MODELING CONTRACTUAL RELATIONSHIPS IN TRANSPORT

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ACRONYMS

BDI	Baltic Exchange Dry Index
BIFFEX	Baltic International Financial futures Exchange
cdf	Cumulated Density function
DMU	Decision Making Unit
GDP	Gross Domestic Product
F.O.C.	First Order Condition
IFR	Increasing Failure Rate
lhs	Left Hand side
MPC	Minimum Purchase Commitment
OECD	Organization for Economic Cooperation and Development
pdf	Probability Density Function

PRC	Price Only Relational Contract
QFC	Quantity Flexibility Clause
rhs	Right Hand Side
SCM	Supply Chain Management
S.O.C.	Second Order Condition
SPE	Sub Game Perfect Equilibria

Part I

PREAMBLE

ACKNOWLEDGEMENTS

Looking back on the first days of the thesis, I can remember the great enthusiasm of starting a new experience and the anxiety of not knowing exactly where I was heading. Both feelings still inhabit me, seven years on. Writing a thesis is surely an enriching experience, both because of the new knowledge garnered along the way but more certainly the discovery of one's capacities. It is also a test of one's self confidence and perseverance. At times, this endeavour seemed so futile and my contribution so tiny that I lost heart. At other times, it was the smug and immodest feeling of building a work so completely immaterial. Most important has been the nagging notion of the overall cost to family, career and financial prospects which hurried me to the finish line.

Along the way, I have met very curious and passionate people. I got to know like minded researchers from very different horizons and walks in life, so different from the ones which had been my workmates in an earlier life.

My gratitude goes first and foremost to my wife Anne Christine who was certainly the most enduring support in this long journey. She was the person to suggest that I start this research. Claude Obadia certainly had a large influence and led me by his path-setting example. For their rigorous methods and painstaking attention to detail and quality, I must thank Philippe Chevalier and Per Agrell.

I dedicate this thesis to my late father who so early in life taught me that one should strive for perfection and that work should always be put back on the loom to be perfected. He always egged me on and never failed to enquire solicitously as to my progress. He would have been proud to be present at the public defence.

Felix qui potuit rerum cognoscere causas !

[*Virgil, Georgics, Book II, Line 490*]
Feci quod potui, faciant meliora potentes.

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PREFACE

The idea of starting this research has sprung from my work experience in the years preceding my doctoral studies.

In the year 2000, I set up a company in Argentina whose object was to bring together hauliers[1] and shippers through a set of web enabled tools. The shippers interested by this company's service were mostly industrial and agro-industrial firms who dealt with scores of carriers to move their mostly low-value goods. In this position, it has been my privilege to be an interested and active party to the negotiations between them when trying to set the terms of transport contracts. My experience is that their relationships are strongly tainted with mistrust and misunderstanding: memories of past conflicts, callous attitudes and real or imagined pilferage rankle on both sides. Opacity, dissimulation and opportunism are cardinal values for survival. In my experience, this background breeds under usage of transport capacities, under investment and short term management by both parties.

In Argentina, a substantial fleet of trucks for all-around use are involved in farm produce transport when harvest comes. Usually, before the start of a harvesting season (wheat, lemon, refined sugar, soybeans, corn, ...) shippers try to enforce a pre-agreed table of prices with large fleet owners and intermediaries. This table of prices is the result of long negotiations between shippers and truck syndicates at country level. However, when the harvest is in full swing, the pace of harvest and the shippers' requirements become so frenzied that the table is no longer respected and prices fluctuate according to supply and demand. Intermediaries in parking lots armed with cell phones arrange demand to meet supply.

A market thus emerges which lasts the whole harvesting season, usually extending from late November for wheat in the North of the country to early May for corn in the South. Shippers pay transport in two times: fuel or fuel money is paid upfront and the remainder is paid as late as a month after transport has taken place. Records are kept from one year to the next both for budget comparison as well as statistical reasons. Given the hectic pace, reputations are important for large players able to mobilize a large number of trucks. Shippers will remember from one harvest to the next who failed them. The large fleet operators (in reality brokers) will also privilege shippers who pay well or rather who pay upfront money. The price for the same distance and same destination can range from 75% to 200% of the "official" rate.

Observing the kilometre-long queues of trucks which wait to unload wheat at the silo facilities in the ports of Argentina at the height of harvest time, one cannot but link this vision to the purpose of Supply Chain Management.

1 Hauliers in this work will take the English meaning of firms transporting goods by road, whereas carriers will address generically any firm which transports goods, whatever the means of transport.

Part II

THESIS

1 INTRODUCTION

1.1 PRESENTATION

THE TRANSPORT INDUSTRY and other related services represent 6% of GDP in the United States (Source OECD) and as much as 8.6 % of the European Union's GDP (Source Eurostat). Even though the value of transport as a share of GDP has fallen over past decades, Eurostat, the EU statistics office, has recorded between 1998 and 2004 a yearly rate of growth of freight tonnage using roads in Europe in the double digits (EUROSTAT, 2005).

Within a supply chain, the firms that need to shift goods downstream usually buy transportation services from a third party. This transport supplier thus becomes part of the supply chain. The process of organizing these movements come under the heading of logistics. As remarked by Christopher (1998), it is through logistics and Supply Chain Management that the twin goals of cost reduction and service enhancement can be achieved.

In all the following, carriers will be used as a generic term. It will mean to include all types of transporting firms which carry goods but not people. Those goods can be solid or liquid, or even gaseous. They can be carried by vans, trucks, railcars, planes, barges or ships. The scope of the study does not cover the infrastructure as railways, pipelines, power grids or roads. Neither does it address the scheduling, routing or vehicle allocation which is central to internal operations of many transport firms (and in effect belongs mostly to operations management). The transporting firm can be a single driver-owner or a logistic company involved in both carrying, storing as well as picking, labeling and other logistic tasks. The concept extends to the parcel moving companies and postal services inasmuch as they have to establish contractual frameworks for the picking up and delivering of goods on behalf of third parties.

These third parties, on the other hand, are the shippers. In short, all firms who have goods to ship from one place to another. This includes a farmer driving his harvest to a port silo as well as a distribution centre distributing consumer goods to retailers. It includes an oilfield operator wanting to transfer oil over thousands of kilometres as well as a steel manufacturer sending coils over rail, road and waterways.

It is commonly observable that a carrier and a shipper may not always be setting up the best contractual framework for their future interaction. Secondly, the market through which they may eventually take recourse to satisfy their needs may not provide the required transparency or efficiency.

This particular research project centres on the workings of the relationship between users and providers of transport services. The first objective is to advance scientific research in the models of shipper-carrier commercial relationships. To do so, the tools developed in literature are applied in suitably modified ways so as to bring forth results that are distinctly applicable to an area which is more akin to logistics management.

The second object of this thesis is to contribute to the actual management practice of both shippers and carriers by providing evaluation tools to help management decision-making. To do so, the models also reflect actual practice of managers: information they lack, risk they face, limited planning horizon for the contracts they wish to enter,. . .

1.2 OBJECTIVES OF THE RESEARCH

The main objectives are to develop and analyze models of contractual relationships in transport. To this end, we shall present:

1 – Normative decision models methods for contractual design,

2 – managerial derived policies which may inform managerial practice.

1.3 PLAN OF THE THESIS

The ambition is to cover some of the managerial mechanisms at work *before* the relationship becomes full-blown. A relationship is taken to include all aspects of operational workings of a relationship: from the day-to-day of operations, to closing jobs, evaluation of the performance of the carrier, invoicing the work done and making the pay-outs. To be exhaustive, one would have to include the operation of service delivery and end of the relationship within the analysis. Given the length and homogeneity requirements of a thesis, we restrict our scope to an in-depth analysis of the birth of this relationship. The overall evolution of a relationship and its correspondence with distinct parts of the thesis are presented in table 1.

In the next chapter on methodology, the ground to be covered and the premises on which the results are built are defined. Some definitions and methodological considerations are presented.

In the *third* chapter, the preliminary aspects of a relationship between a shipper and a carrier are inspected. This period extends from the moment the search for a carrier (or a shipper) ends to the moment when both sit down to negotiate a contract for transport services. At this critical juncture, both still have the liberty to cut short the relationship without any undue damage either to their reputation or their finances. At this point however, both need to consider whether to invest in some relationship specific assets and to anticipate the other's actions once these preliminary investments are made. We wish to research the effect of asymmetrical information and eventual renegotiation of potential contracts on the rent accrued to both partners.

In the *fourth* chapter, the role of information during the life of a relationship and its impact on profits and coordination are shown. The setting described and the model do not overlap with the strategic logistics management issues as described in Christopher (1998) but builds upon the transport outsourcing literature. Some mitigating tactics when super-

Table 1: Life of a relationship between a shipper and a carrier: from start to finish and corresponding parts in thesis

	Steps in the life of a shipper – carrier relationship	Corresponding chapters in the thesis
I	Search and preliminary investment	Chapter 3 – Influence on rent distribution of information about prior specific investments
II	Arms length relations: asymmetric information	Chapter 4 – Rent capture under asymmetric information
III	Convergence in the choice of coordination contract	Chapter 5 – Choosing a contract over multiple periods
IV	Service delivery and payoffs	
V	Termination of relationship	

vision and control a posteriori are costly are presented in a bid to help managerial practice.

We tackle in the *fifth* chapter the moment when the carrier has been selected. How is the budding relationship to be organized? Supported by previous research on the subject, we center our attention on three distinct mechanisms to frame the interactions between carrier and shipper. We show how shipper and carrier proceed to choose among them and draw some conclusions as to the results applicable to the specific case of transport.

The *sixth* chapter concludes this work. We present some scientific results derived from the models in the earlier chapters. Some limitations and weaknesses resulting from the methodology which has been applied are given. We point out the interesting aspects for the practitioners and managers on both sides of the shipper-carrier relationship. We regard the practical applications in terms of management knowhow and practical implementation. We also bring up the limits to actual practice and end with some hints as to new research avenues.

1.4 LIMITATIONS

As can be gathered from the above, this work has a distinct theoretical flavour. Due to lack of resources, the required fieldwork which might have brought confirmation of the results presented could not be carried out.

We further make use extensively of a vision of the market for transport services which is assumed to be imperfect in the economic sense. This assumed imperfection is not the object of any analysis to characterize or model it. Our vision is entirely based on casual empiricism.

2 METHODOLOGY

2.1 RESEARCH STANDPOINT

So as to explain the choices of this work, the typology proposed by Kœnig (1993) to classify works in management science is used. According to Kœnig, two thematic alternatives are sufficiently discriminating as to distinguish between available options when producing knowledge in management science. The first is the "realism" of the theory which may be either "*strong*" or "*weak*". "*Strong*" if the theory must describe the world as it is really; "*weak*" if one considers that the important issue for a theory is not its ability to describe but its power to influence the action of the actors. The second is the status given to reality, either an ontological object which imposes itself upon the actors or an object to be constructed by the actors. Crossing these two dimensions yields four epistemological zones with distinct objectives as shown in table 2.

Table 2: Thematic opposition and epistemological zones – the four zones and their general objectives (*adapted from Kœnig 1993*)

		Essence of reality	
		Ordered	Constructed
Realism of the theory	Strong	Discovery of regularities *The ordering of empirical materials so as to describe and explain an observed reality*	Research-action *Behavioral hypotheses must be tested in the same time as interacting directly on the real situation which the actors are living*
	Weak	Development of predictive instruments *Means that thanks to a simplifying abstraction, to predict the issue of certain phenomena*	Construction of artefacts *Means constructivist approach with the object of inventing valid responses to new situations*

The present thesis is in fact the outcome of a walk through some of these zones. Regularities in behaviours and processes in the first quadrant top left of the table 2 have been observed by casual empiricism through the years by visits and other fieldwork of firms involved in road transport, either because they transported or because they contracted transport. These regularities have defined the object of the research by structuring it. "The development of predictive instruments rests on the boldness and the shortcuts of intuition (zone 2 bottom left of the table). If, as the preceding zone, this second epistemic zone supposes the existence of stable regularities, it is distinguishable by its frankly speculative orientation"[1] (Kœnig,

1 Translated from French by myself.

1993). In this zone, the objective is not to describe but to predict and so to explain observed phenomena. It is a stylization of reality which will serve as framework guiding this type of research. The present research is positioned in this quadrant which enhances modeling over representing reality.

"A fruitful management science must be largely a study of what is not: a construction of hypothetical models for the worlds that could become possible…"[2] (Le Moigne, 1990).

2.2 SCIENTIFIC FOUNDATIONS

Transport can be seen as a chain link within the overall supply chain: influenced and controlled by other chain links. It emits information, financial flows and goods towards other members of the chain as well as receives goods, financial flows and information from them. It is moreover influenced by the outside environment. The research paradigm adopted in this thesis is quantitative and model-based, aimed at developing managerial tools for positive or prescriptive usage by management decision makers. It is supported by the use of the decision sciences, agency theory and game theory. The results are achieved by applying decision sciences and agency theory to decision problems in order to satisfy participation constraints, market feasibility and efficiency objectives. It uses contracts which specify financial flows, attribution of rent and helps to evaluate the overall value of the mechanism for the dyad. The three management theories which principally support this endeavour are described in the following, so as to understand how they are brought to bear.

2.2.1 *Transaction Cost Economics*

This theory enables the observer to capture all the width and depth of the relationship uniting a shipper to his carrier: it assumes that actors have diverging interests and that their behaviours are influenced by different governance modes and by information which is asymmetric and costly (Williamson, 1985). The important contribution of this theory is to have recognized and applied the science of contracts to the realm of the firm and inter-firm relationships, justifying the use of contracts and explaining their impact on firm boundaries and forms (Williamson, 2002).

This theory and the theory of contracts have effectively unified into the notion of contract all the modalities of coordination as mechanisms enhancing some behaviours between parties and they capture and explain several attitudes which can be found commonly in the relationships of carriers and shippers (Williamson, 1975, 1996, Favereau, 1989).

Wang and Zhu (2004) gives justification for shippers' choice of whether to outsource or keep in-house their transport by looking at how observable but unverifiable information can change the benefits of integration.

However, Transaction Cost Economics theory is lacunal in explaining evolution of relations, governance modes or of the implications that different management tools or mechanism design will have on the perfor-

2 Translated from French by myself.

mance of shipper-carrier relationships. The difficulty of appraising the impact and importance of governance, specific assets and alliances in a Transaction Cost Economics setting are highlighted in e.g. Dyer and Chu (2003) or Dyer (1996).

2.2.2 *Agency Theory and Contract Theory*

Agency Theory and Contract Theory provide us with the tools to deal with the aspects that Transaction Cost Economics remains silent on.

The "positive" version of the Agency Theory as described in Eisenhardt (1989) provides us with an analysis framework for the study of conflicting objectives. The complete contracting agency models stem from Malcolmson and Spinnewyn (1988) and Fudenberg et al. (1990).

Fama and Jensen (1983) have applied the principles of adverse selection and moral hazard to the relationships between firms.

The principles involved here come from several sources, in particular from Laffont and Tirole (1988). In this last paper in particular, the results of repetitive short-term contracts enhance the ability by the principal to update the incentive scheme that he offers the agent and hence induces ever higher performance from the agent in a ratchet effect (Weitzman, 1976, 1980). This effect is illustrated in appendix A.1 on page 135 where the carrier is the principal and the shipper the agent. When, on the contrary, the principal is the shipper and the agent is the carrier, this is a result that is used when applied to spot market short-term contracts involving the same shipper and carrier: because of this effect, the carrier ends up deploying the same effort for all customers requiring his services in short-term contracts because he knows that they know what has been his past efforts and performance. This is of course reinforced when shippers and carriers know each other by reputation (which pre-supposes the existence of a market).

2.2.3 *Game Theory*

Games studies beyond Cournot and Bertrand have been applied in economic studies first by von Neumann and Morgenstern (1944). Nash (1950) presented the equilibrium which we apply here together with the advances made by Harsanyi (1967) mostly in chapter 3. Since then, Games Theory as applied in management science plays an important role as founding principles for the models which represent several actors and several periods in non-cooperative settings (Rasmusen, 1989, Fudenberg and Tirole, 1991). One can distinguish "one shot" games where past experience, or reputation do not come into line as in Goeree and Holt (2004) from "repeated games" in which players repeatedly interact and memory, behaviour, reputation become relevant concepts (Selten, 1975, Kreps and Wilson, 1982). Important tools and models are presented in Cachon and Netessine (2004) which showcase the power and versatility of game theoretical tools as applied in SCM.

Game Theory is attractive in modeling the bargaining that goes inevitably on between shipper and carrier. Nash (1950) described the bargaining problem, defining it as "two individuals who have the opportunity to collaborate for mutual benefits in more than one way."(p. 155). Other models more recently, such as Ståhl (1972), Rubinstein (1982), have developed interesting concepts and results. A guide to the history of Bargaining Theory is presented in Wu (2004).

Together with Ertogral and Wu (2002), it is considered in this thesis that additional outside options are easily accessible, and the players involved in the negotiation may at some point choose to abort the current negotiation. In this context, the process of contract negotiation can be more accurately captured by a bargaining process where the players dynamically exchange offers while weighing their current option against potential future options. Thus, the bargaining process captures an important, dynamic dimension of contracting that is present only tangentially in previous research in SCM. We define a specific mechanism to describe this process in appendix A.1. As defined in Muthoo (1995), "...a bargaining situation is a situation in which two players have a common interest to cooperate, but have conflicting interest over exactly how to cooperate (p. 1)." Bargaining Theory is a branch of Game Theory that deals with the bargaining situations between two parties. In particular, if the bargaining game is single shot, one may characterize its Nash equilibria. If the game is repetitive (ie, not dynamic), as is the case in our analyses in chapters 3 and 5, one may characterize its subgame perfect equilibria (SPE) (Selten, 1965). The models developed in chapters 4 and 5 both use Bargaining Theory settings taking advantage of the taxonomy established in Wu (2004) but without the use of an intermediary.

We model the interactions among the players in this work as noncooperative games.

Since most of the explanation of the way partners in a supply chain divide those spoils can be tracked down to pure and simple bargaining power, this thesis adopts the position that whenever possible, the eventual profits generated by any mechanism will not be attributed to one or the other. Apart from alleviating somewhat the demonstrations, it has the added advantages that we escape all assumptions as to the relative power of each player and do not require all cost information to be commonly shared[3].

To recapitulate, this work operates within the realm of game theory, with asymmetric information, non-cooperative bargaining and possible opportunistic behaviour. We develop below how the negotiation process is modeled and used in this thesis in §2.3.1.

2.3 UNDERPINNINGS AND DEFINITIONS

This thesis wishes to present results on precise points within the overall area of the relationships between shippers and carriers. Because of their connections with the problems with which we shall grapple, it is important to substantiate some key issues before presenting the models.

3 A common assumption in most models difficult to sustain in SCM and even more so in the case of shippers and carrier (Rubinstein, 1982, Plambeck and Taylor, 2007, 2005, Ertogral and Wu, 2002, Baker et al., 2002).

When a shipper has identified a need for transport, he must find and select from the population of carriers which can perform this task for him a subset which meets some technical criteria. If a shipper and a carrier select each other and decide to start negotiating, what mechanism is most suitable to frame their future relationship? Once they have started discussing the details of their future relationship, what information do they need from each other? How are they going to ensure adequate response from the other party so that their profit expectations are met?

We review quickly in the following sections the bargaining model, the importance of some types of information before devoting our attention to the choice of contracts as mechanisms to organize the effort of the shipper and carrier.

2.3.1 *Bargaining model*

In chapter 5, we make use of the conclusions from Busch and Horstmann (1999) and the references therein as regard the outcome of iterative bargaining between two parties who can choose between several types of contracts and length. The assumptions in that paper are that bargaining is costly, but that the cost may be different for each party. Through a model of explicit transactions process where agents agree to divide the surplus of an endowment stream, this paper shows that this cost alone can generate in equilibrium different incomplete contracts as outcomes of bargaining. It also shows that if long-term contracts are costlier to evaluate (because of the need of making it complete is higher than making a short-term contract complete), then the players *may* tend to adopt short-term contracts in preference to long-term ones. This higher cost may, however, move the bargaining power to one of the parties thereby making it preferable to the short-term contract branch of the alternative. This paper and the underlying theory fit the observed reality of bargaining in transport in several ways: we see a setting which takes into account (i) bargaining power, (ii) short-term versus long-term contracts, (iii) bargaining and contract evaluation costs, and (iv) initial "structure bargaining" which stipulates the items in the contract to be bargained.

All along this thesis, the assumption is that contract writing and bargaining is costly. Dye (1985) models how each added clause increases costs of writing contracts leading to incomplete contracts. Lipman (1992) presents a cost-of-contracting model in which states of nature can be determined only at some cost. Anderlini and Felli (1994) consider incomplete contracts arising from costs of describing "complex states". Allen and Gale (1992) show that, if agents cannot write contracts contingent on states of nature but on noisy signals, then agents may choose non-contingent contracts in equilibrium. This outcome arises because of both the inability of one of the agents to manipulate noisy signal and the existence of incomplete information about this agent's type.

An often cited paper about bargaining in SCM is Rubinstein (1982). But bargaining between two actors when all required information to arrive at an agreement is commonly known basically boils down to a rent sharing problem: how the rent which is accrued in the supply chain dyad between a shipper and a carrier given costs and revenues is shared out.

The choice of the Rubinstein model above would be difficult to justify or to implement in a transport setting since neither player knows the other's costs or profits. A further hindrance to practical use is the necessity of knowing the *real* discount rates of the players. We do, however, adopt the convention by which all decisions are made using offer-counter-offer bargaining in the style of Rubinstein (1982) in appendix A.1 on page 135. We concur with Busch and Horstmann (1999) that this model highlights several ways in which this bargaining approach to contract determination squares with traditional transaction cost arguments. Bargaining being costly, both will want to arrive at an agreement in a limited number of steps. In this sense, different contract structures, by excluding or including different items in the bargaining process, can imply different costs to a player of "holding out" for more favourable terms. The equilibrium contract results from optimizing each player's expected returns. These costs are determined by the way that the particular contract structure affects the player's ability to hold out for any given allocation. Heterogeneity in the preference structures of the contract across players, for instance, can produce different valuations to them even when transacting via the same contract structure.

New evidence is presented in Lahno (2002) on the way "real life" players actually form their beliefs as to other players and how those beliefs actually shape their strategies and hence the ensuing contract. In real life, either the revenue or the cost is not known by the other party. Moreover, each may have distinct beliefs about the other's costs, revenues, outside opportunities, expected demand, etc. Finally, each actor may have beliefs about the other's beliefs. The shipper may reason along the following lines: "I know what my transport requirements are going to be. If I can induce you into believing that they will be higher, you will allocate more resources to me, even though this advantage to me is costly to you?". This problem has been dealt in a theoretic fashion in Geanakoplos and Polemarchakis (1982). The conclusion is that it is not necessary for both players to have the same information, or even the same beliefs to share the same opinion. The paper demonstrates that, if both actors start with the same universe of possible states of the world, observe commonly an event and agree on an exchange of information process, by a finite number of steps, both arrive at the same opinion by simply exchanging information about their beliefs.

Information asymmetry remains a key feature of real transport and logistic relationships and such asymmetry is difficult to model because the probability structure of a stochastic process may be perceived differently by the parties to the contract, leading to disagreement on the evaluation of expected profits. We prefer to go along the path set in Section 5 of Wu (2004) on bilateral supply-chain bargaining which describes how a pair of supplier and buyer set about splitting a certain system surplus. Before entering the negotiation, each actor has outside options and the surplus to be split is higher than the sum of outside options, ensuring Incentive Compatibility. In the same alternating-offers bargaining as presented in Rubinstein (1982), each actor makes an offer to the other, either accepts or rejects the offer received and with a certain probability, the negotiation breaks down. Though the model in Wu (2004) specifies that the probability of the negotiation breakdown can be exogenous, in this work we take into consideration only endogenous causes stemming from incentive incompatibility or rationality constraint violation.

We use in appendix A.1 on page 135 the *revelation principle*, result of incentive theory, and its application to the problem as presented in Peters (2001) where a principal offers a menu of contracts and, through an exchange of messages with the agent, obtains the revelation of the desired information about the type of the agent. A condition is that the agent uses communication, decision and action strategies which maximize his expected utility for all possible contract offers being made to him by the principal. This enables the principal to compose a menu of contract offers and through the responses of the agent to map the valuations of the contracts into actions, providing a "*direct mechanism*".

In our bargaining process, the *revelation principle* is further satisfied by including in the model the fact that both shipper and carrier must invest in some assets specific to their relationship. Such assets may include specific software to connect each other's information systems, detailed work processes to enable the employees to accommodate the workflow generated by the activity of the other, some customization of labels etc. Given these investments, how does the bargaining process begin? Are there any holdup situations? By the end of the negotiating process, both actors have constructed a belief of the other's outside options and internal costs and establish the corresponding density and distribution functions of the random variables of the other's virtual willingness to pay or opportunity cost (as described in Section 5.1 of Wu, 2004). Chapter 3 covers these aspects in detail and describes how shipper and carrier are linked in a dynamic multi-period game. It is shown how the relationship-specific investments in an asymmetric information setting influences the outcome of their negotiations. In appendix A.1, we model their behaviour when the shipper has private knowledge of her future transport requirements and may wish to induce the carrier into committing more capacity than is truly necessary.

We build upon the results achieved in Geanakoplos and Polemarchakis (1982) about how the exchange of information leads to common equilibrium posterior in the sense that we also use the fact that both actors act rationally, hold different beliefs about the possible states of the world and will arrive at a common opinion about those possible states of the world even though they do not share the same information or beliefs. To do so, both engage in an iterative exchange of information, update their belief on the basis of received information and so on until, in a finite number of steps an equilibrium is achieved. Note here that the setting in Geanakoplos and Polemarchakis (1982) is not a bargaining process per se but rather an information process. We assume in the present work that both processes can run along parallel lines: after all, the simple fact that a shipper and a carrier exchange offers of contracts and contract parameter menus induces an information exchange.

2.3.2 *Power balance*

The impact of the balance of power in a shipper carrier relationship is not an idle discussion. In several industries, shippers are so large and carry such clout as to be able to dictate the contract terms.

The bargaining powers of the parties depend on the "combination of her ability to influence the breakdown probability and her outside options. The player with higher valuation on her outside option is more likely to receive a larger share of the surplus" (Wu, 2004, page 82).

In the international market for deep-sea dry bulk transport, Jing et al. (2008) has found that the "positive" shocks to the price of dry bulk have higher influence than "negative" shocks, meaning that events that trigger an up-move in prices have a larger impact than those that trigger a down-move. This means that customers of the sea transport industry had less control over the market than did the carriers; in other words, the carriers had more bargaining power. This situation seems to have been reverted completely since the middle of the year 2008[4] as the prices for ocean dry bulk ship capacities has nosedived to levels which do not even cover marginal costs of operation as reported in the press (Evans-Pritchard, 2009).

A typical goal of SCM literature is to design channel coordinated contracts where the players' Nash equilibrium coincides with the supply chain optimum, while at the same time satisfying individual rationality and incentive compatibility constraints. The channel surplus created by the coordination contract is split arbitrarily, typically in favour of the "leader" who initiates the contract design (MacLeod, 2002, Zhu, 2000, among others). Ertogral and Wu (2002) show that the dynamics of supplier-buyer contract negotiation would change dramatically if the agents were to enter a repeated, alternating-offer bargaining game on the contract surplus, and the equilibrium condition for the bargaining game may not coincide with contract stipulation.

In the present work, the models and solutions which have been presented strenuously avoid bargaining power assumptions so that they can later be applied in managerial settings where the actual bargaining power position of each party can be taken of *ad hoc*. In terms of scientific approach, the results represent outcome-space solutions.

2.3.3 *Information of shipper and carrier*

Information in this thesis is considered to be heterogeneous and includes prices, costs, utility or willingness-to-pay and performance or capacity.

We look into how each player uses the asymmetry of information to his advantage and how the other party tries to minimize that advantage.

We look into how to make each player *truthfully* reveal his private information. This has been dealt with in the regulation literature in e.g. Baron and Besanko (1984), Laffont and Tirole (1993a).

We deal in future chapters either with a double moral hazard problem (chapter 4) or, as in chapters 3 and 5, with a simple moral hazard problem.

4 As can be gathered from the chart of spot market in dry bulk presented in figure 1.

The anticipation of how information will be used will affect each player's actions and provide incentives for strategic behaviour.

As demonstrated in Williamson (1985), the asymmetry in information can not be corrected by recurring to a court of justice.

Among others, Chen (2004) resumes in a taxonomy most major references of the influence of information on stock policies and production capacity planning. Some of the models present interesting analogies with shipper-carrier models as characterized in the present work. One such is Bonser and Wu (2001) which demonstrate the advantages for an electric utility to use information about demand for electricity and spot market prices for fuel to properly plan its procurement strategy involving both spot market procurement and a contract with both a minimum and a maximum commitment over a period of time. The model and its conclusion are interesting in the way that the impact of information about demand and spot market prices and the existence or absence of volatility impact the electric utility's optimal procurement strategies.

We model how a carrier can extract, through screening iteratively, the demand information that he needs from the shipper in appendix A.1. The results are used in chapter 5.

A demonstration of the interest of the posterior verification of information about capacity (or performance) is given in chapter 4.

2.3.4 *The ratchet effect*

When both shipper and carrier wish to interact repeatedly, post-contractual opportunistic behaviour may emerge. The carrier may offer the shipper less favourable conditions once he has updated his belief of the shipper's expected demand, willingness-to-pay or competitive pressure. This effect is called the "ratchet effect". To mitigate the impact of such behaviour, the shipper may resort to deceptive action detrimental to both players.

This effect as first studied in Weitzman (1976) and companion paper Weitzman (1980) denotes the risk of having one member capture the rent of the other member by using past revealed information. We investigate further these effects on the cost to the shipper and the carrier's profit and present how the shipper can minimize them in appendix A.1.

2.4 CONTRACT FORMS

This thesis shall restrain its studies to the contracts to be found in literature on the basis of their recognized applicability to relationships between shippers and carriers and will try to quantify the results of their use. These contracts as have been found in literature and presented in this work are wholly consistent with observed practice for road transport (see e.g. Hubbard, 2001, Razzaque and Chang, 1998). We refer the reader to, among others, the primary data survey in Sink and Langley Jr (1997) and the survey of New Zealand third party logistics in Sankaran et al. (2002). The literature on contracting in economics has been driven by the transactions cost framework developed by Coase (1937), Klein et al. (1978), Williamson (1985), and subsequently formalized in the Principal Agent literature (Laffont and Tirole, 1988). The basic hypothesis of this approach is that transactions with one or more buyers will be structured so as to minimize the total production and transactions cost of these transactions, including contracting, incentive, and monitoring costs.

We take it for granted that no contract can be exhaustively written nor that all contingencies can be included (i.e. to omit some contingencies, Coase, 1937). However, we adopt the view that all contracts belong to an infinite set representing all possible forms of mechanisms by which shippers and carriers may decide to conduct their commercial interactions. The literature in mechanism design has whittled down this infinity to some special contracts which exhibit characteristics like simplicity, fairness, take into account externalities and effectiveness (Beil and Wein, 2003, Cachon and Zhang, 2006). This limited subset of contracts can still be defined by parameters which can take an infinity of values. It is this subset of contracts, further defined in this work which form the basis of our study. Further, given the assumption of limited procedural rationality of the involved parties (introduction of Orléan, 1994), it is assumed here that the set of contracts which can be of use to a shipper and a carrier is limited.

As the chapter 5 centres on the choice of the contracting mechanism, we deal in this section with the necessary preliminary issues regarding the utility and theoretical framework within which the model operates.

Generally, in modeling interactions in a supply chain with imperfect competition among firms, the game being played or mechanism being designed is viewed as exogenous. The analysis of many games viewed in such isolation leads to a prediction of an inefficient outcome as compared to settings in which there is a choice of mechanisms. Jackson and Wilkie (2005) models a contract in which players can write "side contracts" where they adjust the original contract to affect the outcome of the game and its equilibrium. To escape most of the problems identified by Jackson and Wilkie, we restrict our purpose to a closed choice of mechanisms and contracts that are not contingent on one another. Lagunoff (1992) proves that fully endogenous mechanism selection is non-vacuous when the class of mechanisms is restricted at each stage of a process[5].

In the SCM literature, one paper which addresses procurement through a diversity of contracts and spot market buying is Martínez-de-Albéniz and Simchi-Levi (2005). In the presence of multi-period stochastic demand, Martínez-de-Albéniz and Simchi-Levi devise a portfolio of contracts policy to replenish stock from a variety of suppliers. Minimum commitment and quantity flexibility contracts are shown to be reducible to portfolios of options. An important issue is recognized but not addressed, is the one which chapter 5 wishes to tackle: why would suppliers agree to sell options and not insist on firm commitments, since they will incur the cost of reserving capacity[6]? From a slightly different angle, Corbett et al. (2004) concludes that with three types of contracts, deterministic demand, asymmetric knowledge of the variable cost of a retailer,

5 In the non-restricted variety, within the process, each game results from the choice of a game which in turn results from the choice from another game, etc.

6 Cachon and Lariviere (2001) has also addressed this issue in a different setting.

information has greater value with two-part contracts then with one-part contract.

This way of making endogenous the choices faced by actors in the real world is apparent in Tomlin (2003) which builds upon and refines Cachon and Lariviere (2001) by comparing the contract choices open to manufacturer (buyer) and supplier in the case of variable demand so that the supplier is coordinated into investing into the proper capacity to respond to stochastic demand. When processing costs at the supplier are non-linear, it is shown that three forms of contract dominate the linear-price contract and enhance coordination compared to the centrally organized case: quantity-premium, firm-commitment and option when the supplier has positive capacity cost.

This thesis deals with the following contract forms:

1 – *spot market transactions* (short term contracts),
2 – *price-only relational contracts*,
3 – *minimum purchase commitment*,
4 – *quantity flexibility contracts*.

We go through in detail these classical contracts that can be found in freight transport. We present along the way the references and literature highlights which shall guide and found the models and findings which represent the material of this thesis.

2.4.1 *Open market Spot procurement (Spot)*

The spot market as we see it in transport and by analogy to the commodities markets as described in the literature, involves buying or selling of homogeneous goods between a finite number of actors for short term transactions. These transactions are characterized by : origin and destination pairs, quality of service terms, financial terms, etc. All of which contribute to heterogeneity of conditions.

Given the variety of goods to be transported, modes to do so and costliness of information, there are a number of different markets operating at any time.

The literature within SCM in this type of procurement strategy is abundant. Wu et al. (2002) study the contracting arrangements in the energy sector between a producer and several buyers. The contracting arrangements for capital-intensive, capacity-constrained goods in the energy sector are modeled. They highlight the "two-goods problem": capacity itself, pre-committed to a specific buyer, and output actually delivered "on the day" to the buyer. This gives rise to two different markets where prices are formed: spot pricing 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.

Spinler and Huchzermeier (2006) builds upon Wu et al. (2002) and is one of the few who study spot market price and demand as two random variables: most consider transport prices to be linearly function of demand.

Kleindorfer and Wu (2003) and Spinler and Huchzermeier (2006) provide variations on Wu et al. (2002) where the buyer uses over-the-counter options to secure in advance the necessary resources. Spinler and Huchzermeier (2006) uses options in lieu of future and spot market contracts to increase capacity utilization in the presence of state-contingent demand. It is shown that such a strategy effectively is Pareto improving for both the seller of the option (transport supplier) and the buyer (the shipper). To circumvent the liquidity problem of transport as a non-standardized service, the model assumes that options will be traded on electronic marketplaces. However, as Grieger (2003) reported, carriers and shippers may be wary to trade with partners of unknown quality and customer service levels.

Chen (2007), in a one buyer-multiple seller model, derives an efficient procurement strategy through a comparison of two auction mechanisms. In the first, the provider offers a quantity given a scale of price-quantities from the buyer and in the second, the supplier offers a price for a quantity taken from a scale of quantities provided by the buyer. All suppliers are symmetric and the least cost supplier wins, which would be the case in transport only if there were no incumbents.

Several assumptions underscore the research presented here:

1 – shippers and carriers will readily sign spot based transport contracts for part of their transport capacities or requirements[7],

2 – discovering a counterparty is costly even if the spot market price is commonly available and instantaneously known to both shipper and carrier,

3 – individually, both carriers and shippers are price takers,

4 – the spot market price follows a stationary stochastic process,

5 – spot market prices are positively correlated to demand.

Assumption 4: spot market prices follow a stationary stochastic process. In the general case, this is an unverifiable hypothesis. Due to a lack of recognized historical data, it has mostly been considered that if prices do get out of line with real costs of operating the kind of transport capacity, new entrants in the industry will bring prices back towards a zero economic profit. And if prices get too low, some actors will find it uneconomic to ply this trade and exit the market. This assumption finds some justification in the empirical analysis documented in Yu et al. (2007) where all transport price series except the ocean rates were stationary between 1990 and 2002.

Assumption 5: Positive correlation between demand and transport prices.

Transport spot market transactions do not resemble the on-line auction and electronic markets for commodities as described in Jin and Wu (2004), Seifert et al. (2004) or Spinler and Huchzermeier (2006) to name but a few. To mention just one example, the maritime market for transport capacity is mostly cleared by brokers operating over the phone and is considered generally to be opaque with high price discovery costs, even though

7 It is conjectured that these represent only part of their portfolios of contracts and other, presumably long term, contracts complement them. An article in the Financial Times in January 2009 reports on the losses registered by shipping lines because their customers, mining conglomerates, have reneged on their long term contracts for lack of cargo to transport (Wright, 2009).

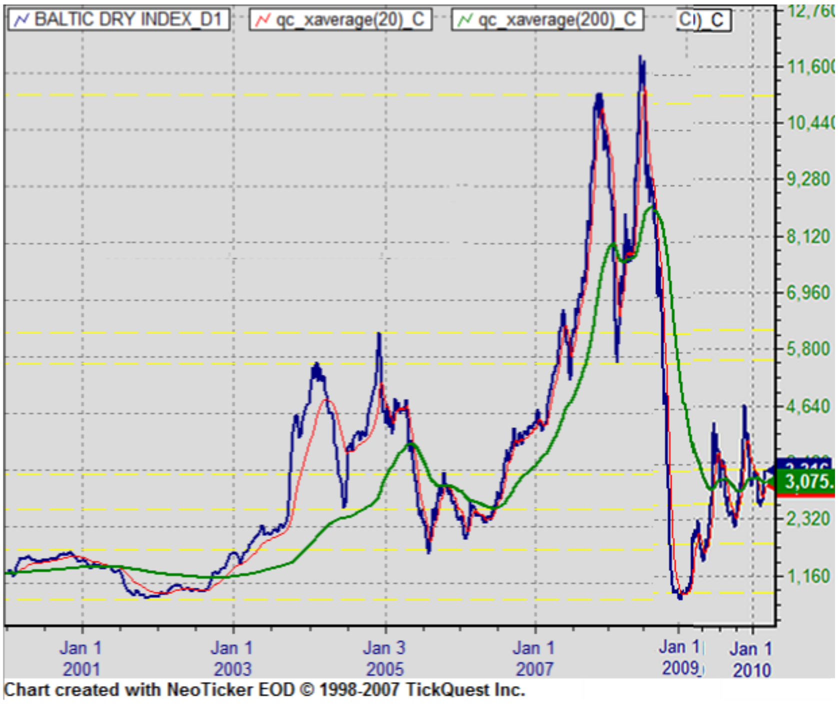

Figure 1: Baltic Exchange Dry Index, Jun 2000-Oct 2009 (Source Investment-Tools.com).

an electronic market, Baltic International Financial futures Exchange (BIFFEX), on indexes exists (Kavussanos and Nomikos, 2001). Several papers exist which study the behaviour of the spot market for ocean freight[8] which show that prices on spot markets may evolve erratically and in a disconnected way from general economic conditions (Kavussanos and Nomikos, 2001, Jing et al., 2008).

The Baltic Exchange[9] monitors shipping prices on several common oceanic lanes in the world (see figure 1). The most commonly watched and studied in literature is the Baltic Exchange Dry Index (BDI) which represents the result of a daily poll of international ship brokers on dry bulk shipping rates practised on the spot market. The random walk hypothesis has been tested and mostly validated over several periods and by several researchers (Jing et al., 2008). This last study of prices between 1995 and 2005 finds that shocks in the daily series have an increasing effect over time, especially in the later part of the time series. This effect can easily be confirmed by the graph plotting the BDI in the last seven years presented in figure 1. The authors even find that from mid-year 2003 to 2005 the data no longer confirm the random walk hypothesis, a result which they explain away as the result of more complex market conditions and of extraordinary outside shocks. They generally find support to the notion that the demand for international commodity transport drives the spot market price for the corresponding capacity. If that same study had covered the period from 2005 to 2009, there might have been additional

8 No similar literature has been found for spot markets for road haulage even though several electronic marketplaces do exist.

