_L(u)\right) \theta_c+\left(Q_L-u\right) \theta_s+\left(Q_L-x_L(u)\right) P_s \end{aligned}$$

But the optimal choice becomes $u_4^*=Q_L, x_{L 4}^*=q_L$, leading to:

$$\begin{aligned}
R_{\Omega 4}(x_{L 4}^*, u_4^* | \Omega 4) &= q_L c + (Q_L - q_L)(P_s - \theta_c) \\
C_{\Omega 4}(u_4^*, x_{L 4}^* | \Omega 4) &= q_L c + (Q_L - q_L)(P_s - \theta_c)
\end{aligned} \tag{10}$$

○ Case 5: $\Omega 5$

In this case, the realized demand exceeds $q_L + q_{La}$ but the spot is lower than the menu of prices less the shipper penalty. The excess over $q_L + q_{La}$ is transported at the spot price, whatever its level. The shipper can lower her cost by allocating capacity between q_L and $q_L + q_{La}$. The shipper will allocate the minimum possible to C and have the difference transported at P_s and pay the necessary penalty to C. For comparison purposes (within scenarios in the next stage), we have supposed that after refusing to allocate cargo within the contract, S_L still gives the difference of $Q_L - q_L$ to C at the spot price. So the revenue still accrues to C. We have:

$$\begin{aligned}
R_{\Omega 5}(x_L | u, \Omega 5) &= q_L c + \min((x_L(u) - q_L), q_{La}) p_{La} - \min((u - x_L(u)), q_{La}) \theta_c \\
&\quad + \min((Q_L - u), q_{La}) \theta_s + \min((Q_L, W) - x_L(u)) P_s \\
C_{\Omega 5}(u | x_L, \Omega 5) &= q_L c + \min((x_L(u) - q_L), q_{La}) p_{La} - \min((u - x_L(u)), q_{La}) \theta_c \\
&\quad + \min((Q_L - u), q_{La}) \theta_s + \min(Q_L - x_L(u)) P_s
\end{aligned}$$

So that the optimal allocation is the same as in Case2 $u_5^* = q_L = x_{L 5}^*$ and we have:

$$\begin{aligned}
R_{\Omega 5}(x_{L 5}^*, u_5^* | \Omega 5) &= q_L c + q_{La} \theta_s + (Q_L - q_L) P_s \\
C_{\Omega 5}(u_5^*, x_{L 5}^* | \Omega 5) &= q_L c + q_{La} \theta_s + (Q_L - q_L) P_s
\end{aligned} \tag{11}$$

○ Case 6: $\Omega 6$

We have the same functions as in case 3 and the optimal is: $u_6^* = Q_L = x_{L 6}^*$

$$\begin{aligned}
R_{\Omega 6}(x_{L 6}^*, u_6^* | \Omega 6) &= q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s \\
C_{\Omega 6}(u_6^*, x_{L 6}^* | \Omega 6) &= q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s
\end{aligned}$$

○ Case 7: $\Omega 7$

$$\begin{aligned}
R_{\Omega 7}(x_L | u, \Omega 7) &= q_L c + \min((x_L(u) - q_L), q_{La}) p_{La} - \min((u - x_L(u)), q_{La}) \theta_c \\
&\quad + \min((Q_L - u), q_{La}) \theta_s + (x_L(u) - q_L) P_s \\
C_{\Omega 7}(u | x_L, \Omega 7) &= q_L c + \min((x_L(u) - q_L), q_{La}) p_{La} - \min((u - x_L(u)), q_{La}) \theta_c \\
&\quad + \min((Q_L - u), q_{La}) \theta_s + (x_L(u) - q_L) P_s + (Q_L - x_L(u)) P_s
\end{aligned}$$

The optimal becomes: $u_7^* = Q_L, x_{L 7}^* = q_L$

The function of this optimal allocation is:

$$\begin{aligned}
R_{\Omega 7}(x_{L 7}^*, u_7^* | \Omega 7) &= q_L c + q_{La} \theta_c + (Q_L - q_L) P_s \\
C_{\Omega 7}(x_{L 7}^*, u_7^* | \Omega 7) &= q_L c + q_{La} \theta_c + (Q_L - q_L) P_s
\end{aligned}$$

○ Case 8: $\Omega 8$

In the following three regions of probability space, the overall capacity of C becomes a constraint which limits the revenue to C. C cannot satisfy all S_L 's transport capacity. There is no such limit on the cost to S_L since we have supposed that the spot market has unlimited capacity to respond to S_L 's needs.