9 More information can be found on their website: www.balticexchange.com.

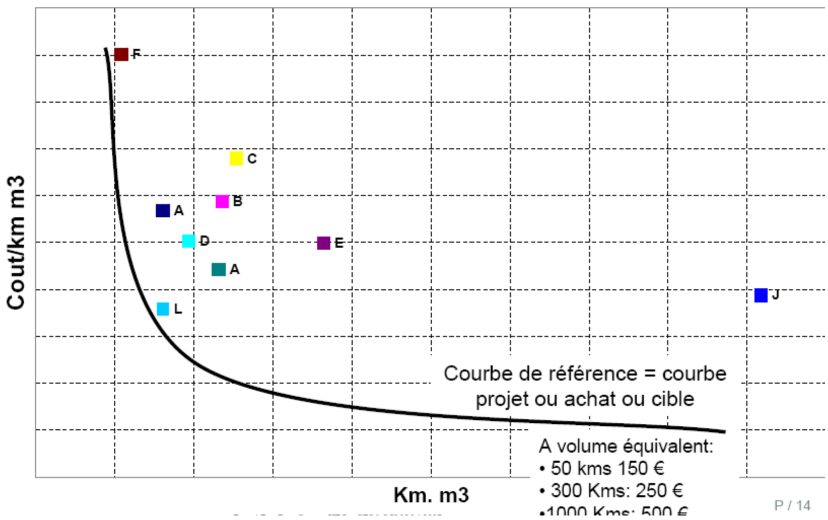

Figure 2: Reference curve and observations of costs per kilometre.m3 for different distances (Source Renault logistics, 2008).

support to both conclusions: prices do not follow a random walk and demand drives transport prices.

A more detailed study of the relationship between transport prices and demand can be found in Yu et al. (2007). In fact, that paper studies the causal link between transportation markets (rail, waterways and high-seas) and cereal markets: how transport prices influence cereal prices and vice versa. It is found that cereal and transport prices are cointegrated. Since cereal prices arguably stand as proxy for demand, we conclude that demand for cereals is positively correlated to transport spot market prices.

Such results tend to confirm that generally spot market prices can be assumed to be positively correlated to the demand of the goods to be transported.

2.4.2 *Informal Price-only Relational Contract (PRC)*

Very often, all that exists between a shipper and his carrier is an "informal relational contract" as first observed in Macauley (1963). This is the commonest type of contract in road transport. It is usually arrived at by picking a price in a menu of correspondences between one-way distances to be covered and price to be paid for full truck loads (see figure 2).

There is no upward limit on quantities to be carried (see figure 3). In literature, some have named this contract the single-price contract (Lariviere and Porteus, 2001) to differentiate it from the type of contract which consists of a menu of prices for different volumes or quantities (Cachon and Lariviere, 2001). In the single-price contract, there may be different prices according to the distance to be covered but not to quantity. In distance-price relationship, the correspondence is not linear: short distances charge higher prices per kilometre to account for delays on loading and unloading. This type of contract usually specifies how much

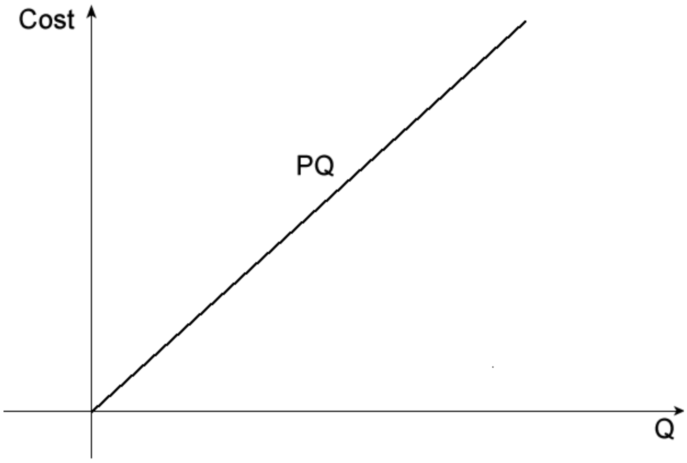

Figure 3: Example of the cost profile of a PRC for a shipper.

time for loading and unloading are included in the price. Sometimes, a penalty is also agreed upon for demurrage at either end. Depending on the bargaining power of the carrier, the carrier may invoice the shipper if she incurs this extra idle time (Brusset, 2005).

This contract is called in literature "relational contract". The substantive foundations are to be found in several papers: first observed in Macauley (1963) and developed in Baker et al. (2001, 2002). The differences between this type of contract and other forms of transactions such as e-marketplaces pertain to information structures of the markets involved as exposed in Tunca and Zenios (2006) and Grey et al. (2005). In a repeated period model, Levin (2003) shows how stationary relational incentive contracts achieve self-enforcement even in the case of hidden information (including both adverse selection and moral hazard). Stationarity in this case means that at every period on the equilibrium path the payout to the agent is always the same if observed performance is the same. The supporting arguments for the informal PRC enforced by reputational concerns and between parties who interact repeatedly are presented more thoroughly in Baker et al. (2001, 2002). Namely, repeated interaction introduces dynamics in relationships that influence the costliness and effectiveness of actions in the future. These repeated interactions facilitate the use of informal agreements not sustained by court system, but by the ongoing value of the relationship.

This contract is based on fiat and reputation. It is usually settled by a handshake and will rarely be broken except when one of the parties suffers a change of ownership or the object of the trade disappears. However, because third parties are often unable to verify that obligations have been met, the parties face important incentive problems (Brown et al., 2004).

Plambeck and Taylor (2007) and Plambeck and Taylor (2005) give an extensive discussion of a game of repeated informal price-only relational contracts where two successive members of a supply chain have to negotiate investment into productive capacity ahead of demand under diverse assumptions of information asymmetry.

The formalized single-price contract has been classified as an example of a two-part tariff where the fixed fee is set to nil in the supply chain management literature review in Tsay et al. (1999). Lariviere and Porteus (2001) examines the supply chain surplus when a manufacturer sells to a retailer when relative variability of stochastic demand changes using a take-it-or-leave-it single-price offer. That model suggests that the manufacturer (seller) fares much better than the buyer, especially when the variability of demand is low. It is remarked in that paper that the price-only contract may be simple and popular but does not coordinate the supply chain. The price-only contract which does coordinate the supply chain requires that the price be a convex relationship of the demand faced by the buyer (Cachon and Lariviere, 2001). In this case, the buyer can induce the supplier into setting up or allocating the required capacity, but this is no longer a single-price contract.

2.4.3 *Minimum Purchase Commitment (MPC)*

The MPC as studied in Porteus (1990), Cachon and Lariviere (2001), among others consists in a *fixed fee* r that the buyer agrees to pay the provider at each period proportionate to an agreed capacity committed q and a *variable fee* c for each unit effectively bought in the period (see figure 4). The fixed fee is paid whether the buyer uses the capacity or not. As proven in Cachon and Lariviere (2001), it is a coordinating mechanism to ensure that the buyer (who has private information on the demand she will face before the contract is signed) will not over-estimate the service necessity and that she will use it, independently from the level of the open market spot price. The interest is clearly for the carrier to be able to identify and commit limited shares of his overall capacity to each customer and thus achieve higher financial visibility of his business. The motivation of the shipper is to set *ex ante* the price of the service. This price may or may not be higher than the possible spot market price on the day the demand is realized but at least the uncertainty is reduced. This fact hints at a risk-averse shipper even though in most papers the risk profile of the shipper is not clearly identified.

Cachon and Lariviere (2001) draw attention on the information imbalance prevalent in most supply chains which has important consequences when the supplier is hamstrung by tight capacity and varying contract compliance (full or voluntary on the provider's part). Contracts that allow the supply chain to align incentives, correcting these imbalances are studied. The buyer solicits the supplier for too much capacity so as to be able to meet more than the average expected demand. The supplier must contrive a contract which enables the buyer to credibly signal the necessary capacity. In voluntary compliance, Cachon and Lariviere (2001) shows that signaling of demand forecast information is best done by committing to use capacity at sufficiently high level so as to be credible. As a result, the supply chain is better coordinated under assumption of asymmetric information when both players set up a firm commitment for capacity for which the buyer promises to pay a lump sum upon realization of demand.

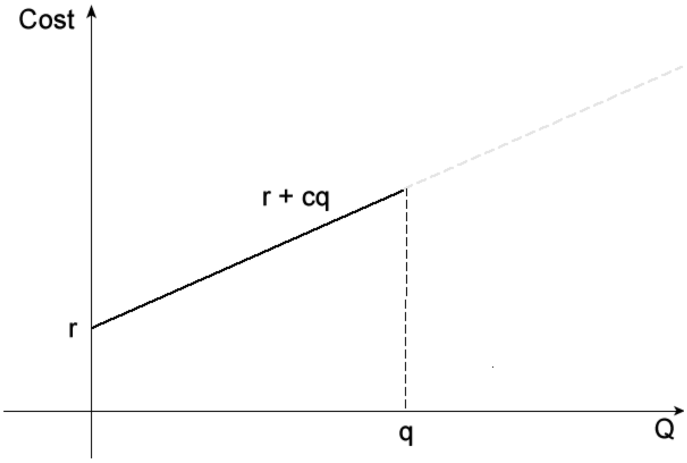

Figure 4: Example of the cost profile of a MPC for a shipper. Note the absence of a cost when $Q > q$.

We use a different model to achieve the same result: it is presented in chapter 3 and is used in chapter 5.

In the model of the MPC in chapter 5, the result presented in Condition 2 can be related to the result from the use of the "advanced contract" and asymmetric information in the model presented in Cachon and Lariviere (2001).

One difference is that in our case q is the total capacity reserved by the carrier for the shipper's needs, whereas Cachon and Lariviere make a distinction between the "firm commitment" by the carrier to the manufacturer (analogous to the commitment by the carrier to the shipper) and the total capacity that the carrier actually reserves to the manufacturer (shipper, in our case). However, they make no attempt at characterizing literally the optimal capacity in the asymmetric information, voluntary compliance case, which is what we attempt to do here.

Another difference is that they consider that the demand not met by the contract is lost to the manufacturer, whereas we let the shipper solve extra demands she may receive using the spot market price.

This type of contract has not been found in transport probably because it entails an upfront fee which a shipper, given his usual position as the master of the game, would find an unacceptable concession to make.

2.4.4 *Quantity Flexibility Contract (QFC)*

The QFC which will inspire this research is defined in Bassok and Anupindi (1997) later revisited in Anupindi and Bassok (1998): the *total minimum quantity commitment* where a buyer guarantees that his cumulative orders across all periods in the planning horizon will exceed a specified minimum quantity. The goods transacted can be stored and unmet demand backlogged. The optimal purchase policy f the buyer for a given total minimum quantity and a discounted price is characterized by order-up-to levels. Because of the buyer's ability to store excess goods, Bassok and

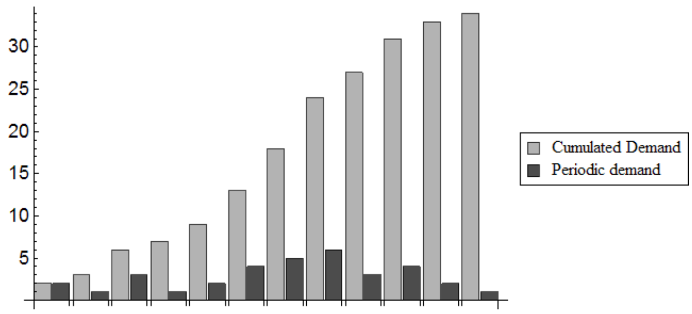

Figure 5: Example of the cost profile of a QFC contract over 12 periods, given periodic demands.

Anupindi (1997) assumes that the buyer is tied by a forced compliance contract. When storage is not possible, as in transport, the buyer cannot be forced int taking delivery. Added features have been included in the models presented here to take care of such implied voluntary compliance.

This contract covers cases where transport requirements evolve over time (maybe following some seasonal pattern) but overall a forecast quantity will have to be transported by the end of the contract.

A similar example is given in Sethi et al. (2005) where a one-period and a multi-period, single-echelon, two stage quantity-flexibility supply contract makes it possible for a buyer to increase by a certain percentage her initial order in a later stage at another price. In these models, both the demand and the price of the product can vary and the buyer has the ability to buy either from the spot market or from the contracted supplier. As the product which is being exchanged bears backlogging and storing, this is in fact a newsvendor setting. The power of the models, moreover, are hampered by the fact that the spot market price is reduced to a Bernoulli process. The models presented in chapter 4 and 5 are more adapted to the reality of transport because the spot market is considered as behaving like a full fledged random variable and because transport cannot be stored nor backlogged.

In chapter 5, we extend the results valid for the SCM theory to the specific case of transport management. The contribution to literature is that the results presented build upon the fact that the contract modeled is more akin to those used in transport, the spot market price and demand are not directly linked and finally the players can build upon past experience to increase the accuracy of their forecasts (demand and costs).

The interest of this form of contract is to give the shipper some flexibility and yet make a credible commitment so reducing the risk to the carrier and enhancing overall coordination and efficiency of the dyad. The underlying rationale for the shipper is that with a contract in place, she limits the risk of not being able to transport the goods she wishes to ship in time and at a “reasonable” price. The risk faced by the carrier can be compared with the proverbial character caught between a rock and a hard place: either he has too much capacity, his fleet is under-used (he has been promised more cargo than he effectively has to carry) or he is caught with not enough capacity to service his clients (the case when he overbooks his transport capacity).

2.5 CONCLUSION AS TO THE CHOICES AND CONCEPTS USED

To conclude this chapter, the thesis provides insight on the implications of some of the contracting mechanisms that can link a shipper and a carrier on their profit, coordination, and information sharing, given that they are distinct organizations with separate decision making processes and objectives. The thesis draws upon SCM literature but adapted to the particularities of freight transport. The methodology builds upon Game Theory, Principal Agent Theory and Transaction Cost Theory. In particular, the mechanisms presented are evaluated in terms of the information, coordination and moral hazard between shipper and carrier. The behaviours of both actors are represented using mathematical models.

3 INFLUENCE ON RENT DISTRIBUTION OF INFORMATION ABOUT PRIOR SPECIFIC INVESTMENTS

3.1 INTRODUCTION

In this chapter we present some models related to research into the preliminary aspects upon which the relationships between shipper (termed a she from now on) and carrier (he)[1] are built. Carriers and shippers often invest in specific assets to better mesh their operations and increase the efficiency and productivity of their operations. We consider within the scope of these investments all that are non contractible or not part of any specific understanding between the shipper and carrier. For example, specific temperature control equipment, security controls are specific investments to enhance some aspect of the service offered by the carrier or because they help to qualify the carrier as a potential supplier to the shipper. When a shipper adds a new carrier to the number with which she works, she must add some type of control and performance measurement infrastructure to the one she already has. She may have to buy some special loading or unloading equipment to accommodate the carrier's transport units. We include in that category the adjustments made to the shipper's and carrier's information systems so that both systems can interact seamlessly. These investments are often committed prior to any work or operation and even *prior* to the contract negotiating process. We follow the literature in assuming that the investment is non-contractible, either because it is non-verifiable or because its description is prohibitively difficult. It is common that after these initial steps, both players start a bargaining process to establish targets, volumes, pay-outs, service levels etc.

In the present work, the eventual contract that can be entered into is presented in its generic form. Namely, the contract is a tool to formalize an exchange between two parties who operate in a market economy with a functioning legal system. The shipper promises to pay the carrier a lump sum of money for the service of transporting some cargo. We are not looking at how the contract has to be set up or the characteristics it must possess.

The shipper is looking at working with the carrier and evaluates the cost of doing so. As is usual in transport procurement, the shipper has a choice of suppliers with comparable characteristics and will commit with the one which yields her the best returns given both the relationship specific investments required and the specific service provided. Once chosen, the shipper works with the chosen carrier only and can only switch when the contract comes up for renewal. The shipper keeps open the possibility of

1 In difference with the convention in supply chain management litterature which considers the upstream partner to be a "she", we shall term the shipper a "she" to remain coherent throughout the thesis.

eventually working with a second carrier as a back-stop solution in case the first one fails for some reason. The carrier also knows that the shipper keeps other options open when studying his offers.

The present work considers only the eventual investment done by the shipper and not the one done by the carrier. Looking at it another way, it is as if the carrier's prior relationship-specific investments were sunk.

We wish to provide answers on the question of the holdup problem arising from the relationship-specific investments under different assumptions of information available to the carrier. In the first case, information about the shipper's outside opportunities and relationship specific investments is common information. This case of common information can be found in centralized organizations where the carrier is one division and the shipper some manufacturing unit. We then shall look at the case where information about outside opportunities and relation specific investment cost is private to the shipper. This situation can be found in tenders organized by the shipper and where the carrier is not aware of the type of competition he is facing.

We also consider a time axis. In the case where both players agree that the contract terms shall be binding for the whole life of their relationship, the carrier and shipper can not take advantage of the possible information revealed in the course of the life of this relationship to renegotiate this contract. We further provide answers regarding what happens when both decide beforehand that a contract can be re-opened a set number of times.

When this is the case, the shipper can switch carrier but we show how the carrier is able to extract extra rent from the shipper under three different circumstances:

- when the carrier and shipper do not bargain (as described in appendix A.1 on page 135),
- when he is not fully informed about the shipper's other outside opportunities or investment cost,
- when the contract is not to be re-opened.

This rent transfer is the result of the carrier's belief about the shipper's real costs or opportunities and is not related to the potential contract that is to be negotiated in a second step.

The models lead us to formulate some propositions regarding the generic contracts that the carrier and shipper may enter under each scenario. In the following section, we give some elements of related literature on the subject. The third section describes the model in which five distinct cases are investigated. In the first two, the contract is binding and information is common (Subsection 3.3.1) or private (Subsection 3.3.2). The following three all consider that the contract will be renegotiated: Subsection 3.3.3 covers the full information case, Subsection 3.3.5 covers the case where the shipper is unaware of the investment costs that the shipper faces, and Subsection 3.3.6 covers the case where the carrier also lacks the information about the shipper's outside options. To enable the reader to grasp some of the significant points, a numerical instance helps to position the different tradeoffs in Section 3.4. We conclude in Section 3.5.

3.2 LITERATURE REVIEW

In literature, the specific investments by partners in a supply chain in general are often dealt with using Transaction Cost Economics or relational exchange theory. When those investments are the subject of contracts, game, bargaining and contract theories are often used to explain the interactions. In the particular case of logistics, Knemeyer et al. (2003) has surveyed the outsourcing practice and shown that it involves investments in specific assets and non-retrievable commitments of resources. The model presented in this chapter has also been used in Brusset (2009b). Here, building upon that reference, we have enlarged the model to include asymmetric information and renegotiation over n periods. The setting we present here most resembles the sequential bargaining or renegotiation of rental price with one buyer under asymmetric information about his willingness-to-pay. Fudenberg and Tirole (1983) characterize the set of equilibria of two-period bargaining games when the seller and buyer each have two potential types (two-sided incomplete information), when the seller makes the offers and when the players alternate making offers. The single-buyer interpretation of this problem when the buyer is willing to trade and profitable mutual interaction is given has been looked into by Fudenberg et al. (1985) which demonstrate that a perfect Bayesian equilibrium exists. This results stands under the assumption that the buyer's type can follow a smooth bounded density.

The papers Tirole (1986), Edlin and Reichelstein (1996) deal with investment in cost reduction by the seller which results in an advantage over the uninformed buyer. In the present model, it is the buyer who invests and the seller who is not informed of the size of the investment (he observes the reality of the investment ex post if he obtains the shipper's custom). In Tirole (1986), the seller obtains an information rent whereas in our model the buyer hides the size of the investment from the seller so as to mitigate the risk of being held up by the seller in future periods.

The present model is inspired from the model presented in Brusset (2009b). In that model, the shipper and carrier commit to a contract for the length of their relationship. We shall, in the present model, also study the case when the contract can be reopened at some future dates.

We consider that the carrier is a Bayesian rational player in the sense that he separates his beliefs from his preferences by quantifying the former with a subjective probability measure and the latter with a utility function and seeks to maximize his expected utility.

In the scenario where the carrier lacks information as to the outside options and investment costs of the shipper and yet a contract can be re-opened (Section 3.3.4), the carrier is able to update his belief of the shipper's cost and outside option using past responses by the shipper to his past offers. This mechanism is generally called Bayesian updating with cutoff. This procedure by which each period brings new information allowing decision makers to update their beliefs about an unknown random variable has been the object of inventory theory since Scarf (1959, 1960). More recently, inventory management literature lists papers applying it in supply chain management environments (Azoury and Miller, 1984, Azoury, 1985, Milner and Kouvelis, 2005, among others).

Prior to his first offer to the shipper, he builds a probability measure of the possible values of his unknowns which is called his *prior*. After observing the response from the shipper, he is able to update his prior which then becomes his *posterior*. In difference to the inventory theory's use of Bayesian updating, the fact that the shipper refuses a contract means that her outside option or investment cost is lower than the prior with probability equal to one[2]. This means that the posterior is built using the prior as lower bound, whereas in inventory theory, revealed demand can still be lower than previous realized demands of earlier periods and hence the posterior can only take realized demand as an indication by which to update the mean of the distribution of beliefs. The updating of beliefs using cutoffs has been studied in Hart and Tirole (1988) but the Bayesian updating mechanism used cannot be applied here because of the difference in the buyer's and seller's motivations and utilities.

In this model the new prior, based upon the updating of the posterior, is defined using a simplicity criterion, or "*Simplicity Postulate*" as defined by Harold Jeffreys[3] in the sense that the prior must be built with as little parameters as possible. The idea is to find conditions under which the prior distribution on the unknown parameter has a specific form that can be characterized by a small number of parameters, the posterior distribution on the parameter (after updating using Bayes'rule) has the same distributional form as the prior and updating these parameters can be done easily (Porteus, 2002). The trick would be to find one family for the distribution of the unknown variables and another for the prior on the unknown parameter in the first distribution such that the above conditions hold (conjugate priors). As shall be shown when we start solving the multi-period scenarios, the problem is that the solution to the offers that the carrier makes have to be calculated in a backward induction starting with the last period. This means that the last period's prior has to be built from unknown posteriors in previous periods. In the present model, the issue has been resolved by adopting the "*single-parameter conjugate problem*" approach outlined in Porteus (2002), namely, the parameter prior at period t is fully specified by a single (dimensional) parameter, independent of the period, and by the period index t. In this way, the parameter is a known function of time and the original prior of the first period. Backward induction can thus be applied.

3.3 MODEL LINKING SHIPPER AND CARRIER UNDER DIFFERENT INFORMATION SCENARIOS AND IN TIME

We are interested in the general case where a shipper and a carrier set up a long term relationship and the shipper invests in specific assets with

2 Unless the shipper is affected with a "Trembling Hand", a feature developed in Game Theory first in Selten (1975) and discussed in page 145 of Rasmusen (1989) and Section 8.4 of Fudenberg and Tirole (1991) where a player can, against his better interest, choose a dominated strategy by mistake.

3 The Bayesian Harold Jeffreys made the goal of simplicity a fundamental postulate of his theory of probabilistic inference published in 1937.

cost A (strictly positive) to enable their ongoing interaction. The shipper has some prior engagements to deliver some goods downstream which she must honour. Her objective is to minimize the cost C of doing so. The carrier's objective is to maximize his partial profit function Π_c from working either for the shipper or some third party. The carrier is private to his costs and opportunities. In this model, the investments made by the shipper are unobservable and unverifiable by the carrier but accepting a contract and working with him are both observable. The starting point for the modeling exercise is the standard contracting model with complete but unverifiable information and "ex ante renegotiation" (Maskin, 1999, Maskin and Moore, 1999, Watson, 2006). Note that the shipper is forced to work either with the carrier or with some other carrier: she *has* to have her products transported (see table 4 for a two-period example).

In time (see figure 6), the sequence of events is the following: the carrier offers a contract in a way which shall be made clearer later. If the shipper rejects the offer, both turn to outside options: the shipper must find another carrier and the carrier must find another shipper (this option is not represented in figure 6). Setting up a relationship with another counterparty entails a cost in specific asset a (strictly positive) for the shipper and a_c (also strictly positive) for the carrier. For example, if the shipper decides to work with the carrier in period one but in period two turns to another carrier, she incurs investment A in period one and the investment a in period two. She can decide in any posterior period to work again with the first carrier. In this case, she does not incur the cost of the specific asset which is considered to have been borne in the first period. This is to reflect the fact that a shipper and a carrier have an interest in maintaining a relationship even though the initial cost of this relationship is sunk. Note that this setting means that the successive periods are interrelated and not exchangeable as in many multi-period with renegotiation game theoretic settings (Watson, 2006).

If, on the other hand, the shipper finds the offer of the carrier interesting, a contract is agreed upon and the shipper invests in the required specific assets. Demand is realized and revealed instantly to both. Transport and payout take place. At some future time, in some scenarios which will be defined later, one or the other decide to re-open the negotiations[4]. The carrier has the ability to revise the offers he makes to the shipper and the shipper compares these offers to outside options. If a contract is agreed upon, the relationship can continue. At any future date, both can again come together to negotiate for a new contract, no additional relationship specific investment is necessary since those are already in place (assuming that they have worked together in the past).

In this model, to economize on notation, the period number shall be presented in superscript form. The number of periods is a finite number n, assumed to be commonly known, at the beginning of which the contract shall be renegotiated.

The contract is named U^i with $i \in \{1, \dots, n\}$. The strictly positive contract which the shipper may sign with some third party is labeled u and

4 This process is different from the commitment and renegotiation as defined in Laffont and Tirole (1993b).

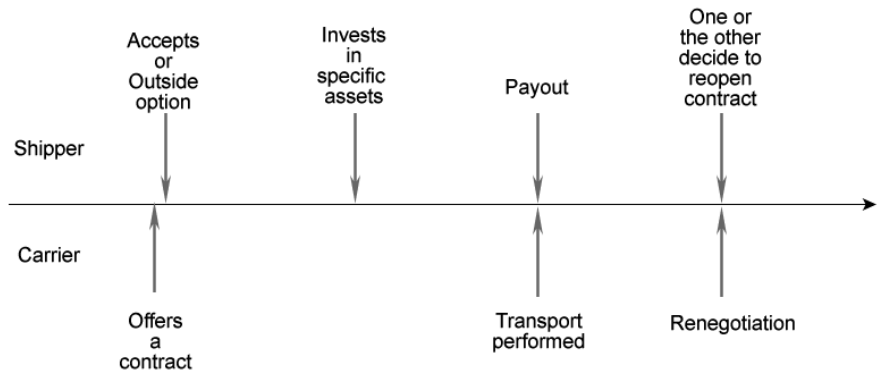

Figure 6: Timeline of events when shipper and carrier agree on a contract and to a new relationship. If the shipper does not agree to a contract, the timeline is stopped on this disagreement, each starts a new timeline (not represented here).

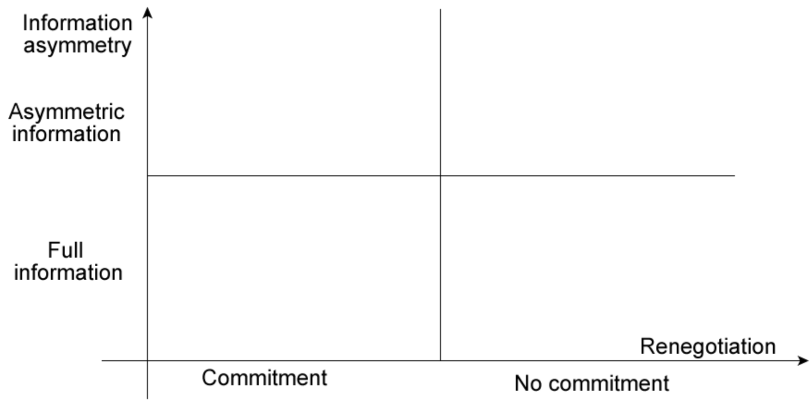

Figure 7: Dimensions of relationship between shipper and carrier: renegotiation and information.

shall be considered to be time invariant. The carrier can also sign a strictly positive time-invariant contract u_c with a third party. The contracts are members of a finite set $\mathcal{P}$ which describes all relevant contracts. We call δ_s^i the shipper's participation decision variable in period i which can take binary values. We present all the notation relative to this chapter in table 3.

To investigate fully this general case, we have to consider the effect of potential renegotiation in the future; and we have to evaluate the impact of full or asymmetric information about the cost of investing in specific assets and eventual outside options. The motivation for those different scenarios are that the carrier may not be aware of the shipper's outside options when he negotiates the terms of a contract. For example, he may not know the cost to the shipper of the investment in specific assets to work with him. Further, he may not be aware of the contractual terms that the shipper has obtained from some unnamed third party. This asymmetric

Table 3: Table of notations

Type	Notation	Definition
Shipper	A	Specific asset investment with the carrier
	a	Specific asset investment with outside option
	u	contract available to shipper from outside option
	$C^i(.)$	shipper's transport cost in period i for the shipper
	δ_s^i	binary decision variable, 1 when agreeing with carrier
Carrier	U^i	contract offered in period i to shipper
	a_c	specific investment by carrier in outside option
	u_c	outside option contract available in period i
	$\Pi_c^i(.)$	carrier's profit function in period i
Carrier beliefs	$f_Z(A)$	Probability Density Function (pdf) of $Z=u+a-A$
	$F_Z(Z)$	Cumulated Density function (cdf) of $Z=u+a-A$
	$f_A(A), F_A(A)$	pdf and cdf of belief of A
	$f_a(a), F_a(a)$	pdf and cdf of carrier's belief of a
	p_1	belief distribution parameter set in period 1
	ω	increment added to p_1 in each period in case of shipper refusal
	$f_{Ai}(A^i), F_{Ai}(A^i)$	pdf and cdf of carrier's revised belief of A in period i
	L^i	$F_{Ai}(A^i)\big((n-i+1)u - A^i\big) + \overline{F_{Ai}}(A_i)\big(u_c + L^{i+1}\big)$
	f_{Z1}, F_{Z1}	pdf and cdf of belief $Z_1 = u - A$
	f_{Z2}, F_{Z2}	pdf and cdf of belief $Z_2 = u + a$
	f_{Z3}, F_{Z3}	pdf and cdf of belief $Z_3 = u$
	K^i	$\overline{F_{Z3}^i}(Z_3^i)\big(Z_3^i(n-i+1)\big) + F_{Z3}^i(Z_3^i)\big(u_c + K^{i+1}\big)$
	P^i	$\overline{F_{Z1}^i}(Z_1^i)\big(Z_1^i + K^{i+1}\big) + F_{Z1}^i(Z_1^i)\big(u_c + P^{i+1}\big)$
	v_{si}	strategy vectors available to shipper in state i
	R_{si}	set of strategies available to shipper in state i
	v_{ci}	strategy vectors available to carrier in state i
	R_{ci}	set of strategies available to carrier in state i
Time	n	common information about the number of times a contract can be reopened in renegotiation scenario

information may hamper the carrier in his own offer as compared to the case where this information is common to both shipper and carrier.

We shall consider four cases which are set along two dimensions. One is the dimension of renegotiation, the other is information (see figure 7). In the bottom right square, we have the case where the parties enjoy full information and no renegotiation. The interesting case is when the players are subject to asymmetric information and both have the ability to renegotiate (top righthand corner).

In the right hand side of figure 7, shipper and carrier agree beforehand to have the option of renegotiating: periodically, both may agree to consider a new contract by which to conduct their business. We shall consider here that the number of times in which renegotiation can take place is finite. In a further bid to simplify the model, we assume that all amounts in any period are net present values and hence the discount rate used is implicit and common to both players. We posit that the results would not be affected if discount rates were used. We acknowledge that the results would be different if the discount rates were different for each player as some values accrue to a player only after some periods have elapsed.

In the top half of figure 7, the shipper is private to the transport cost related to the delivery of the demand which she has to serve. The cost of the specific assets are also private to the relevant investing party. The relevant cases are treated later in the sections 3.3.2 and 3.3.4.

In the bottom half of figure 7, the carrier and the shipper share the same information about specific asset costs, transport costs from outside options. These cases are discussed in sections 3.3.1 and 3.3.3 below.

It is often seen in literature that the carrier, as Stackelberg leader, offers a menu of contracts. We shall assume here that the carrier makes an initial estimate using all the information at his disposal and makes *one* final offer that either the shipper accepts or rejects. If the carrier's offer is rejected, the shipper turns to her outside option. We consider here that this outside option is not a strategic player. Contrary to what is presented in the section 2.2.3 of chapter 2, we assume that no negotiation takes place. This model describes a two-player, pure-strategy, non-cooperative, dynamic, multi-period Stackelberg game with time dependence which falls within the applications of Game Theory in supply chain management literature, as characterized in Cachon and Netessine (2004) and references therein.

3.3.1 *Full information and commitment*

In this case both parties wish to set up a contract for the first and only period because they agree to commit to its terms for any future period in the same way. The carrier's objective function is

$$\max \mathbb{E}\Big(\Pi_c\big(U^1\big) \mid \delta_s^1\Big)$$

$$\text{s.t.} \begin{cases} \mathbb{E}\Big(C_s|\delta_s^1 = 1\Big) \leq \mathbb{E}\Big(C_s|\delta_s^1 = 0\Big), \\ \mathbb{E}\Big(\Pi_c|\delta_s^1 = 1\Big) \geq \mathbb{E}\Big(\Pi_c|\delta_s^1 = 0\Big), \end{cases} \tag{3.1}$$

with $\delta_s^1 \in \{0,1\}$ and where $\mathbb{E}$ is the expectation sign. Given that we shall deal in all the following with expected outcomes, to alleviate the notation, we shall drop the expectation sign.

The shipper's objective function is to minimize her cost in terms of her decision parameter δ when the carrier presents his offer U

$$\min_{\delta}(C) = (U + A)\delta + (u + a)(1 - \delta). \tag{3.2}$$

So, in turn, the carrier must

$$\max_{U^1} \Pi_c(U^1) \mid \delta_s^1$$

$$\text{s.t.} \begin{cases} U^1 + A \leq u + a, \\ U^1 \geq u_c - a_c. \end{cases} \tag{3.3}$$

The carrier must offer the shipper a contract which at least offers the shipper the minimum cost which beats or equals the expected cost from her outside options, given her investment costs for both options. The carrier must be able to make more from working with the shipper than his outside option u_c less the investment in relationship specific assets a_c. If his return from the contract with the shipper is higher than $u_c - a_c$, he will bear to work for the shipper.

Proposition 1. *Full information and commitment contract*
Under full information and potential for mutual profitable interaction ($u + a - A \geq u_c - a_c$), the optimal contract is

$$U^1 = u + a - A. \tag{3.4}$$

Proof. The proof follows directly from the application of the first and second participation constraints in (3.3) as binding. ∎

This proposition simply states that, for the whole duration of the contract, the shipper will elect to work with the carrier if he provides better return than her outside option and symmetrically for the carrier.

3.3.2 *Asymmetric information and commitment*

In this case, the carrier and shipper also negotiate for just one period. The carrier forms a belief about the shipper's reservation contract and investment in relationship specific assets. Using this belief, he estimates a value Z which shall be the base of his offer to the shipper.

If the carrier had the corresponding information, he would offer, from equation (3.4),

$$Z = u + a - A. \tag{3.5}$$

As he does not have this information, the carrier holds a belief about Z which can go from a lower bound $\underline{Z}$ to an upper bound $\overline{Z}$. The carrier forms a belief about the estimated distribution of Z. This belief has a distribution law which follows a density function $f_Z(.)$ and a cumulative density function $F_Z(.)$ which we shall assume to be IFR (increasing failure rate) as defined in Barlow and Proschan (1965). The cumulative density functions which are IFR include quite a large variety of classical statistical distributions such as the uniform, normal, gamma, Weibull, modified extreme value distribution, truncated normal and log normal for most types of common parameter sets as characterized in Barlow and Proschan (1965)[5]. The carrier maximizes his profit in terms of this belief by setting it at a certain threshold level which we shall now evaluate.

The *expected* profit function of the carrier in terms of this threshold level Z is written

$$\max_Z \left(\Pi_c(U^1, Z) | \delta_s^1\right) = U^1 \overline{F_Z}(Z) + (u_c - a_c) F_Z(Z). \tag{3.6}$$

The contract offered must be solution to

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

Proof is provided in Appendix B.2 on page 144.

Does this contract satisfy the shipper? For that, we must have $U \leq u + a - A$. The solution is very similar to the one spelt out in Proposition 1, except that this time the shipper may have some rent left. In effect, the carrier's offer will range between $u_c - a_c$ and $u + a - A$.

Using the optimal Z^* which solves the equation (B.20) as the optimal contract for the carrier, we can spell out the following proposition.

Proposition 2. *Asymmetric information and commitment contract Under asymmetric information about the shipper's outside opportunities and relationship specific investment costs, given conditions for mutual interaction potential, the optimal full commitment contract $U^1 = Z^*$ for the carrier is characterized by the following equation*

$$Z^* = u_c - a_c + \frac{\overline{F_Z}(Z^*)}{f_Z(Z^*)}. \tag{3.8}$$

Remark 1. *The link between Proposition 1 and this one is the precision of the information available to the carrier. This precision can be modeled as the variance of the distribution of the belief Z: the better the information, the lower the variance. In this way, when information becomes perfect, Z tends to $u + a - A$ from below. To get a better grasp of this link, we refer the reader to the figure 11 on page 50 in the numerical illustration in Section 3.4.3.*

Remark 2. *With this offer, the carrier optimizes his profit given his estimate of the shipper's investment cost and his own outside opportunity. When the carrier cannot make an estimate of the shipper's costs, he must offer the same contract as he would obtain from working with his outside option, here $u_c - a_c$. This represents a very interesting proposition to the shipper since we have supposed that $u + a - A > u_c - a_c$. The carrier has a high incentive to understand the shipper's environment and costs. This can explain why carriers usually prefer to offer their services to shippers in an industry they know well even if their transport capacities can be used in others.*

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

Table 4: The shipper's investment in relationship specific assets according to her decisions in first (horizontal) and second (vertical) period.

δ_s^2		δ_s^1 = 0	δ_s^1 = 1
	1	$A + a$	A
	0	a	$A + a$

Table 5: The carrier's investment in relationship specific assets according to the shipper's decisions in first (horizontal) and second (vertical) period.

δ_s^2		δ_s^1 = 0	δ_s^1 = 1
	1	a_c	0
	0	a_c	a_c

It is clear that such commitment appears as overly rigid and impracticable. In the upcoming two scenarios presented in subsections 3.3.3 and 3.3.4, we study the cases where the carrier (and the shipper) can reopen the contract.

3.3.3 *Full information and renegotiation*

In this case, the parties may decide periodically to renegotiate the contract under full information. The corresponding outcomes in terms of the relationship specific investments which they are presented in table 5 for a two-period example.

Since in every period, the shipper has the choice to work with the carrier or with a third party, the model will evaluate all the shipper's possible strategies. We start with the decisions to be taken at the leaves of the decision tree.

We shall characterize those leaves according to the state the shipper finds herself in. In state 1, the shipper has only undertaken investment A; in state 2, she has incurred both investment A and investment a, whereas in state 3, she has only invested a.

STATE 1:
shipper has only invested A in period one.

In period n, her cost becomes

$$C^n = \min(U^n, u + a). \tag{3.9}$$

In this last period, the carrier's dominant offer must be

$$U^n = u + a, \tag{3.10}$$

as will become clear shortly.

In period $n - 1$, the shipper looks for

$$C^{n-1} = \min(U^{n-1} + u + a, 2u + a), \tag{3.11}$$

so $U^{n-1} \leq u$.

It follows that in any period j, $j > 1$, the shipper has to solve

$$C^j = \min(U^j + (n-j)u + a, (n-j+1)u + a), \tag{3.12}$$

so to ensure incentive compatibility, the carrier is limited to

$$U^j \leq u, \qquad \forall j, 2 \leq j < n. \tag{3.13}$$

In state 1, the overall minimized cost function becomes

$$C = nu + a. \tag{3.14}$$

The carrier's maximized profit is

$$\Pi_c = nu + a - A. \tag{3.15}$$

The carrier will consider working with the shipper during n periods if the following participation constraint is satisfied

$$nu + a - A \geq nu_c - a_c. \tag{3.16}$$

Let us define the carrier's strategy which consists for the carrier to act in each period by offering the profit maximizing contracts as an n-sized vector

$$v_{c1} = ((u - A), u, \ldots, u + a). \tag{3.17}$$

Let us call the shipper's strategy when she is in state one the n-sized vector comprised of the decisions δ_s^i in response to the offers as

$$v_{s1} = (\delta_s^1, \delta_s^2, \ldots, \delta_s^n), \quad \forall i, 1 \leq i \leq n, \ \delta_s^i = 1. \tag{3.18}$$

The strategy sets R_{c1} and R_{s1} for each player are reduced to just one vector in each.