$$R_{\Omega 8}(x_{L8}^*, u_8^* | 8) = q_L c + q_{La} \theta_s + (W - q_L) P_s$$

$$C_{\Omega 8}(u_8^*, x_{L8}^* | \Omega 8) = q_L c + q_{La} \theta_s + (Q_L - q_L) P_s$$

○ Case 9: $\Omega 9$

$$R_{\Omega 9}(x_{L9}^*, u_9^* | \Omega 9) = q_L c + q_{La} p_{La} + (W - q_L - q_{La}) P_s$$

$$C_{\Omega 9}(u_9^*, x_{L9}^* | \Omega 9) = q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s$$

○ Case 10: $\Omega 10$

$$R_{\Omega 10}(x_{L10}^*, u_{10}^* | \Omega 10) = q_L c + q_{La} \theta_c + (W - q_L) P_s$$

$$C_{\Omega 10}(x_{L10}^*, u_{10}^* | \Omega 10) = q_L c + q_{La} \theta_c + (Q_L - q_L) P_s$$

The following table recapitulates the results synthetically:

Ω_i	u_i^*	x_{Li}^*	R_{Ω_i}	C_{Ω_i}
$\Omega 1$	Q_L	Q_L	$Q_L c + (q_L - Q_L) \theta_s$	$Q_L c + (q_L - Q_L) \theta_s$
$\Omega 2$	q_L	q_L	$q_L c + (Q_L - q_L)(P_s + \theta_s)$	$q_L c + (Q_L - q_L)(P_s + \theta_s)$
$\Omega 3$	Q_L	Q_L	$q_L c + (Q_L - q_L) p_{La}$	$q_L c + (Q_L - q_L) p_{La}$
$\Omega 4$	Q_L	q_L	$q_L c + (Q_L - q_L)(P_s - \theta_c)$	$q_L c + (Q_L - q_L)(P_s - \theta_c)$
$\Omega 5$	q_L	q_L	$q_L c + q_{La} \theta_s + (Q_L - q_L - q_{La}) P_s$	$q_L c + q_{La} \theta_s + (Q_L - q_L) P_s$
$\Omega 6$	Q_L	Q_L	$q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s$	$q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s$
$\Omega 7$	Q_L	q_L	$q_L c + q_{La} \theta_c + (Q_L - q_L) P_s$	$q_L c + q_{La} \theta_c + (Q_L - q_L) P_s$
$\Omega 8$	q_L	q_L	$q_L c + q_{La} \theta_s + (W - q_L - q_{La}) P_s$	$q_L c + q_{La} \theta_s + (Q_L - q_L) P_s$
$\Omega 9$	Q_L	Q_L	$q_L c + q_{La} p_{La} + (W - q_L - q_{La}) P_s$	$q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s$
$\Omega 10$	Q_L	q_L	$q_L c + q_{La} \theta_c + (W - q_L) P_s$	$q_L c + q_{La} \theta_c + (Q_L - q_L) P_s$

Table 1: Expressions of optimal allocation of demand and capacity among different regions of probability space

3.5.5. Redefining optimal decisions by C to include allocations of capacity to market

So far, we have dealt with the optimal allocation of demand coming from the contractual shipper S_L . C also has to contend with demand coming from the market at spot prices. This second demand upon his capacity comes second by priority and in time. The discussion of the optimal allocation is guided by the level of the spot price P_s versus the variable cost of C: VC.

We now have to adjust the response to the demand from the market to take into account the limit in capacity W .

So the profit function of C that has to be maximised depends upon the regions of probability space and can be written:

$$\pi_i(x_L, x_s | u, Q_s, \Omega_i) = R_i(x_{Li} | u, \Omega_i) + \min(W - x_L, x_s)P_s - VC(x_L + x_s)$$

$$\text{s.t. : } \begin{cases} x_L + x_s \leq W \\ 0 \leq x_L \leq u \\ 0 \leq x_s \leq Q_s \end{cases}$$

The decision regarding the demand received from the spot market Q_s depends upon the value of the spot price: if $P_s < VC$ then, C has no interest in allotting any capacity and $x_s = 0$. So when $P_s < VC$ then the profit function is written as follows:

$$\pi_i(x_L, x_s | u, Q_s, \Omega_i) = R_i(x_{Li} | u, \Omega_i) - x_L VC$$

The equations of the optimal allocation according to the regions of probability space reflect exactly the results established in 3.5.4.

We now consider the case when $P_s > VC$.

We must once again optimize according to the variables x_L and x_s in each region of probability space:

○ Case 1: Ω_1

$$\pi_1(x_L, x_s | u, Q_s, \Omega_1) = x_L(u)c + (q_L - x_L(u))\theta_s + \min(W - x_L(u), x_s)P_s - VC(x_L(u) + x_s)$$

We first optimize in x_L because this is the first decision to be taken by C:

$$x_L^* = u^* = Q_L$$

$$\pi_1(x_L^*, x_s | u^*, Q_s, \Omega_1) = Q_L c + (q_L - Q_L)\theta_s + \min(W - Q_L, x_s)P_s - VC(Q_L + x_s)$$

The optimization in x_s comes immediately:

$$x_s^* = Q_s$$

$$\pi_1(x_L^*, x_s^* | u^*, Q_s, \Omega_1) = Q_L c + (q_L - Q_L)\theta_s + \min(W - Q_L, Q_s)P_s - VC(Q_L + Q_s)$$

Much as in 3.5.4, we can write the other profit functions in the distinct regions of probability space. We will just recapitulate the results in the following table:

Ω_i	u_i^*	x_{Li}^*	π_{Ω_i}	C_{Ω_i}
Ω_1	Q_L	Q_L	$Q_L c + (q_L - Q_L)\theta_s + \min(W - Q_L, Q_s)P_s - VC(Q_L + Q_s)$	$Q_L c + (q_L - Q_L)\theta_s$
Ω_2	q_L	q_L	$q_L c + (Q_L - q_L)(P_s + \theta_s) + \min(W - Q_L, Q_s)P_s - VC(Q_L + Q_s)$	$q_L c + (Q_L - q_L)(P_s + \theta_s)$
Ω_3	Q_L	Q_L	$q_L c + (Q_L - q_L)p_{La} + \min(W - Q_L, Q_s)P_s - VC(Q_L + Q_s)$	$q_L c + (Q_L - q_L)p_{La}$
Ω_4	Q_L	q_L	$q_L c + (Q_L - q_L)(P_s - \theta_c) + \min(W - Q_L, Q_s)P_s - VC(Q_L + Q_s)$	$q_L c + (Q_L - q_L)(P_s - \theta_c)$
Ω_5	q_L	q_L	$q_L c + q_{La}\theta_s + (Q_L - q_L - q_{La} + \min(W - Q_L, Q_s)y)P_s - VC(Q_L + Q_s)$	$q_L c + q_{La}\theta_s + (Q_L - q_L)P_s$
Ω_6	Q_L	Q_L	$q_L c + q_{La}p_{La} + (Q_L - q_L - q_{La} + \min(W - Q_L, Q_s))P_s - VC(Q_L + Q_s)$	$q_L c + q_{La}p_{La} + (Q_L - q_L - q_{La})P_s$
Ω_7	Q_L	q_L	$q_L c + q_{La}\theta_c + (Q_L - q_L + \min(W - Q_L, Q_s))P_s - VC(Q_L + Q_s)$	$q_L c + q_{La}\theta_c + (Q_L - q_L)P_s$
Ω_8	q_L	q_L	$q_L c + q_{La}\theta_s + (W - q_L - q_{La} + \min(W - Q_L, Q_s))P_s - VC(Q_L + Q_s)$	$q_L c + q_{La}\theta_s + (Q_L - q_L)P_s$
Ω_9	Q_L	Q_L	$q_L c + q_{La}p_{La} + (W - q_L - q_{La} + \min(W - Q_L, Q_s))P_s - VC(Q_L + Q_s)$	$q_L c + q_{La}p_{La} + (Q_L - q_L - q_{La})P_s$
Ω_{10}	Q_L	q_L	$q_L c + q_{La}\theta_c + (W - q_L + \min(W - Q_L, Q_s))P_s - VC(Q_L + Q_s)$	$q_L c + q_{La}\theta_c + (Q_L - q_L)P_s$

3.5.6. 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 conditional expected cost as a function of the received demand Q_L and P_s .

$$E\left(C(u^*, x_L^* | Q_L, P_s)\right) = \int_0^\infty \int_0^\infty C(u^*, x_L^*, Q_L, P_s) f(Q_L, P_s) dQ_L dP_s$$

When we open up this equation among the different regions we now have:

$$\begin{aligned}
E\left(C(u^*, x_L^* | Q_L, P_s)\right) = & \int_{P_s \in \Omega 1} \int_{Q_L \in \Omega 1} (Q_L c + (q_L - Q_L) \theta_s) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{P_s \in \Omega 2} \int_{Q_L \in \Omega 2} (q_L c - (Q_L - q_L)(P_s - \theta_s)) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{P_s \in \Omega 3} \int_{Q_L \in \Omega 3} (q_L c + (Q_L - q_L) p_{La}) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{P_s \in \Omega 4} \int_{Q_L \in \Omega 4} (q_L c + (Q_L - q_L)(P_s - \theta_c)) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{P_s \in \Omega 5 \cup \Omega 8} \int_{Q_L \in \Omega 5 \cup \Omega 8} (q_L c + (Q_L - q_L)(P_s - \theta_s) + (Q_L - q_L - q_{La}) P_s) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{P_s \in \Omega 6 \cup \Omega 9} \int_{Q_L \in \Omega 6 \cup \Omega 9} (q_L c + q_{La} P_{La} + (Q_L - q_L - q_{La}) P_s) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{P_s \in \Omega 7 \cup \Omega 10} \int_{Q_L \in \Omega 7 \cup \Omega 10} (q_L c + q_{La} \theta_c + (Q_L - q_L) P_s) f(Q_L, P_s) dQ_L dP_s
\end{aligned} \tag{14}$$