STATE 2:
shipper has invested both A and a, carrier has invested a_c. In period n, the shipper's objective function is

$$C^n = \min(U^n, u) \Rightarrow U^n \leq u \tag{3.19}$$

for acceptance. And, as in the preceding state, $U^j \leq u$, in periods j, $2 \leq j \leq n$.

The shipper's action which generates the lowest profit to the carrier is to accept the carrier's bribe in the first period and to refuse to work with him in the second period, so that

$$C^2 = u + a, \tag{3.20}$$

whether or not the carrier offers u. The total cost remains over n periods

$$C = nu + a, \tag{3.21}$$

with the carrier's corresponding profit as

$$\Pi_c = (n-1)u + u_c - A - a_c \tag{3.22}$$

Imagine that in period k, $1 < k \leq n$, S invests A, the profit function becomes

$$\Pi_c' = (k-1)u - A - a_c + u_c + (n-k)\max(u, u_c), \tag{3.23}$$

and $\Pi_c' \leq \Pi_c$.

The strategies of shipper and carrier are now described by the following sets of vectors

$$R_{c2} = \{v_{c2}, v_{c2} = \big((u-A), u, \ldots, u\big)\} \tag{3.24}$$

$$R_{s2} = \{v_{s2}, v_{s2} = (\delta_s^1, \delta_s^2, \ldots, \delta_s^n), \qquad \exists i, 1 < i < n,\ \delta_s^i = 0\} \tag{3.25}$$

STATE 3:
shipper has only invested a, so the carrier offers

$$U^j = u - A, \qquad \text{if } \forall i \in \{1, \ldots, j-1\}, \delta_s^i = 0, \tag{3.26}$$

under the participation constraints: $(n-j)u - A \geq (n-j)u_c$ or the carrier would simply walk away. In successive games, he repeats his offers until $j \leq n - \frac{A}{u-u_c}$ is violated. For all j below that limit, the carrier turns to his outside option. If the shipper agrees in period k, $k \leq n-j$ the stream of profits to the carrier over n periods is:

$$\Pi_c = (k-1)u_c - a_c + (n-k+1)u - A, \tag{3.27}$$

under the participation constraint

$$(n-k+1)u - A \geq (n-k+1)u_c. \tag{3.28}$$

In any case, the cost to the shipper remains

$$C = nu + a. \tag{3.29}$$

In this state, the sets of vectors representing the strategies available to the players are

$$R_{c3} = \{v_{c3}, v_{c3} = \big((u-A), u, \ldots, u\big)\}$$

$$R_{s3} = \{v_{s3}, v_{s3} = (0, \delta_s^2, \ldots, \delta_s^n), \exists i, 2 \leq i \leq n, \delta_s^i = 1\}. \tag{3.30}$$

Using the PC in State 1 (3.16), we present in figure 8 two graphs of the areas in which the multiperiod contract is accepted or rejected by the shipper. In the left-hand graph, A is greater than $a + a_c$, in the right-hand graph, $A < a + a_c$, leading to a larger area in which the carrier will offer mutually interesting terms to the shipper. In this last case, the shipper's transport cost with her outside option can even be lesser than what the carrier would obtain from his own outside option. This is because the cost for the relationship specific asset that the shipper has to invest in to work with the carrier is less than what both would have to invest separately if they turned to their respective outside options.

In the two-period case, the carrier considers the horizon profit as

$$\Pi_c = \max(U^2, u_c - a_c), \tag{3.31}$$

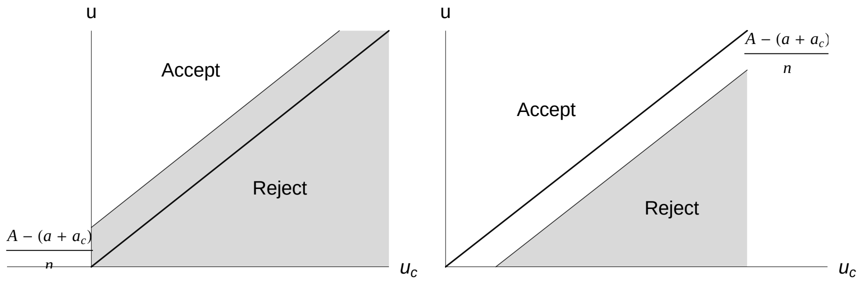

Figure 8: Representation of areas in which carrier and shipper would work together over n periods in terms of u, u_c. Area above $u_c + \big((A-a)-a_c\big)/\mathrm{n}$, carrier's participation constraint satisfied, agreement.

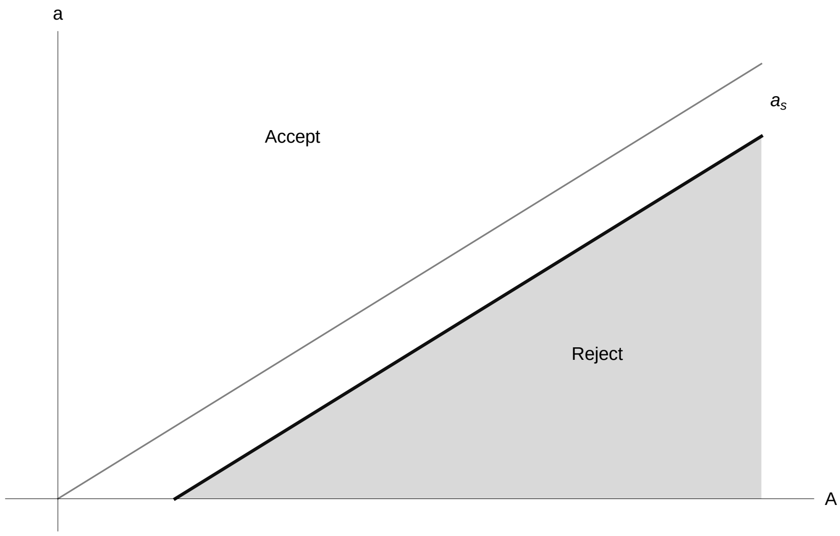

Figure 9: Representation of influence of the hierarchy of the specific investments in the decision to work together or not for the carrier and the shipper. The thick line represents $A - a_c$.

with

$$U^2 \leq u + a$$

and

$$\begin{aligned} U^1 + U^2 + A &\leq 2u + a \\ U^1 + u + a &\leq 2u + a \end{aligned} \tag{3.32}$$

If $2u + a - A > 2u_c - a_c$, the shipper accepts the carrier's offer. We represent in figure 9 the relative importance of the specific investments. In the dark grey shaded area, the shipper rejects the carrier's offer. In the white areas, she agrees because $a + a_c > A$.

We can now bring together the conditions of the emergence of a Nash Equilibrium. When the carrier knows exactly the outside option and relationship specific investments, the offers he makes match the shipper's outside option thus capturing the entire rent of the dyad and can be spelt in the following proposition.

Proposition 3. *Full information and renegotiation*
Given mutual interaction potential for shipper and carrier ($nu - A + a \geq nu_c - a_c$), the following optimal contracts is a weak Nash Equilibrium

$$\begin{cases} U^1 = u - A, \\ U^i = u, \qquad \forall i, 2 \leq i < n, \\ U^n = u + a. \end{cases} \tag{3.33}$$

This proposition's interest shall appear better when contrasted with propositions we present given asymmetric information of the shipper's costs.

Before proceeding to these information scenarios, we first make some remarks about this proposition.

Remark 3. *The carrier after initially sweetening the offer to the shipper by paying for the investment cost that the shipper makes to work with him, later extracts the maximum rent possible in the last period. The shipper agrees because the costs are the same to her.*

Remark 4. *In the present model, we do not include the rent generated by the relationship specific asset which the carrier paid to the shipper. This extra rent could possibly justify the shipper's choice of working with the carrier. In our model, the shipper obtains the same outcome as if she had turned to her outside option from the start.*

Remark 5. *The supply chain's rent is optimized in the sense that only the necessary investments are made, something which is no longer the case in the asymmetric information scenarios presented later.*

We offer here the proof of the weakness of the Nash equilibrium presented in Proposition 3.

Proof. When comparing the strategies among the three states, we see that in the first state, the carrier exploits the incumbent's advantage of the relationship specific investment with the shipper's outside option only in the very last game. If he were to try doing so before, the shipper would simply defect. If the carrier's participation constraint

$$nu + a - A \geq nu_c - a_c, \tag{3.34}$$

is satisfied, the profit extracted in state 1 is larger than the ones in either other states. This justifies that he offers in all periods

$$U^i = u, \quad \forall i, 1 < i < n. \tag{3.35}$$

Given that the carrier is Stackelberg leader and the shipper is reduced to accepting or rejecting the offers and that both work in a full information environment, the Nash Equilibrium strategy is the one presented in the case of state 1: the shipper agrees to the contract offered in the first period and, under sequential rationality (Watson, 2002), subsequently accepts all the offers made by the carrier without deviating by working with her outside option.

Table 6: Outcome for shipper and carrier when the shipper applies trembling-hand strategies.

Outcome		State
Shipper	Carrier	
$nu + a$	n u + a - A	State 1
	$(k-1)u - A - a_c + (n-k)\max(u, u_c)$	State 2
	$(k-1)u_c - a_c + (n-k+1)u - A$	State 3
	$nu_c - a_c$	No contract

We will now investigate the weakness of this Nash Equilibrium. The cartesian set $R_c \times R_s$ represents all the available strategies of both players. This set is larger than the union of the three sets defined when describing the three states in which the shipper finds herself. However, all the strategies which do not belong to the sets R_{c1}, R_{c2}, and R_{c3} are evidently not profit maximizing ones or do not satisfy the participation constraints as binding constraints and shall be discarded.

For the carrier, it can easily be seen that, with v_{s1} as defined in (3.18),

$$\forall v_s \in R_s \text{and}\, v_s \neq v_{s1}, \Pi_c(v_{s1}) > \Pi_c(v_s). \tag{3.36}$$

For the shipper, evidently

$$R_s = R_{s1} \cup R_{s2} \cup R_{s3}, \tag{3.37}$$

so

$$\forall v_s \in R_s, C(v_s) = nu + a, \Rightarrow \nexists\, v_s^* \in R_s \,|\, C(v_s^*) > C(v_s). \tag{3.38}$$

Hence, the Nash Equilibrium is weak.

If the shipper chooses other responses, her strategies can be assimilated to the "Trembling Hand" (Selten, 1975). The three states presented above are in fact occurrences of this Trembling Hand argument: as can be seen in table 6, the shipper may costlessly play a different strategy which hurts the carrier. Due to the Stackelberg structure, we do not explore the other rent-appropriation possibilities and conclude that the Nash equilibrium is not a trembling-hand perfect equilibrium.

■

3.3.4 *Asymmetric information and renegotiation*

To analyze the situation faced by both carrier and shipper when information is asymmetric, it is fruitful to distinguish two different cases. In the first case, covered in section 3.3.5, we consider that the carrier is informed of the shipper's cost of her outside option for transport u. His only unknowns are the cost in relationship specific assets A and a. In the second case, covered in section 3.3.6, we study the outcome of the negotiation when the carrier is uninformed of either A, a or u, the shipper's cost of outside option.

Updating process for the carrier

As presented in §3.2, in this model, we have not been able to model the full *Bayesian updating process* (Selten, 1975) using cut-offs (Hart and Tirole, 1988). Instead, we apply Jeffreys' simplicity postulate and use the single parameter conjugate problem method as outlined in Porteus (2002).

In the two asymmetric information scenarios defined below, prior to making an offer to the shipper, the carrier must make an assumption about the unknowns so as to calibrate his offer. In this model we assume that the carrier is a Bayesian rationalist who builds his assumptions from his experience at the start of the first period. Using these priors, he calculates his most profitable estimate of the variables involved and makes the corresponding offer to the shipper. This belief is based upon a distribution of the unknowns which can be described by continuous distribution functions with increasing failure rates (IFR) as defined in Barlow and Proschan (1965). These distributions are fully characterized by some parameters. One of these is a parameter which is a function of the period and a prior estimate of this parameter in period 1. Unless the shipper agrees to the first contract offered, in the following period the carrier update his belief by updating this parameter in the following way. If we name p^1 in period 1 this parameter, which henceforth we shall call a seed, we define the new parameter in period i as

$$p^i = p^1 + i\omega, \tag{3.39}$$

where ω is the increment between periods. If we consider that p^1 is the mean of the distribution, ω is the scaling coefficient. The scaling coefficient in the distribution has the following characteristic: $F(x+\omega) < F(x)$ for all x in the domain of the variables.

Each period's prior is updated using the posterior from the preceding period. Since the shipper refused the earlier period's offer, then the prior was too low and the parameter should be increased by this posterior to define the new parameter. However, given that we shall proceed in a backward recursion to solve the evaluation of the unknowns in previous periods, applying H. Jeffreys' *Simplicity Postulate* and following the method provided in Porteus (2002), we set ω as fixed in all periods.

In applications or practice, the distribution can thus be scaled by a parameter using a function of the belief about the unknown to enhance the likeliness of the shipper's acceptance but without compromising the carrier's profit. We have

$$F^i(.|p^i) = F^{i-1}(.|p^{i-1}) \tag{3.40}$$

with F^i as the distribution function of the belief about the unknown in period i. In the following we shall indicate each unknown's distribution function only by its period superscript.

Note that this is not the *ratchet effect* as mentioned in Weitzman (1976, 1980) or Hart and Tirole (1988).

3.3.5 *Prior belief about the relationship specific investment cost and knowledge of shipper's cost of outside option*

Apart from the fact that in this section the carrier and shipper can reopen negotiations, another distinction with the case presented in section 3.3.2 is that the carrier must estimate separately A and a. The carrier estimates the distribution of A as supported by $[\underline{A}, \overline{A}]$ and following a cumulative density distribution F_A, and estimates a as supported by $[\underline{a}, \overline{a}]$ and following a cumulative density distribution F_a. We assume, as in Section 3.3.2 that these functions are IFR. The carrier must evaluate the thresholds A^{1*}, a^* and eventually the updated thresholds A^{i*} in periods i so that he maximizes his profit. In the same way, given the offers the shipper receives, she must minimize her cost over all periods.

The demonstrations have been relegated to §B.3 on page 145 of the Appendix.

We spell out a new proposition applicable to the present scenario which present the best strategies for the carrier and shipper.

Proposition 4. *Asymmetric information about relationship specific investments and renegotiation*
Given asymmetric information about investment specific costs A and a and mutual interaction potential over some of the n periods, the contracts offered are

$$\begin{cases} U^1 = u - A^{1*}, \\ U^i = u, & 1 < i < n, \\ U^n = u + a^*. \end{cases} \tag{3.41}$$

In the first period, the threshold A^{1*} is solution to

$$A^{1*} + \frac{F_{A1}(A^{1*})}{f_{A1}(A^{1*})} = (n-2)u - u_c - L^2, \tag{3.42}$$

with

$$L^i = F_{Ai}(A^i)\big((n-i+1)u - A^i\big) + \overline{F_{Ai}}(A_i)\big(u_c + L^{i+1}\big), \quad 1 < i < n. \tag{3.43}$$

The threshold a^* evaluated in period n is solution to

$$(u + a^*) - (u_c - a_c) = \frac{\overline{F_a}(a^*)}{f_a(a^*)} \tag{3.44}$$

and If $A^{1*} < A$, the carrier offers in subsequent periods i contracts such that

$$\begin{cases} U^i = u - A^{i*}, & i \leq \max_j(n-j), \\ U^t = u, & i < t \leq n, \qquad \text{iff } \delta_s^i = 1. \end{cases} \tag{3.45}$$

with

$$\begin{cases} A^{i*} + \frac{F_{Ai}(A^{i*})}{f_{Ai}(A^{(i*)})} = (n-i+1)u - u_c - L^{i+1}, \\ L^i = F_{Ai}(A^i)\big((n-i+1)u - A^i\big) + \overline{F_{Ai}}(A_i)\big(u_c + L^{i+1}\big) \\ n - j \geq \frac{A^{j*}}{u-u_c}, & \text{(PC)} \\ A^{i*} > A^{(i-1)*}. & \text{(IC)} \end{cases} \tag{3.46}$$

Remark 6. *The carrier has to estimate two unknown quantities A and a. He does so ex ante so as to formalize his best offer to the shipper. In fact, he needs those estimates at two different times in the relationship. Estimating* A^* *has to be done in the early part of the relationship, whereas the estimate of* a^* *can be done in the last period (if at all). Our model dos not include the possibility that the carrier collects further information in the intervening periods between his initial estimate done ex ante and the moment when he must reveal by his offer his last estimate made in period* $n-1$*. In real life, the carrier most probably updates this prior enabling him to extract in rent an amount* a^* *very close to the actual value of* a*.*

Our model captures the carrier's and shipper's ex ante calculation and optimization of objective functions, not the actual development of the relationship. This would require an altogether different model which should reflect better the carrier's information gathering and estimate updating during the duration of their relationship.

Remark 7. *If the carrier errs in estimating A or a, the shipper has to invest in other relationship-specific assets*[6]*. Having the shipper invest in a second relationship has two effects on the supply chain's rent. (a) The duplicated investment by the shipper has no economic value other than mitigating the rent extorsion attempt. (b) The relationship with the outside option by the shipper is supposed to be second best (or she would have turned to it as her first source for transport in the first place) and induces a comparative loss of efficiency to the supply chain.*

3.3.6 *Asymmetric information on shipper's outside option*

We now turn to the case where the carrier does not possess *any* information as to the shipper's investment costs or outside opportunities. The carrier is uninformed about either A, a, or u.

The relevant calculations and demonstrations are given in §B.4 on page 151 of the Appendix.

We offer the following proposition to formulate the possible offers that the carrier can make when information is asymmetric.

Proposition 5. *Full asymmetric information and renegotiation*
Under full asymmetric information, given mutual interaction potential, the unique Trembling Hand perfect Nash Equilibrium must respect the following conditions.

6 We have considered here that the outside option is not a strategic player which helps us to focus on the pure dyad problem within the supply chain.

For the first period,

$$U^1 = Z_1^{1*}, \tag{3.47}$$

with Z_1^{1*} solution to the equation

$$\begin{aligned} Z_1^{1*} - \frac{\overline{F_{Z1}^1}(Z_1^{1*})}{f_{Z1}^1(Z_1^{1*})} = {} & u_c - a_c + P^2 - \\ & \overline{F_{Z3}^2}(Z_3^2)\left\{(n-2)Z_3^2 + \overline{F_{Z2}}(Z_2)Z_2 + \right. \\ & \left. F_{Z2}(Z_2)(u_c - a_c)\right\} - F_{Z3}^2(Z_3^2)(u_c - a_c + K^3). \end{aligned} \tag{3.48}$$

P^2 is defined as the case where $i = 2$ of

$$P^i = \overline{F_{Z1}^i}(Z_1^i)\left(Z_1^i + K^{i+1}\right) + F_{Z1}^i(Z_1^i)\left(u_c + P^{i+1}\right). \tag{3.49}$$

K^3 is defined as the case where $i = 3$ of

$$K^i = \overline{F_{Z3}^i}(Z_3^i)\left(Z_3^i(n - i + 1)\right) + F_{Z3}^i(Z_3^i)\left(u_c + K^{i+1}\right). \tag{3.50}$$

If $\delta_s^1 = 1$, he offers a contract in period two such that

$$Z_3^{2*} - \frac{\overline{F_{Z3}^2}(Z_3^{2*})}{f_{Z3}^2(Z_3^{2*})} = \frac{u_c - a_c + K^3 + \overline{F_{Z2}}(Z_2)Z_2 + F_{Z2}(Z_2)(u_c - a_c)}{n-2}, \tag{3.51}$$

and if that one is accepted, he offers a contract in period n

$$U^n = Z_2^*, \tag{3.52}$$

with Z_2 solution to the equation

$$Z_2^* - \frac{\overline{F_{Z2}}(Z_2^*)}{f_{Z2}(Z_2^*)} = u_c - a_c. \tag{3.53}$$

In all periods j, $2 < j \leq n$ if $\exists i \mid i < j, \delta_s^i = 0$, he offers

$$U^j = Z_3^{j*}, \tag{3.54}$$

with Z_3^{j*} as solution to the equations

$$\begin{aligned} Z_3^{j*} - \frac{\overline{F_{Z3}^j}(Z_3^{j*})}{f_{Z3}^j(Z_3^{j*})} &= \frac{u_c + K^{j+1}}{n - j + 1}, \quad 1 < j < n \\ Z_3^n - \frac{\overline{F_{Z3}^n}(Z_3^{n*})}{f_{Z3}^n(Z_3^{n*})} &= u_c. \end{aligned} \tag{3.55}$$

If $\forall i < k$, $\delta_s^i = 0$, he offers a contract in period $k < n$ such that

$$U^k = Z_1^k, \tag{3.56}$$

with Z_1^{k*} as solution to

$$Z_1^{k*} - \frac{\overline{F_{Z1}^k}(Z_1^{k*})}{f_{Z1}^k(Z_1^{k*})} = u_c + P^{k+1} - K^{k+1}. \tag{3.57}$$

Remark 8. *In this last scenario, the carrier is bidding in a tender for transport services. The shipper collects the bids from several carriers with each carrier uninformed about the others' bids. The shipper here holds all the cards and is able to play the carriers against each other. This does not prevent the carrier from estimating the different costs involved and making offers as precise as possible given his knowledge of the shipper's industry, his competition and his own other outside opportunities. The present model captures the information which the carrier can gather as the contract comes up for renewal and he knows if the shipper has made other investments with his competition.*

Remark 9. *The profit to the carrier in this scenario is lesser than what he obtains in any of the other scenarios because, in addition to the lack of knowledge about investment costs, he also lacks the information about his competition's bids which induces take-it-or-leave-it offers which are less or equal to the competition's actual bids.*

Remark 10. *The fact that here the equilibrium is a Trembling Hand Perfect one enables the carrier to be sure that if he makes an offer undercutting the competition, the shipper will certainly accept it.*

Remark 11. *The shipper recovers part of the rent extracted by the carrier's opportunistic behaviour thanks to the information asymmetry. The extent of this recovery is proportionate to the imprecision of the carrier's information. In a sense, the shipper's optimal strategy is to signal to the bidders involved in the tender distorted information regarding her investment costs. Some of the effects of such signaling are presented in the numerical illustration below.*

3.4 NUMERICAL ILLUSTRATION

We illustrate the above information scenarios with a simple numerical instance. Suppose that a shipper and a carrier decide to work together for $n = 20$ periods. Before negotiating the contract terms, the shipper invests in relationship specific assets. Let

$$\begin{aligned} U^i &= 100, & i &\in \{1,2\}, & A &= 50 \\ u &= 100, & a &= 60, & u_c &= 80, \\ a_c &= 55, & p_1 &= 30, & \omega &= 1. \end{aligned} \tag{3.58}$$

3.4.1 *Scenario of full information and commitment*

In this first scenario, the carrier is informed of the shipper's investment A and outside opportunity u, a contract will be binding for all their relationship. Using the result outlined in Proposition 1, namely that $U^1 = u + a - A$, we get

$$U^1 = 110. \tag{3.59}$$

This contract is accepted by the shipper and results in a cost for her of $C_s = 160$, equal to the cost of choosing her outside option. The carrier's profit is $\Pi_c = 110$, better than his outside option (25). All the results for the scenarios are presented together in table 13 on page 61.

Table 7: Thresholds Z^* when the mean of the distribution of the belief about the outside option ranges between 50 and 210. When this mean is higher than 110, the shipper would refuse the contract.

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

3.4.2 *Scenario of full information and renegotiation*

In the case of renegotiation with common information, the outcome of the negotiation is straightforward and, according to the results obtained in Proposition 3, yields the following multiperiod contract

$$\begin{cases} U^1 = 100 - 50, & \\ U^i = 100, & \forall i, 2 \leq i < 20, \\ U^{20} = 100 + 60. & \end{cases} \tag{3.60}$$

The shipper pays over 20 periods 2060 (including $A = 50$), exactly the same cost than her outside option (2060). The carrier earns a larger profit than with his outside option (1545).

3.4.3 *Scenario of asymmetric information and commitment*

Over just one period and when the carrier lacks the knowledge about the shipper's outside option, he has to estimate the distribution of this outside option as following a one-sided truncated normal distribution $\mathcal{N}(\mu, \sigma)$ truncated at 0. Using the result in Proposition 2, we must calculate x such that

$$x - \frac{\overline{F_Z}(x)}{f_Z(x)} = 25. \tag{3.61}$$

This equation yields $Z^* = 90.9$ when $\mu = 110$ and $\sigma = 20$, which is slightly less than the shipper would have paid if the carrier had known this information (110). The shipper accepts the offer and the carrier still comes out ahead as compared to turning to his outside option. The thresholds Z^* vary according to μ, the expected mean of the distribution of Z. Table 7 presents some of the results when μ ranges between 50 and 210. For $\mu > 133$, the shipper would reject the contract since she would be better off by turning to her outside option (see figure 10).

The carrier's participation constraint is always met. We record the results in table 13.

How do we relate this result with the case of full information and commitment presented in 3.4.1? To do so, we vary the degree of certainty of the information available to the carrier. This certainty is modeled as the standard deviation of the distribution function that the carrier builds to embody his belief. The higher the certainty of the information in his possession, the lower the standard deviation of the distribution function. When the standard deviation of the distribution is equal to 0, the carrier

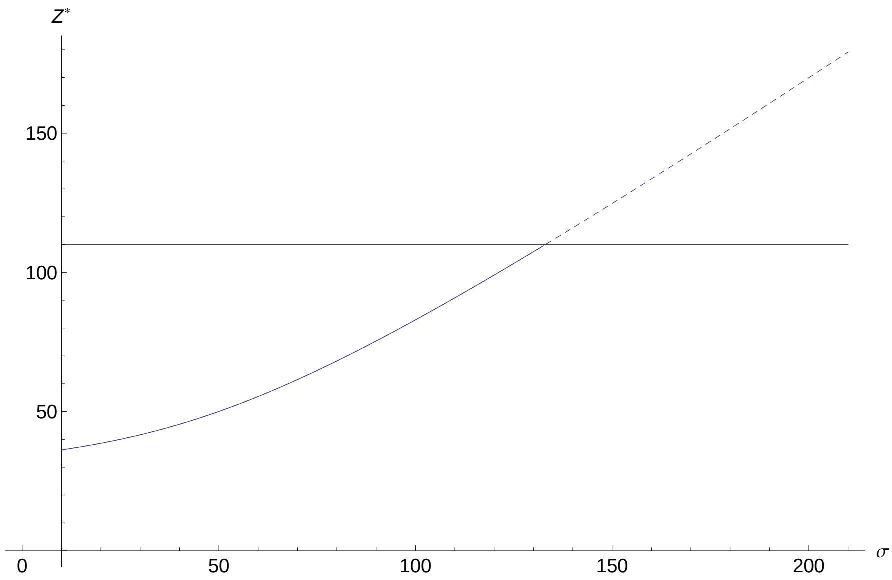

Figure 10: Evolution of Z^* when the expected demand μ increases from 50 to 210. The shipper rejects the offer when $\mu > 132$.

is perfectly informed about the true u, A and a. We present in figure 11 the change of Z^* when the standard deviation of the normal distribution of Z around 110, varies from 0.1 to 100. As can be seen, when it goes from 23 to 0, Z^* approaches $u + a - A$ from below. The result presented in Proposition 1 of Section 3.3.1 represents the limit when σ goes to 0 of the result presented in Proposition 2 of Section 3.3.2.

Another interesting observation which can be made from this figure is the way that Z^* also increases when the standard deviation σ increases from 23 to 100. This is due to the fact that as the carrier's information becomes more approximative, he will have a tendency to overestimate the true value for $u + a - A$ and thus will expose himself to a refusal from the shipper. This tendency is due to the fact that the alternative source of revenue for the carrier, here set at $u_c - a_c = 25$ serves as a backstop revenue in case of error in the estimate. The turning point is $\sigma = 23$ when $Z^* = 90.6$. If the alternative revenue had been set higher, the standard deviation which would have generated the minimum Z^* would have been even lower (eg, if $u_c - a_c = 55$, $\sigma = 15$ generates the lowest $Z^* = 97$).

Here, when the carrier uses a standard deviation $\sigma > 63$, the shipper refuses the offer because it is cheaper for her to go with her outside option. Note that we use in the present case a normal distribution so that a high standard deviation means that the carrier's estimates of Z can take negative values. Economically, this could be interpreted as the case when the carrier estimates that the shipper actually takes a rent out from the relationship instead of investing in relationship specific assets.

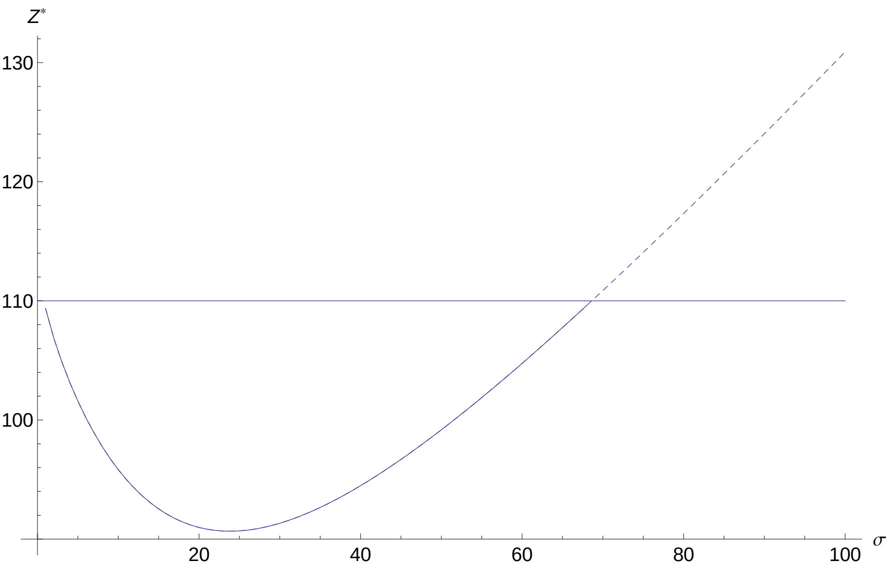

Figure 11: Evolution of Z^* when, using a normal distribution with a mean of 110, the standard deviation of the carrier's belief increases from 0.1 to 100. When $\sigma > 63$, the threshold Z^* is too high: the shipper turns down the offer. The carrier estimates that the shipper has a 66% probability that $u + a - A$ is between 47 and 173.

3.4.4 *Scenario of asymmetric information, known outside contract and renegotiation*

When information about investment in relationship specific assets is asymmetric, the carrier must establish the thresholds for A and a which will maximize his profits.

We implement here the updating procedure described in section 3.3.4 for the belief about A. In the first period, the carrier must set up his prior belief about A, define the seed p^n and the step ω by which this parameter will decrease between period 20 and period 1. In this illustration, we shall present the results for several values of the seed p^n but a fixed increment ω. Let A follow a one-sided truncated normal distribution function such that $\mathcal{N}_A(p^n, 10)$ truncated at 0. As regards the threshold a^*, we do not need to consider that it has to be updated given that it is already conditional upon the information gleaned from the posteriors of A and can only be evaluated once if the shipper agreed with A^{1*}, the first period threshold [7]. Initially, the carrier sets the belief about a to follow a one-sided truncated normal distribution function $\mathcal{N}_a(60, 10)$ truncated at 0.

We apply the results assembled in Proposition 4. We first look for the optimal a^* so as to later find the optimal A_{s1^*}. From (3.44), we have to solve

$$a^* - \frac{\overline{F_a}(a^*)}{f_a(a^*)} = -75, \tag{3.62}$$

which yields $a^* = 42.22$.

7 We present on page 56 a revised updating process to build upon the new information available after the shipper's acceptance in the full asymmetric case.

Table 8: The results when $p^{20} = 50$ and $\omega = 1$ of applying the algorithm for evaluating the A^{i*} recursively from period 20 back to period 1. The shipper would accept the carrier's offer in period 3.

Period	$(n-i+1)(u-u_c)$	A^{i*}
1	400	48.99
2	380	49.99
3	360	*50.99*
4	340	51.99
5	320	52.99
6	300	53.99
7	280	54.99
8	260	55.99
9	240	56.99
10	220	57.99
11	200	58.99
12	180	59.99
13	160	60.99
14	140	61.99
15	120	62.97
16	100	63.78
17	80	*62.37**
18	60	*51.00**
19	40	*34.68**
20	20	*17.18**

In our first approach, we evaluate A^{j*} using (3.46) and updating the distribution functions with $\omega = 1$ and $p^{20} = 50$ so that $p^1 = 30$. This yields the results listed in table 8.

The first two period estimates do not allow the carrier to win over the shipper's agreement: he has to wait till the third period to obtain an agreement by the shipper[8]. However, in the meantime, both have had to invest in their outside option's specific relationship assets a and a_c. Hence, the carrier is no longer able to extract the amount a from the shipper in the last period. The carrier's profit accrues to: $2\times80-55+100-50.99+17\times100 = 1854.01$, which can be compared to what he would have obtained from using his outside option from the start: $20 \times 80 - 55 = 1545$. The shipper's cost in this setup is: $60 + 2 \times 100 + 100 - 50.99 + 50 + 17 \times 100 = 2059.01$ which is to be compared to the cost incurred if she had turned to her outside option from the outset of: $60 + 20 \times 100 = 2060$. The shipper is marginally better off accepting the carrier's offer in the *third* period

8 Also, as can be seen from table 8, the thresholds for A starting from period 17 do not respect the incentive compatibility constraint $A^{i*} > A^{(i-1)*}$, even though the constraint (B.27) is respected (comparing the second and third columns).

because she has had to invest *both* a and A and because the carrier's offer in period 3 is not very generous.

Let us now enlarge the previous numerical example to different seeds p^{20}.

Table 10 presents the result for p^{20} going from 20 to 130 in steps of 10. We fix $\omega = 1$ so that for example, when we start with a normal distribution with $p^{20} = 50$ in period 20, the threshold $A^{20*} = 17.2$. In period 1, from (3.39), we write the mean of the distribution as $p^1 = p^{20} - 20 \times 1 = 30$ and $A^{1*} = 48.99$.

In that case, since $A^{1*} < A$, the contract $U^1 = 100 - 49 = 51$ would have been refused by the shipper. She would have agreed only in period 3, as seen above. However, if we take the cases where $p^{20} \geq 60$, the thresholds in period 1 A^{1*} are higher than A and hence the contracts offered (presented on the ante-penultimate line of table 10) would have been accepted in the *first* period. In all those cases, the carrier entices the shipper into accepting his first offer. thereafter, the carrier can extract the last period investment cost a without the shipper refusing to work with him.

We present in the last three lines of table 10 the contract in the first period, the profit to the carrier given the acceptance by the shipper of the relevant contracts and the cost to the shipper. Note that the carrier generates a substantially higher profit when he manages to obtain the shipper's agreement in the first period as opposed to the case where he misses (compare the profit in fourth column with all other ones in the following columns). Even when he substantially overestimates the investment A (last column: $p^1 = 110$), he still comes out ahead as compared to the first column result. These results are also in the table 13 comparing the results among scenarios.

Note that the first contract offered when $p^{20} \geq 110$ is a *payment* by the carrier to the shipper! Even in these cases, the profit over the 20 periods is higher than the one obtained by turning to his outside option or by missing the shipper's first period agreement (see figure 12).

When the seed is $p^{20} = 130$, this translates into a normal distribution $\mathcal{N}(110, 10)$ when evaluating A^1, which means that the carrier uses a mean for his belief which is 6 times the standard deviation above the real value. On the contrary, when p^1 is substantially lower than the true value for A (as in the first four column of table 10 on page 58), A^{1*} may be lower than A, inducing the shipper into refusing the contract in the first few periods. The profit in this case is much lower than when the first contract is accepted as can be seen when comparing the profit in the first and last columns of table 10 on page 58: the carrier is better off by overestimating A since this enables the capture of the shipper's cost of outside option in the last period. The carrier's profit is maximal when he slightly underestimates the shipper's investment cost A in the first period (when $p^{20} = 60$, $p^1 = 40$).

The attentive reader will note that the shipper's cost is also lower in all cases when the carrier over-estimates A than when the carrier makes an accurate evaluation of A.

Note on table 10 on page 58: when we make the seed p^{20} range over a set of values from 20 to 130, and using the same step for the decrease $\omega = 1$ of p^i, we see that the same evolution between each period's threshold

Table 9: Case of unknown investments and known outside contracts: Threshold A when the seed $p^{20} = 40$ and $5 \leq \sigma \leq 14$.

Period number	σ = 5	6	7	8	9	10	11	12	13	14
1	32	33	35	36	38	39	40	42	43	44
2	33	34	36	37	39	40	41	43	44	45
3	34	35	37	38	40	41	42	44	45	46
4	35	36	38	39	41	42	43	45	46	47
5	36	37	39	40	42	43	44	46	47	48
6	37	38	40	41	43	44	45	47	48	49
7	38	39	41	42	44	45	46	47	49	**50**
8	39	40	42	43	45	46	47	48	**50**	51
9	40	41	43	44	46	47	48	49	51	52
10	41	42	44	45	47	48	49	**50**	52	53
11	42	43	45	46	48	49	**50**	51	53	54
12	43	44	46	47	49	**50**	51	52	54	55
13	44	45	47	48	**50**	51	52	53	55	56
14	45	46	48	49	51	52	53	54	56	57
15	46	47	49	**50**	52	53	54	55	57	58
16	47	48	**50**	51	53	54	55	56	57	58
17	48	49	51	52	53	54	55	56	57	57
18	46	47	47	48	48	48	48	48	48	48
19	36	35	34	34	33	32	31	31	30	29
20	80	80	80	80	80	80	80	80	80	80

value for A: increasing at first before abruptly diving in the last periods. The inflexion point comes earlier as the seed is set higher compared to the real value of A. Remember that the standard deviation is kept constant at 10.

Let us also present the evolution of the estimated thresholds when instead of the seed, we let the standard deviation of the estimated distribution vary. We fix $p^{20} = 40$, $\omega = 1$ and let σ vary from 5 to 14 in steps of 1. We present in table 9 the results. When the threshold matches the actual value of A, the result is boxed. As can be seen, when the seed is too low compared to true value of A, the fact that the standard deviation is increased can only mitigate the effect of the underestimate partially. When $\sigma = 14$, the shipper agrees to the carrier's offer in period 7 instead of period 12 (when $\sigma = 10$). When the standard deviation is too low, the carrier's thresholds never allow him to obtain the shipper's agreement (columns 2 to 3: $5 \leq \sigma \leq 6$). The results when $\sigma = 10$ are the same as the ones presented in 10 on page 58 where $p^{20} = 40$.

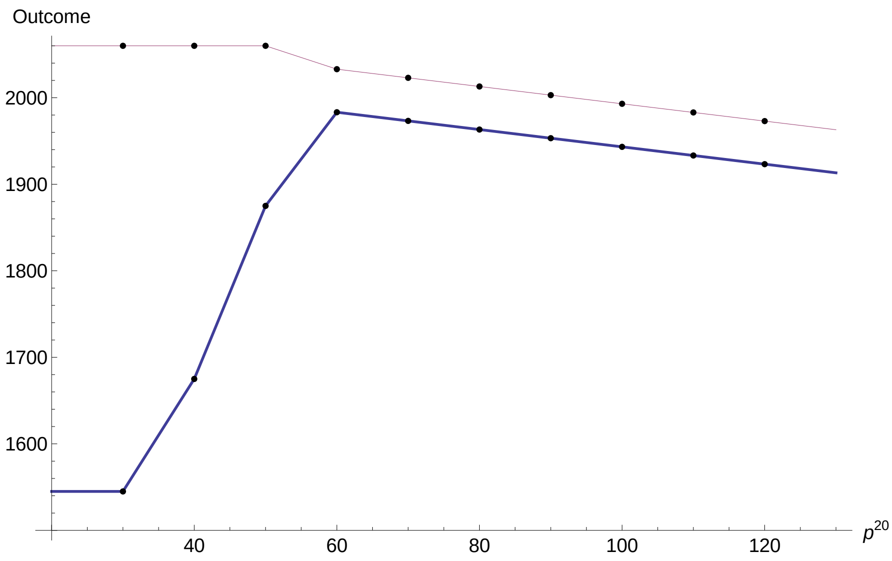

Figure 12: Evolution of the carrier's profit (thick line) and shipper's cost (thin) when p^{20} goes from 20 to 130. When $p^{20} \geq 60$, the shipper accepts the carrier's first offer and is held up in the last period of the carrier's threshold value for a.