The variance of such conditional expected cost can be calculated when the conditional compound probability mass function of the spot price and demand addressed to S_L can be inferred from field observations.

4. INFORMATION SCENARIO ANALYSIS

We can now start modelling how each actor behaves according to the information he holds privately or that is common to both and see analytically the impact on the objective functions of C and S_L . Figure 5 describes the chain of events in time.

Each scenario is based on a different information assumption, as described above. In the first scenario, the information about the realized demands for the shippers is common knowledge to both shipper and the carrier, so is the spot market price for carrying that particular cargo at that particular period. In the second scenario, the capacity of C is unknown to S_L . In the third scenario, C 's capacity is unknown to S_L and S_L 's demand is unknown to C . As mentioned earlier, a fourth scenario where the carrier's capacity is known to S_L but S_L 's demand is not known to the carrier will be studied in a future extension of this paper.

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).

4.1. Scenario 1: Perfect information:

In this benchmark scenario, the carrier and shipper share information truthfully, as if coordinated by a single centralized organization. We assume common knowledge of: W , total capacity of C ; θ_c , penalty incurred by C for not performing contractual service to S_L ; θ_s , penalty incurred by S_L for not calling on the contracted services of C ; Q_L and Q_s , the realized demands received by S_L and the spot market respectively; and of course the spot price P_s . This scenario generates the maximum total profit. We consider it as the "benchmark" efficiency scenario against which we measure the differences induced by asymmetrical information and strategic action.

According to the observed demands and spot price, shipper S_L decides to allocate the maximum of the realized demand to C and C allocates the maximum of his capacity to satisfy S_L .

$$u = Q_L, \quad x_L = \min(W, Q_L) \tag{15}$$

So, their situation can be resumed below:

- $Q_L \in \Omega 1$: realized demand is less than contracted capacity. C offers remaining capacity to the market according to revealed demand Q_s . Any capacity of C left over is lost. C performs the transport service. Payout occurs, Shipper S_L pays a penalty to C for committed capacity unused.

$$C_{\Omega 1}^1(u^{1*} | x_L, \Omega 1) = Q_L c + (q_L - Q_L) \theta_s$$

$$R_{\Omega 1}^1(x_L^{1*}, u^{1*} | \Omega 1) = Q_L c + (q_L - Q_L) \theta_s$$

- $Q_L \in \Omega 2 \cup \Omega 3 \cup \Omega 4$: realized demand is more than contracted capacity but still within range of menu of prices included in the contract. Shipper buys additional capacity to C at the corresponding price in the contract menu. For this part of the demand received, S_L forfeits using the spot market, so no account is taken of the level of the spot versus p_{La} and the penalties. The excess capacity of C is offered to the market in accordance with market realized demand. Any remaining capacity of C is lost. Transport is performed and paid for. No penalties are due. The revenue and cost equations for S_L and C are the same as (9) in Case 3 above:

$$R_{\Omega 2 \cup \Omega 3 \cup \Omega 4}^1(x_L^{1*}, u^{1*} | \Omega 2 \cup \Omega 3 \cup \Omega 4) = q_L c + (Q_L - q_L) p_{La}$$

$$C_{\Omega 2 \cup \Omega 3 \cup \Omega 4}^1(u^{1*}, x_L^{1*} | \Omega 2 \cup \Omega 3 \cup \Omega 4) = q_L c + (Q_L - q_L) p_{La}$$

- $Q_L \in \Omega 5 \cup \Omega 6 \cup \Omega 7$: realized demand exceeds not only contracted capacity but also the extra capacity of the menu of prices included in the ex-ante contract. Shipper S_L must complement the committed capacity of C by buying from C extra capacity at the going spot market price of that period. If $Q_L > W$ than S_L can still buy any remaining necessity from the spot market as we have considered that it has an unlimited capacity. Remaining capacity is offered to the market in the limit of Q_s and $W - Q_L$. Payout occurs. The revenue and cost equations for S_L and C are the same as (12) in Case 6 above:

$$R_{\Omega 5 \cup \Omega 6 \cup \Omega 7}^1(x_L^{1*}, u^{1*} | \Omega 5 \cup \Omega 6 \cup \Omega 7) = q_L c + q_{La} p_{La} + (\min(W, Q_L) - q_L) P_s$$

$$C_{\Omega 5 \cup \Omega 6 \cup \Omega 7}^1(u^{1*}, x_L^{1*} | \Omega 5 \cup \Omega 6 \cup \Omega 7) = q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s$$

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

$$\pi_c^1(x_L^{1*}, x_s^{1*}, Q_L, Q_s, P_s) - VC(x_L, x_s) = \begin{cases} Q_L c + (q_L - Q_L) \theta_s + \min(W - Q_L, x_s) P_s, \forall (Q_L, P_s) \in \Omega 1 \\ q_L c + (Q_L - q_L) p_{La} + \min(W - Q_L, x_s) P_s, \forall (Q_L, P_s) \in \Omega 2 \cup \Omega 3 \cup \Omega 4 \\ q_L c + q_{La} p_{La} + ((Q_L - q_L - q_{La}) + \min(W - Q_L, x_s)) P_s, \forall (Q_L, P_s) \in \Omega 5 \cup \Omega 6 \cup \Omega 7 \end{cases} \quad (16)$$

The optimized cost function of S_L becomes:

$$C^1(u^{1*}, x_L^{1*}, Q_L, P_s) = \begin{cases} Q_L c + (q_L - Q_L) \theta_s, \forall (Q_L, P_s) \in \Omega 1 \\ q_L c + (Q_L - q_L) p_{La}, \forall (Q_L, P_s) \in \Omega 2 \cup \Omega 3 \cup \Omega 4 \\ q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s, \forall (Q_L, P_s) \in \Omega 5 \cup \Omega 6 \cup \Omega 7 \end{cases} \quad (17)$$

In the present scenario, the objective is to maximise both revenues for the carrier and minimize the costs for the shipper, since we can coordinate both at once. In this scenario, the Stackelberg position of S_L does not influence the outcome since no deviation will occur.

The conditional expected cost as a function of the received demand Q_L subject to P_s comes to:

$$\begin{aligned}
E\left(C^1(u^{1*}, x_L^{1*}, Q_L, P_s)\right) &= \int_{P_s \in \Omega 1} \int_{Q_L \in \Omega 1} (Q_L c + (q_L - Q_L) \theta_s) f(Q_L, P_s) dQ_L dP_s + \\
&\int_0^\infty \int_{Q_L \in \Omega 2 \cup \Omega 3 \cup \Omega 4} (q_L c + (Q_L - q_L) p_{La}) f(Q_L, P_s) dQ_L dP_s + \\
&\int_0^\infty \int_{Q_L \in \Omega 5 \cup \Omega 6 \cup \Omega 7} (Q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s) f(Q_L, P_s) dQ_L dP_s
\end{aligned} \tag{18}$$

The conditional variance can here also be calculated.

4.2. Scenario 2: Asymmetric information:

In the second scenario, C has private information on W , the transport capacity. When negotiating for the contractual capacity in the contract, S_L has verified that C has at his disposal sufficient capacity to comply with q_L . She did not or could not verify the existence or size of the additional capacity S_L has to invest in to meet the commitments of the menu of prices (possible subcontractors 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_s is higher than $p_{La} + \theta_c$. If C deviates, the demand in excess of q_L by S_L has to be offered to the spot market. So the cost increases for S_L . C has been modelled 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_L of S_L is here assumed observable by both S_L and C. In this scenario, the deviation is one-sided and limited to the carrier; in the next scenario, we will also take into account deviation on the part of the shipper S_L . The cost function of S_L and the revenue function of C are the following:

- $(Q_L, P_s) \in \Omega 1$

The same pattern as in scenario 1, no change in decisions nor functions:

$$C_{\Omega 1}^2(x_L^{2*}, u^{2*}, P_s) = Q_L c + (q_L - Q_L) \theta_s$$

- $(Q_L, P_s) \in \Omega 2 \cup \Omega 3$

Here again the same pattern of behaviour is observed for both actors as in scenario 1

- $(Q_L, P_s) \in \Omega 4$

S_L wishes to allocate $\min(Q_L, q_L + q_{La})$ to C. C refuses and decides to allocate all his capacity in excess of q_L to the spot market, he pays a penalty to S_L . S_L turns to the spot market for $(Q_L - q_L)$, and receives the penalty from C. The cost and revenue functions are the same as (10) in case 4 above:

$$R_{\Omega 4}^2(x_L^{2*}, u^{2*} | \Omega 4) = q_L c + (Q_L - q_L)(P_s - \theta_c)$$

$$C_{\Omega 4}^2(u^{2*}, x_L^{2*} | \Omega 4) = q_L c + (Q_L - q_L)(P_s - \theta_c)$$