3.4.5 *Scenario of full asymmetric information and renegotiation*

In this scenario, the carrier has to estimate initially three values: Z_1^1, Z_2, Z_3^2. Eventually, he may have to update his beliefs about Z_1 and Z_3 in posterior periods. Let the seed for Z_1 be p_1^{20} and the seed about Z_3 be p_2^n. Let these beliefs follow one-sided truncated normal distributions with $Z_1^n \sim \mathcal{N}(p_1^n, 8)$, $Z_2 \sim \mathcal{N}(160, 32)$, $Z_3 \sim \mathcal{N}(p_2^n, 16)$ all truncated at 0. We present below the calculations for seeds ranging from $p_1^{20} = 25$ to $p_1^{20} = 95$ and p_2^{20} ranging from 40 to 110. The increment $\omega = 1$, as in the previous scenario. We present in table 11 the Z_1 from period 1 to 19 according to the seeds for the distribution of beliefs about A in period 19 and in table 12 the threshold values for the belief Z_3 in the periods 2 to 20 and corresponding seeds p_2^{20}.

We start by evaluating Z_2^*, result of equation (3.53). We obtain $Z_2^* = 129.563$. We then evaluate $P^{20} = 80$ and $K^{20} = 80$.

We apply the updating procedure described earlier for the iterative Z_3^i and corresponding P^i starting with the last. Knowing the P^i, we obtain the Z_1^i and K^i. From those come the first value for Z_1 in period 1 and Z_3 in period 2.

It can be gathered from those tables that the carrier would have his first offer accepted by the shipper when the seed for $p_1^{20} = 45$. This seed yields a distribution function in the first period of $Z_1 \sim \mathcal{N}(25, 8)$. The thresholds increase period after period. For all *other* choices of the seed, given that we have chosen a one-sided truncated normal distribution for the belief, the ensuing contract is refused by the shipper as her participation constraint would not be satisfied. If the shipper suffers from Trembling Hand and refuses the carrier's first offer of $U^1 = 47.2$, she can still recover by accepting in all posterior periods the carrier's offer up till period 3.

However, her cost in doing so increases since she has to pay both A and a.

Note that the hypotheses that we have retained for the different distributions of the belief Z_1 all have a constant standard deviation of 8. For the distributions with a low mean in the early periods, this has the effect of pushing the threshold value for Z_1 higher. This explains why when $p^1 = 5$ we still have a $Z_1^1 = 78.9$, much higher than $Z_1^1 = 47.2$ when $p_1^1 = 25$. We could have made the variance of these distributions proportional to the seed but felt that it would be difficult to compare the ensuing results.

Turning our attention to the table 12, the belief about Z_3 being conditional on the acceptance of Z_1, not all seeds p_2^{20} would be feasible since the expected $Z_3 - Z_1 = p_2^{20} - p_1^{20} = A$ and A is assumed by the carrier to be strictly positive. If we suppose that $p_2^{20} = 40$, for example, $p_1^{20} < 40$. Here, since $p_1^{20} = 45$, p_2^{20} must range between 50 and 60. In table 12, we see that $Z_3^{2*} > 100$ for all $p_3^{20} > 60$. The third period thresholds for all seeds are sharply lower due to the reduced profit to be expected by the carrier in the case that he erred in period 2 in his offer. For example, if $p_2^{20} = 70$, the shipper refuses $U^2 = 100.80$, invests a and the carrier invests a_c. In the third period, the carrier offers $U^3 = 94.0$ which is accepted by the shipper.

As can gathered from the above, the choices of seeds and distributions by the carrier are evidently of high importance. Some choices would clearly result in both choosing their outside options in all periods. Having made this precautionary statement, we feel that it is still illustrative for our purpose to choose some "ad hoc" distributions which do result in trade.

If we suppose that $p_1^{20} = 45$ and $p_2^{20} = 60$, what are the carrier's profit and shipper's cost? In the first period, the carrier offers $U^1 = 47.2$ and in the second period $U^2 = 96.2$. The last period's contract is $U^{20} = 129.56$. All three offers satisfy the shipper's participation constraints so are accepted. The total cost to the shipper is

$$C = 47.2 + 18 \times 96.2 + 129.6 + 50 = 1958.4, \tag{3.63}$$

to which corresponds the carrier' profit

$$\Pi_c = 47.2 + 18 \times 96.2 + 129.6 = 1908.4. \tag{3.64}$$

If we choose $p_1^{20} = 45$ and $p_3^{20} = 50$, we get

$$C = 47.2 + 18 \times 93.5 + 129.6 + 50 = 1909.8, \tag{3.65}$$

to which corresponds the carrier' profit

$$\Pi_c = 47.2 + 18 \times 93.5 + 129.6 = 1859.8. \tag{3.66}$$

We now regroup in table 13 the results from the different information and commitment scenarios. Depending upon the choice of the seed, the carrier can mitigate the information asymmetry especially in the multi-period scenario. It emerges also that the shipper cannot really take advantage of the information asymmetry to reduce her cost except when there is commitment.

Refining the Bayesian updating process...

We wish to make a further comment on the possible refinement that can be brought into the Bayesian process presented in this chapter. After the shipper's acceptance of a contract, the carrier can use this information to update his belief of Z_2. Since Z_3 represents the belief about u and Z_2 about $u + a$, the shipper's acceptance represents precious information. He now knows that $Z_3^* < u$ and since $Z_2^* > Z_3^*$, he can use for his updated belief about Z_2 a truncated normal distribution function, truncated at Z_3^*.

Using the above examples, let us apply the revised updating process. Let us suppose that the first period offer is based on $Z_1^{1*} = 47.2$ and that the carrier offers in second period a contract based on $Z_3^{2*} = 96.2$. The shipper accepts both. In period 20, the carrier now updates his estimate of Z_2 such that $Z_2 \sim \mathcal{N}(160, 10, 96.2)$ where the third parameter is the left truncation limit of the one-sided truncated normal distribution instead of the prior estimate $Z_2 \sim \mathcal{N}(160, 32, 0)$. We also reduce the variance since the shipper can update the prior on the variance too. Applying the formula in equation (3.53), we obtain $Z_2^* = 142.218$, substantially greater than the prior $Z_2 = 129.56$. Note that the shipper still agrees to work with the carrier. Had the carrier kept the variance and only updated the left cut-off point, the resulting $Z_2^* = 129.932$ would still be higher (if only marginally).

3.5 CONCLUSION

In this chapter, we have presented a framework to model the behaviour of a shipper and a carrier when the shipper still has to invest in the relationship specific assets required to work with the carrier and has private information about her outside options and the cost of such investment. We characterize the Nash Equilibria when the carrier's Bayesian belief about the shipper's investment costs follows a distribution which exhibits an Increasing Failure Rate. We have derived results which apply for one period or multiple periods as they decide to renegotiate the terms of the contract that binds them.

We have pointed out the conditions in which a carrier, when engaging with the shipper in a multi-period relationship, can extract from her a rent proportional to the cost for the shipper of investing in relationship specific assets with a third party. This ability is only partly impaired when the shipper is private about her cost of outside opportunities. We show however, that this rent extraction can only take place in the last period, an attempt at holding up the shipper any earlier can only be met by evasion.

It has been further shown how the carrier intents to induce the shipper into accepting to work with him as early as possible by sweetening his initial offer and is thus motivated to renew his relationship till the last period initially agreed upon and extract a rent in this last period.

If the carrier is informed of the cost of operating with a third party, the shipper is indifferent as to whether she elects to work with the carrier or her outside option. In the case that the shipper is private as to both her outside transport cost and the investment cost to establish a relationship with this third party, her best course is to agree with the carrier's offers whenever it is less onerous.

Finally, the purpose of this chapter was to explore the extra-contractual links between a shipper and a carrier when engaged in multi-period relationships: if and when the shipper invests in some relationship specific assets to work with the carrier, the carrier can subsidize this investment and so is motivated to renew the relationship even when he is not constrained by any specific asset investments himself. In this pursuit, we establish the relationship between this subsidy and the outside opportunities available to the carrier. This effect is independent of other incumbency effects or other entry barriers as described in the literature (learning curve effects, increased information, etc.). This research puts the incumbent effect under different lighting than the one provided by the bidding or procurement literature.

The numerical illustration shows how the temporal relationship works and develops the Bayesian updating process of the initial beliefs held by the carrier, translating the beliefs about the unknown information into contractual offers. We are aware that the Bayesian updating mechanism which is presented here does not do justice to the information which is gathered by the carrier when the shipper refuses his offers. This mechanism is a compromise between a simple method which does bring interesting results and another which might have implied repeated evaluations of whole trees of strategies each time the shipper declines the carrier's offer. A way forward is sketched in the concluding remarks of the numerical illustration on page 56.

Table 10: Unknown investments and known outside contracts: threshold A when seed p^{20} ranges between 20 and 130, $\omega = 1$ and '$sigma = 10$. The last three lines present the first accepted contract, total profit and cost to the carrier and shipper. The estimates of A violating the shipper's IC constraint are boxed.

Period number	Seed p^{20}: 20	30	40	50	60	70	80	90	100	110	120	130
1	22.1	29.8	39.1	48.99.	[59.]	[69.]	[79.]	[89.]	[99.]	[109.]	[119.]	[129.]
2	22.8	30.6	40.1	49.99	60.	70.	80.	90.	100.	110.	120.	130.
3	23.5	31.5	41.	[51.]	61.	71.	81.	91.	101.	111.	121.	131.
4	24.2	32.4	42.	52.	62.	72.	82.	92.	102.	112.	122.	132.
5	24.9	33.4	43.	53.	63.	73.	83.	93.	103.	113.	123.	133.
6	25.7	34.3	44.	54.	64.	74.	84.	94.	104.	114.	124.	134.
7	26.4	35.2	45.	55.	65.	75.	85.	95.	105.	115.	125.	135.
8	27.2	36.2	46.	56.	66.	76.	86.	96.	106.	116.	126.	136.
9	28.1	37.1	47.	57.	67.	77.	87.	97.	107.	117.	127.	137.
10	28.9	38.1	48.	58.	68.	78.	88.	98.	108.	118.	128.	138.
11	29.8	39.1	49.	59.	69.	79.	89.	99.	109.	119.	129.	139.
12	30.6	40.1	[50.]	60.	70.	80.	90.	100.	110.	120.	130.	139.9
13	31.5	41.	51.	61.	71.	81.	91.	101.	110.9	120.8	130.5	*139.3*
14	32.4	42.	52.	62.	72.	82.	91.9	101.8	111.4	*120.1*	*126.6*	*130.3*
15	33.4	43.	53.	63.	72.9	82.8	92.4	*100.9*	*107.1*	*110.5*	*112.*	*114.*
16	34.3	44.	53.9	63.8	73.3	*81.7*	*87.6*	*90.7*	*92.2*	*94.2*	*95.8*	*96.9*
17	35.1	44.6	54.1	*62.4*	*68.*	*70.9*	*72.4*	*74.4*	*75.9*	*77.*	*77.6*	*78.*
18	*33.8*	*41.8*	*48.*	*51.*	*52.6*	*54.5*	*56.1*	*57.*	*57.7*	*58.1*	*58.4*	*58.6*
19	*23.*	*28.2*	*32.2*	*34.7*	*36.2*	*37.1*	*37.7*	*38.1*	*38.4*	*38.6*	*38.8*	*40.*
20	*13.*	*15.*	*16.3*	*17.2*	*17.7*	*18.1*	*18.4*	*18.6*	*18.9*	*20.*	*20.*	*20.*
U^i	78	70	61	51	41	31	21	11	1	-9	-19	-29
Π_c	1545	1545	1675	1875	1983	1973	1963	1953	1943	1933	1923	1913
C	2060	2060	2060	2060	2033	2023	2013	2003	1993	1983	1973	1963

Table 11: The threshold values for Z_1 in each period and according to the seed p_1^{20}. The list stops in period 19 since there is no point in offering a rebate to the shipper in the last period. The threshold which would result in an accepted contract is boxed. Note that the lower seeds generate high thresholds because of the truncated nature of the belief distribution and large standard deviation: when $p_1^{20} = 20$, the distribution in period 1 is $\mathcal{N}(5, 8)$ and truncated at 0.

p_1	25	35	45	55	65	75	85	95
1	78.9	69.	47.2	51.7	58.9	67.	75.7	84.7
2	79.1	70.	47.9	51.6	58.7	66.7	75.3	84.2
3	79.3	71.2	49.3	51.7	58.8	66.8	75.3	84.2
4	79.5	72.3	51.2	51.9	58.9	66.9	75.4	84.3
5	79.7	73.3	53.5	52.1	59.	67.	75.5	84.4
6	79.9	74.3	56.2	52.4	59.2	67.1	75.6	84.4
7	80.	75.2	58.9	52.7	59.3	67.2	75.7	84.5
8	80.2	76.1	61.8	53.1	59.5	67.3	75.8	84.6
9	80.3	76.9	64.5	53.6	59.7	67.5	75.9	84.7
10	80.5	77.6	67.1	54.6	60.	67.6	76.	84.8
11	80.6	78.3	69.6	56.2	60.3	67.8	76.1	84.9
12	80.7	78.9	71.9	58.8	60.7	68.	76.3	85.
13	80.8	79.5	74.	62.3	61.3	68.3	76.5	85.1
14	80.9	79.9	75.9	66.3	62.3	68.7	76.7	85.3
15	80.9	80.4	77.6	70.4	64.3	69.2	77.	85.5
16	81.	80.7	79.	74.2	67.9	70.2	77.4	85.7
17	81.1	81.	80.2	77.5	73.	72.4	78.1	85.9
18	81.1	81.2	81.1	80.2	78.4	77.3	80.2	86.6
19	81.1	81.3	81.7	82.2	83.1	84.7	87.8	92.7

Table 12: The threshold values for Z_3 in each period and according to the seed p_2^{20}. The list starts in period 2 with the value of Z_3^{2*} when the first contract has been accepted and stops in period 20. The values for Z_3 which would result in a contract being agreed are in boxes. Note that when p_2^{20}, the first agreement is in period 17, a situation which still yields a profit to the carrier of 1622.6, better than the outside option of 1545.

p_2	40	50	60	70	80	90	100	110
2	*92.2*	*93.5*	*96.2*	100.8	107.2	114.5	122.5	130.9
3	85.2	86.7	89.4	*94.0*	100.2	107.4	115.2	123.4
4	85.2	86.6	89.3	93.8	100.	107.1	114.9	123.
5	85.2	86.6	89.2	93.6	*99.7*	106.8	114.5	122.6
6	85.2	86.6	89.1	93.4	99.4	106.4	114.1	122.2
7	85.2	86.5	89.	93.2	99.1	106.	113.7	121.7
8	85.2	86.5	88.9	93.	98.8	105.6	113.2	121.2
9	85.2	86.5	88.8	92.8	98.4	105.2	112.7	120.6
10	85.2	86.5	88.7	92.5	98.	104.7	112.2	120.1
11	85.2	86.4	88.6	92.3	97.6	104.2	111.6	119.4
12	85.2	86.4	88.5	92.	97.2	103.6	110.9	118.7
13	85.2	86.4	88.4	91.8	96.7	103.	110.2	117.8
14	85.2	86.3	88.2	91.5	96.2	102.3	109.3	116.9
15	85.2	86.3	88.1	91.1	95.6	101.5	108.3	115.8
16	85.2	86.3	88.	90.8	95.	100.6	107.2	114.5
17	85.1	86.2	87.9	90.4	94.2	*99.4*	105.7	112.7
18	85.1	86.2	87.7	90.	93.3	97.9	103.6	110.2
19	85.1	86.1	87.5	89.4	92.	95.5	100.	105.5
20	85.1	86.1	87.5	89.4	92.	95.5	100.	105.5

Table 13: The results from the different information and commitment scenarios in the numerical illustration under favourable hypotheses of choice of seeds by the carrier. CI : Common Information; AI : Asymmetric Information; O : Outside option; AI 1 : Asymmetry about A; AI 2: Asymmetry about both u and A. The Δ% column presents the difference percentage-wise with the benchmark common information scenario.

Scenario		Shipper Cost		Carrier Profit	
		Min	Max	Min	Max
Commit.	CI	160		110	
	AI	100.0	155.4	50	95.4
	Δ	-37.5%	-2.88%	-54.5%	-13.3%
	O	160		25	
Renegotiation	CI	2060		2010	
	AI 1	1933	2059	1854	1983
	Δ	-6.2%	-0.05%	-7.8%	-1.3%
	AI 2	1909.8	1958.4	1622.6	1908.4
	Δ	-7.3%	-4.9%	19.3%	-5.0%
	O	2060		1545	

4 RENT CAPTURE UNDER ASYMMETRIC INFORMATION IN TRANSPORT

4.1 INTRODUCTION

We wish to shed light on the impact that some type of information and ensuing behaviour can have on the rent repartition in the dyad constituted by the shipper, as customer, and the carrier within a transport services relationship. A model is set up to give an example of a reiterated single period, single echelon, shipper-carrier transport relationship. The demand addressed to the shipper and the spot market price for transport capacity are two exogenous stochastic dependent variables. The objective functions of the carrier and shipper are evaluated when they have the possibility to use a stylized contract and supplement it by taking recourse in spot-buying under five information scenarios.

This contract includes both characteristics of commitment and of optional compliance, as well as additional penalties to enforce coordination. This stylized contract allows us to capture several possible situations observed in practice. We consider in the commitment part that both work in a forced compliance, firm commitment setting as described in Cachon and Lariviere (2001), referred to thereafter as the base contract. As in Cachon and Lariviere (2001), while not explicitly modeled, it is implicitly assumed that failing to fill the shipper's order within the limit of this base capacity q results in a penalty so stiff, and imposed with such certainty, that not covering the order is not even a consideration.

Above this first part, there may be additional capacity contracted in a voluntary compliance setting. When some extra capacity has been stipulated and the shipper calls *only partially* upon this added capacity which the carrier has set aside, she has to pay a penalty to the carrier for the unused capacity. The fact that a penalty is imposed on a shipper by a carrier is a situation encountered in the transport industry only in very special markets (we provide references in the literature review). Symmetrically, if the carrier is unable to comply with a requirement for capacity within the limit of the extra capacity in the contract, he has to pay a penalty to the shipper. Another aspect often seen in the transport industry is that the available capacity which can be assigned to serve the shipper's requirements is often inversely correlated to the shipper's demand. This is due to the fact that the carrier also has to serve other customers in the same industry and all will require additional capacity at the same time since all shippers' demands are correlated. When this available capacity is so low that the carrier may not be able to satisfy the shipper's requirement, information about its existence becomes an important factor for both shipper and carrier[1]. It should be of interest both to practitioners and to other researchers to look into how rent is shared according to whether the shipper possesses this information or not.

We show how, under opportunistic behaviour, rent is shared and how fine tuning the contract parameters can somewhat mitigate the effects of asymmetric information. To close the chapter, an instance where spot price and demand follow a bivariate exponential probability distribution function is presented to materialize the conclusions and further explore the results when the correlation coefficient between demand and spot market price varies.

4.2 LITERATURE REVIEW

We start from the remark in Chen (2004) and ensuing literature that coordination in a supply chain involves some form of information sharing and that supply chain efficiency can thus be increased (see Chen, 2001, 2007, Chen and Yu, 2005, Anupindi and Bassok, 1998, Porteus and Whang, 1991, Lee and Whang, 2000, Cachon and Lariviere, 1999, Zhao et al., 2002).

We extend those results to the case of transport when demand or capacity is not freely observable. This unobservability can lead to hidden action which leads to a double *moral hazard problem*[2]. This situation is not new in the supply chain management literature as exemplified in Plambeck and Taylor (2004) and Cachon and Lariviere (2005) or in a slightly less comparable setting in Elmaghraby (2000). The shipper faces stochastic demand. This randomness represents a risk in terms of procuring the required transport capacity. In other words, she wishes to transfer the risk onto the carrier. To introduce some flexibility in the contract, one can set up a menu of extra capacities at pre-arranged prices (see the characterization of the forward contract in Dong and Liu, 2007): if the demand effectively exceeds the base contractual capacity, the shipper calls up extra capacity to meet it at a pre arranged price (in inventory management literature, see Anupindi and Akella, 1993). It is equivalent to a forward contract (Cachon and Lariviere, 2001) because its execution depends on the revelation of demand addressed to the shipper. 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 and Nahmias (2000) a fixed and a proportional penalty serve to transfer risk between shipper and carrier.

In the present setting, 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 and Kouvelis, 1999).

The gas transport industry is an example of an industry in which the carrier can impose a penalty on the shipper for failing to use up all contracted capacity: an imbalance occurs which has to be compensated by the

1 An additional unknown, not modeled here, is the fact that a carrier may have idle capacity but that capacity may not be positioned where his customers need it. In effect, this idle capacity is unsaleable capacity.

2 As defined by Moe (1984), "moral hazard arises from the unobservability of the actual behaviour of agents in the *ex post* contracting situation."

shipper to the pipeline operator (Kalashnikov and Rios-Mercado, 2006). This type of penalty is equivalent to the one in supply chain management literature as described in §10.4.3 of Tsay et al. (1999) which refers to Cachon and Lariviere (2001). Usually one observes that fees are levied on excess capacity requirements. This is the case of the port authorities imposing penalties on shippers when congestion arises due to lorry delivery time-window obligations all scheduled in the same periods (as reported by Andrew Traill on European ports in his address to the workshop on Ports policy, Naples, April 19-20, 2007, and as practised by the PierPass organization in the United States and known as the OffPeak Program). It is more usual to study options on capacity in supply chain management literature because of the cost implied (Sebestyén and Juhász, 2003, Erkoc and Wu, 2005, Özalp Özer and Wei, 2006, Wu et al., 2005).

Our market mechanism draws on the model in Seifert et al. (2004) for simultaneous long-term and short-term (spot) buying of commodities by a shipper from one or various carriers. The shipper can simultaneously buy through long term contracts and through spot transactions the needed transport capacity.

As in Gavirneni et al. (1999), the model presented here compares five scenarios that differ by the information level of the participants.

This chapter is organized as follows. In §4.3 we describe the model involving one single tier in the supply chain: the contractual relationship between one shipper as client and one carrier as transport supplier. We then describe all objective functions for all states of nature in §4.4. In §4.5 we describe the information asymmetries that both shipper and carrier may face through five scenarios of behaviour: in the *first* the information is common to both, decisions are centrally coordinated. In the *second*, base scenario, both carrier and shipper enjoy common information and stick to the letter of the contract but may privilege their particular interest when warranted. In the *third* scenario, the carrier retains information from the shipper. In the *fourth*, both shipper and carrier hide information from each other. In the *fifth*, the shipper retains private information on her received demand but capacity of the carrier is common information. Section 4.6 is devoted to the comparison of the scenario when information is common to the ones where at least some information is private. In §4.7, the impact of contract parameters when in presence of an instance of a bivariate exponential distribution function is presented. Finally, we draw conclusions from the results in §4.8.

4.3 TRANSPORT MODEL

This model builds upon the one presented in Brusset and Temme (2005). In difference to their presentation, we add two additional information scenarios: in one, the shipper is private about information of her demand and in the other the carrier has private information about his capacity. In all other respects, Brusset and Temme's model is the same as the present one.

The shipper faces stochastic demand from her own customers and each unit of demand requires one unit of capacity of transport.

The carrier owns a homogeneous fleet with a common marginal cost of operation equal to the marginal cost of other carriers in the market. This cost has been normalized to 0. 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 the shipper. This fixed cost is deemed to be fixed over the capacity W. It is also normalized to 0. The carrier's capacity is pooled among all his customers. Depending upon demand from those other customers, remaining capacity W may vary.

Both carrier (he) and shipper (she) are price takers: their action does not influence the overall level of demand so inducing spot prices movements. Both privilege their relationship but may take recourse in the market for "on the spot" transport capacity. It is assumed that information about the going spot price is common to both players.

In the scenarios presented below, information about W may be private. This remaining capacity W is assumed to be fixed[3].

Players are considered rational and the results are extreme as compared to actual behaviour. The economic impact of information about demand or about idle capacity is exaggerated by the fact that we have considered a high fixed idle capacity and systematic opportunistic behaviours by both parties. The purpose of the present chapter is more as a guide for practitioners and a warning to researchers to properly account for the possibility of both behaviours rather than an exact evaluation of the impact of these pieces of information.

The shipper's risk is of not finding available capacity "on the day". It is this risk which motivates her to sign up a contract with a carrier. The carrier also faces a risk: that of not finding enough cargo to fill his capacity "on the day".

4.3.1 *Demand and capacity characteristics*

Stochastic variables

We assume that the shipper S must satisfy an exogenous demand X that is a stochastic stationary process whose probability distribution is a unimodal at least twice differentiable distribution $F_x(X)$ on a bounded support $[0, Q_{Hi}]$ with $0 < Q_{Hi}$ density $f_x(X)$, mean μ_x, $0 < \mu_x < Q_{Hi}$ and variance σ_x^2. The spot market price of transport capacity P is also assumed to be an exogenous variable with similar characteristics $(P, F_p(P), f_p(P), \mu_p, \sigma_p^2)$ and taking values in the interval $[v, P_{Hi}]$ with

3 The remaining capacity W should in fact be modeled as a random variable which is conditional upon the demands addressed by all the carrier's customers. It is an exogenous variable which is inversely correlated to demand X if we assume that the carrier has a transport fleet dedicated to a particular industry and the shipper S and C's other customers belong to that same industry. In this aspect the model should include this third variable and contemplate the covariance of remaining capacity W to D and P. When D and P are both high, W is low. W varies between q, which is in effect the minimum capacity that the carrier must have at the disposition of S at all times, and the total capacity of the carrier (when none of his other customers require any capacity). The carrier C knows the mean and variance of this remaining capacity. When W is low, the carrier may not be able to satisfy in full the shipper's requirement.

$0 < v < P_{Hi}$, v being a low price deemed to be equal to the common marginal cost of operation among operators in the spot market. In what follows, this price has been standardized to 0 without loss of generality. The high limit P_{Hi} is a large value compared to μ_p. In the same way, let us call F the continuous, twice-differentiable *joint* unimodal distribution and f the *joint* density function of P and X with mean μ, variance σ^2 and correlation coefficient ρ, $(0 \leq \rho \leq 1)$[4]. The demand has to be satisfied in full at each period.

All other production costs of S are ignored.

4.3.2 *Contract*

C (carrier) and S (shipper) have signed and are bound by a contract with known and fixed parameters which extends over one period. In the forced compliance part of the contract, S agrees to reserve a *base capacity q* at *price per unit s* and pays a *fixed fee r* for this privilege. This is the Minimum Purchase Commitment as described in chapter 5 and references mentioned in chapter 2.

Additionally to the base contract, the partners include a menu of prices, or forward contracts which in our model, for the sake of simplicity and without loos of generality, will be reduced to just *one* price p_a per unit for an additional quantity q_a. The results can be extended to any number of other prices and capacities. This price p_a is per unit for quantities up to a maximum of q_a that the carrier offers to the shipper S to help her meet demand in excess of the contracted base capacity commitment q (see figure 13). We have $s \leq p_a$ because this additional capacity is in fact capacity not earmarked for this shipper, it represents some sort of buffer capacity which the carrier holds in case of extra demands and is shared among all his customers. Calling up this capacity to allocate it to S clearly hampers the carrier in satisfying other customers. Additionally, this capacity is called up "on the day" since it is required only when the shipper knows of actual demand she has to satisfy[5].

Since the players operate within a voluntary compliance setting for this part of the contract, to enforce the menu of prices, two penalties are set: θ_c is the penalty paid by C for not picking up the extra cargo within the

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4 We assume here, and it has been demonstrated in the case of the maritime dry bulk freight rate in Tvedt (2003), that the spot market price does not follow a random walk but is a stationary process

5 This seems counter intuitive: one would expect that the higher the capacity sought by the shipper, the less the marginal cost to the carrier, so that the carrier would be motivated to make a volume discount to capture the excess demand. In fact, every time a shipper solicits the carrier for more capacity, she reduces his ability to respond to other customers since capacity is a constraint which cannot be lifted in the short term. It has been established that this price hierarchy increases efficiency in the supply chain (Tsay et al., 1999, Tsay and Lovejoy, 1999, Tsay, 1999). The reader is also referred to Lee and Rosenblatt (1986) which evaluates the discount which the supplier offers to a buyer in an inventory management setting where both supplier and buyer face set-up and holding costs: the supplier's profit function is concave in the discount rate.

limit of the extra capacity q_a, θ_s is the penalty paid by S for not offering her extra cargo within the limits of q_a[6].

The capacity W is assumed to be such that $W > q + q_a$.

We now turn to the hierarchy in prices between the marginal price p_a and the average spot market price. On average, this spot price represents the price which clears out the extra capacity available and the remaining demands who yet have to find a carrier to perform the transport service on a particular date. Since this capacity, as a service, is time dependant, its value diminishes as time goes by. Whereas shippers may have some ability to reprogram their shipments from one day to the next. Here we apply the results obtained in Rubinstein (1982), namely that the preferences of the two agents in our problem resolve to their rates of time discount. In the present case, we find reasonable to assume that the carrier's time discount rate is higher than the shipper's[7]. In conclusion,

$$s \leq p_a, \qquad \mu_p \leq p_a. \tag{4.1}$$

This hierarchy in prices leads to revenue or cost piecewise linear functions as represented in figure 14 on page 71 and figure 15 on page 72.

We have not modeled, so as not to increase the complexity of the models any further, the possibility that the shipper may not find available capacity "on the day" once she knows of her exact requirement, nor of the carrier not being able to sell the remaining idle capacity on the spot market "on the day" either.

In time, the actions and decisions happen in the following order (see figure 13).

1 – Demand X and Spot price P are realized, S observes both, C observes P
2 – S asks C for capacity u
3 – C decides to allocate v capacity to S
4 – S observing v, completes her transport requirement by buying $[X - v]^+$[8] from the spot market
5 – C allocates his available idle capacity to the spot market
6 – transport is performed and payout occurs.

We list the variables and parameters in table 14 on the facing page.

6 Of course, these penalties can only be enforced if the party who might receive it can observe the opportunistic behaviour: C must know of all cargo to be carried and S must know of all the remaining available capacity W at C.

7 We also refer the reader to the discussion about volatility of spot market prices in Wu et al. (2001); the experience recorded in Seifert et al. (2004) that spot prices are at a premium to contract prices because of the "convenience yield" and references therein; or also the notion in Kleindorfer and Wu (2003) that liquidity in the spot market is a random variable whose value is 1 when the buyer of capacity has no difficulty in finding available capacity and 0 when she cannot. In the case of a shipper and a carrier who have mean-variance preferences over their risky profits, Dong and Liu (2007) show that the contract price is higher than the expected spot market price and increases with the variance of spot market prices.

8 If $X < v$, $[X - v]^+ = 0$, else $[X - v]^+ = X - v$.

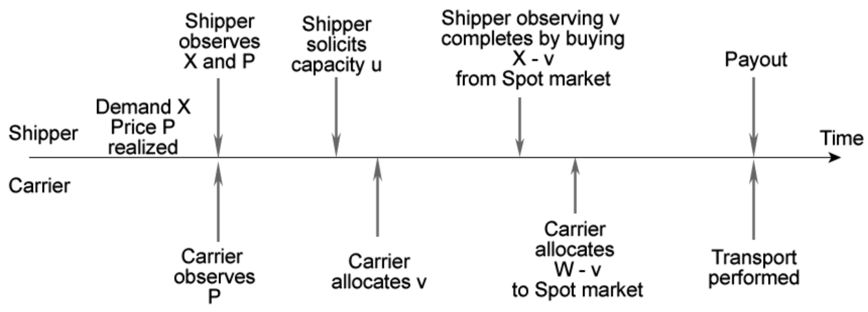

Figure 13: Sequence of events and capacity allocation

Table 14: Notations in this chapter

C	Carrier
S	Shipper
q	Base capacity contracted
s	Contract per unit price for the base capacity q
r	Fixed fee to reserve base capacity q
q_a	Additional capacity that S can call upon from C specified in contract
p_a	Per unit price for additional capacity q_a, specified in contract
θ_s	Penalty per unit paid by S to C for breach of contract
θ_c	Penalty per unit paid by C to S for breach of contract
$F_x(.)$	Cumulative distribution function of demand X
$F_p(.)$	Cumulative distribution function of spot price P
$f_x(.)$	Marginal probability distribution function of X
$f_p(.)$	Marginal probability distribution function of P
$F(.)$	Bivariate cumulative distribution function of demand X and price P
$f(.)$	Bivariate probability distribution function of demand X and price P
ρ	Correlation coefficient between P and X
μ_x, σ_x	Mean and standard deviation of X
μ_p, σ_p	Mean and standard deviation of P
u	Decision variable of S: what quantity of her demand to allocate to C
v	Decision variable of C: what quantity of capacity to allocate to S
W	Remaining capacity of carrier C available to S

4.4 OBJECTIVE FUNCTIONS

4.4.1 *Regionalizing the probability space*

We divide the probability space Ω into regions so as to facilitate the discussion regarding the objective functions of both S and C (see figure 16). We assume that the carrier's participation constraint is not violated.

We restate in table 15 all the contract characteristics as defined above:

Table 15: Contract characteristics

$W \geq x$	Available transport capacity of C
$0 < q + q_a \leq W$	contracted capacity plus negotiated additional capacity
$0 \leq \theta_s < p_a$, $0 \leq \theta_c < p_a$	per unit penalties paid by shipper or carrier
$0 \leq q_a$	additional capacity is positive but may be equal to 0.
$0 \leq s \leq p_a$	price for additional capacity
$0 \leq u \leq X$	capacity u, decision variable of the shipper
$0 \leq v \leq u$	x, carrier's decision variable

4.4.2 *Carrier objective function*

In our setting, carrier C has already met his other customers' requirements and is left with remaining capacity $W > q + q_a$ when receiving S's capacity requirement (see figure 13). If the capacity required to carry the realized demand from S does not reach total remaining capacity W, the excess capacity is sold on the spot market.

The objective function of the carrier is to increase revenue. His *ex post* decision variable is x, the capacity he allots to S. $W - x$ is the remaining capacity which can be sold on the spot market.

We have normalized the objective function with respect to the individual participation constraints. The revenue function is conditional upon the allocation by S and the spot market price P:

$$R(v|u) = \begin{cases} r + vs + (W - v)P & : 0 \leq v < q, v = u \\ r + qs + (v - q)p_a + [u - v(u) - q]^+\theta_c - & \\ [X - u - q]^+\theta_s + (W - v)P & : q \leq v \leq u \leq q + q_a \\ r + qs + q_a p_a + (W - q - q_a)P & : q + q_a < v \leq W. \end{cases} \tag{4.2}$$

The graph of such a function is represented in figure 14.

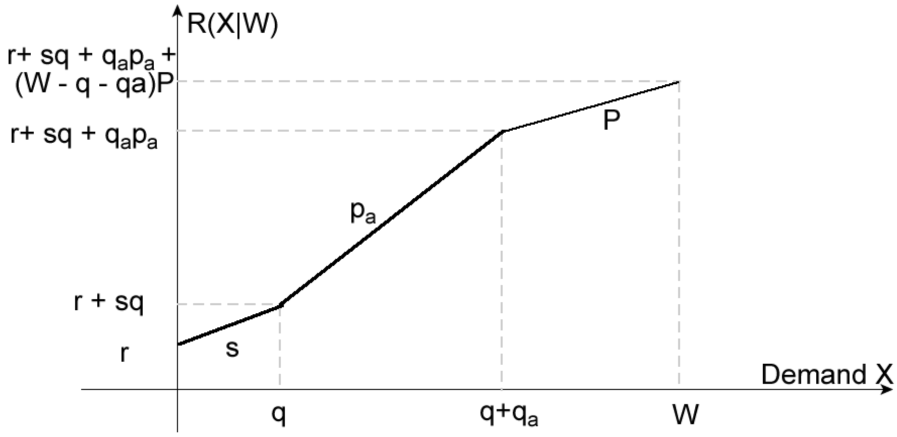

Figure 14: Behaviour of the revenue function $R(X|W)$.

4.4.3 *Shipper objective function*

Shipper S decides to allocate quantity u to carrier C from the total revealed X.

The decision variable u can take all values between 0 and total received demand X (see figure 15). Whatever transport necessity is not being allocated to C will be offered to the spot market at the going spot price P. The objective function of S is conditional upon the response she receives from C, which is represented by $v(u)$. When $u \leq q$, the carrier always attributes u in capacity, so when $u \leq q$, $v(u) = u$. Let us call O the shipper's objective function which has to be minimized (see figure 15):

$$O(u|v) = \begin{cases} r + su + (X-u)P & : 0 \leq u \leq q, v = u \\ r+sq+\big(v(u)-q\big)p_a - [u-v(u)-q]^+\theta_c + & \\ [X-u-q]^+\theta_s + (X-v(u))P & : q < v(u) \leq q+q_a \\ r + sq + q_a p_a + (X-q-q_a)P & : q+q_a < v(u) \end{cases} \tag{4.3}$$

4.4.4 *Defining optimal decisions in each probability space*

In each region of probability space as represented in figure 16, each player's optimal decisions vary. Let us call $R_{\Omega i}$ and $C_{\Omega i}$ the revenue and cost functions over each separate region identified by its number

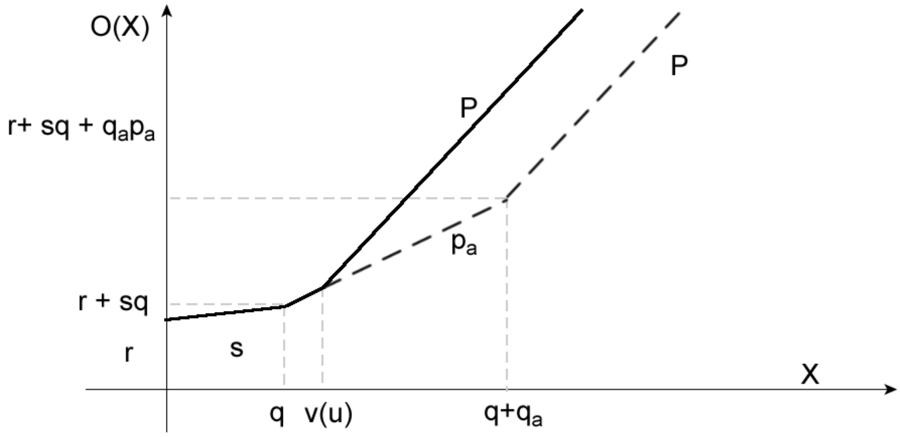

Figure 15: Plot of $O(X)$. When the carrier decides to assign $v(u)$, $O(X)$ increases since $P > p_a$.

i, $i \in \{0, 1, 2, ..., 10\}$. The profit function of C that has to be maximized and the objective function of S that has to be minimized can be written:

$$R_i\,(v|u, \Omega i)$$

$$\text{s.t.}: \begin{cases} v & \leq W \\ \min(u,q) & \leq v \leq u \\ 0 & \leq u \leq X \\ 0 & \leq P \\ 0 & \leq \theta_c \leq p_a \\ 0 & \leq \theta_s \end{cases} \tag{4.4}$$

4.5 INFORMATION SCENARIO ANALYSIS

We can now start modeling how each actor behaves according to the information he holds privately or that is common to both and see analytically the impact on the objective functions of C and S. In all scenarios, the spot market price for carrying cargo in each period is revealed to both. This models depicts extreme behaviours by the actors, as would be warranted were they sure of never being caught shirking their contractual obligations.

We put a superscript index for each scenario on the carrier revenue, shipper cost and standard deviation functions (e.g. $u^1; v^1; O^1; \sigma^1; R^1$ for scenario 1).

4.5.1 *Scenario 1: centralized decision-making*

The carrier and shipper share information truthfully, and are coordinated by a single decision maker. According to the observed demands and spot price, shipper S allocates the maximum of the realized demand to C and C allocates the maximum of his capacity to satisfy S.

$$u = X, \quad v = \min(W, X) \tag{4.5}$$

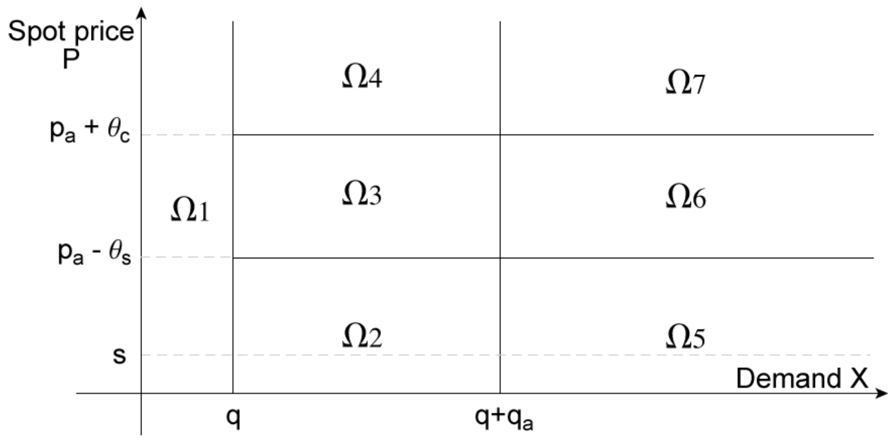

Figure 16: Probability spaces for spot price and demand addressed to S in scenario 2

We examine region per region what the optimal decisions by each player become and present the results in table 16:

Table 16: Scenario 1: optimal decisions and objective function for each probability region.