- $(Q_L, P_s) \in \Omega 5 \cup \Omega 6$

As in scenario 1, both stick to the contract and the equations of cost and revenue are the same as in (12) in case 6 above.

$$R_{\Omega 5 \cup \Omega 6}(x_L^{2*}, u^{2*} | \Omega 5 \cup \Omega 6) = q_L c + q_{La} p_{La} + (\min(W, Q_L) - q_L) P_s$$

$$C_{\Omega 5 \cup \Omega 6}(u^{2*}, x_L^{2*} | \Omega 5 \cup \Omega 6) = q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s$$

- $(Q_L, P_s) \in \Omega 7$

C misbehaves when the spot is above the added menu of prices plus penalty for the portion of demand that is equal to q_{La} . The revenue and cost functions are the same as (13) in case 7.

$$\begin{aligned} R_{\Omega 7}^2(x_L^{2*}, u^{2*} | \Omega 7) &= q_L c + q_{La} \theta_c + (\min(W, Q_L) - q_L) P_s \\ C_{\Omega 7}^2(x_L^{2*}, u^{2*} | \Omega 7) &= q_L c + q_{La} \theta_c + (Q_L - q_L) P_s \end{aligned}$$

This leads to the following cost function for S_L :

$$C^2(u^*, x_L^*, Q_L, P_s) = \begin{cases} Q_L c + (q_L - Q_L) \theta_s, \forall (Q_L, P_s) \in \Omega 1 \\ q_L c + (Q_L - q_L) p_{La}, \forall (Q_L, P_s) \in \Omega 2 \cup \Omega 3 \\ q_L c + (Q_L - q_L) (P_s - \theta_c), \forall (Q_L, P_s) \in \Omega 4 \\ q_L c + q_{La} p_{La} + (Q_L - q_L - q_{La}) P_s, \forall (Q_L, P_s) \in \Omega 5 \cup \Omega 6 \\ q_L c + q_{La} \theta_c + (Q_L - q_L) P_s, \forall (Q_L, P_s) \in \Omega 7 \end{cases} \quad (19)$$

(14)

4.3. Scenario 3: Private information:

In this scenario, C has private information on W , S_L has private information on the demand Q_L : so both have an option to behave opportunistically according to the spot price P_s . Both carrier and shipper monitor whether the counterparty effectively sticks to the letter of the contract, but they cannot ensure that each receives the most out of the other. So each sticks to q_L , basic capacity contracted for. In this last scenario, the menu of prices is unenforceable. In effect, for any spot price either higher or lower than the menu price p_{La} 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.

- $(Q_L, P_s) \in \Omega 1$

No deviation occurs, the functions are the same as in scenario 1.

- $(Q_L, P_s) \in \Omega 2$

S_L deviates and prefers to deal at the spot price and declares to C that, as there is no extra cargo to be taken, she has no penalty to pay. We have included in the model revenue to C for that cargo allocated to the spot market for comparison purposes, but the penalty that S_L would have paid had C known about that extra cargo is not included in the revenue. The revenue and cost functions differ from (8) in case 2 above:

$$\begin{aligned} R_{\Omega 2}^3(x_L^{3*}, u^{3*} | \Omega 2) &= q_L c + (Q_L - q_L) P_s \\ C_{\Omega 2}^3(u^{3*}, x_L^{3*} | \Omega 2) &= q_L c + (Q_L - q_L) P_s \end{aligned}$$

- $(Q_L, P_s) \in \Omega 3$

The penalties are sufficient to dissuade both shipper and carrier to deviate in this region of probability space, so the revenue and cost functions for the optimal allocations are the same as in scenario 1.

- $(Q_L, P_s) \in \Omega 4$

The carrier deviates as in scenario 2 and allocates his capacity to the market, to the detriment of S_L . However, no penalty is paid, hence, the cost and revenue functions change to:

$$\begin{aligned} R_{\Omega 4}^3(x_L^{3*}, u^{3*} | \Omega 4) &= q_L c + (Q_L - q_L) P_s \\ C_{\Omega 4}^3(u^{3*}, x_L^{3*} | \Omega 4) &= q_L c + (Q_L - q_L) P_s \end{aligned}$$

- $(Q_L, P_s) \in \Omega 5$

S_L reports less demand to C, completes for the rest from the spot market. C has no way to check, so does not ask for, nor receive, the corresponding penalty. The cost and revenue functions are now written:

$$R_{\Omega 5}^3(x_L^{3*}, u^{3*} | \Omega 5) = q_L c + (\min(W, Q_L) - q_L) P_s$$

$$C_{\Omega 5}^3(u^{3*}, x_L^{3*} | \Omega 5) = q_L c + (Q_L - q_L) P_s$$

- $(Q_L, P_s) \in \Omega 6$

As in scenario 1, no deviation takes place. We have the same revenue and cost functions.