Ωi	u^*	v^*	$R_i(v^*\|u^*)$	$O_i(u^*\|v^*)$
$\Omega 1$	X	X	$r + Xs + (W - X)P$	$r + Xs$
$\Omega 2 \cup \Omega 3 \cup \Omega 4$	X	X	$r + qs + (X - q)\, p_a + (W - X)P$	$r + qs + (X - q)\, p_a$
$\Omega 5 \cup \Omega 6 \cup \Omega 7$	X	W	$r + qs + q_a p_a + (W - q - q_a)P$	$r + qs + q_a p_a + (X - q - q_a)P$

4.5.2 *Scenario 2: common information, distinct profit centres*

In this scenario, transport is outsourced and both partners, though they act as independent Decision Making Units (Decision Making Unit (DMU)), are being truthful about their information. Two situations arise in difference with scenario 1: when $P < p_a - \theta_s$, the shipper reduces her cost by paying the penalty θ_s agreed upon in the contract to the carrier for the cargo that is being diverted to the spot market above base capacity q.

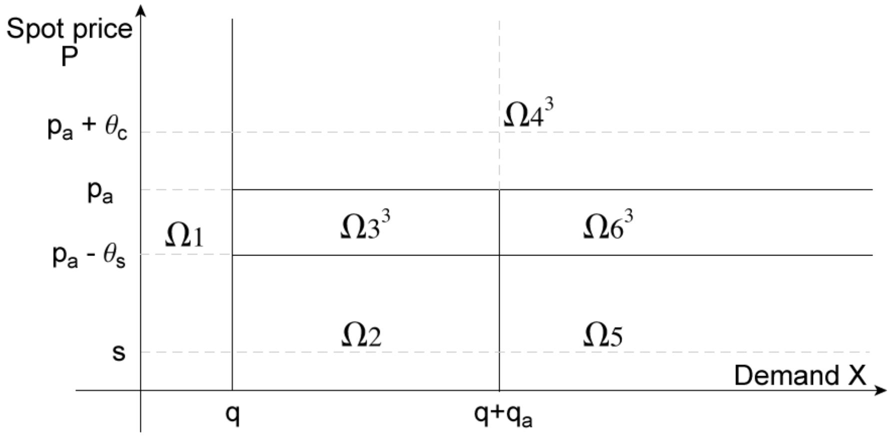

Figure 17: Probability regions in scenario 3

When $P > p_a + \theta_s$, the carrier increases his profit by refusing all cargo in excess of q from S, paying a penalty θ_c and selling this capacity at the spot price. S has to buy her requirements from this spot market. The division of the probability region is the one represented in figure 16 on the previous page.

In table 17 are presented the optimal decisions taken by both players for the relevant regions, region by region.

Table 17: Scenario 2: optimal decisions for each probability region.

Ωi	u^*	v^*	$R_i(v^*\|u^*) - r$	$O_i(u^*\|v^*) - r$
$\Omega 2$	q	q	$qs + (X-q)(P+\theta_s) + (W-X)P$	$qs + (X-q)(P+\theta_s)$
$\Omega 3$	X	X	$qs + (X-q)\,p_a$	$qs + (X-q)\,p_a$
$\Omega 4$	X	q	$qs + (X-q)(P-\theta_c)$	$qs + (X-q)(P-\theta_c)$
$\Omega 5$	q	q	$qs + q_a\theta_s + (W-q)\,P$	$qs + q_a\theta_s + (X-q)\,P$
$\Omega 6$	X	$\min(X,W)$	$qs + q_a p_a + (W-q-q_a)\,P$	$qs + q_a p_a + (X-q-q_a)P$
$\Omega 7$	X	q	$qs - q_a\theta_c + (W-q)\,P$	$qs - q_a\theta_c + (X-q)\,P$

4.5.3 *Scenario 3: carrier hides information*

C has private information on W, the remaining transport capacity. The shipper S cannot verify the existence or size of this remaining capacity. So C has an opportunity to deviate when $P > p_a$. S has to buy the transport capacity in excess of q from the spot market. C sells all remaining capacity in excess of q on the spot market. The demand X is here assumed observable by both S and C. We have a new drawing of the region boundaries (figure 17).

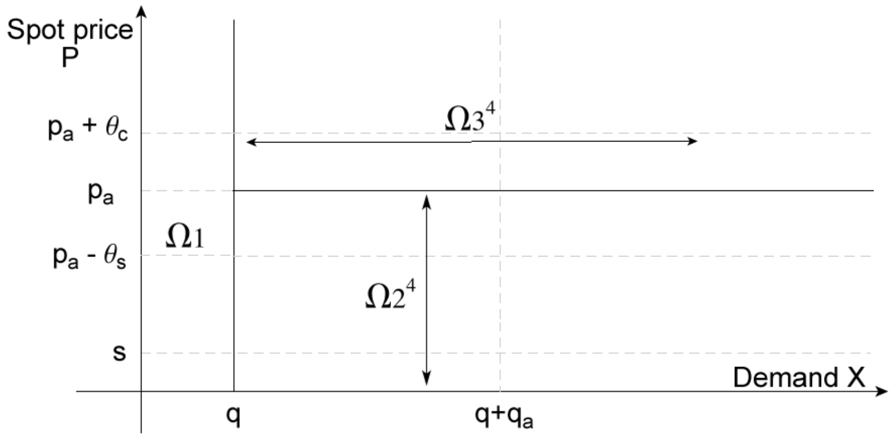

Figure 18: Probability regions for scenario 4

4.5.4 *Scenario 4: carrier and shipper hide information*

In this scenario, C has private information on W, S has private information on the demand X: so both have an option to behave opportunistically according to the spot price P. Each sticks to q, basic capacity contracted for. In this scenario, the menu of prices and penalties are unenforceable. For any spot price either higher or lower than the menu price p_a according to the additional capacity necessary, either the shipper or the carrier decides to go to the spot market. The other party, for lack of knowledge of capacity or cargo, cannot ask for nor receive any compensation.

The contract is reduced to the basic *minimum purchase commitment* as described in section 5.3.3 on page 102 of chapter 5.

The regions' boundaries are redrawn into barely 3 regions (figure 18).

4.5.5 *Scenario 5: shipper hides information*

In this scenario, the shipper knows the remaining capacity of the carrier but the carrier is not aware of the exact demand received by the shipper. The carrier cannot shirk his contractual engagements but the shipper can. She does not have to pay any penalty to the carrier since the carrier is unaware of the extra cargo to ship.

As compared to the mapping of overall probability space in scenario 1, the lower regions are larger (figure 19 on the following page).

4.6 comparison between scenarios

The purpose of comparing the outcomes of the different scenarios is to draw conclusions applicable to managerial practice as to the impact of information on the behaviours of both shipper and carrier when they are distinct profit and decision centers. We are able to show just how important this information is and when. Since the relevant private information can sometimes be obtained by the uninformed party through costly data collection or inspection, the expected cost differences between scenarios

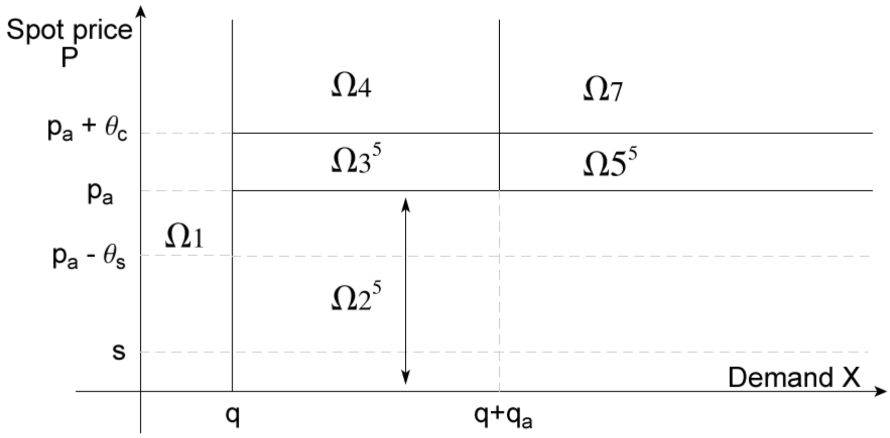

Figure 19: Probability regions for scenario 5

help decision makers into deciding whether to engage in these costly information discovery activities or not.

In the subsections 4.6.2, 4.6.3 and 4.6.4, we present the result of the difference for each DMU, member of the dyad, between the common information scenario (scenario 2) and the other scenarios from 3 to 5. We infer some guidelines as to how to structure a contract in certain circumstances. The numeric illustrations which are presented in Appendix C starting on page 159 serve as guides to practitioners about the expected cost of the absence of information and hence how much to potentially allocate for information discovery.

To be exhaustive, we also present in the next subsection the difference between an integrated supply chain and a dyad.

4.6.1 *Comparison between scenario 1 and 2*

The difference between these scenarios is between one profit centre and decentralized profit centres with common information. This is the case of the logistics department of a large organization. The differences occur only when P is either lower than $p_a - \theta_s$ or higher than $p_a + \theta_c$. The results are presented here as a matter of record, the reasons of such difference – namely, the reasons for outsourcing – escape the scope of this work.

The difference between integrated and decentralized but truthful dyads is in the regions where the spot price exceeds the extra capacity p_a and the penalty to be paid to the shipper or when the spot market price is less than that price p_a less the penalty to be paid to the carrier. In both cases, the decision makers will divert capacity or cargo to the spot market and not to their partner.

Comparing both scenarios in our model does not do justice to the decision of outsourcing transport in the first place: we have excluded the fixed costs of operating a transport fleet. The fixed cost to the shipper would have to be compared with the increased cost of transport using a third-party supplier. The higher both penalties and the extra capacity are, the lower the difference.

Proposition 6. *The rent transfer between the shipper to the carrier is minimized if the distribution of spot prices is equal around the mean spot price (eg normal distribution) and*

$$\begin{cases} p_a = & \mu_p \\ \rho = 0 & \\ \theta_c = & \theta_s. \end{cases}$$

The proof can be found in appendix C.2.

Remark 12. *When the spot market price for transport is uncorrelated to demand, the price for additional capacity above q is set to equal the mean spot market price and the penalties are even, the upside and downside risks of rent transfer between shipper and carrier even out, minimizing the overall rent transfer which takes place when the shipper and carrier are two independent decision makers as opposed to a centralized supply chain.*

Given that today most large industrial companies have outsourced their transport operations, the most interesting results are not in this comparison.

We focus on the situation where one or both parties are independent DMU *and* manage to hide pertinent information from the other. They thus can engage in opportunistic behaviour. In the following, we compare the outcomes of their behaviour under varying information scenarios.

4.6.2 *Comparison between scenario 2 and 3*

There is a transfer of rent from S 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 to sell it to the spot market at a higher price.

The difference between both scenarios is in evidence within the menu of prices for additional capacity q_a: when the spot market price is higher than p_a, the carrier simply declares that he has no capacity over q and sells his remaining capacity at the spot market. The shipper, in this case, has to apply also to the spot market. The carrier wishes to maximize the difference in profit between scenario 3 and 2, whereas the shipper wishes to minimize the same expression.

Proposition 7. *The shipper can reduce the carrier's information rent by setting the carrier's penalty to 0 and increasing either or both q_a and p_a.*

The proofs are in appendix C.3 on page 163.

Remark 13. *Increasing the price p_a and the capacity commitment q_a simultaneously directly reduces the information advantage of the carrier, as intuition would indicate. Increasing both induces a cost which must however be compared to the cost of gathering information about the real remaining capacity. As mentioned in section 4.3, the result exaggerates what the actual difference would be in a real world case. Yet, it provides guidance to the shipper so that she can evaluate the economic return of inspection cost about the carrier's real idle capacity.*

The important conclusion is presented in the following proposition.

Proposition 8. *The difference in cost between scenario 3 and 2 is* positive *for whatever bivariate distribution of demand and spot market prices when both are positively correlated*[9].

The proof is relegated to appendix C.4.

Remark 14. *It can be shown that, whatever the bivariate distribution used, the first differentials of this difference in both q_a and θ_c are strictly positive. Or, in other words, a larger penalty and/or a larger commitment increases coordination between shipper and carrier when information about idle capacity is common but does not when the carrier can hide this information from ex post investigation by the shipper. Hence it is counter productive for the shipper to try to coordinate the carrier when she is unable to monitor the carrier's capacity.*

Another important aspect to be taken into account even though we have not modeled it here is the impact on the variance of the transport cost to the shipper and on the revenue of the carrier. This result can be formulated in the following proposition.

Proposition 9. *In scenario 3 the variance of cost or revenue is higher than the variance under common information.*

The proof is relegated to appendix C.5.

Remark 15. *The variance of the transport cost to S increases with the variances of the component marginal pdf: X and P. It also increases for the carrier: it is up to him, given the historical data he can gather about price and demand, to study whether this increased variance in his revenue counterbalances the added rent he extracts from the shipper.*

Remark 16. *Added variance to cost and profit will generate added uncertainty which has been proven to entail double marginalization (Spengler, 1950, Tirole, 1988, Boyaci, 2005).*

4.6.3 *Comparison between scenario 2 and 4*

In scenario 4, both players' behaviours diverge from the one in scenario 2 over all regions except Ω1. The difference is hence the largest. The calculations are relegated to appendix C.6 on page 164.

Proposition 10. *In the absence of information both of demand and of available capacity, only the full commitment part of the contract will induce coordination, so $q_a = 0$ and $p_a = 0$ and of course $\theta_s = \theta_c = 0$.*

The proof is presented in appendix C.7.

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9 In the case that demand and spot market prices are inversely correlated ($\rho < 0$), high demand appears when spot market prices are low so that the shipper would consistently take recourse in the spot market whenever the spot price is less than $p_a - \theta_s$ and would bargain for a low or even null penalty and extra capacity. This situation is trivial and will not be considered here.

Remark 17. *When both shipper and carrier can engage in opportunistic behaviour, the purpose of including penalties in the contract is defeated: none can be enforced when the need arises.*

Remark 18. *The minimum capacity commitment q is the forced compliance part of the contract. The voluntary compliance part of the contract, namely the additional capacity commitment, is unenforceable when price and demand are not linked by a strict linear relationship as is the case here. Compare this situation with the voluntary compliance one described in Cachon and Lariviere (2001). The manufacturer-buyer is relegated to specifying a price-only contract and the capacity induced to satisfy the buyer is less than the centralized organization or the full compliance scenario would obtain. This result is achieved even though the model does not include the possibility by both buyer and seller to turn to a spot market.*

Proposition 11. *For any $q_a > 0$, $p_a > 0$, $\theta_s > 0$ and $\theta_c > 0$, the difference exists between both scenarios and the variance of the cost to the shipper and of the revenue for the carrier are higher than those in scenario 2.*

The proofs are relegated to appendix C.8.

Remark 19. *Both shipper and carrier must compare the cost of gathering information about the other in light of this difference. The possibility of surprise monitoring (or the risk of) might be sufficient to deter opportunistic behaviour. The cost of such monitoring must be set against the evaluation of the eventual rent transfer in case of opportunistic behaviour as presented here.*

Remark 20. *The best course when information about capacity and demand is unverifiable is to reduce the contract to the full commitment capacity q for which neither carrier nor shipper will deviate. Setting compliance parameters to non-zero values will yield higher variance of results for both partners.*

4.6.4 *Comparison between scenario 2 and 5*

Because of the lack of information about demand addressed to the shipper, the carrier can not ask for any penalty when due from the shipper, and when the spot price is lower than p_a, the shipper does not derive cargo in excess of q to the carrier.

This difference decreases in both q_a and p_a. The carrier can only try to mitigate the effect of private information about demand by asking for a price for additional capacity as close as he can manage to the expected mean spot market price (discouraging the shipper from shirking) and for an additional capacity as small as possible. In short, he is better off by not offering any extra menu of prices and capacity if information about demand is scarce or too costly. This calculation can help him evaluate to what expense he can go to pay for information about actual demand faced by the shipper.

We can formulate a proposition applicable to such an information asymmetry.

Proposition 12. *When the carrier is not informed of the shipper's demand, his revenue is lower than when he is informed and decreases in q_a, p_a and θ_s.*

The proofs are presented in appendix C.9.

Remark 21. *The carrier must compare the cost of gathering information about the demand which the shipper faces and the potential rent capture by the shipper for the parameter sets he wishes to set. If that information cost is too high, he is better off by sticking to the commitment part of the contract, ie set a high value for q and $q_a = 0$.*

Proposition 13. *The variance of the cost to the shipper and to the revenue to the carrier is increased when information about demand is private to the shipper.*

Proof in C.10.

Remark 22. *The shipper who looks to reduce the risk of not finding available transport capacity "on the day" sees here her first objective defeated. She needs to look for ways to convey to the carrier that she is being truthful about demand information if the carrier is to agree to extra capacity.*

Remark 16 can also be made in this case.

4.7 INSTANCE USING AN EXPONENTIAL BIVARIATE DISTRIBUTION

In this section we analyze the differences in cost or revenue between the scenario of common information (scenario 2) and the scenarios where some information is not available (scenarios 3 to 5). Demand and spot market price follow a bivariate exponential distribution with $\mu_x = \mu_p = 2$ and variances $\sigma_x^2 = \sigma_p^2 = 4$. We initially set the correlation coefficient at $\rho = 0.5$. In the first subsection, the shipper's cost function is presented in the common information scenario; the results are analogous for the carrier. We then present in the three following subsections the differences between the cost function of the shipper and the revenue function of the carrier under the different information scenarios.

We use the bivariate exponential presented in appendix C.12 and the algorithms developed in Brusset and Temme (2007) suitably adapted to our needs as presented in appendix C.11.

4.7.1 *Evaluating the shipper's cost function in scenario 2*

We first present some results for the evaluation of the shipper's cost function so as to understand the changes wrought by other information scenarios.

Over $\Omega 1$, the demand which the shipper requires the carrier to transport comes from the well known newsvendor solution. Let $S(q)$[10] be the

10 See definition of $S(K)$ in §2 of Cachon and Lariviere (2001).

expected demand given capacity q. Given the cdf of demand $F_X(.)$, $S(q)$ can be written as:

$$S(q) = q - \int_0^q F_X(x)dx \tag{4.6}$$

So on $\Omega 1$ the cost to the shipper and the revenue to the carrier becomes:

$$R_1(q) = O_1(q) = r + sS(q). \tag{4.7}$$

We are not interested here in determining the optimal level of the minimum quantity commitment q of the contract as this is a matter which is covered in chapter 5.

We represent the resulting overall cost to the shipper using some characteristics as fixed: $r = 0.5$, $s = 0.5$, $\theta_s = \theta_c = 1$, $\rho = 0.5$. When q varies for different values of q_a in figure 20, we see that when q increases, the overall cost decreases given that s is low compared to $\mu_p = 2$. The impact of the additional capacity adds to the overall cost.

In figure 21, the minimum requirement q is considered set at $q = 2$, which is the expected demand (and corresponds to the commitment which coordinates the dyad given that the shipper has to signal her expected demand as shown in Cachon and Lariviere (2001)[11]. In this graph, one can see that the additional capacity has more influence over the total cost than the price p_a alone. However, after a certain level, the overall cost does not change much more.

In figure 22, the five curves represent the way in which the overall cost to the shipper reaches a minimum for some combinations of additional commitment with the price p_a. In each case, the penalties is set at $p_a/2$.

The figure 23 shows how important the correlation of spot market prices and the demand addressed to the shipper is to the overall cost of transport for the shipper even when she has in place a contract which covers twice the expected demand. Here $q = 2\mu_X$, $p_a = \mu_P + 0.1$ and $q_a = \mu_X$, the overall cost to the shipper in a scenario with common information, penalties set at $\mu_P/2$, goes from 1.53 to 3.38. This tends to show that if a shipper facing possible disruptions in the transport industry is not prepared, she can be saddled with considerably higher transport costs than she bargained for[12].

4.7.2 *Numerical instance: private information about capacity vs common information (3-2)*

Let us look at the case of private information about capacity as opposed to common information and evaluate the required optimal contract parameters.

We see that when $q = 2$ and the penalty to the carrier $\theta_c = 1$, the cost overrun for unknown information about capacity of the carrier at first

11 See also section 5.3.3 on page 102.

12 A typical example of disruptions in the transport market is the behaviour of spot market prices as exhibited by the Baltic Exchange Dry Index which reflects the volatility of the dry bulk shipping market as studied in Jing et al. (2008) and which is graphically illustrated in the figure 1 on page 19.

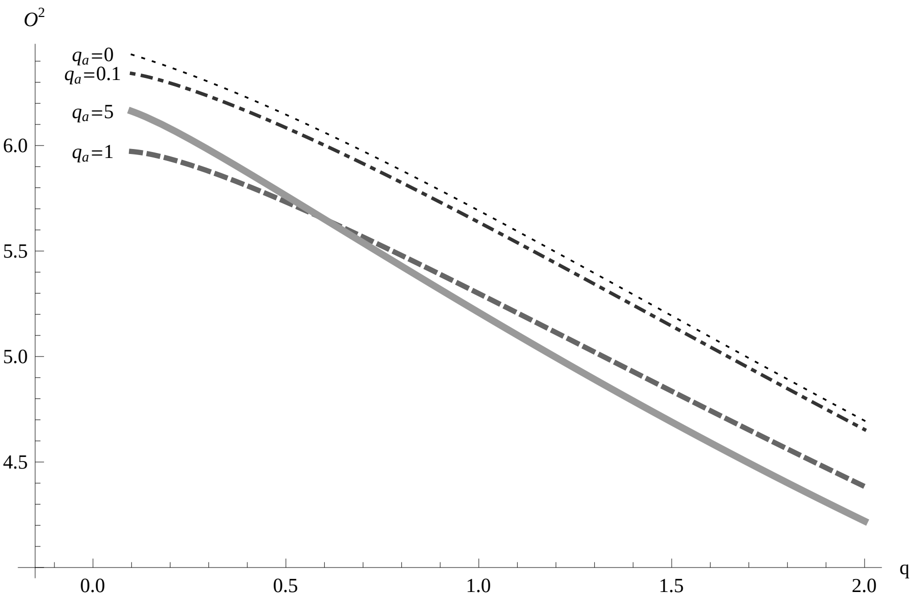

Figure 20: Scenario 2: Shipper's cost when $r = 0.5$, $s = 0.5$, $\rho = 0.5$, $p_a = 2.1$ and penalties set at 1 in terms of q and q_a

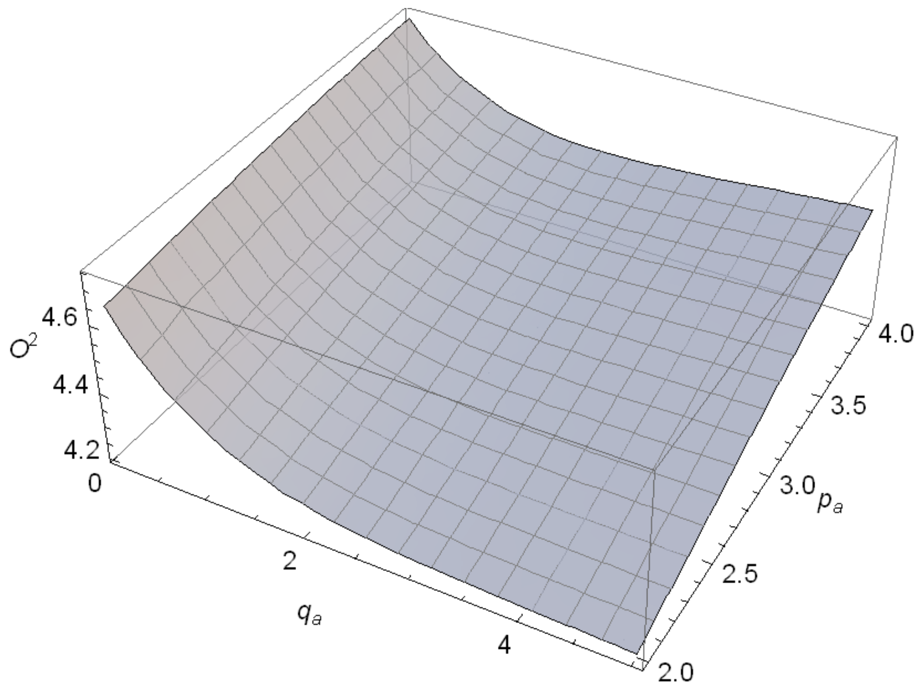

Figure 21: Scenario 2: Shipper's cost when $r = 0.5$, $s = 0.5$, $q = 2$ $\rho = 0.5$, and penalties set at 1 in terms of q_a and p_a

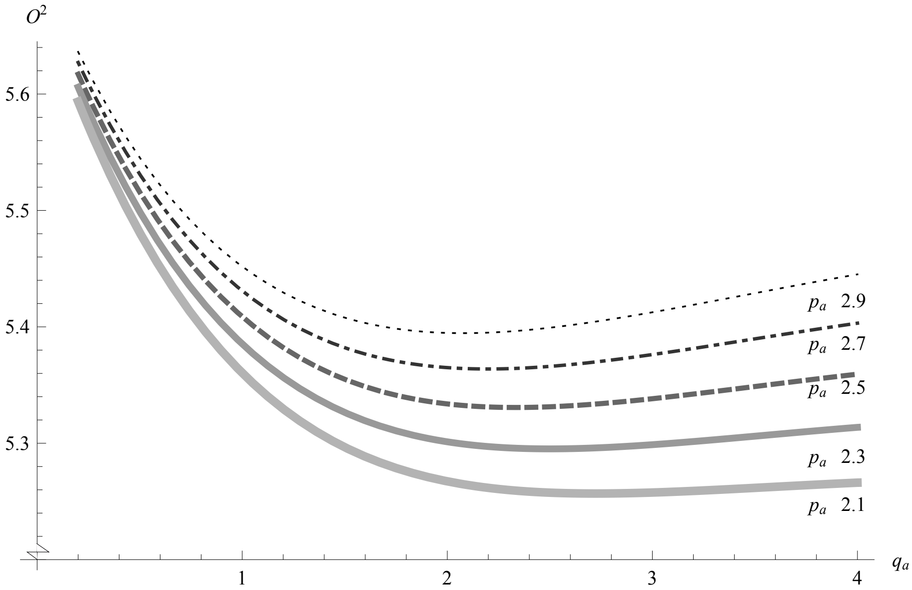

Figure 22: Scenario 2: For price p_a in $\{2.9, 2.7, 2.5, 2.3, 2.1\}$ and penalties set at 0.8 the optimal commitment increases.

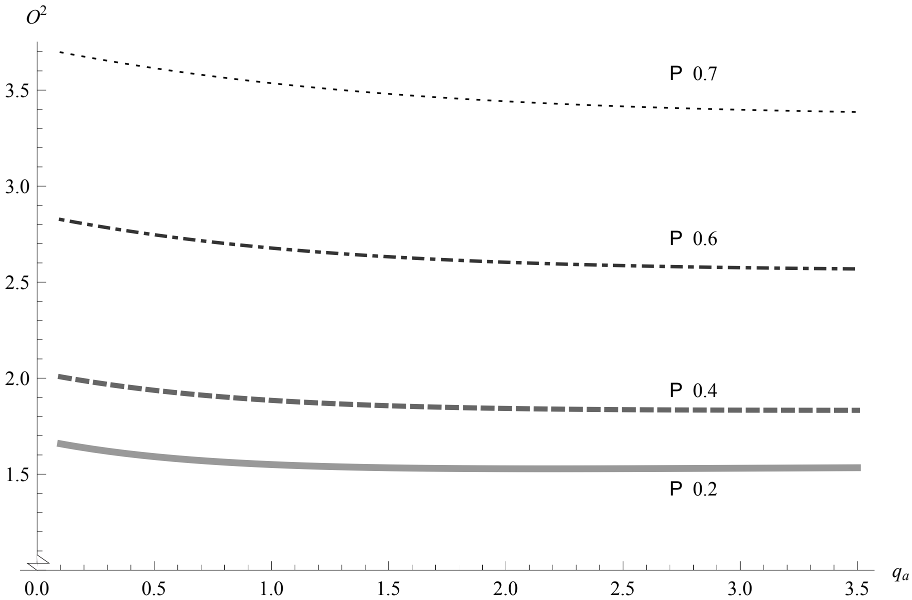

Figure 23: Scenario 2: Cost to shipper for different levels of the correlation coefficient with $r = 0.5$, $s = 0.5$, $q = \mu_X$, $p_a = \mu_P + 0.1$, $\theta_s = \theta_c = \mu_P/2$.

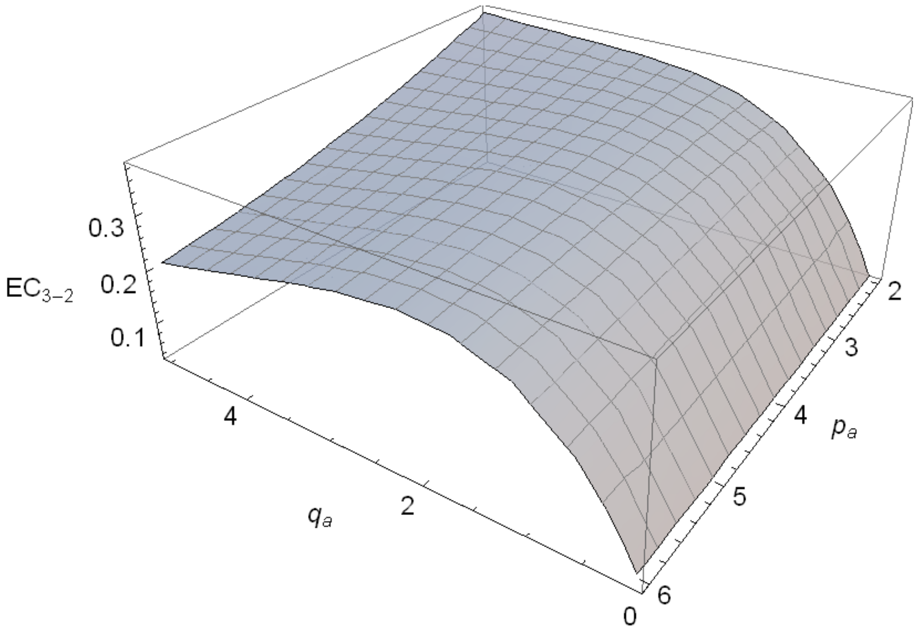

Figure 24: Scenario 3 - 2: cost to the shipper when $q = 2$, $\theta_c = 1$ in terms of q_a and p_a.

increases with q_a before leveling off and decreases slightly with p_a (in figure 24) or increases with q_a and penalty θ_c (in figure 25), as would be expected. If in doubt as to the truthfulness of the carrier, the shipper should try to increase the size of the additional capacity rather than the price for this capacity and keep the penalty at a minimum (as it is not very useful).

An interesting observation is that if demand and spot market prices are decreasingly correlated, the lack of information about available capacity proves increasingly irrelevant, whatever the level of q_a. However, if q_a is set "high" an increasing correlation coefficient has multiplying effects (see figure 26), whatever the level of the penalties (a graph representing the same parameters but with varying penalties is not presented here but testifies to this).

In conclusion, one can observe that the possibility of concealing idle capacity from the shipper induces a rent transfer from the shipper to the carrier. The correlation coefficient between demand and spot market prices is a factor which has a large influence on the expected outcome whatever the level of additional capacity and penalties set in the contract.

4.7.3 *Numerical instance: private idle capacity and demand vs common information (4-2)*

Here are the evaluations of the contract parameters in the case of private information as to demand and capacity. The graphs support the intuition of a rent transfer in detriment of the shipper as can be gathered from the figures presented here (see figures 27 and 28). The effect of lack of information can somewhat be mitigated for the shipper by increasing substantially both q_a and p_a. When the correlation factor increases, once

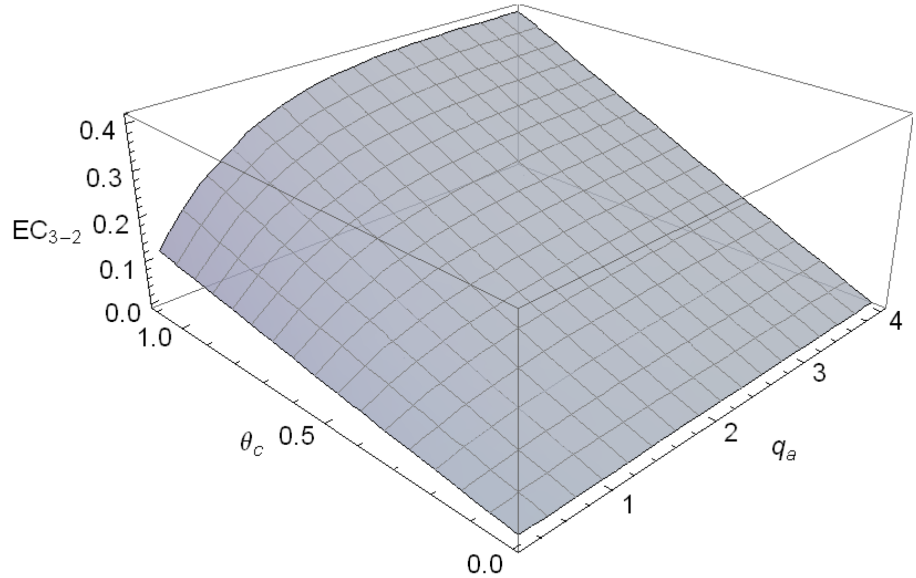

Figure 25: Scenario 3 - 2: cost to the shipper when $q = 2$, $p_a = 1.2$ in terms of q_a and θ_c.

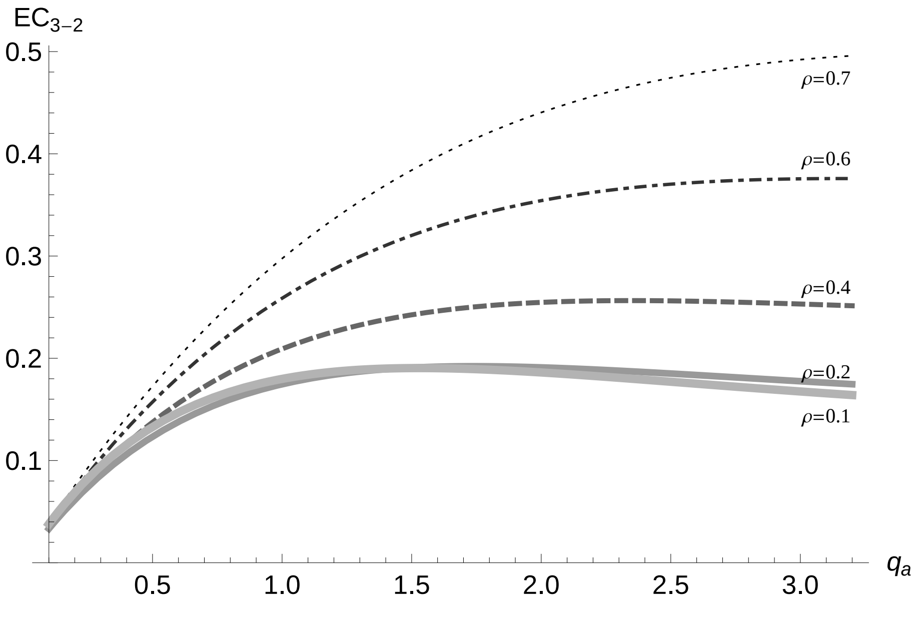

Figure 26: Scenario 3 - 2: increase in cost overrun for fixed q, p_a and penalty in q_a when ρ increases.

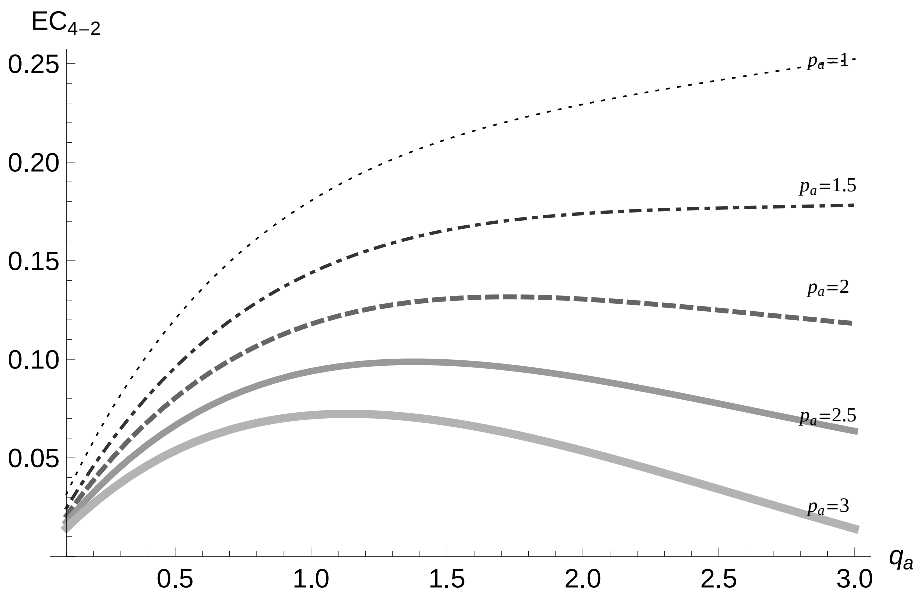

Figure 27: Scenario 4 - 2: extra cost to the shipper when $q = 1$, $\theta_c = \theta_s = 0.5$ in terms of q_a and p_a.

again we observe an increase in the cost to the shipper. This increase is exacerbated the higher q_a is set.

Of course, it stands to reason that the increase in the additional capacity contract parameters has to be set bearing in mind the information cost incurred if the shipper wishes to ascertain the exact capacity available during the contract. If the cost is low, the logistics manager will prefer to incur this cost rather than pay more through the contract prices. The carrier in turn knows this and will adopt the corresponding behaviour.

4.7.4 *Numerical instance: private demand vs common information (5-2)*

Finally, we investigate the case of *S* keeping realized demand private. This enables her to engineer a rent transfer to the detriment of the carrier: the cost in scenario 5 is *less* than in scenario 2. As is to be expected, this is exaggerated for higher p_a (see figures 30 and 32). However, as can be seen in figure 32, when q_a is set above certain levels, the shipper can not benefit from the value of the demand information and, indeed, the cost to her is even higher than in the common information scenario, which is counterproductive. The maximum rent transfer when $\theta_s = 1$ and $q = 2$ occurs for a "high" price $p_a = 2.5$ relative to the mean spot market price but with a moderately sized extra capacity $q_a = 1.25$.

When we consider the correlation coefficient of demand and spot, we see here again that if both are strongly correlated, the increase in q_a enables the shipper to increase the rent transferred to her as compared to the full information scenario. On the other hand, if demand and spot are barely correlated, a counterintuitive result appears. The carrier is better off by aiming for a high q_a as he manages to reverse the rent transfer in his favour (see figure 33).

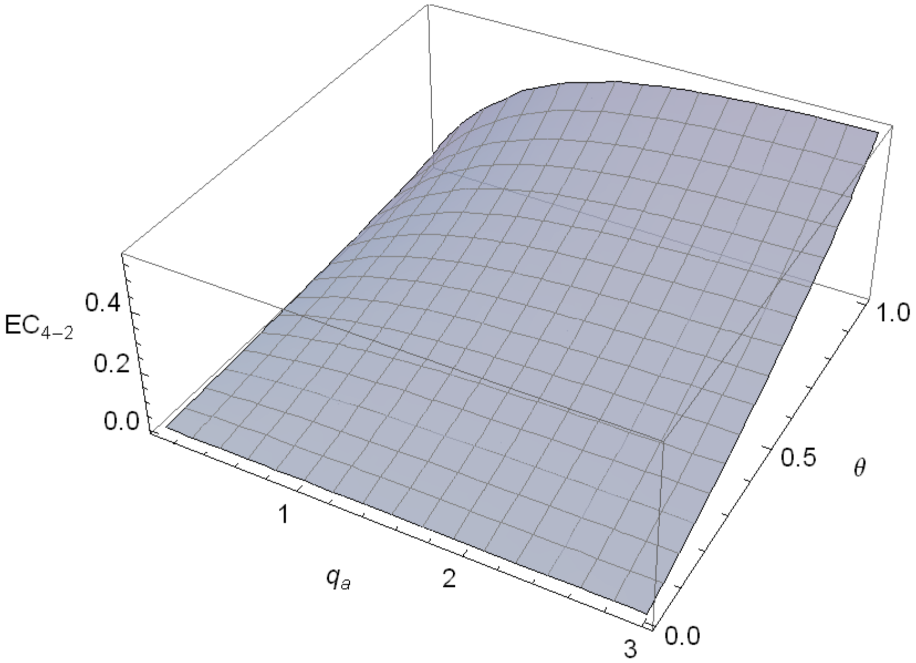

Figure 28: Scenario 4 - 2: extra cost to the shipper when $q = 1$, $p_a = 1.2$ in terms of q_a and $\theta_c = \theta_s$.