- $(Q_L, P_s) \in \Omega 7$

As in scenario 2, C refuses to carry any cargo above q_L and does not pay any penalty either, arguing that he lacks capacity (unobservable by S_L):

$$R_{\Omega 7}^3(x_L^{3*}, u^{3*} | \Omega 7) = q_L c + (\min(W, Q_L) - q_L) P_s$$

$$C_{\Omega 7}^3(u^{3*}, x_L^{3*} | \Omega 7) = q_L c + (Q_L - q_L) P_s$$

The cost and revenue functions are the ones previously mentioned but with the extra portion of realized demand exceeding contractual obligations that in any case will be allocated to C at spot market price.

The optimal cost function for S_L is now reduced to:

$$C^3(u^{3*}, x_L^{3*}, Q_L, P_s) = \begin{cases} Q_L c + (q_L - Q_L) \theta_s, & \forall (Q_L, P_s) \in \Omega 1 \\ q_L c + (Q_L - q_L) P_s, & \forall (Q_L, P_s) \in \Omega 2 \cup \Omega 4 \cup \Omega 5 \cup \Omega 7 \\ q_L c + \min((Q_L - q_L), q_{La}) p_{La} + (Q_L - q_L - q_{La}) P_s, & \forall (Q_L, P_s) \in \Omega 6 \\ q_L c + (Q_L - q_L) p_{La}, & \forall (Q_L, P_s) \in \Omega 3 \end{cases} \quad (20)$$

4.4. Conclusion

4.4.1. 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_L comes in between q_L and $q_L + q_{La}$ and the spot price is above $p_{La} + \theta_c$, which belongs to partition $\Omega 4$.

$$\forall (Q_L, P_s) \in \Omega 4$$

$$\pi^2(x_L^{2*}, u^{2*}, Q_L, P_s) - \pi^1(x_L^{1*}, u^{1*}, Q_L, P_s) = (Q_L - q_L)(P_s - \theta_c - p_{La}) \quad (21)$$

$$C^2(u^{2*}, x_L^{2*}, Q_L, P_s) - C^1(u^{1*}, x_L^{1*}, Q_L, P_s) = (Q_L - q_L)(P_s - \theta_c - p_{La}) \quad (22)$$

So we can write:

$$\forall (Q_L, P_s) \in \Omega$$

$$\pi^2(x_L^{2*}, u^{2*}, Q_L, P_s) - \pi^1(x_L^{1*}, u^{1*}, Q_L, P_s) \geq 0$$

$$C^2(u^{2*}, x_L^{2*}, Q_L, P_s) - C^1(u^{1*}, x_L^{1*}, Q_L, P_s) \geq 0$$

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_L . By design of the contract, these situations should arise often unless the penalty is "high", ie, in the case of spot price following a normal distribution, if $p_{La} + \theta_c = \mu_s + 2\sigma_s$ than S_L will suffer in the 5% of cases when the spot is above its average plus 2

standard deviations. Moreover this will only be the case when the demand received will also exceed the base commitment q_L of the contract. However, it remains to be seen whether C will allow θ_c to be that high.

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

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

$$\begin{aligned} E\left(C^2\left(u^{2*}, x_L^{2*}, Q_L, P_s\right) - C^1\left(u^{1*}, x_L^{1*}, Q_L, P_s\right)\right) &= \int_{P_s \in \Omega 4} \int_{Q_L \in \Omega 4} \left((Q_L - q_L)(P_s - p_{La})\right) f(Q_L, P_s) dQ_L dP_s \\ &= E\left(\pi^2\left(x_L^{2*}, u^{2*}, Q_L, P_s\right) - \pi^1\left(x_L^{1*}, u^{1*}, Q_L, P_s\right)\right) \end{aligned} \quad (23)$$