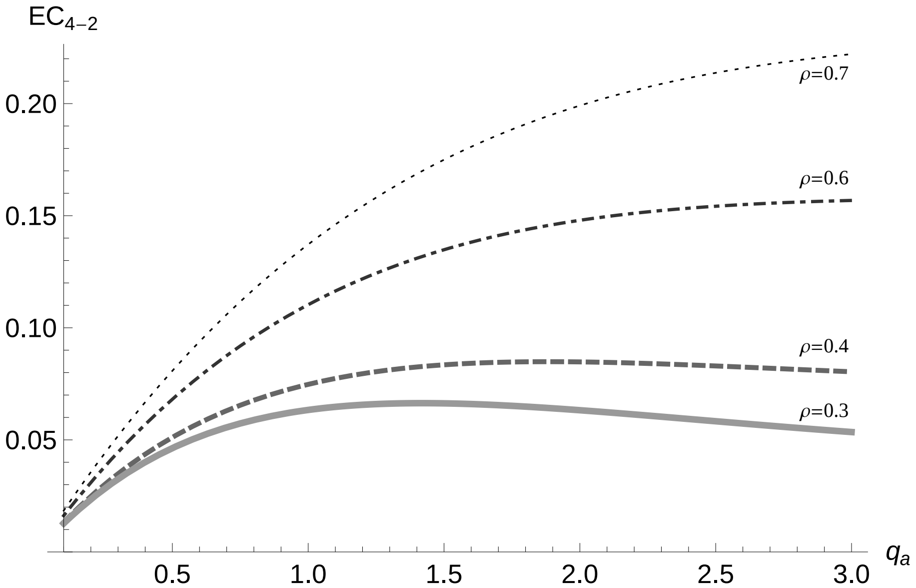

Figure 29: Scenario 4 - 2: increase in cost overrun in q_a for fixed q, p_a and penalty when ρ decreases.

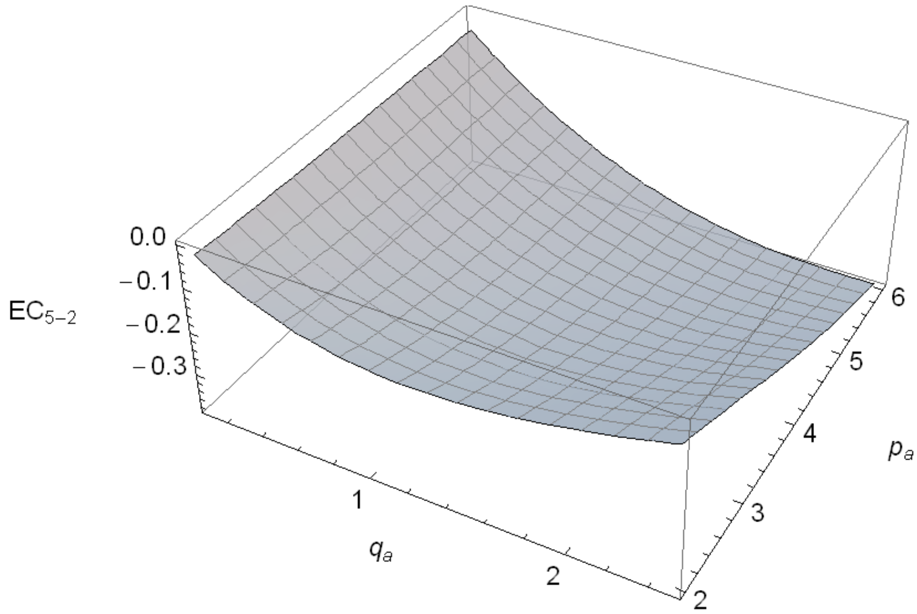

Figure 30: Scenario 5 - 2: rent transfer in favour of the shipper when $q = 2$, $\theta_s = 1$ in terms of q_a and p_a.

Let us again state here the obvious : namely that the carrier will compare the information cost to the rent he is liable to lose because of this asymmetric information. He will adapt his contractual offers accordingly and the shipper, knowing the information cost to the carrier, will also adapt his behaviour.

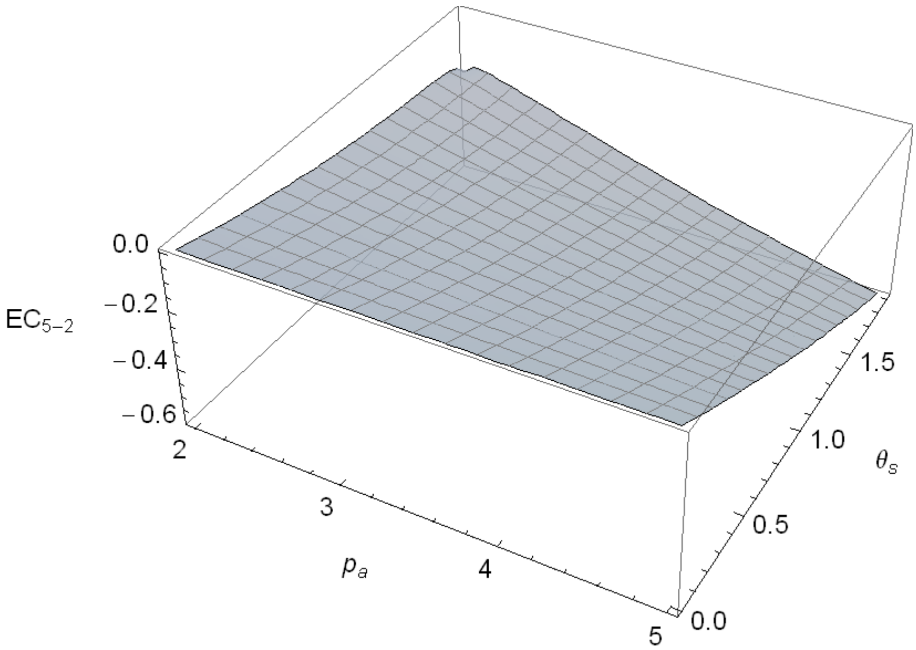

Figure 31: Scenario 5 - 2: rent transfer to the shipper when $q = 2$, $q_a = 2$ in terms of p_a and θ_s.

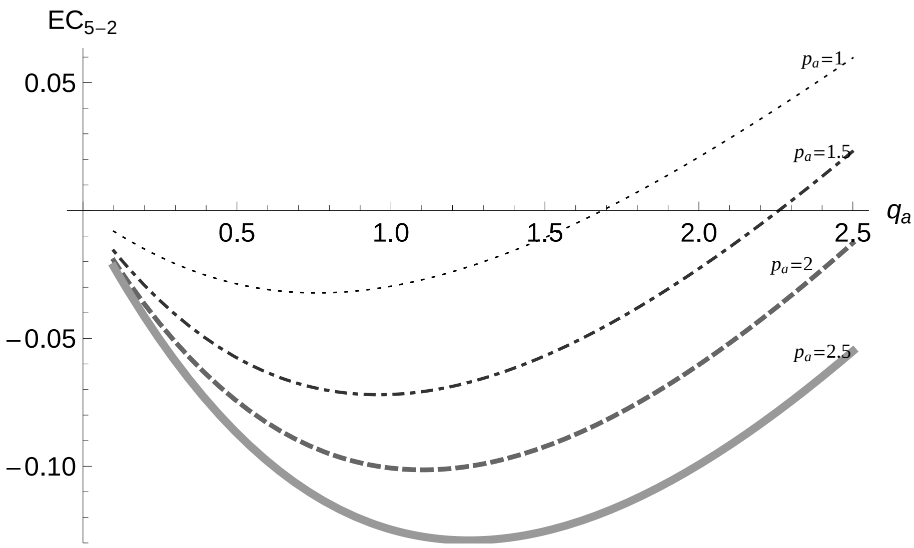

Figure 32: Scenario 5 - 2: rent transfer to the shipper when $q = 2$, $\theta_s = p_a/2$ in terms of q_a when $p_a \in \{1, 1.5, 2, 2.5\}$.

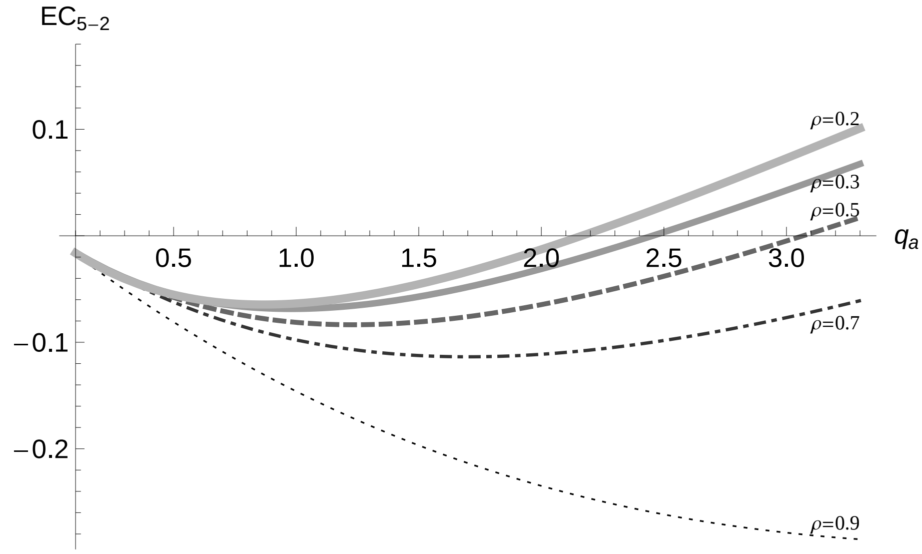

Figure 33: Scenario 5 - 2: rent transfer to the shipper when $q = \mu_X$, $p_a = \mu_P + 0.1$ and penalty $\theta_s = \mu_P/2$ in terms of q_a and ρ.

4.8 CONCLUSION

In this chapter, we point out how transport management as it is practised in road transport for bulk and commoditized goods can lead to disappointing results when information about demand and available capacity is difficult to obtain. The present model is an exaggeration of prevalent behaviours to serve two purposes: (a) to present some contractual tools which mitigate the impact of asymmetric information, (b) to enable decision makers to compare the loss induced by the absence of information and the cost of collecting such information.

Through the model of a stylized contract in short-term rent sharing, the impact and influence that asymmetric information has on the revenues of the carrier and on the cost to the shipper have been quantified. The results show that according to which party can behave opportunistically, rent is being shared differently[13]. The model, however, does not evaluate the overall performance or efficiency of the dyad within the supply chain. We have shown how a type of contract which can coordinate both members of the dyad when information is common has substantially different outcomes when either or both can behave opportunistically.

According to the distribution of demand and spot market prices, the model enables both actors to set parameters so as to reduce two types of risk : the risk of the available capacity of the carrier not being used and of the shipper's transport capacity requirement not being met. The two players evaluate the impact of information asymmetry and hence compare it with their respective monitoring cost. In turn, each party's information cost can be evaluated by the other party and taken into account when negotiating the terms of the contract as well as when deciding to behave opportunistically.

13 Note that this rent sharing does not affect the efficiency of the dyad since production and sales are identical under all information scenarios.

If information about available capacity or available demand is cheap to obtain, the potential victims of opportunistic behaviour will prefer paying this cost rather than tweak the contract parameters to protect himself. This limits the ranges of the contract parameters even when demand and spot market prices are highly correlated.

It has been established that:

1 – In all cases of asymmetric information, the shipper suffers from increased variance of her cost and the carrier of his revenue.

2 – If information about available capacity or about exact realized demand are not known to the other party, we offer some parameter sets in the contract which can be implemented so as to mitigate this information asymmetry.

3 – When information about demand and available capacity are private to each actor, only "forced compliance" contract (Cachon and Lariviere, 2001) will enable coordination.

4 – The numerical example points out that when demand and spot price are highly correlated, the asymmetry of information is detrimental to the uninformed player. His best recourse in this case would be to go for a "forced compliance" contract.

5 – The information imbalances induced by keeping private information as to the real transport capacity by the carrier, and as to the real demand received by the shipper affects rent sharing, because it encourages shirking on the carrier's and/or the shipper's part and hence induces a rent transfer and increases overall revenue or cost volatility. The exact cost of these two types of information asymmetry can be calculated for any distribution of spot price and of demand, whether correlated or not.

6 – Evidence from the numeric instance presented in Section 4.7 shows that the correlation coefficient between spot market price and demand must be taken into account when setting up the contract parameters in presence of asymmetric information. The higher the correlation coefficient, the higher the probability of opportunistic behaviour. However, when the demand and spot market are decorrelated, the lack of information does not pose a significant risk. Both parties should however monitor the evolution of this coefficient. The recent behaviour of the spot market price of dry bulk cargo as monitored by the Baltic Exchange (see figure 1 on page 19) would tend to show that the demand and spot price have witnessed increased correlation between 2003 and 2010. Extreme prices in 2008 have been often said to be the cause of unscrupulous shipping lines withholding ships from the market. The posterior economic crisis has been invoked by some shippers for reneging on cargo commitments, thus causing several shipping lines severe financial damage (Wright, 2009).

5 CHOOSING A CONTRACT OVER MULTIPLE PERIODS

5.1 INTRODUCTION

IN THIS CHAPTER, we wish present a model[1] which bounds the rent sharing exercise between shipper and carrier using the endogenous choice of contracts when a shipper faces unknown future transport requirements and unknown future spot market prices for transport. The proposed model provides a profit-maximizing carrier and a budget-optimizing shipper with guides to a mutually agreeable contract and its corresponding parameters. The model is a repeated game exercise: at set points in time they reopen the contract and a new negotiation starts. Negotiations can break down which does not impede both players to work again at a future time. Two of the three contracts studied have been proven to coordinate the dyad of shipper and carrier within the supply chain. The third one, alos named the single-price relational contract, has been included because of its prevalence in transport contracts. We provide a set of algorithms to allow the comparison of the outcomes of each contract when demand and spot market prices for transport are stochastic stationary processes.

We investigate the conditions of emergence of an agreement and ensuing rent sharing.

The interest of the present model and its conclusions is both to give practitioners guidance as to which of the three contracts should be chosen when demand and prices for transport on the spot market fluctuate and, on the other hand, to provide a basis for future research into mechanism design in the contract literature applied to transport. In the experience of the author, even a company distributing frozen fruit over Europe which has to rent additional storage capacity from third party warehouses to face seasonal peaks can also take advantage of this model[2]. When available storage capacity over Europe is scarce because unsold frozen food piles up, should this company rent additional storage for the short term (spot market) or make a long term arrangement, and if so, at what type of conditions?

Three types of contracts are compared: **Price Only Relational Contract (PRC)** which we will abbreviate in the following as PRC; **Minimum Purchase Commitment (MPC)** over a single period; and the **Quantity Flexibility Clause (QFC)** over several periods.

In §5.2 we review the relevant literature, in §5.3 we explain the model, in §5.4 we present the equilibrium parameters when each contract is taken in isolation and then we present the new equilibria when the actors have the

1 An earlier version of this work which presents substantially the same results has been published in Brusset (2009a).

2 After all, storage is a service performed by logistic service providers and cannot be back-ordered.

choice of the contract. In §5.5 three numerical examples are presented to enable the reader to understand how this choice of contracting mechanism works. In the third example we look at how a shipper who decides to procure all his transport requirements from the spot market would fare and compare the variance of the ensuing objective functions. We present our conclusions and managerial insight in §5.6.

5.2 LITERATURE REVIEW

As most of the relevant literature about the contracts and general framework studied in this chapter has been presented in chapter 2, we present and discuss below the literature whose results bear closer relation to the subject at hand.

Spinler and Huchzermeier (2006) models an option pricing menu consisting in a reservation price and an execution fee ahead of revelation of demand. This option on capacity problem bears close resemblance to the setting which we will use in the present chapter as the Minimum Purchase Commitment contract. There are two differences. One is that here the buyer *must buy* from the seller the contracted quantity, even when the spot price is lower than the variable fee that she pays for each effectively bought unit (alternatively, realized demand is instantly and freely observable by the carrier). The other difference is that in Spinler and Huchzermeier (2006), the buyer can decide to backlog his requirements if the spot price is too high, which is not the case here: the buyer *always* serves exogenous demand addressed to her and consequently has to buy the equivalent transport capacity, either from the carrier or from the spot market.

A hypothesis in Spinler and Huchzermeier (2006) which has not been observed in the environment of transport is that the market for transport capacity is deemed to be always in a state of sufficient liquidity. The seller, in our case the carrier, is deemed to be always in a position to sell options to buyers in quantities consistent with his available capacity. This understates the risk to both seller and buyer of not finding a counterparty on a regular basis.

The model in Spinler and Huchzermeier (2006) assumes that information is costless. This understates the actual discovery and transaction costs. This cost of information is explicitly modeled here.

The states of the world being envisaged in Spinler and Huchzermeier (2006) include the exogenous risk faced by the buyer or the seller of not being able to find a counterparty in the spot market. This risk of not finding a *buyer* is being modeled as a random variable monotonically *decreasing* in the spot price[3].

This last random variable makes the model in Spinler and Huchzermeier (2006) a model based on a *four-dimensional* state of the world: demand, costs, spot price and a spot market risk factor. These variables

3 Issue must be taken here to this way of modeling of market liquidity. As has been observed in spot markets for very different types of commodities from financial futures to raw commodities to electricity to transport capacity, market disruptions exist which are sufficiently frequent even in the most liquid and transparent markets as to render such modeling of reality too simplistic.

are considered to evolve in a joint direction together with "economic conditions". But the four variables are considered to be linearly linked and thus the complexity of the model is reduced to just one dimension.

A principal difference with this model is that we assume statistical correlation only between demand and spot market price. We believe that the present model is more realistic in the interaction between seller and buyer in the spot market even when neither have an influence on it.

In the following, an attempt is made to better integrate reality of the spot market for transport capacity and of the relationship between carriers and shippers.

5.3 Description of the Model

Repeated game with bivariate output demand and input price

The shipper (termed a "she" as in the preceding chapters) has to satisfy transport for her product and to do so must buy transport services either from a carrier through a prior arrangement or from a spot market. Remember that transport, as a service, cannot be stocked and has no salvage value if unused. One unit of transport capacity used corresponds to one unit of product carried. The shipper's residual demand not covered by the long-term contract is resolved by buying additional transport capacity either from the carrier at the going spot market price or from the spot market in which case the shipper incurs a fixed discovery cost. The spot market is the place where excess demand and excess transport capacity meet and transactions take place at fluctuating prices which usually clear the market. The potentially remaining unused capacity is considered as lost and the remaining transport demand is rescheduled for the following day. A necessary condition for the existence of a spot market is the existence of standardized capacity and demand[4].

We assume that the shipper must satisfy an exogenous stochastic demand X_t, i.i.d. for each integer value of time t, that is a stationary process whose probability distribution is at least a twice differentiable unimodal distribution $F_X(X)$ on a support $[0, Q_{Hi}]$ with $0 < Q_{Hi}$ and density $f_X(X)$, mean μ_X and variance σ_X^2. The spot market price for transport capacity is also assumed to be an exogenous stochastic variable P with analogous characteristics (P, $F_P(p)$, $f_P(p)$, μ_P, σ_P^2) and taking values in the interval $[v, P_{Hi}]$ with $0 < v < P_{Hi}$, v being the variable marginal transport cost common to all carriers and P_{Hi} being a large value compared to μ_P. In the same way, let us call F the continuous, twice-differentiable *joint* unimodal distribution and f the *joint* density function of P and X with mean μ, variance σ^2 and correlation coefficient ρ, $(0 \leq \rho \leq 1)$[5]. Demand and spot market are assumed to be positively correlated due to supply-demand effects. Note that there may exist realizations of high

4 This is the case for example for non-dangerous palletized products and tautliners: Loads or trucks can be exchanged among themselves.

5 This situation can be contrasted with Spinler and Huchzermeier (2006), Kleindorfer and Wu (2003) where demand is an inverse function of the spot price, but is similar to the setting in Seifert et al. (2004).

demand and low spot prices as well as low demand with high spot prices[6]. In addition, we shall also present a case where spot market price is fixed and demand is the only random variable.

Asymmetric information about demand and utility functions

Only the shipper knows the parameter μ_X and can estimate the transport capacity she will require. By applying the negotiation process outlined in appendix A.1, we consider that the carrier can make an estimate of expected demand μ_X.

The shipper's utility function is private to her. The carrier is private to his own costs and other opportunities. He needs credible information about the capacity that the shipper expects to require so as not to commit more transport capacity than necessary, even though we have not modeled any limit to his existing capacity.

The revelation of demand is observed by both shipper and carrier. We assume that the maximum possible demand that the shipper may conceivably ask to be transported is limited to Q_{Hi}. This limit is assumed to be common knowledge. On the other hand, the information about the spot market price, mean, variance and distribution is assumed to be instantly observable by both. The spot market is not well organized so information about available loads or capacities is sparse and spot market counterparty discovery is assumed to be costly, in difference with models in Spinler and Huchzermeier (2006), Kleindorfer and Wu (2003), Seifert et al. (2004), Wu and Kleindorfer (2005). To access this information, a shipper who wishes to use this spot market incurs a fixed cost I per period. This is not the case of the carrier whose business it is to sell in this spot market in every period his potentially remaining idle capacity once all his customers have been served.

The carrier has only one technology at his disposal and hence his production facility is homogeneous, which simplifies fixed cost attribution. Capacity is shared among all his customers, minimizing risk of capacity under-usage by pooling it.

The model represents here the carrier as enjoying *unlimited capacity*. In reality, this type of carrier usually is a third-party logistics operator who just out-sources transport requirements to a vast number of owner-operated trucks or a trucking company calling up extra capacity from sub-contractors or other trucking companies when faced by demand in excess of his available fleet capacity.

As in transportation models, no storage, holding or shortage costs are incurred for the transport capacity by the carrier. The supply lead time is normalized to zero.

Our model is of more general application than the one exposed in Seifert et al. (2004) because that paper models market spot price and demand as a Bivariate Normal Distribution only.

6 In contrast to the assumptions underlying the model in Spinler and Huchzermeier (2006).

Prior mutual selection of shipper and carrier and cost thereof

The shipper and the carrier have selected each other either through previous transport experience or because the carrier has been selected through an active search among potential carriers by the shipper. The carrier has also been active in soliciting the business of the shipper. This type of relationship is known in the marketing literature as "relationship marketing" as presented in Knemeyer et al. (2003) and references therein. According to the field study in Knemeyer et al. (2003), logistics outsourcing involves investments in specific assets and non-retrievable commitments of resources by both partners. We assume that each new relationship requires an investment in a new specific asset with a fixed cost. Such cost constitutes an incentive to limit the number of counterparties. In effect, this induces both parties to play together game after game inasmuch as their individual rationality constraints in each game are satisfied. The development in chapter 3 gives further justification to relationships based on specific assets.

N games of two-stage decision processes

There are N games to be played if no contract is ever broken, N being a finite number representing the long term decision planning horizon. To make this notion more tangible, consider that shipper and carrier wish to work together for 5 years ($N = 5$) and that they wish to open a renegotiating process every year. To satisfy demand addressed to the shipper, the players face a two-stage stochastic decision process within each game. In the first stage, they have to set up a transport arrangement whereby the shipper gets a privileged access to a certain transport capacity and the carrier ensures use of a certain amount of his overall capacity. In the second stage, the two actors operate according to this arrangement given the realizations of demand and spot market price. At the end of the second stage, payout occurs and the game is finished.

Let us now look in detail at how the first stage works.

The carrier offers the shipper a menu of contracts and corresponding price and capacity parameters in accordance with the negotiating process described in appendix A.1. If both select the same contract and agree on the contract terms, then the first stage is over, the second can then start (see figure 34 on the next page).

The second stage extends over n periods. In each period from t_1 to t_n (say every working day of the year, in which case, taking our earlier example of the multi-year agreement, $n = 251$), i.i.d. demand and spot price are revealed to both shipper and carrier and the shipper buys transport capacity from the carrier according to the terms of the contract to meet the demand addressed to her. In each period, if the revealed demand exceeds committed capacity, both shipper and carrier refer to the going spot market price at which this remaining demand is to be carried. Delivery and payout occur in the last period, the game stops, a new negotiation process can start.

We propose here to restrict our comparison to a closed set of mechanisms, with no renegotiation within a game and with contracts that are

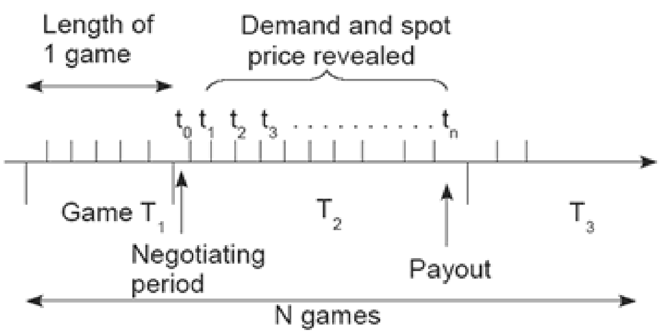

Figure 34: N games with $n+1$ smaller periods in each.

not contingent on one another. So the shipper has the choice among three contracts with a set of contract parameters and not signing a contract.

If a contract and associated parameters are chosen, this stage is finished, the contract is signed and both start to operate within it: the second stage begins. In the case that both choose not to sign a contract, the first and second stage are considered over, the game ends. In the following period (the following year in our illustration), both can initiate new negotiations for a new game. This possibility represents the reservation profit level given outside opportunities. The carrier can allocate more transport capacity to some other customer (Corbett et al., 2004). In the same way, the shipper can decide to privilege another carrier within her pool of known carriers. In the following, we normalize the participation and individual rationality constraints for both at zero. Intertemporal relationship is still incentivized by the mutual initial investments by each player as presented in chapter 3.

Fixed and variable cost of the carrier

We consider here that the required capacity allocation, result of the strategic decision of the carrier to work with this shipper, takes into account the updated estimate of expected demand as obtained by the carrier through the negotiation process described in appendix A.1. All costs have been considered to be *aggregated* into a fixed cost K and a variable cost c, given the fixed capacity set by the carrier.

Spinler and Huchzermeier (2006) distinguishes between the marginal cost of production related to long-term contract-based capacity allocation and the marginal cost of production associated with short-term spot allocation. We assume, along with Spinler and Huchzermeier, that the marginal cost is lower for the contract than for the spot market. In Spinler and Huchzermeier (2006), both costs are assumed to increase in the state of the economy, a modeling artefact which has been eliminated by considering the marginal cost and the spot market to be independent. The carrier is an active participant in the spot market in his own right as he daily has to balance his transport requirements and available capacity. As they are independent of the transport requirement expressed by the shipper, the information cost and all other costs incurred while dealing in the spot market are considered as included in his fixed cost.

Shipper cost and budget

Before the start of the first game, the shipper knows the demand distribution parameter μ_X which defines $F_X(x)$, and which we interpret as her forecast of demand. The shipper has obtained from another carrier (non strategic player) an offer B proportionate to the expected demand and spanning the periods of a game for the same service which is the outside option against which the shipper will evaluate the carrier's offers. We consider without loss of generality that this offer B is net of the initial investment in specific assets that the shipper has to make if she wishes to work with this other carrier. She evaluates all the potential contracts and corresponding parameters against this third-party offer. We consider this option as the shipper's binding individual rationality constraint: her transport cost must be lower than this other offer or she simply turns to this outside option, whichever game we may be considering. In what follows, this expected difference shall be termed a "residual budget". The shipper's objective is to maximize it.

In the same way the carrier's individual rationality constraint must be satisfied: if an offer by the shipper does not cover his fixed and variable cost under the expected demand stemming from the signal sent by the shipper, he turns down the offer.

The table 18 on the following page lists all the notation in this chapter.

5.3.1 *Types of contracts*

Two of the three contracts chosen here, as mentioned in the literature review, represent contracts which can coordinate a shipper and carrier when information is asymmetric[7]. Here, in a key difference from other models, the process of buying transport capacity from the spot market is assumed to entail a higher cost than the one attributed to contract buying. This is to represent that information gathering, service quality and counterparty discovery all cost significantly more than the transaction cost involved in buying from the contracted carrier.

The objective maximizing functions are described in the following sections for the shipper and carrier under three settings : *price-only relational contract* (PRC), a *minimum purchase commitment contract* (MPC) and a contract with single price but with *quantity flexibility clause* (QFC).

5.3.2 *Price-only relational contract*

In this form of contract, the shipper's cost function varies linearly with the quantity to be carried:

$$V_1(x_t, p_r) = p_r x_t, \quad \forall t \in \{1, \ldots, n\} \tag{5.1}$$

7 Coordination is here seen as the power of a contract to induce both players into settling for the parameters of the contract which maximize the supply chain's profit, regardless of how this profit is shared between them (see Cachon, 2004b)

Table 18: Table of notations

Environment	Notation	Definition
demand	x_t	realization of demand in period t
	$f_X(.), F_X(.)$	probability and cumulated density functions of random v. X
	p_X	discrete marginal probability of demand
	μ_X, σ_X	average and standard deviation of demand
spot market price	$f_P(.)$	probability density function
	$F_P(.)$	cumulated density function
	μ_P, σ_P	average and standard deviation of spot price
bivariate spot	$f(X,P)$,$F(X,P)$	probability and cumulated density functions of bivariate demand and spot
and demand	μ, σ	average and standard deviation of bivariate
shipper	$B(.)$	Alternative transport cost function of n
	E_i^s	Expected profit function in contract i
carrier	β	capacity available to the shipper in any time period
	c, K	variable per unit and fixed per period production costs
	E_i^c	Expected profit function in contract i
spot market	I	information cost for spot market transactions
	v	common variable cost for all carriers ($v \equiv c$)
	p_t	spot price in period t
time	N	number of games (multiple of $n+1$)
	t_0	period within which contract is set up
	$t_1 \dots t_n$	n periods of *any* contract
PRC	p_r	linear price per unit
MPC	r	fixed fee paid in each t
	q	capacity commitment per period t
	s	variable per unit per period fee
	$\varphi^s(q)$	$\frac{1}{\overline{F}_X(q)} \int_v^{P_{Hi}} \int_q^{Q_{Hi}} (x-q) y f(x,y) dx dy$
	$\varphi^c(q)$	$\frac{1}{F_X(q)} \int_v^{P_{Hi}} \int_0^q (q-x)(y-c) f(x,y) dx dy +$ $\frac{1}{\overline{F}_X(q)} \int_v^{P_{Hi}} \int_q^{Q_{Hi}} (x-q)(y-c) f(x,y) dx dy$
	$\mu_X(q)$	$q - \int_0^q F_X(x) dx$
QFC	n	number of periods in contract
	α	variable per unit per period fee within total commitment β
	θ	penalty paid per unit for unused commitment
	β	planned commitment over n periods
	Y_n, f_{Y_n}	$\sum_{i=1}^n X_i$, probability density function of Y_n
	$g_1(\beta, n)$	$\frac{1}{F_{Y_n}(\beta)} \int_0^\beta u f_{Y_n}(u) du$
	$g_2(\beta, n)$	$\frac{1}{\overline{F}_{Y_n}(\beta)} \int_\beta^{QY_{Hi}} u f_{Y_n}(u) du$
	$\Psi(\beta, \theta, n)$	$\theta\big(\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta, n)\big) + \mu_P\big(g_2(\beta, n) - \frac{\beta)}{\overline{F}_{Y_n}(\beta)}\big)$

where p_r is the negotiated single price ex-ante and x_t is the realized demand in period t. The carrier's objective function is the profit function

$$\pi_1(x_t, p_r) = p_r x_t - c x_t - K, \quad \forall t \in \{1, \dots, n\}. \tag{5.2}$$

In this type of contract, the shipper does not signal any demand forecast and the carrier cannot make an educated decision on the capacity to allocate to the shipper's requirements. The downfall is that the shipper cannot be sure that the carrier will always satisfy all her transport capacity requirements.

It must be noted that, if the shipper's cost of accessing the spot market $I = 0$, the price which makes the contract eligible as compared from sourcing the shipper's transport requirements exclusively from the spot market would be $p_r = \mu_P$, the mean spot market price,

In the general case, we spell the expected residual budget or profit at both firms as

$$\begin{aligned} E_1^s(p_r) &= B - \mathbb{E}(\sum_{t=1}^{n} V_1(x_t, p_r)) \\ &= B - n p_r \mu_X; \end{aligned} \tag{5.3}$$

$$\begin{aligned} E_1^c(p_r) &= \mathbb{E}(\sum_{t=1}^{n} \pi_1(x_t, p_r)) \\ &= n\left(p_r \mu_X - c\mu_X - K\right); \end{aligned} \tag{5.4}$$

with superscript c for the carrier, s for the shipper and $\mathbb{E}$ the expectation sign.

Some mention must be made here as to the choices available to the shipper and carrier. If the shipper enjoys a cost of information about available capacity in the spot market equal to 0 ($I = 0$), then her choice *ab initio* is to take her transport requirements to the spot market or to the carrier, which if she hadn't incurred any specific asset related costs in the first place, would mean that the cost p_r of the PRC would be reduced to the mean of the spot market price μ_P:

$$p_r = \frac{1}{\mu_X} \iint XPf(X, P)dXdP.$$

In fact, it is a better representation of reality to model a positive cost of information and a positive search and specific asset investment amortization cost that the shipper incurs in procuring her transport capacity requirements. In the following, we shall consider that both these costs are not null for all transactions involving a contract: PRC, MPC or QFC.

By the individual rationality and participation constraints, we must have jointly

$$\begin{aligned} B - n p_r \mu_X &\geq 0 \\ n\left(p_r \mu_X - c\mu_X - K\right) &\geq 0. \end{aligned} \tag{5.5}$$

The following condition follows directly from the above.

Condition 1. ***Conditions for a PRC***
For the PRC to exist and be eligible by both carrier and buyer, the chosen p_r must meet the following participation constraints:

$$c + \frac{K}{\mu_X} \leq p_r \leq \frac{B}{n\mu_X}. \tag{5.6}$$

Save for the trivial case where the carrier's costs are higher than the buyer's outside opportunity, the above proposition admits a non-empty set of values apt to satisfy both players.

Remark 23. *The result which is presented does not solve the rent distribution problem. Bargaining power attribution would do so. This remark is applicable to all posterior conditions. The point is more to present how the endogenous choice of contract constricts the participation constraints rather than establishing the actual rent distribution result.*

Remark 24. *The carrier's participation constraint here makes use of the expected demand, of which the carrier is uninformed. In the case of exogenous choice of contact, the carrier would have to estimate this expected demand. The minimum price which he would be prepared to accept would be inversely correlated to the estimate of demand to be carried because of the fixed cost K. For example, a carrier who expects the shipper to face low demand would be offered a higher price than one who is expected to face high demand. A shipper considered to be of a low-demand type pretending for a low price would be turned down.*

Remark 25. *The real use of this condition is when the contract can be chosen among several contracts. As described in A.1, the carrier can use a mechanism based upon the MPC to narrow the estimate of the expected demand.*

Remark 26. *The contract does not coordinate the participants: the shipper transfers to the carrier the demand variance risk (Lariviere and Porteus, 2001). This effect may induce the "double marginalization" effect first noted in Spengler (1950) because the carrier might protect himself by pretending for a higher price and might also restrict capacity when the shipper asks for too much. The carrier and shipper would be coordinated if the price were a convex function of demand (Cachon and Lariviere, 2001) which is not the case here.*

5.3.3 *Minimum purchase commitment contract*

The minimum purchase commitment consists in a *fixed fee r* that the shipper agrees to pay the carrier at each of the *n* periods within the contract, a capacity commitment *q* and a *variable fee s* for each unit effectively carried in the period[8]. The fixed fee is paid whether the shipper takes delivery of the committed transport capacity or not. This type of contract plays two roles: convincing the carrier that her future requirements are

8 This contract is on purpose very similar to the option contract presented in Spinler and Huchzermeier (2006).

genuine and inducing him to reserve adequate capacity so that he will not fail her.

This is very similar to the Supply Chain Management (SCM) model presented in Cachon and Lariviere (2001) for the price-only contract, voluntary compliance, asymmetric information case. As in Cachon and Lariviere's case, our model also falls into the type of economic models known as "signalling" models. In it, Cachon and Lariviere present a manufacturer who requires from a supplier $K \geq 0$ units of production capacity at $w(K)$ wholesale price, proportionate to the capacity required. The point is to motivate the supplier to build or reserve adequate capacity so as to be able to serve the realized demand. The manufacturer, being private to the forecast demand, wishes to communicate this forecast credibly. He does so by paying an additional "lump sum" to the supplier *ex ante*. Cachon and Lariviere establish in their Lemma 2 that if the manufacturer can make a request for a capacity somewhat larger than what he expects and commit to a lump sum payment *ex ante*, then the expected demand is credibly signalled to the supplier. They further establish in their Theorem 6 that the manufacturer's profit is higher when he requests more capacity than what he expects to buy when demand is realized. We use these results in the following as the settings are clearly similar. One notable difference however is that the wholesale price paid by the manufacturer in their model requires him to know the production costs of the supplier, an information which the shipper does not possess in our model and which is frequently unavailable in the transport industry.

The fact that the shipper also buys transport capacity from the spot market is also envisaged in Cachon and Lariviere (2001) in §6 : "a second source" where it is showed that the single supplier model can be used to study a two supplier model and still derive the same conclusions. The information cost I of our model can be included as part of the extra cost of the second supplier in their model.

Hence, we consider that the shipper will signal her expected demand per period through her proposed parameters for a MPC. An alternative mechanism which enables the carrier to discover the expected demand which can be considered is the one described in §A.1 of Appendix A on page 135. Our discussion of the evaluation of the variable per unit fee s shall depart from their model.

From period t_1 to period t_n demand and the spot market price are realized. The shipper buys the necessary transport capacity from the carrier who delivers demands at or below q at the contracted price and extra demand above q at the spot market price. The remainder of committed capacity is sold on the spot market. Payout occurs at every period. The game ends after period n.

For a given outcome the shipper's cost function is per period

$$V_2(x_t, p_t) = \begin{cases} r + qs + (x_t - q)p_t + I, & \text{when } x_t > q, \\ r + x_t s, & \text{when } x_t \leq q; \end{cases} \tag{5.7}$$

whereas, for the carrier it is

$$\pi_2(x_t) = \begin{cases} r + q(s-c) + (x-q)(p_t - c) - K, & \text{when } x_t > q, \\ r + x_t(s-c) + (q - x_t)(p_t - c) - K, & \text{when } x_t \le q. \end{cases} \tag{5.8}$$

The expected profit for shipper and carrier are functions of q, s, r, contract parameters which become decision variables of both players. From the definition of the conditional distribution and of conditional expected values, we define new functions φ such that

$$\begin{aligned} \varphi^s(q) &= \mathbb{E}\big((x_t - q)p_t)\,|\, X > q\big), \qquad \forall t \in \{1, \dots n\} \\ &= \frac{1}{\overline{F_X}(q)} \int_v^{P_{Hi}} \int_q^{Q_{Hi}} (x-q)yf(x,y)dxdy; \\ \varphi^c(q) &= \mathbb{E}\big((q - x_t)(p_t - c)|X \le q\big) + \mathbb{E}\big((x-q)(p_t-c)|X > q\big), \forall t \in \{1, \dots n\} \\ &= \frac{1}{F_X(q)} \int_v^{P_{Hi}} \int_0^q (q-x)(y-c)f(x,y)dxdy + \\ &\quad \frac{1}{\overline{F_X}(q)} \int_v^{P_{Hi}} \int_q^{Q_{Hi}} (x-q)(y-c)f(x,y)dxdy, \end{aligned} \tag{5.9}$$

with $\overline{F_X}(q) = 1 - F_X(q)$.

The carrier fills the transport requirement of the shipper subject to the limit of commitment q made by the shipper. Let $\mu_X(q)$ be expected transport under constraint of the committed capacity q[9]:

$$\begin{aligned} \mu_X(q) &= \mathbb{E}\left[X - (X-q)^+\right] \\ &= q - \int_0^q F_X(x)dx. \end{aligned} \tag{5.10}$$

So, in each game where this contract has been chosen, the buyer's expected profit is

$$\begin{aligned} E_2^s(q,s,r) &= B - \mathbb{E}\left(\sum_{t=1}^{n} V_2(x_t, p_t)\right), \\ &= B + n\left[-r - s\mu_X(q) - I\overline{F_X}(q) - \varphi^s(q)\right]. \end{aligned} \tag{5.11}$$

For the carrier:

$$\begin{aligned} E_2^c(q,s,r) &= \mathbb{E}(\pi_2(X,P)) \\ &= n\Big(r + (s-c)\mu_X(q) + \varphi^c(q) - K\Big). \end{aligned} \tag{5.12}$$

For each to choose this contract, the individual rationality constraints are:

$$\begin{cases} B/n - r - s\mu_X(q) - I\overline{F_X}(q) - \varphi^s(q) \ge 0 \\ r + (s-c)\mu_X(q) - K + \varphi^c(q) \ge 0. \end{cases} \tag{5.13}$$

Note that the above conditions are satisfied when B is higher than the carrier's cost $c\mu_x(q) + K$ and hence there exist a non-empty solution set.

9 See the definition for S(q) in (4.6) presented in Section 4.7.1 on page 80 and in Section 2 of Cachon and Lariviere (2001).

Proof of the existence of such sets are given in the numerical instances in Sections 5.5.1 and 5.5.2.

On the domains of q and s in which the shipper's objective functions is concave, the interesting variable to determine is the optimal quantity q^*, object of the commitment.

Proposition 14. *In the case of a Minimum Purchase Commitment, if and only if the shipper's objective function is concave, and the rationality constraints in (5.13) are satisfied, the optimal parameters q and s which satisfy the shipper are solution to the equation*

$$s = \frac{I f_X(q) - \varphi^{s\prime}(q)}{\overline{F_X}(q)} \tag{5.14}$$

See appendix D.1 on page 173 for the proof.

The carrier will always be looking for the highest possible commitment within his other constraints. This result can be compared to the one obtained in Spinler and Huchzermeier (2006), where the boundaries over optimal parameters of the options to be bought are expressed in terms of one another in Corollary 3 and are also only optimal to the *buyer*. Further, in Spinler and Huchzermeier (2006), the result is only valid when a mapping of the demand to the spot price exists whereas here, any relationship between demand and spot price is accommodated.

For the MPC to be retained, the individual rationality constraints have to be satisfied in every period. This condition is satisfied when the shipper's outside option B is high enough. In the case of a concave objective function for the shipper, this leads us to spell out the following condition:

Condition 2. ***Conditions for a MPC***
For the MPC contract to be chosen by both carrier and buyer and also enjoy the coordinating powers described in Cachon and Lariviere (2001)[10]*, the contract parameters q, r and s, if they exist,must meet the following conditions*

$$\begin{cases} r \le \frac{B}{n} - s\mu_X(q) - I\,\overline{F_X}(q) - \varphi^s(q), \\ r \ge K - \varphi^c(q) - (s-c)\mu_X(q), \\ s = \frac{1}{\overline{F_X}(q)}\left(I f_X(q) - \varphi^{s\prime}(q)\right), \\ r, s \ge 0, q > 0. \end{cases} \tag{5.15}$$

Remark 27. *The contract could have been defined differently given the number of parameters involved. However, as we shall see later, not all parameters can be selected as either the participation constraint would be violated or the parameter would have no economical validity (eg when the fixed fee is set to be negative, meaning that it would be the carrier who would pay the shipper for the privilege of picking up her cargo).*

Remark 28. *The fixed fee r has been chosen here as the parameter which is adjusted according to the bargaining powers of the players. The rent is apportioned according to where it is set within the range defined by the participation constraints.*

10 See the discussion in appendix D.5.2 on page 180.

Remark 29. *The commitment and the per unit fee are to be set together. the expected demand and demand distribution function will help the shipper to choose the one which optimizes her profit.*

5.3.4 *Quantity flexibility contract*

Consider the case of a price α per unit of cargo and a minimum quantity commitment β by the shipper to the carrier over n periods. To ensure coordination, at the end of the game, a penalty[11] per unit θ is charged by the carrier to the shipper for all transport requirements over the n periods which the shipper did *not* need. That is, the total transported units are summed and compared to β, the amount paid by the shipper to the carrier equals the shortfall in units times the penalty.

The difference with the MPC lies in the ability given to the shipper to spread demand peaks and troughs over a number of periods.

If the shipper has had β carried before the end of the contract, she can purchase additional capacities from the carrier at the revealed going mean spot market price P_i for the remaining periods within the total n. This is possible by making an adjustment at the end of the n periods to the observed daily spot market price. Since she knows the carrier, she does not incur the information cost I. The carrier will be at the receiving end of the variance of the demand that the shipper faces. He will accommodate within his own transport capacity what he can and derive the excess to the spot market in pursuance of his best interest: satisfy his customer, increase his knowledge of the demands that the shipper faces for future reference in future bargaining rounds in the next games and finally to increase his presence and visibility in the spot market[12]. We argue that the payout he receives from such dealings will not generate any profit but the other intangible side benefits should still make it worthwhile.

Payout and penalty occur at the end of the n periods. Note that in this contract the penalty, if due, is paid only *after revelation of the demand of the* n^{th} *period.*

The shipper's and carrier's expected objective functions can now be written using the random variable of the sums of demands:

$$\begin{aligned} E_3^s(\alpha,\beta,\theta,n) &= B - n\alpha\mu_X - \Psi(\beta,\theta,n) \\ E_3^c(\alpha,\beta,\theta,n) &= n\big[\alpha\mu_X - c\mu_X - K\big] + \Psi(\beta,\theta,n), \end{aligned} \tag{5.16}$$

with the random variable $Y_n = \sum_{i=1}^{n} x_i$ and Ψ defined as

$$\Psi(\beta,\theta,n) = \theta\Big(\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta,n)\Big) + \mu_P\Big(g_2(\beta,n) - \frac{\beta}{\overline{F_{Y_n}}(\beta)}\Big) \tag{5.17}$$

11 As mentioned in 5.2, the reasons for this penalty is to ensure that the shipper conveys demand forecasts in a credible way. Note that in this contract no other lump payment is made which would otherwise ensure such credibility. The reader can refer to Chen (2004) and Cachon and Lariviere (2001) among others for further justifications.

12 Note that the carrier will use his capacity first, unless the going spot market price $P_t < c + K/X_t$ and the quality of the service provided by players in the spot market is at least equal to his own.

Let us define $g_1(.,.)$ the conditional or truncated mean of the sum of n demands being less than β and $g_2(.,.)$ the conditional mean of the sum of n demands being higher than β:

$$\begin{aligned} g_1(\beta,n) &= \frac{1}{F_{Y_n}(\beta)}\int_0^{\beta} u f_{Y_n}(u)du, \\ g_2(\beta,n) &= \frac{1}{\overline{F_{Y_n}}(\beta)}\int_{\beta}^{Q_{Hi}} u f_{Y_n}(u)du. \end{aligned} \tag{5.18}$$

where Q_{Hi} and P_{Hi} are suitably high numbers above which the probability of a demand or a spot market price are considered suitably low[13].

The definitions of the random variable Y_n and of functions Ψ, g_1 and g_2 are also recorded in table 18 on page 100.

The development of the objective functions can be found in appendix D.2 on page 174.

The conditions of existence and the characterization of the optimal values of α, β, θ and n are discussed in appendix D.3.

Condition 3. ***Conditions for existence of a QFC***
For the QFC to be chosen by both shipper and carrier, the contract parameters α, β, θ, n, if they exist, must meet the following conditions

$$\begin{cases} \alpha \geq 0, \wedge\ \theta \geq 0, \wedge\ \beta > 0 \\ \theta\Big(\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta,n)\Big) \leq B(n) - n\alpha\mu_X - \mu_P\Big(g_2(\beta,n) - \frac{\beta}{\overline{F_{Y_n}}(\beta)}\Big) \\ \theta\Big(\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta,n)\Big) \geq nK + nc\mu_X - n\alpha\mu_X - \mu_P\Big(g_2(\beta,n) - \frac{\beta}{\overline{F_{Y_n}}(\beta)}\Big). \end{cases} \tag{5.19}$$

Remark 30. *As for the MPC, the penalty here has been chosen to be the adjustment variable which can be set in accordance to the relative bargaining power but within the range of the participation constraints.*

Remark 31. *The quantity commitment and the per unit fee can be set independently one from the other but cannot take negative values so as to retain economic sense. The number of periods which would be of interest in this contract cannot be defined from within the contract: other considerations not taken into account in this model will determine it (like the economic life of the relationship-specific assets which both have invested in).*

Remark 32. *This contract finds its justification for shippers facing seasonal demand. The exact moment when the demand will peak is not known but the overall demand over the period (eg sales in the apparel industry in the course of one season) can be estimated with greater certainty.*

5.4 CHOOSING A CONTRACT

Which contract should the players choose? The model assumes that the carrier is unaware of the forecast of demand made by the shipper. He

13 We are interested in feasible and tractable solutions, not mathematical proofs.

updates his Bayesian belief as to the expected demand that the shipper holds using the mechanism presented in Appendix in §A.1 on page 135. He also relies on the memory of past demands he has observed in previous games. The reasoning presented in Section 5.3 of Cachon and Lariviere (2001) prove that lump sum payments in these type of settings the case when the manufacturer (the equivalent of our shipper in their model) knows of the costs of the supplier and when the supplier can decide upon the exact capacity which he dedicates to the manufacturer are efficient signaling instruments for the manufacturer.

In our model, the shipper does not have the power to force the carrier into committing capacity because the contracts in our model do not presuppose forced compliance. We have two contracts which induce lump sum payments: r in the MPC and θ, the penalty, in the QFC. So a series of offers by the shipper in any of those contracts signals the level of forecasted demand to the carrier.

In the following sections, we first compare each contract to one another before spelling out the conditions for the dominating contract. These conditions do not dictate the supply chain dyad's rent distribution. In effect, as noted in Tsay et al. (1999), a practical concern which is left unattended by the existing supply chain management literature and also in this chapter is that of prescribing how the benefits ought to be divided among the parties. There are opportunities here to integrate the existing literature with the substantial body of knowledge from the field of Game Theory.

5.4.1 *Minimum commitment versus price-only relational contract*

The difference between the expected values to the buyer of the MPC and relational contract is labeled D_{2-1}; a function of the contract parameters p_r, q, s and r. In the following, the decision variables shall be omitted when no confusion can ensue to alleviate the notation.

From (5.3) and (5.11) for the shipper and from (5.4) and (5.12) for the carrier,

$$\begin{aligned} D^s_{2-1} &= E^s_2(q,s,r) - E^s_1(p_r) \\ &= n\left[-r - s\mu_X(q) - I(1-F_X(q)) - \varphi^s(q) + p_r\mu_X\right] \\ D^c_{2-1} &= E^c_2(q,s,r) - E^c_1(p_r) \\ &= n\left[r + s\mu_X(q) + \varphi^c(q) - p_r\mu_X - c(\mu_X(q)-\mu_X)\right]. \end{aligned} \tag{5.20}$$

We are interested in the signs of the differences: for both to choose the same contract, the differences must be of the same sign.

$$\begin{aligned} D^c_{2-1} \geq 0 \wedge D^s_{2-1} \geq 0 &\quad\Rightarrow\quad \text{MPC weakly preferred} \\ D^c_{2-1} < 0 \wedge D^s_{2-1} < 0 &\quad\Rightarrow\quad \text{PRC strictly preferred.} \end{aligned} \tag{5.21}$$

However, the conditions of existence and satisfaction of rationality constraints on q from Condition 2 must also be met for a MPC to prevail. Similarly, Condition 1 must be satisfied if a PRC is to prevail. All of which lead to the following set of inequalities stated in the following condition.

Condition 4. ***Conditions of preeminence of a MPC over a PRC***
The MPC exists and will be weakly preferred over the PRC when Condition 2 and

$$\begin{cases} r \le p_r\mu_X - I\overline{F_X}(q) - \varphi^s(q) - s\mu_X(q) \\ r \ge p_r\mu_X - \varphi^c(q) + c\big(\mu_X(q) - \mu_X\big) - s\mu_X(q), \end{cases} \tag{5.22}$$

are fulfilled. The PRC exists and will be preferred when

$$\begin{cases} r > p_r\mu_X - I\overline{F_X}(q) - \varphi^s(q) - s\mu_X(q) \\ r < p_r\mu_X - \varphi^c(q) + c\big(\mu_X(q) - \mu_X\big) - s\mu_X(q), \end{cases} \tag{5.23}$$

and Condition 1 are satisfied.

Remark 33. *In the above condition, the unit fee s and the commitment q have already been specified. The remaining parameter r, which in the exogenously chosen MPC is bounded by the players' participation constraints, is here further constrained by the ability of the players to elect two different contracts. The ability to choose a contractual form here marks a restriction to the capacity by the most powerful player to abuse his power. The rent distribution between players is different if the contracts are chosen exogenously or endogenously.*

5.4.2 *Quantity flexibility versus price-only relational contract*

Let D_{3-1} be the function of the difference between QFC and PRC over n periods. We are again interested in the sign of this function. The difference D_{3-1} is a function of the decision variables p_r, α, β, θ, and n.

From (5.3), (5.4) and (5.16)

$$D^s_{3-1} = n\left[p_r\mu_X - \alpha\mu_X\right] - \Psi(\beta,\theta,n), \tag{5.24}$$

$$D^c_{3-1} = n\left[\alpha\mu_X - p_r\mu_X\right] + \Psi(\beta,\theta,n), \tag{5.25}$$

which are exactly opposite from each other. In practical terms, for *both* players to choose the QFC contract means that both (5.24) and (5.25) must be positive or null at the same time.

The only solution is when both contracts yield the same utility to both players. Hence,

$$p_r\mu_X = \alpha\mu_X + \frac{\Psi(\beta,\theta,n)}{n}, \tag{5.26}$$

because $n > 0$. For all other values, each player would not choose the same contract. The other conditions which render the QFC or the PRC eligible also have to be satisfied (rationality constraints). The following set of conditions is enunciated.

Condition 5. ***Conditions for a QFC to be equivalent to a PRC***
Both carrier and shipper are indifferent between PRC and QFC if

$$p_r = \alpha + \frac{\Psi(\beta,\theta,n)}{n\mu_X} \tag{5.27}$$

and conditions 1 and 3 are satisfied. In all other cases, no agreement on these two contracts can be reached.

Remark 34. *Given the characteristics of the contracts, they are mutually exclusive : if one is chosen by a player, it is refused by the other. The only case where both players would choose simultaneously the same contract is when the choice of parameters yield the same profit for both. Note that this result is independent of the bivariate distribution of demand and spot market prices or of any internal costs or outside opportunities.*

Remark 35. *The above result has not been seen in any of literature streams which have been surveyed. Yet it does portend far reaching consequences in future research.*

Remark 36. *In the experience of the author, no shipper has had to compare these two contracts when confronting offers by carriers. The interest of the QFC is to reduce the impact of variance of demand on the overall transport cost to the shipper but also on the carrier's revenue. This is not the case of the PRC, as presented earlier. If the shipper's intent is to transform her transport cost into a variable one, she would always prefer the PRC and so would not contemplate the QFC. If, on the contrary, the shipper's purpose is to establish a long term relationship with the carrier and enhance the possibility for the carrier to generate stable revenues, she would choose the QFC and not compare it to the PRC.*

5.4.3 *Quantity flexibility versus minimum commitment*

Building from previous results, we now try to help the shipper and carrier choose between QFC and MPC, but *also* include the conditions for both contracts to dominate the PRC. Let us call D_{3-2} the functions of the differences between QFC and MPC in terms of the decision variables α, β, θ, n, r, s and q. According to (5.11), (5.12) and (5.16),

$$\begin{aligned} D^s_{3-2} &= n\left[-\alpha\mu_X + r + s\mu_X(q) + I\overline{F_X}(q) + \varphi^s(q)\right] - \Psi(\beta,\theta,n), \\ D^c_{3-2} &= n\left[\mu_X(\alpha - c) - r - (s-c)\mu_X(q) - \varphi^c(q) + \Psi(\beta,\theta,n)\right]. \end{aligned} \tag{5.28}$$

The following set of conditions can be enunciated (proof in annex D.4).

Condition 6. ***Conditions of dominance of a QFC over a MPC***
When carrier and shipper have the choice between a QFC and a MPC contract, they will choose the QFC when Condition 2 and 3 and the following inequalities are satisfied

$$\begin{cases} r + s\mu_X(q) + I\overline{F_X}(q) + \varphi^s(q) > \Psi(\beta,\theta,n)/n + \mu_X\alpha \\ c\mu_X + r + (s-c)\mu_X(q) + \varphi^c(q) < \Psi(\beta,\theta,n)/n + \mu_X\alpha. \end{cases} \tag{5.29}$$

The MPC shall prevail when Condition 2, Condition 3 and

$$\begin{cases} r + s\mu_X(q) + I\overline{F_X}(q) + \varphi^s(q) < \Psi(\beta,\theta,n)/n + \mu_X\alpha \\ c\mu_X + r + (s-c)\mu_X(q) + \varphi^c(q) > \Psi(\beta,\theta,n)/n + \mu_X\alpha \end{cases} \tag{5.30}$$

are satisfied. Both will be equivalent when Conditions 2, 3 and

$$\begin{cases} r + s\mu_X(q) + I\overline{F_X}(q) + \varphi^s(q) = \Psi(\beta,\theta,n)/n + \mu_X\alpha \\ c\mu_X + r + (s-c)\mu_X(q) + \varphi^c(q) = \Psi(\beta,\theta,n)/n + \mu_X\alpha \end{cases} \tag{5.31}$$

are satisfied.

Remark 37. *The above condition is very difficult to interpret because of the number of parameters involved. Some sense will be made from these inequalities in the numerical illustrations below.*

Remark 38. *As in the comparison between the PRC and MPC, the above inequalities also constrain the bargaining powers and rent of each player.*

5.4.4 *Conditions for a contract to dominate the others*

We now consider that both carrier and shipper have the choice among all three contracts at the same time. For this to happen, all three have to be already agreeable *per se* and also be mutually compatible. This means that we must have simultaneously the choice of a PRC agreeable to both and the choice of a QFC agreeable to both, so that we require Condition 5 to be satisfied before even comparing them to the MPC. If that is the case, we then have Condition 4 and Condition 6 which also must be satisfied either in favor of a QFC (or its equivalent PRC) or of a MPC.

Let us recapitulate the conditions for each contract to dominate both others.

Condition 7. ***Conditions for dominance of a PRC over a MPC and equivalence with a QFC***
A PRC will be equivalent to a QFC and preferred over a MPC when

$$\begin{cases} p_r = \alpha + \frac{\Psi(\beta,\theta,n)}{n\mu_X} \\ c + \frac{K}{\mu_X} < p_r \leq \frac{B}{n\mu_X} \\ r > p_r\mu_X - I\overline{F_X}(q) - \varphi^s(q) - s\mu_X(q) \\ r < p_r\mu_X - \varphi^c(q) + c\big(\mu_X(q) - \mu_X\big) - s\mu_X(q). \end{cases} \tag{5.32}$$

Condition 8. ***Conditions for dominance of a MPC over both a QFC and a PRC***
A MPC will be preferred when

$$\begin{cases} r \leq \frac{B}{n} - s\mu_X(q) - I\,\overline{F_X}(q) - \varphi^s(q) \\ r \geq K - \varphi^c(q) - (s-c)\mu_X(q) \\ r < p_r\mu_X - I\overline{F_X}(q) - \varphi^s(q) - s\mu_X(q) \\ r > p_r\mu_X - \varphi^c(q) + c\big(\mu_X(q) - \mu_X\big) - s\mu_X(q). \end{cases} \tag{5.33}$$

Condition 9. ***Conditions for a QFC to dominate the MPC and be equivalent to the PRC***

The QFC will be preferred over the MPC and weakly preferred over the PRC when the following conditions are met

$$\begin{cases} \alpha \geq 0, \wedge \theta \geq 0, \wedge \beta > 0, \\ p_r = \alpha + \frac{\Psi(\beta,\theta,n)}{n\mu_X} \\ \theta \leq \frac{1}{\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta,n)} \left[B(n) - n\alpha\mu_X - \mu_P\left(g_2(\beta,n) - \frac{\beta}{\overline{F_{Y_n}}(q)}\right)\right] \\ \theta \geq \frac{1}{\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta,n)} \left[nK + nc\mu_X - n\alpha\mu_X - \mu_P\left(g_2(\beta,n) - \frac{\beta}{\overline{F_{Y_n}}(q)}\right)\right], \\ r + s\mu_X(q) + I\overline{F_X}(q) + \varphi^s(q) > p_r\mu_X \\ c\mu_X + r + (s-c)\mu_X(q) + \varphi^c(q) < p_r\mu_X \end{cases} \tag{5.34}$$

Remark 39. *These results differ from those presented in literature due to the endogenous choice of contractual mechanism.*

Remark 40. *The fact that the eligible PRC and QFC have to be set so as to generate exactly the same profit to both players means that the ensuing range of participation constraints have now been considerably reduced as compared to the ranges when the contracts were imposed exogenously. This fact will appear more clearly when presenting the numerical illustration*

Remark 41. *The possibility that no contract is elected jointly exists. In this case, no agreement can be reached and this particular game ends. The carrier will prefer to attend to his other customers, whereas the shipper will look among her other carriers. This does not preclude that in the following game both agree on a common contract and corresponding parameters*[14].

Remark 42. *In the case that one player enjoys such bargaining power that he (she) is able to impose her choice of contract is of course not contemplated here. Such a possibility is covered in the previous sections as it leads to the conditions of emergence of a contract as if it were imposed exogenously.*

To grasp the results and their significance, let us present three numerical examples. The first presents a case where both demand and spot market prices for transport fluctuate in a bivariate normal distribution. In the second, we fix the transport price and let demand fluctuate in a normal distribution. The last example is a case where both carrier and shipper use only the spot market and do not interact together: this last example uses also a bivariate normal distribution of demand and spot market prices. Further examples applying exponential distributions of demand and prices have not been presented here because the results are functionally the same.

5.5 NUMERICAL EXAMPLES

5.5.1 *First example: a binormal stochastic process*

We instantiate the preceding results in the following way. Let $f(X, P)$ be a bivariate normal distribution with their supports, the information cost

14 Unless this is the N^{th} game, in which case the sunk investments have come to the end of their useful lives.

for the spot market, the carrier's fixed and variable cost take the following values:

$$\mu_X = 10, \quad \sigma_X = 3, \quad \mu_P = 8, \quad \sigma_P = 1.5, \quad \rho = 0.5,$$
$$I = 2, \quad v = 2, \quad P_{Hi} = 14, \quad Q_{Hi} = 25, \quad K = 20, \quad c = 1.8, \tag{5.35}$$

The shipper's outside option for transport is estimated in terms of the average per unit spot market price. This cost is a function of the number of periods over which a contract runs

$$B(n) = \mu_P(1.2)n\mu_X.$$

By the Central Limit Theorem, the expected sum of the demands over a large number of periods (generally assumed to be more than 10 periods) behaves like a normal distribution which has the following characteristics:

$$Y_n = \sum_{t=1}^{n} x_t \sim \mathcal{N}(n\mu_X, \sqrt{n}\sigma_X) \sim \mathcal{N}(10n, 3\sqrt{n}). \tag{5.36}$$

To show the impact of the choice of contract on each player, let us now evaluate the objective function of the shipper and carrier when the choice of contract is exogenously given and when the choice is endogenous[15]. We present the results in table 19.

Table 19: Bivariate demand: table of ranges of contract outcomes for each player separately and parameter conditions for exogenous or endogenous choice of contract.

$n = 40$	Carrier			Shipper		
	exogenous	endogenous		exogenous	endogenous	
		Max	*Min*		*Max*	*Min*
PRC	2320	2320	1812	2320	508	0
	$p_r = 9.6$	9.6	8.33	3.8	8.33	9.6
	$q = 1$	$q = 1$		$q = 1$	$q = 1$	
		$r = 12.7$	0		0	12.7
MPC	5158.4	2798	1720	833.6	833.6	431.3
	$q = 22$	11	8	8	8	11
	$s = 8.87$,	7.11	5.98,	5.98,	5.98,	7.11,
		$r = 0$			$r = 0$	
		$7.51 < p_r < 9.6$			$7.51 < p_r < 9.6$	
QFC	2320	2320	1812	2320	508	0
	$\alpha = 9.30$	$6.73 < \alpha < 99$,		$\alpha = 1$	$6.73 < \alpha < 99$,	
	θ = low bound			θ = low bound		
		$q = 1$	1		1	1
		$r = 12.7$	0		0	12.7
Spot	1680	−−	−−	470	−−	−−

We assume in the following that the number of periods of a game is 40.

15 The details of all calculations are available upon request to the author.

The details of the calculations first of the exogenous choice of each contract are relegated to the sections D.5.1, D.5.2 and D.5.3 in the appendix.

Once the required domains for the emergence of the contracts are defined, we compare the contracts. The details of the calculations can be found in D.5.4 for the comparison of the QFC and PRC, D.5.5 for MPC versus PRC, D.5.6 for the comparison of QFC and MPC. The conditions for the dominance of a contract are presented in D.5.7.

The outcome resulting from the choice of contracts once the comparison is endogenous are very different from the ones when each contract is looked at individually. The range between maximum and minimum are smaller and the sets of possible parameters also. The reader will note that neither partner can pull the cover to himself: each can expect to make a profit or retain some budget. The results from the numerical illustration would tend to yield a preference for the MPC which is adopted when $1 < q < 12$. The PRC and QFC prevail only when the partners agree to a commitment per period of $q = 1$ for the MPC, hardly an optimal setting when the expected demand faced by the shipper is at least 10.

If we suppose that the MPC is not retained, the choice, in terms of outcome only, is between the two contracts, QFC and PRC, their parameters must be such that they yield exactly the same outcome to each partner.

What happens when the spot market price does not move? This is the case of a market for transport capacity which is not subject to sudden variations and hence where both shippers and carriers can withhold excess demand or capacity from destabilizing the price. Would the hierarchy among the contracts change? The results of a second numerical study are presented in the next section.

5.5.2 *Second numeric example: case of univariate stochastic process*

Let us consider now the case of a transport market where the spot price is *fixed*: $P = 8$. In this case, the shipper's outside option for transport in terms of the number of periods is rewritten as

$$B(n) = 8 \times 1.2 \times \mu_X \times n$$

We deal with a *univariate* stochastic process consisting of just the demand faced by the shipper.

The evaluations of the different objective functions and conditions of emergence of a contract when chosen exogenously are presented in appendix D.6 on page 188: the MPC in subsection D.6.1, the QFC in subsection D.6.2. Once the conditions of emergence of a contract are given, we proceed to compare them two by two: the MPC versus the PRC in subsection D.6.3, the QFC and PRC are compared in subsection D.6.4, the QFC and MPC in subsection D.6.5. Finally, in subsection D.6.6 we present the conditions of emergence of a PRC over a MPC and equivalence with a QFC, in subsection D.6.7 the condition of dominance of the MPC over both other contracts and in subsection D.6.8 the conditions for the QFC to be equivalent to the PRC and dominate the MPC.

We give here a brief sketch of the results.

For a MPC to emerge as the favoured contract for both shipper and carrier, we need to set $2 \leq q \leq 12$, which leads to a fixed fee $0 \leq r \leq 23.09$ and $5.984 \leq s \leq 8.498$. For this to happen, we have as well $8.20 < p_r \leq 9.6$ and the corresponding vectors $\{\alpha, \beta, \theta\}$ which enable Condition 5 to be satisfied.

For a QFC to emerge as a dominant contract, we must have $q = 1$, $7.99 \leq p_r \leq 8.20$ and the other parameters of the QFC as required for its existence.

We recapitulate the results in table 20 on the next page.

As can be seen, the MPC emerges as the dominant contract over large swathes of parameter domains. The emergence of one or the other contractual form is of course once again largely dominated by the bargaining powers of the players. If the carrier can force the shipper into accepting his terms, then he is better off overall in picking a MPC with $q = 22$.

The choice of contract parameters presented in the table do not do justice to the range of available values which still yield the same profit or retained budget, but the calculations involved (in all, 5 parameters can change independently: q, r, β, α and θ) were too complex and too large, so we chose to just present some particular ranges of interest. Note that given the alternatives of the QFC or PRC, to retain the MPC when the choice is endogenous, the shipper has to accept to push her commitment up to $q = 11$ thus enabling the carrier to make a large profit of 2849, with $r = 13$.

These results still beg the question of when and why the shipper and carrier would choose one contractual form or another in a more general context. To address these issues, we take now a look at what would happen if both took recourse in the spot market and the impact of the variance of both the spot market price and demand. We enlarge the scope of the results by first evaluating the cost and opportunity for shipper and carrier to engage in a pure spot market sourcing strategy in the next section before addressing the issue of the variance of all four strategies in the section after that.

5.5.3 *Third numerical example: pure spot procurement strategy*

In this case, the shipper decides to forego a contract with a carrier and decides to procures all her transport needs directly from the spot market.

In this example, we are very near to the SCM case presented in Wu et al. (2002) where a buyer has the possibility of combining procurement from a contract and from a spot market to resolve his necessities. In that paper's model, the buyer can choose to privilege either the contract or the spot market, depending on the relative cost of either. However, since demand is modeled as being a function of spot market price, we feel that the answers provided in that paper do not reflect the real world practice of transport, where, as seen before, spot market prices may be only weakly positively correlated with demand or even not at all.

The shipper buying exclusively from the spot market her transport capacity requirements can be considered as a particular case of a MPC

Table 20: Univariate case: table of maximum and minimum contract outcomes and selected parameters for the exogenous or endogenous choice of contract.

$n = 40$	Carrier			Shipper		
	exogenous	endogenous		exogenous	endogenous	
		Max	*Min*		*Max*	*Min*
PRC	2320	2320	1675	2320	645	0
	$p_r = 9.6$	9.60	7.99	3.8	7.99	9.60
		$q = 1$			$q = 1$	
		$r = 16.12$	0		0	16.12
MPC	5146	2849	0	923	923	0
	$q = 22$	11	8	8	8	12
	$s = 8.87$	7.11	5.98	5.98	5.98	5.98
		$p_r = 9.6$	7.99		7.99	9.6
		$r = 13$	0		0	23
QFC	2320	2320	1675	2320	645	0
	$\alpha = 9.30$	14.4	14.6	5.5	14.4	14.6
	$\beta = 400$	398	398	400	398	398
	$\theta = 0$	1.33	0	0	0	1.33
		$p_r = 9.60$	7.99		7.99	9.60

where both the commitment q and the fixed fee r are set to nought. The profit function and expected profit of the shipper can be written as

$$V_{Spot}(x_t, p_t) = B(n) - x_t p_t \tag{5.37}$$

$$\begin{aligned} E^s_{Spot} &= B - n\Big[I + \mu_X \mu_P + Cov(X, P)\Big] \\ &= B(n) - n[I + \mu_X \mu_P + \sigma_X \sigma_P \rho]. \end{aligned} \tag{5.38}$$

When we evaluate it for $n = 40$, we obtain an expected residual budget of 470.

In the case of the carrier, the profit to be had by simply selling all his available capacity on the spot market yields 1680 since he does not incur the information cost which affects the shipper. Both results are included in table 19 on page 113.

As mentioned earlier, we do not consider these alternative strategies as viable in the long term because of considerations which are difficult to include in the present model such as transaction costs (Williamson, 2002) or (Wang and Zhu, 2004), but also because of the variable liquidity of the spot market on a long term basis (see the behaviour of the dry bulk overseas shipping market chart presented in 1 on page 19). Another issue is the variance of the cost or the profit to be had in this type of transaction. We now turn our attention to the evaluation of the variance of residual budget or profit for all strategies previously presented.

5.5.4 *Variance of results from contracts for shipper and carrier*

In effect, if the shipper decides to source all her transport requirements from the spot market, she is letting herself be affected by the variance of the spot market price. Even when the shipper simply has to respect a budget, this variance is bound to substantially impact it.

The calculations of the variance of the three contracts and the variance of the spot market are relegated to appendix D.7.

We compare the three contracts over 40 periods. The results are tabulated in table 21. As can be observed, the possibility of contracting transport capacity clearly exhibits important differences in terms of the variance of the cost of transport for the shipper. The most favourable contract when chosen exogenously is clearly the QFC, a result which is intuitive: the shipper reduces uncertainty when her commitment is cumulated over several periods. It must be noted that even the lower bound on the penalty θ is large when $\beta > 400$ as can be observed in figure 44 on page 183.

This result is no longer verified when the constraints on the parameters imposed by the comparison with the MPC are taken into account (see the results presented in the column "endogenous"). When the choice of contract is endogenous and the commitment equals expected demand, the MPC enjoys the lowest variance. The QFC's variance is also marginally higher than the one achieved by the PRC in the same circumstances. This counter-intuitive result may be related to the fact that, in the endogenous case, the cost of transport is influenced by the level of α, the per-unit price for cargo, whereas in the exogenous case, the cost of transport is basically due to the penalty θ. In other words, the carrier's economic profit is reduced to 0 and the shipper's retained budget remains relatively constant due to the contract's large number of periods.

Table 21: Table of maxima and minima of the variances of the different transport procurement strategies according to the capacity commitment over 40 periods (bivariate demand and spot market).

Variance ($\times 10^6$)	Exogenous Max	Exogenous Min	Endogenous Max	Endogenous Min
Spot	1.898			
PRC	1.327	0.130	0.919	0.968
	$p_r = 9.6$	3.8	8.20	7.99
MPC	6.3×10^3	0.723	1.668	0.723
	$q = 22$	10	2	10
QFC	> 10.8	0.05	> 10.6	0.998
	$\beta \geq 420$	396	≥ 410	362
	$\alpha \geq 10$	0	≥ 27.18	7.37
	$\theta \geq 200$	$\theta_{\min} = 6.41$	$\theta_{\max} \geq 2.88$	0.04

It is further interesting to note in table 21 the hierarchy between the variance of the results to both the shipper and the carrier when the maximum yielding transport procurement contract is adopted. Clearly, the strategy to procure or sell transport capacity by using exclusively the spot market, which is given here as reference, not only produces less interesting results for both carrier and shipper (even though the carrier does not have to pay a fixed information cost to access it) but it induces the highest level of variance of the results. Such a strategy should only be adopted by shippers and carriers when

- they cannot engage in other types of contractual arrangements;
- both demand and spot market volatilities are very low;
- the specific assets that are needed by both for a relationship are of low value compared to the benefits of spot market transactions.

This result is similar to the observations in the market and to results presented in SCM literature as in Kleindorfer and Wu (2003).

When the volatility of demand and spot market prices are high, the volatility of the MPC can become as high as the one for the PRC, even for high values of p_r, undermining its interest for both players. In such a case, the QFC becomes attractive, especially if β is set just below or at the number of periods times the expected demand (which enables a low value for α and induces a low value for θ).

5.6 CONCLUSION

The conclusions presented here regroup those for managers and practitioners together with those that interest researchers.

Managers involved in transport procurement for their organizations will probably be upset by the large amount of mathematical matter, even though most of it has been put away in the appendices. The conclusion for them is that the traditional, one-size-fits-all contract of one price per unit of quantity, without any limit as to the quantity, may not be the best solution in their particular case. The preceding developments should alert them to the possibilities of other contractual mechanisms. By following the algorithms described here, they can appraise the opportunities given their knowledge of costs, opportunities, expected demand and spot market prices.

The model presented here provides a methodic process for the comparison of Price Only Relational Contract, Minimum Purchase Commitment and Quantity Flexibility Clause contracts when demand and transport spot market prices are stochastic and stationary. This process involves comparing the contracts two by two before comparing each winning contract with the remaining one. The decision makers involved can choose the contract and parameters which will satisfy their rationality constraints and confront their choices. Ultimately, relative bargaining power resolves the rent sharing exercise. As noted in Tsay et al. (1999), a practical concern which is left unattended by the existing supply chain management literature and also in the present work is that of prescribing how the benefits ought to be divided among the parties. There are opportunities here to integrate the existing literature with the substantial body of knowledge from the field of Game Theory.

The choice of contracts studied here yield rent distribution constraints within a Game Theoretic framework which includes multiple periods, asymmetric information and stochastic demand and input price but does not prescribe the distribution itself. This model contributes to the SCM and logistic management literature by providing algorithms which prescribe the rent distribution constraints for the dyad when both partners

- have the faculty to suggest, evaluate and agree upon different types of contracts and corresponding parameters,
- have had to invest in assets specific to this relationship, with a known limited economic life,
- work in a world where demand for transport capacity and spot market price for this capacity are both variable and correlated,
- lack information about their respective utility, cost and outside opportunities,
- enjoy varying bargaining powers which condition the partitioning of the dyadic rent.

The closed form results thus established are resumed in table 22 on page 121. They show in a new light the choice of contract open to shippers and carriers and, by extension, to suppliers and manufacturers in the SCM environment. Any joint or independent distributions of stochastic demand and spot market prices for transport can be used to abet the choice of one or the other contractual form. The numeric result also show how the choice of a contract also depends on what other contract is on the table at the same time. These results do not intend to resolve bargaining power issues but present some clues as to how the dyadic rent might be shared. The way the numeric illustration is conducted provides a blueprint of the way the comparison can be conducted in other practical cases.

We proceed to point out some simplifications and shortcomings of our approach. Among the most interesting ones, a brief discussion is presented below dealing with the asymmetry of information about demand, the carrier's cost function, his transport capacity limit and the exclusion of variance from the objective functions.

Asymmetric information

The present model requires the knowledge of the expected demand for the carrier to be able to build appropriately his offers. However, it is usual, as represented in the model described here, that the carrier does not possess complete information regarding the distribution of the shipper's forecast demand. As mentioned in section 5.3 on page 95, the carrier must first use his initial knowledge of the industry the shipper is in and then take advantage of the signaling powers of the bargaining process presented in appendix A.1 and of the MPC. This model builds upon Cachon and Lariviere (2001) in that the lump sum payments and commitments made in both QFC and MPC are key to signal the expected demand to the carrier. The menu of contracts offered by the shipper and the responses to his offers help him obtain a signal as to the expected demand and hence to make valid assumptions about the demand distribution's moments.

Carrier cost function

In the model, the cost of operating a fleet of transport units has not been properly taken into account in the model presented here for two reasons:

- the important implications in terms of tractability of the calculations involved,
- adding another layer to the model would have been in detriment to the readability and clarity of the results.

Proper accounting for the cost of operating a fleet should account for several different factors. Let us list here some which stand out particularly:

- not all transport units have the same operating cost;
- opportunities to deploy each unit separately to other assignments may yield different returns (due to its geographic location ahead of an assignment);
- the cost to a carrier of subletting units from third parties may be higher than the cost of those in his fleet.

Transport capacity limit

The carrier is not considered to be capacity constrained in this model which is quite a departure from actual practice and other literature. The purpose of the model and the demonstration did not warrant it. Additional research is required to address this restriction.

Variance of economic outcomes

Even though the variance of outcomes is not modeled, some indications, using numeric examples, are presented which enable the reader to gain insight into each contract's comparative advantage. The returns and variance of the returns for each player and each contract have been presented separately. In the numeric instances, the QFC is the lowest ranking one when chosen exogenously, spot market buying the highest ranking one. The MPC ranks lowest in variance when it results from an endogenous choice, beating the QFC. Variance is higher for all procurement policies except the QFC as the number of periods in the contract is extended.

However, some conclusions can still be drawn from the present model. The MPC can claim to be the best overall contract since it achieves both the best result for shipper and carrier and simultaneously the lowest variance when the players settle for the expected demand per period as the capacity commitment.

Table 22: Table of negotiation outcomes and parameter conditions in each game.