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

4.4.2. Comparison between scenario 1 and 3

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

$$\forall (Q_L, P_s) \in \Omega 2$$

$$\pi^3\left(x_L^{3*}, u^{3*}, Q_L, P_s\right) - \pi^1\left(x_L^{1*}, u^{1*}, Q_L, P_s\right) = (Q_L - q_L)(p_{La} - P_s) \quad (24)$$

$$C^3\left(x_L^{3*}, u^{3*}, Q_L, P_s\right) - C^1\left(x_L^{1*}, u^{1*}, Q_L, P_s\right) = (Q_L - q_L)(p_{La} - P_s) \quad (25)$$

$$\forall (Q_L, P_s) \in \Omega 4$$

$$\pi^3\left(x_L^*, u^*, Q_L, P_s\right) - \pi^1\left(x_L^*, u^*, Q_L, P_s\right) = (Q_L - q_L)(P_s - p_{La}) \quad (26)$$

$$C^3\left(x_L^{3*}, u^{3*}, Q_L, P_s\right) - C^1\left(x_L^{1*}, u^{1*}, Q_L, P_s\right) = (Q_L - q_L)(P_s - p_{La}) \quad (27)$$

$$\forall (Q_L, P_s) \in \Omega 5$$

$$\pi^3\left(x_L^*, u^*, Q_L, P_s\right) - \pi^1\left(x_L^*, u^*, Q_L, P_s\right) = q_{La}(P_s - p_{La}) \quad (28)$$

$$\forall (Q_L, P_s) \in \Omega 7$$

$$\pi^3\left(x_L^*, u^*, Q_L, P_s\right) - \pi^1\left(x_L^*, u^*, Q_L, P_s\right) = q_{La}(P_s - p_{La}) \quad (29)$$

$$\forall (Q_L, P_s) \in \Omega 1 \cup \Omega 3 \cup \Omega 6$$

$$\pi^3\left(x_L^*, u^*, Q_L, P_s\right) - \pi^1\left(x_L^*, u^*, Q_L, P_s\right) = 0 \quad (30)$$

$$C^3\left(x_L^*, u^*, Q_L, P_s\right) - C^1\left(x_L^*, u^*, Q_L, P_s\right) = 0 \quad (31)$$

The conditional expectation of this difference subject to P_s and Q_L can be written as:

$$\begin{aligned}
E\left(C^3(x_L^{3*}, u^{3*}) - C^1(x_L^{1*}, u^{1*}) \mid Q_L, P_s\right) = & \int_{P_s \in \Omega 2} \int_{Q_L \in \Omega 2} ((Q_L - q_L)(p_{La} - P_s)) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{P_s \in \Omega 4} \int_{Q_L \in \Omega 4} ((Q_L - q_L)(P_s - p_{La})) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{P_s \in \Omega 5} \int_{Q_L \in \Omega 5} (q_{La}(P_s - p_{La})) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{P_s \in \Omega 7} \int_{Q_L \in \Omega 7} (q_{La}(P_s - p_{La})) f(Q_L, P_s) dQ_L dP_s
\end{aligned} \tag{32}$$

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

$$\begin{aligned}
E\left(\pi^3(x_L^{3*}, u^{3*}) - \pi^1(x_L^{1*}, u^{1*}) \mid Q_L, P_s\right) = & \int_{\Omega 2} \int_{\Omega 2} ((Q_L - q_L)(p_{La} - P_s)) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{\Omega 4} \int_{\Omega 4} ((Q_L - q_L)(p_{La} - P_s)) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{\Omega 5} \int_{\Omega 5} (q_{La}(p_{La} - P_s)) f(Q_L, P_s) dQ_L dP_s + \\
& \int_{\Omega 7} \int_{\Omega 7} (q_{La}(p_{La} - P_s)) f(Q_L, P_s) dQ_L dP_s
\end{aligned} \tag{33}$$

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_L and C .

5. CONCLUSION AND POSSIBLE EVOLUTION

There is a lack of research and practice in approaching transport as a full fledged member of a supply chain. 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. Another dimension which we have totally obviated but which singularly influences the behaviour of both shipper and carrier, and hence the supply chain efficiency, is the lead time between revelations of demand addressed to the shipper and realization of the transport by the carrier. This lead time is influenced by whether the shipper receives an immediate response from the carrier or if he has to go out and buy transport capacity on the spot market; it is also influenced by the time that the carrier has to wait for orders to come in from other shippers before answering to the shipper with which he is linked by a contract.

Given these limitations, 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 such an important element as transport.

1. First, as in Seifert 2003, 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. Another will deal with multiple carriers and multiple shippers.

The aim of the supply chain manager should be to reduce standard deviation because added cost standard deviation is an incentive, in a multi-period game, to increase margins at both levels of the supply chain increasing 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_s and the demand Q_L (along the lines of Seifert 2003 or Gavinerni et al 1999).

It would be interesting to enlarge the study by adding further information variables germane to the transport industry: time schedules of the carrier, projections of future demand (entails sharing sales forecasts by the shipper), advance knowledge of points of delivery among others. 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). All these sets of information demand a much higher level of trust and cooperation between shipper and carrier but are key to further unlock value in the supply chain.

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