Conditions on contract parameters	Outcome
$p_r = \alpha + \frac{\Psi(\beta,\theta,n)}{n\mu_X}$ $c + \frac{K}{\mu_X} < p_r \leq \frac{B}{n\mu_X}$ $\theta \leq \frac{1}{\frac{\beta}{F_{Y_n}(q)} - g_1(\beta,n)}\Big(B(n) - n\alpha\mu_X - \mu_P\big(g_2(\beta,n) - \frac{\beta}{\overline{F}_{Y_n}(q)}\big)\Big)$ $\theta \geq \frac{1}{\frac{\beta}{F_{Y_n}(q)} - g_1(\beta,n)}\Big(nK + nc\mu_X - n\alpha\mu_X - \mu_P\big(g_2(\beta,n) - \frac{\beta}{\overline{F}_{Y_n}(q)}\big)\Big)$ $r > p_r\mu_X - I\overline{F}_X(q) - \varphi^s(q) - s\mu_X(q)$ $0 \leq r < p_r\mu_X - \varphi^c(q) + c\big(\mu_X(q) - \mu_X\big) - s\mu_X(q)$	PRC
$s = \frac{1}{\overline{F}_X(q)}\big(If_X(q) - \varphi^{s\prime}(q)\big)$ $r < p_r\mu_X - I\overline{F}_X(q) - \varphi^s(q) - s\mu_X(q)$ $r > p_r\mu_X - \varphi^c(q) + c\big(\mu_X(q) - \mu_X\big) - s\mu_X(q)$ $0 \leq r \leq \frac{B}{n} - s\mu_X(q) - I\,\overline{F}_X(q) - \varphi^s(q)$ $r \geq K - \varphi^c(q) - (s - c)\mu_X(q)$	MPC
$p_r = \alpha + \frac{\Psi(\beta,\theta,n)}{n\mu_X}$ $\alpha \geq 0, \wedge\ \theta \geq 0, \wedge\ \beta > 0, \wedge\ n > 10$ $\theta \leq \frac{1}{\frac{\beta}{F_{Y_n}(q)} - g_1(\beta,n)}\Big[B(n) - n\alpha\mu_X - \mu_P\big(g_2(\beta,n) - \frac{\beta}{\overline{F}_{Y_n}(q)}\big)\Big]$ $\theta \geq \frac{1}{\frac{\beta}{F_{Y_n}(q)} - g_1(\beta,n)}\Big[nK + nc\mu_X - n\alpha\mu_X - \mu_P\big(g_2(\beta,n) - \frac{\beta}{\overline{F}_{Y_n}(q)}\big)\Big]$ $r + s\mu_X(q) + I\overline{F}_X(q) + \varphi^s(q) > \Psi(\beta,\theta,n)/n + \mu_X\alpha$ $c\mu_X + r + (s - c)\mu_X(q) + \varphi^c(q) < \Psi(\beta,\theta,n)/n + \mu_X\alpha$	QFC
$p_r \neq \alpha + \frac{\Psi(\beta,\theta,n)}{n\mu_X}$ $s^* \neq \frac{1}{\overline{F}_X(q)}\big(If_X(q) - \varphi^{s\prime}(q)\big)$ $\theta > \frac{B - n\alpha\mu_X - \mu_P\left(g_2(\beta,n) - \frac{\beta}{\overline{F}_{Y_n}(q)}\right)}{\frac{\beta}{F_{Y_n}(q)} - g_1(\beta,n)}$ $\begin{cases} r + s\mu_X(q) + I\overline{F}_X(q) + \varphi^s(q) < \Psi(\beta,\theta,n)/n + \mu_X\alpha \\ c\mu_X + r + (s - c)\mu_X(q) + \varphi^c(q) < \Psi(\beta,\theta,n)/n + \mu_X\alpha \end{cases}$ $\begin{cases} r + s\mu_X(q) + I\overline{F}_X(q) + \varphi^s(q) > \Psi(\beta,\theta,n)/n + \mu_X\alpha \\ c\mu_X + r + (s - c)\mu_X(q) + \varphi^c(q) > \Psi(\beta,\theta,n)/n + \mu_X\alpha \end{cases}$	No agreement

PRC= Price-only Relational Contract, QFC= Quantity Flexibility Clause, MPC= Minimum Purchase Commitment.

6 THESIS CONCLUSION

THIS LAST CHAPTER presents some general conclusions on the work developed in the previous pages. The result of the research is a series of stylized and normative models of relationships between carriers and shippers in the freight transport industry through the contract as a managerial tool. These models are designed with both researchers and practitioners in mind to advance research in logistics and transport management.

My guess as to this state of affairs is that a shipper and a carrier are perceived as not being in the same supply chain: most of the SCM literature misses the interest of investigating this type of relationship in particular.

From a certain point of view, it could be argued that the logistics and transport link between shipper and carrier are covered in the general description of the supplier-buyer one in SCM literature. I hope that the preceding chapters will have increased awareness of the particularities of this relationship. The results presented in the thesis differs from general SCM work in that the various models draw on all or a subset of the following specificities:

- transport as a service differs qualitatively from the provision and sales of goods;
- costs and utilities may be private information;
- spot interaction is enabled but may carry information costs;
- outside opportunities exist but carry discovery costs;
- relationship-specific asset investments may be required.

We detail briefly the differences.

A number of situations involving a shipper and a carrier have been presented. In one, shipper and carrier have private information about the transport requirement and the idle capacity and since monitoring is costly can gouge their partner. In the second, shipper and carrier must choose among different forms of contracts. In these situations, the relevant SCM literature is reviewed. In that literature, relationships are deep and suppliers and buyers apparently do not change very often. Further, even in the literature which is nearest to the problems we have identified as chronic in the transport industry, the models do not take into account the realities of the spot market for transport services and the corresponding results do not translate to common practice in transport. In particular, spot markets for commodities or financial products are generally better organized than those for transport services, especially in road transport. Models from mainstream SCM literature like Kleindorfer and Wu (2003), Wu and Kleindorfer (2005), Seifert et al. (2004), Spinler and Huchzermeier (2006) to name but a few, refer explicitly to transparent, organized, efficient markets, some being even electronic trading platforms.

In the models presented in this thesis, the shipper and carrier are not informed of the utility, cost or opportunities available to the other party. The shipper is not informed of the available capacity of the carrier, the carrier is not informed of expected future demand that the shipper expects to have carried. They operate as two independent decision making units (DMU) who may or may not be in the same supply chain.

Wherever relevant, some managerial insights have been presented which provide blueprints as to how the methods can be translated into actual practice. Using these, the shippers and carriers can devise policies for transport procurement or contract mechanisms in accordance with their environments.

Let us now recapitulate the results and caveats before exploring the paths for future research.

6.1 WHAT HAS BEEN ACHIEVED

As stated in the introductory chapter, our ambition was to present tools to model the behaviours of shippers and carriers before the relationship between either becomes full blown. In these preliminary steps, we have looked at several issues which both future partners face.

The third chapter presents the tactics that the carrier can engage in when he foresees that he will work with a shipper during a number of periods. He ensures that the shipper invests in the relationship-specific assets needed by sweetening the initial contract and holds her up in the last contract for the required investment in third-party relationship specific asset. We show how the result varies when information about outside opportunities and relationship-specific investment costs are private information. The ensuing rent transfer is compared to the common information case and numerical results are provided.

The fourth chapter presents the impact of unilateral and bilateral information asymmetry about demand and capacity on the profit or cost of the other partner when comparing it to the case where both are fully informed. The model supports the possibility that both demand and spot market prices may vary or not. The chapter also suggests some mitigating contractual mechanisms which can be put in place when information is known beforehand to be asymmetric. Proof is presented as to the variance induced in the cost of transport and revenue to the carrier by this asymmetry of information. The numeric illustration also provide clues as to the extent of the impact under different parameter settings relatively to the underlying demand and spot market prices for transport distribution characteristics.

The fifth chapter tries to bridge a gap in literature by presenting a mechanism to help shipper and carrier choose a contract among three possible which are deemed to be of interest when cost and demand information are asymmetric and contracts can be reopened. We enumerate the conditions under which the parameters of a contract would be chosen for each contract in turn, thus choosing the contract for them exogenously, and then providing the conditions for an endogenous choice of a mutually agreeable contract and attending parameters. We illustrate those conditions in the case of several scenarios of spot market price distributions. These results are compared with a procurement strategy which privileges the spot market. The variance of the objective functions according to the contract chosen is only indicated by the numeric examples.

6.1.1 *Caveat*

The models and attending demonstrations in this thesis present the reader with *theoretic behaviours* by actors on the transport scene. The tools do not cover all types of markets in transport services nor do they provide the actors with enough power to solve all types of managerial coordination issues. These results, though, are aimed to inform managerial practice and policy analysis. They stem from the combination of casual empiricism and of existing models developed in SCM literature. As such, they suffer from shortcomings in their representations of reality. How really applicable to *any* carrier versus shipper relationships are the models developed here? Even though great care has been put in developing those models and make them as generally applicable as possible, this still remains a work which would benefit from contribution from other specialists in freight transport management research (not to be confused with transport as an Operational Research problem of networks and traveling salesmen) and from validation by field study.

Another limitation of the work which affects the models of contracts presented here is the fact that sources which might bring *justification to the types of contract* used have not been found. For example, primary data on the percentages of contracts in road transport using the MPC would have been interesting. This work draws heavily on empiric private experience which is most certainly not a statistically significant one. In its defense, at least in Argentina, empirical evidence collected over three years by polling actors from large and small shippers in all types of industries and carriers has conveyed the overwhelming impression that almost all transactions and contracts in the road transport market were of the Price-Only Relational Contract type. Even in volume terms, the proportion of contracts involving some kind of indication of volume over time represented a small percentage of all tonnes per kilometre[1]. Considering that managerial practice in Argentina is maybe not up to European standards, one is entitled to ask whether this proportion of single price contracts also prevails in Europe? In our experience, even in Europe the examples to which I have been exposed show a high proportion of PRC and of spot market transactions for the remainder.

These observations are based upon both professional experience and logistic surveys of practice at Imerys®Specialty Minerals, Division of Imerys and at L'Oréal®Belgilux (Brusset, 2005, 2006). Lately, it has come to our attention that an important importer and distributor of frozen and fresh fruit in Belgium actually contracts space at refrigerated warehouses under a MPC: some storage space is reserved over several years and, during peak season, additional space can be rented at spot market prices. These warehouses all set up similar contracts with other shippers and the use of their storage space is conditional upon economic activity (or lack thereof

1 A volume commitment is always for very large amounts spread over a year, whereas spot transactions are numerous but represent small volumes each time.

in the case of the years 2008-2009) and competition within some kind of spot market for idle capacity. This situation is very similar to transport.

In another example, given that almost all the goods coming out of both plants at Imerys® and warehouses at L'Oréal are loaded on trucks under condition of a price only contract, some attention might be given to the alternative: the combination of a long-term flexibility commitment over several years and a price only contract or a menu of prices for the extra cargo above the commitment. This combination, in the absence of a spot market for the relevant transport capacities, should be of interest to the carriers because it reduces the inherent variance of the shipments and to the shippers because they may be able to extract price concessions for the long-term commitment which might not be accessible otherwise.

Other firms identified in literature which casually rely on the spot market for some or most of their transport procurement might also benefit from using this type of research (Remmert and Reifenberg, 2004, Elmaghraby and Keskinocak, 2004, TUB, 2002).

Are there advantages which warrant the superiority of the PRC over other forms of procurement which have not been identified? Does the ease with which a contract of this type is set up or the comparability of the prices proposed really bring so much more to a shipper than the other types? No easy answer could be found and primary data on this subject is patchy to say the least.

Let us now dig into some issues arising from some of the chapters taken together.

6.2 ISSUES STEMMING FROM THE MODELS

6.2.1 *Information asymmetry*

As transport is a service often performed by an arms-length carrier, knowledge of his available capacity at any given time is of considerable interest to the shipper, especially when the spot market price tends to be higher than the stipulated price in the contract. There is empirical evidence that it is when the spot market is at its highest that the carrier declares an absence of capacity to the shipper. Symmetrically, it is when the carrier has a lot of extra capacity that the shipper tends to have no loads to carry. The results presented in chapter 4 help both to adapt the contract that they set up to skirt these pitfalls, given available information about capacity, expected demand and distribution of spot market prices.

With this model as well as the one in chapter 5, any situation where the carrier's costs and the shipper's estimated transport requirements are private information is addressed. This type of situation is often not modeled in SCM literature as, for example, in Cachon and Lariviere (2001) where the manufacturer who buys some input from a supplier is assumed to know the supplier's fixed and variables costs of production. The model applies in a straightforward manner to all cases where a shipper describes to the carrier lanes with defined origin, destination and frequency of service and expects the carrier to be able to provide the corresponding service. The carrier does not know exactly if the frequency will be the one effectively solicited. He knows the origin and destination and can evaluate the corresponding cost of operation to him, given other opportunities of return cargo he may have in other parts of the network he operates. Knowing the industry the shipper is in, the carrier makes a guess as to the seasonality and real volumes to be carried. This guess is refined game after game, much as in reality a carrier becomes acquainted with the shipper's idiosyncrasies.

6.2.2 *Counterparty discovery cost*

The availability of prices for spot markets does not preclude the difficulty for the players of finding a counterparty to deal at such prices. The models in chapter 4 and 5 try to capture such discovery costs: in chapter 4, it is the spot market information cost I which represents a per-period cost of finding a counterparty; in chapter 5, the shipper and carrier resolve additional requirements above contractual capacity at spot market prices preferentially.

The demand which the shipper expects to fill is modeled as a stochastic process with certain probabilistic characteristics. Even though the literature has recognized the importance of the information about those characteristics to the suppliers in any supply chain, showing how his information also impacts the carriers is new and this thesis is the first to present managerial tools which help the carrier dealing with risk on both fronts (spot market prices and demand). The model in appendix A.1 shows how a carrier can entice a shipper into revealing relevant information about the expected demand by successive bargaining offers.

6.2.3 *Arms-length relationships*

Contrary to what most SCM and logistics management literature considers, a shipper clearly distinguishes between carriers she has worked with and those which she “discovers” in the spot market. This distinction, included in the models presented in this work, enables us to show how and why a carrier and a shipper interact and the consequences in terms of economic returns to both. The propensity by both shipper and carrier to work together and invest in relationship-specific assets are offered with a model which describes the way in which a relationship between a shipper and a carrier can sour using asymmetric information, outside opportunities and specific-asset investments (chapter 3).

As is usually the case in practice, shippers and carriers “know” each other: they have worked together and have set up correspondingly arrangements in their respective organizations to do so repeatedly. This way of working has been modeled in chapters 3 and 5 by enabling shipper and carrier to refrain from working together in a period but do so in the next. Both models, however, make a distinction between actors who thus “know” each other from those that come from a spot market background.

6.2.4 *Variance of economic results*

The models presented here, along with most models in SCM logistics and transport management literature, yield results of expected economic returns. In one sense, this enables some broad comparisons of results. The variance of these results also interests the shippers and carriers (Danielis et al., 2005).

Variance of several other variables are tackled in the literature which we have not addressed here. The SCM literature has focused on demand variance and its corollary stock variance as demonstrated in Ganeshan et al. (1999). The transport and logistics management literature has instead focused a lot on quality of service variance as seen in MacGinnis (1990), Gibson et al. (1993, 1995).

6.2.5 *Choice in procurement strategy*

A limitation of the model presented in chapter 5 is the fact that the choice is among only three forms of procurement. Even though some care has been taken so that the contracts reflect the widest possible use and the ranges of contract parameters are so large as to allow extreme forms to be also part of the domain of application, there can exist some transport contracts which are not represented.

For example, the QFC we have presented in chapter 5 is not at all like the one presented in Tsay and Lovejoy (1999), Tsay (1999) which includes a rolling horizon and the possibility of revising the target capacity.

The contracts do not allow to discriminate between types of jobs or of goods to be carried within the same contractual framework even though in practice such cases may be found.

6.3 FUTURE EXTENSIONS TO THIS RESEARCH

6.3.1 *Incumbent advantage*

Apart from measuring the values of multi item bids in an auction, there are further reasons to apply auction literature to the auctions in transport. This has to do with the necessity to "level the playing field" between incumbents and other carriers. In effect, firms who have practised a shipper for a long time have learnt all about what is usually not written in a Request For Proposals: the proportion of urgent or rush jobs, the demurrage before loading, the particular habits of customers of the shipper: time windows, unloading equipment, etc. It would be worthwhile to research mechanisms to neutralize the advantages of the incumbent. As a side issue, it would be as interesting for the shipper to be able to measure the extra profit that the carrier has extracted from the relationship resulting from his better knowledge or extra business captured using the backhauls.

Future research will try to apply the research in multi-item auctions and multi-criteria to the transport auctions as defined in Keller et al. (2002) using models from Beil and Wein (2003) or the dynamic resolution of a linear program like the one presented in Gallien and Wein (2005) which also helps in neutralizing the incumbent's advantage.

Apart from the initial selection process, several other opportunities for research have been identified. We proceed to present some of them.

An extension could generate further insight into the so-called incumbent's advantage in the case of the transport industry. In effect, beyond the existence of some specific investments made by both actors, there are positive returns that both the shipper and the carrier make from their relationship which can not be covered by this thesis: knowledge of the carrier's performance and abilities helps the shipper into making the best use of the carrier given her requirements. The carrier knows about the loading and unloading times, payment performance, quality monitoring and controls practised by the shipper; information which is costly to acquire. What mechanism might a shipper set up so as to neutralize this effect when calling other carriers to compete for a new round of negotiations?

6.3.2 *Types of information*

We have seen how the notion of the total load that the shipper has to transport, the real available capacity of transport do have an impact on the profit that both players can extract.

Among the information which are much more difficult to model but which have an equally important impact are information about the urgency of the transport or rather, the lead time between transport requirement and pick up date: if a haulier knows about a required transport hours before he is due to pick up a load, he may not have time to rearrange the schedules of his available trucks. Or perhaps, this urgent trip may be really more costly because of overtime or the necessity to subcontract a third party transport. This type of lead time has been dealt with in the supply chain literature in several papers. These do not account for the specificities of transport, but the differences can be considered as secondary as the lead time in transport between notification of a transport requirement and pick up time can be considered as "production lead time". The reader can refer to, among others, Wu et al. (2005), Cachon (2004a), Schwarz and Weng (2000).

Another type of information which would qualify as performance enhancing for both the carrier and the shipper is the one described by Ulrich Thonemann as "Aggregated Advanced Demand Information" and "Detailed Advanced Information" in Thonemann (2002). In effect, to the carrier it would be a big plus if he were to know in advance where his trucks (or ships, or barges, ...) will be positioned ahead of the actual movement because he could then redeploy this future idle capacity more efficiently. The application in the above paper does not apply to transport but with some minor modifications could model the value of this kind of information to the carrier.

Other types of information which bring added value to the operations of both the shipper and the carrier include the information as to when, where and to whom all goods that a carrier picked up are delivered. This is called tracking and so far is not common practice except for the parcel delivery industry. Yet it provides valuable information as to the flow of goods in a supply chain and can be of interest also the final customer receiving those goods. Good carrier management would also use this type of information as part of an evaluation of quality of service: on-time delivery and shipping errors. This quality information yields benefit in terms of lead times and goodwill from the end customer which is translated into repeat business. It is however more difficult to model with the tools available.

6.3.3 *Incentives for coordination*

In the preceding chapters, two types of incentives have been modeled: the lump sum payment in the MPC enables both the shipper and the carrier to be aligned in booking and providing the required capacity in certain conditions of both exogenous demand and spot price. The penalty is another "negative" incentive which helps to ensure good behaviour both on the shipper as well as the carrier. In chapters 4 and 5, the penalties were levied on capacity or lack of use of such capacity as was solicited. Other penalties could be applied which have not been included here. These include for example penalties for demurrage. If a carrier must wait for more than a contracted waiting time to pick up or unload, he is entitled to receive a penalty *pro rata temporis*. Given the propensity of some shippers to foist their forecasting or administrative errors on the carriers, penalties could also be levied for urgent, rush orders or late cancelations applying yield management techniques already very developed in passenger transport to fleet management in road and rail transport industries.

A second decision is the one the shipper and her client make when deciding upon the stock level each has to maintain which allows for delivery time and demand variance. The impact of coordinated decisions and visibility through the transport link show up when the overall supply chain picture is evaluated: when all three supply chain partners (shipper, carrier and customer) satisfy the other's need for advance information, all can dispense with some buffers, even in the face of demand or lead time volatility (see e.g. double marginalization Spengler, 1950, Tirole, 1988, Boyaci, 2005).

6.3.4 *Endogenous capacity investments*

Further study might profitably include two decisions with increasing importance in these times of just in time and short lead time transport. One is the prior investment decision of the carrier into added capacity to face either unexpected demand from one shipper or the aggregated demand of several shippers in the same industry (Özalp Özer and Wei, 2006).

The capacity constraints on the carrier are not modeled explicitly but the fact that he has to earmark some capacity for use by a certain shipper is taken into account as well as the fact that "left over" capacity has to be disposed of by selling it on the spot market. Both reflect the actual practice of a carrier who has a limited ability to "juggle" his available fleet on the day to accommodate his customer's needs but still has to plan for the long term by investing in capacity which will enable him to satisfy the anticipated needs of his customers.

6.3.5 *Risk aversion*

In the models presented in chapters 4 and 5, the parties to the contracts have been modeled as risk neutral. In future research both mean-variance and time preferences of both shipper and carrier will be integrated (following the example of Seifert et al., 2004). This should allow for better representation of each partner's time discount factor and aversion to the variance of objective functions. Potentially, we should be able to present results which should be of interest when transport costs and demand can become very volatile. In this case, the shipper would probably be even keener to set commitments which overshoot the expected demand. The fact that this would blur the implied expected demand signal for the carrier means that the research needed goes beyond simply replacing the players' utility functions.

6.3.6 *Private information and bargaining*

In chapter 3, we have assumed that the number of periods in the game was common information and known ex ante, enabling both the shipper and carrier to tailor their strategies accordingly. Further research into how these strategies would be impacted should the number of games be also part of the asymmetric information might provide insight into the timing and pace of the rent extraction by the carrier and evasion or free-riding strategies by the shipper. Another avenue which might yield interesting results would be to include in the model some decisions by the carrier about his own relationship specific investments.

6.3.7 *Valuing carrier network extensions*

An extension of research which would interest the carriers in all types of transport involving network or hub and spoke operations would be mathematical tools measuring the benefit to a carrier of adding a particular node to his existing network. As mentioned in chapter 2, several papers dig into the evaluation of a network under several simplifying assumptions Díaz (1982, 1983, 1988), Díaz and Cortés (1996), Díaz (2000), Díaz and Basso (2003). In the last one, the author demonstrates that transport network expansions must be viewed through the concept of economies of scope and not economies of scale. Díaz and Basso (2003) establishes the cost structures of a carrier and demonstrates how, in a three node system, adding a new route brings added benefit without significantly adding to cost. So far, no satisfactory analytical model has been built which captures the cost functions of a network serving many lanes at distinct frequencies.

Such a model would enhance carriers' insight into the potential from multi-bid auctions or the profit of conquering a new client among others. According to Dr Jara Díaz, the mathematics involved are proving unfeasible. Perhaps the whole problem needs to be treated differently? Perhaps an approach using multi-agent based intelligent systems might be a potentially effective tool as this method provides the opportunity to construct large complex systems out of relative simple, autonomous parts. Some references on the subject in SCM include Jansen (2003), Mangina and Vlachos (2005) and Dorer and Calisti (2005).

6.3.8 *Economies of scope*

We wish to share here several hopes for the future of research in transport management. A new model might take into account the impact of other type of information on the behaviour and objective functions of both parties. We list below some of the information which affects that behaviour.

The carrier is able to take advantage of economies of scope in his network by building on the backlegs or on the more intimate knowledge of the industry the shipper is in to acquire business from other shippers in the same or related industries. An extension would model the economies of scope to the carrier both of the business brought by the shipper as well as of outside opportunities. As investigated in Plambeck and Taylor (2005), the carrier and shipper pay for research and development in mutually compatible work and information processes which are mutually beneficial: how are the returns split? Are the investments imbalanced? If so, to what extent does this influence the balance of bargaining power, since those investments are sunk once made?

Part III

APPENDIX

A

APPENDIX TO CHAPTER 2

A.1 ASYMMETRIC INFORMATION AND THE RATCHET EFFECT

A.1.1 *Introduction*

In this appendix, we are interested in how best the carrier can take advantage in the contract that he will offer to carry each unit of the shipper's expected demand when that particular information is only known to the shipper. The shipper S (she) and carrier C (he) [1] set up a long term relationship and bargain over the contract and contract terms that are best for them. The shipper can also take recourse "on the day" in the spot market to resolve her shipping necessities when the carrier does not provide her with the required capacity. In the case that the shipper takes recourse in the spot market, she incurs an information gathering cost I. They agree ex ante to the possibility of reopening that contract at set dates in the future (say every period). Each party is uninformed of the other's cost or utility. Demand is a stochastic exogenous stationary process whose probability distribution is at least a twice differentiable unimodal distribution $F_X(X)$ on a support $[0, Q_{Hi}]$ with $0 < Q_{Hi}$ and density $f_X(X)$, mean μ_X and variance σ_X^2. The demand, when realized, is instantly observed by both carrier and shipper. As in chapter 3, the shipper and carrier must invest in relationship specific assets. The shipper's problem is to reduce the transport cost given that the demand in excess of the contracted capacity has to be carried at higher cost through the spot market. The carrier's problem is to maximize his profit. One of his means of so doing is to tailor his offering to the shipper in such a way that the unused capacity after each realization of demand, and consequently of transport, is the lowest. The carrier is not informed of the shipper's demand. He has to form a belief as to the shipper's type. He also has to update this belief contract after contract.

A.1.2 *Literature review*

This problem was first mooted in Myerson (1979), presented and treated in Laffont and Tirole (1993b) as the dynamic commitment and renegotiation case with intertemporal commitment, and extended to mechanism design with direct revelation and non-linear utility functions in finite-space in Lovejoy (2006). We argue that since this is a repeated game between the same actors, the carrier will be able to update his belief of the expected demand game after game in such a way that it is in the shipper's interest to indicate even in the first game her expected level of demand. We now

1 In difference with the convention which considers the seller to be a "she", we shall term the shipper, even though a buyer here, a "she" to remain coherent throughout the thesis.

show how this problem can be solved by devising a menu of fixed fees and capacity commitments.

A.1.3 *Model*

In time, the sequence of events is the same as in figure 6 on page 32 of chapter 3. We refine the part where the players negotiate the contract, assuming that the shipper has not yet committed to investing in the required relationship-specific assets whereas the carrier already has. A game starts with the negotiation process and ends when both players decide that it ends or when the contract has to be renewed.

The carrier requires an indication which truly reflects the expected demand of the shipper so as to be able to dimension his capacity among all his customers in a profit maximizing way given stochastic demands on his capacity by those customers. We assume here that the shipper and carrier are able to reopen negotiations when this suits them to set up a new contract. In all periods after the first in which they have worked together, both are able to use past experience of performance and revelations of demand to correct the offers they can make and those they accept. The carrier is embedded in a Bayesian universe in which parties have an a priori belief on the information they do not possess (a *prior*), and they revise this prior as the interaction unfolds. So, the carrier has a Bayesian belief about the distribution of the expected demand to be carried in an interval $[\underline{\tau}, \overline{\tau}]$.

Before the first game, the carrier will exaggerate the possible cost by underestimating the average demand and overestimating the variance of this demand. Game after game, he is able to update his estimates of demand and corresponding distribution function and refines his evaluation of demand.

To refine the first estimate, he builds a menu of Minimum Purchase Commitment (MPC) contracts as defined in section 2.4.3 of chapter 2 or section 5.3.3 of chapter 5[2]. Since the initial investment cost A_{s1} and the fixed fee r are fixed whatever the choice of the other parameters q and s and whatever the realized demand, the carrier does not include them in the menu. He builds the menu in terms of q and s. The objective function of the shipper changes somewhat and can be written as

$$\min_{q,s}\big(C_s(q,s)\big) = s\mu_X(q) + I\overline{F_x}(q) + \varphi^s(q), \tag{A.1}$$

where $\overline{F_x}(q) = (1 - F_x(q))$, I is the information cost to the shipper of gathering information on the spot market, $\mu_X(q)$ is defined as in equation (5.10) on page 104 and $\varphi^s(q)$ is suitably defined in equation (B.8).

The shipper has to minimize this function in both q and s.

If both interact repeatedly and agree beforehand to reopen negotiations periodically, the carrier will not be able to obtain in the first period his best profit, whereas the shipper can take advantage of this asymmetric

2 Note that the carrier at this point is not in a position to evaluate $s(q)$ as characterized in (5.14) on page 105 because this requires an estimate of the expected demand as well as a distribution of such demand on his part.

information by overestimating the capacity she needs and reduce the carrier's overall profit. As shall be demonstrated, the carrier can at first obtain information about the shipper's type by offering a suitable menu of contracts. In later games, the carrier will update his estimate of the shipper's demand using past performance and narrow the range of contract menus. He thus updates his estimate to reduce the advantage of the shipper in what is called the *ratchet effect* (Weitzman, 1976, 1980).

The carrier makes an initial estimate of the shipper's probable demand as belonging to a discrete range of $[\underline{\tau}, \overline{\tau}]$. This range is included in a much larger discrete range which extends from 1 to a maximum possible capacity W which is the limit of the carrier's capacity once the expected demands addressed to him by his other customers have been satisfied. The carrier also estimates that the shipper's cost function is concave. Without loss of generality we can assume that there exist two other non-empty discrete ranges $[a, \underline{\tau} - 1]$ and $[\overline{\tau} + 1, b]$ which are also included in the large range $[1, W]$. We define $1 < a < \underline{\tau}, \overline{\tau} < b < W$. The carrier initially estimates the probabilities of the shipper's demand to fall within one of these ranges and builds a menu of three capacity commitments q so that one fits in each segment.

The carrier now builds his menu in the following way. He chooses s and q such that

$$q \in [a, \underline{\tau} - 1], \qquad \exists\, s \,|\, s\mu_X(q) > \overline{IF_X}(q) + \varphi^s(q) \qquad (A.2)$$

$$q \in [\overline{\tau} + 1, b], \qquad \exists\, s \,|\, s\mu_X(q) < \overline{IF_X}(q) + \varphi^s(q). \qquad (A.3)$$

These inequalities can be interpreted as meaning that if the capacity commitment is less than expected demand, then the carrier must offer price terms such that the contract is more expensive to the shipper than relying on the spot market for her transport necessities. If the capacity commitment is higher than the expected demand, than the carrier must offer price terms for the contract which are less costly to the shipper than the spot market.

The carrier then formulates the offer to the shipper of two ranges for quantities q and their two per unit prices s. The offer states that the shipper must select for each s a quantity q taken from the corresponding range. The shipper's answer is hence composed of two tuples.

If the carrier effectively has correctly evaluated the expected demand of the shipper (meaning that $\underline{\tau} \leq \mu_X \leq \overline{\tau}$), and if the shipper has a concave cost function, the optimal commitment request from the shipper $\widehat{q} = a$ when condition for s satisfy (A.2). In the same way, it is optimal for the shipper to ask that $\widehat{q} = b$ when s is chosen such that (A.3) is satisfied.

If the carrier has *not* correctly evaluated this demand (eg, $\mu_x \in [\overline{\tau}+1, b]$), the shipper might choose $\widehat{q} = a$ when s satisfies (A.2) and $\widehat{q} = b$ or $\widehat{q} = \overline{\tau}+1$ when s satisfies (A.3). If on the other hand, $\mu_x \in [a, \underline{\tau}]$, the shipper will choose $\widehat{q} = \underline{\tau} - 1$ or $\widehat{q} = a$ when s satisfies (A.2). The carrier would guess incorrectly in which of the three segments the shipper's expected demand lies.

Note that the carrier does not yet make an offer for any quantity between $\underline{\tau}$ and $\overline{\tau}$.

According to the answer of the shipper, the carrier may update the ranges $[a, b]$ and $[\underline{\tau}, \overline{\tau}]$. He may also make a new guess about the order between $\underline{\tau}$, μ_x and $\overline{\tau}$. Having reevaluated the ranges, the carrier may formulate a new menu of two ranges for q and the corresponding prices s. The shipper will thus provide him with another update of the possible order between μ_x, $\underline{\tau}$ and $\overline{\tau}$. The process can be repeated a finite number of steps[3]. The carrier narrows the range for his belief of the expected demand to such a point that he is able to include an updated estimate of the shipper's demand to his other planned requirements and outside opportunities. He can now make a take-it-or-leave-it offer to the shipper setting all three parameters of the MPC $\{q, s, r\}$ so as to maximize his profit.

A.1.4 *Numeric illustration*

To illustrate this information process, let us present a small numerical illustration. Demand being a stochastic variable, the states of the world for it are $\Omega = \{1, 2, 3, 4, 5, 6\}$. These states have equal probabilities of realizing themselves such that $p(i) = 1/6$, for all $i \in \{1, \ldots, 6\}$. The spot market price of transport is fixed at $p = 10$. The information cost of taking recourse in the spot market for the shipper $I = 2$.

The shipper's objective is to minimize the transport cost. She has as objective function the one presented in (A.1) suitably adapted to the present case as described in the numeric example of univariate demand and fixed spot price in Appendix D.6 on page 188 and characterized in equations (D.36). The shipper knows that according to the possible offers from the carrier, if

$$
\begin{aligned}
q = 1, \Rightarrow \qquad & C_s(1, s) = \frac{5}{6}s + \frac{5}{3} + 30 \\
q = 2, \Rightarrow \qquad & C_s(2, s) = \frac{3}{2}s + \frac{4}{3} + 25 \\
q = 3, \Rightarrow \qquad & C_s(3, s) = 2s + 1 + 20 \\
q = 4, \Rightarrow \qquad & C_s(4, s) = \frac{7}{23}s + \frac{2}{3} + 15 \\
q = 5, \Rightarrow \qquad & C_s(5, s) = \frac{5}{2}s + \frac{2}{6} + 10 \\
q = 6, \Rightarrow \qquad & C_s(6, s) = \frac{5}{2}s.
\end{aligned}
\tag{A.4}
$$

Suppose that the carrier estimates that $\mu_x = 3$.

The strategy for the carrier is to proceed in several steps in his offers. In the initial step, he first partitions the range of possible values for q in three. In the present case, $a = 1$, $b = 6$, $\underline{\tau} = 3$ and $\overline{\tau} = 4$. Second, he builds a menu of prices and capacities for the top and bottom ranges of capacities. The menu for each range looks like this: "for a quantity that is comprised between a and $\underline{\tau} - 1$, the per unit price is $s = s_l$. For a quantity between $\overline{\tau} + 1$ and b, the per unit price is $s = s_h$". The shipper responds

3 The number of steps is finite as established in Geanakoplos and Polemarchakis (1982). See also §2.3.1 in Chapter 2.

by indicating for each of the two ranges the tuple which interests her the most.

The carrier formulates a menu of tuples using some values of s coherent with the price observed in the spot market (information known to the shipper and carrier), such that he offers the following menu of tuples and the shipper can evaluate her cost correspondingly.

$$s = 10, \quad \begin{cases} q = 1 & \Rightarrow C_s(1,10) = 40 \\ q = 2 & \Rightarrow C_s(2,10) = 41 + \frac{1}{3}, \end{cases} \tag{A.5}$$

$$s = 8, \quad \begin{cases} q = 5 & \Rightarrow C_s(5,8) = 30 + \frac{1}{3} \\ q = 6 & \Rightarrow C_s(6,8) = 20. \end{cases} \tag{A.6}$$

The shipper informs the carrier that her choice of tuples of parameters are $\{1,10\}$ and $\{6,8\}$: she prefers to book as much capacity as possible when the price s is low compared to the spot market price and on the contrary to book as little as possible when that same price is high (even if we include a cost of accessing the spot market for her).

In the following step, the carrier updates his estimate of a (here the new $a = 2$) by increasing it and of b by decreasing it (now $b = 5$). He can also do the same for $\underline{\tau}$ and $\overline{\tau}$ (not needed in this example). He thus closes both the overall range and the smaller range which is his estimate of the expected demand. By iterating these steps he can obtain truthfully the shipper's estimate within a reasonable limit. He can then use this updated estimate of the shipper's expected demand to evaluate the capacity that he must earmark for the shipper.

In the final step, the carrier will restrict his offer for q to the range $[\widehat{\underline{\tau}}, \overline{\widehat{\tau}}]$ and optimize s according to his objective function. Most probably, the shipper's objective function over this range will also be concave and she will select one of the bounds. In our example, the carrier offers as final offer $q \in \{3,4\}$ and sets s so as to maximize his profit. The shipper can then either accept or refuse (this case might be if the price s violates her participation constraint).

A.1.5 *Conclusion*

This mechanism requires only a finite number of steps since the capacity commitments q is included within a discrete bounded range.

The carrier can now also offer other types of contracts such as the Quantity Flexibility Clause and do so using the parameters which suit him best given the updated belief about the expected demand to be carried!

This result is achieved even though the first game has not even started. After the first period is over, the carrier has now the benefit of the realized demand during the past period to update his beliefs on the expected demand of the shipper. If the carrier and shipper had signed a contract extending over several periods (as presented in chapter 5), this past information is even more interesting when the contract comes up for renewal because the carrier can build a distribution of past realized demands as well as update the probability distributions for the three ranges described above $[a, \underline{\tau} - 1]$, $[\underline{\tau}, \overline{\tau}]$ and $[\overline{\tau} + 1, b]$.

B

APPENDIX TO CHAPTER 3

B.1 PROPERTIES OF DISTRIBUTIONS WITH INCREASING FAILURE RATES

Let f and F be respectively the pdf and cdf of a distribution with an increasing failure rate as defined in Barlow and Proschan (1965).

$$F(x) = \int_{-\infty}^{x} f(u)du \tag{B.1}$$

$$\lim_{x\to\infty} F(x) = 1, \tag{B.2}$$

B.1.1 *Problem*

The principal must maximize the following objective function

$$\begin{aligned} R(x) &= \alpha F(x) + x\overline{F}(x), \\ &= F(x)(\alpha - x) + x, \end{aligned} \tag{B.3}$$

where α is defined as a real, the price received by the principal when the agent refuses the offer. The case where $\alpha = 0$ is the one covered in Lariviere (2006).

We propose to prove that a unique interior point within the range $[\underline{X}, \overline{X}]$ does indeed maximize it. We first show that the point, if it exists, is a maximum. We then prove that it is unique and finally that it does exist.

Is the optimum a maximum?

We first mention a corollary of the increasing failure rate of interest in what follows.

An increasing failure rate has equivalently the following property

$$r'(x) \geq 0. \tag{B.4}$$

This means that

$$f'(x)(1 - F(x)) + f(x)^2 \geq 0. \tag{B.5}$$

The F.O.C. requires that

$$R'(x) = f(x)(\alpha - x) + \overline{F}(x) = 0. \tag{B.6}$$

We describe in corollary the properties of this first differential

Corollary 10. *If F is such that $F(1) = 1$, then $x = 1$ is solution and is also a maximum because $R''(1) < 0$. This covers the case when the properties of the IFR distributions cannot be applied since at $x = 1$, $r(x)$ is not defined. Similarly, if $f(\underline{X}) = 0$, then $\underline{X}$ is a maximum if $\underline{X} \leq \alpha$ because $R''(\underline{X}) \geq 0$.*

For all cases such that $f(x) > 0$, we can write the F.O.C. as

$$\alpha - x = -\frac{\overline{F}(x)}{f(x)}. \tag{B.7}$$

The S.O.C. for a maximum requires that

$$R''(x) = (\alpha - x)f'(x) - 2f(x) < 0. \tag{B.8}$$

In the case when $f(x) > 0$, when we replace $(1 - x)$ from (B.7) in (B.8), we obtain

$$f(x)R''(x) = -r'(x) - f(x)^2. \tag{B.9}$$

By definition of the first differential of the failure rate $r'(x) \geq 0$. So, because $f(x) > 0$, $R''(x) < 0$.

So, if

$$\exists x_0 \,|\, R'(x_0) = 0 \Rightarrow R''(x_0) < 0. \tag{B.10}$$

If a value exists which is an extremum for the objective function, it is a maximum.

Let us now see whether this maximum is unique.

Is the maximum unique?

Reasoning by the absurd, if

$$\exists (x_0, x_1) \in [\underline{X}, \overline{X}]^2, \,|\, x_0 < x_1,\ R'(x_0) = R'(x_1) = 0, \tag{B.11}$$

then by (B.10),

$$R''(x_0) < 0 \wedge R''(x_1) < 0. \tag{B.12}$$

Since $R(.)$ is continuous by construction, it decreases for values in the vicinity and above x_0, whereas it increases for values in the vicinity but below x_1. Hence, between x_0 and x_1, $R'(.)$ changes sign, so that

$$\exists x_2 \in]x_0, x_1[, \,|\, R'(x_2) = 0, R''(x_2) \geq 0, \tag{B.13}$$

This contradicts (B.10). Hence there cannot exist another point x_1, distinct from x_0, for which $R'(x_1) = 0$.

We conclude that the point which represents the maximum of the objective function in the interval $[\underline{X}, \overline{X}]$, if it exists, is unique.

Does it exist?

We now prove that such a maximum exists.

For that, we proceed to prove that

$$\begin{cases} R'(\underline{X}) \geq 0, \\ R'(\overline{X}) \leq 0. \end{cases} \tag{B.14}$$

By construction of $F(.)$, even though $f(x) > 0$ and $F(x) < 1$, at the limit,

$$\begin{cases} \lim_{x\to\underline{X}} R'(x) = f(\underline{X})(\alpha - \underline{X}) + 1 \\ \lim_{x\to\overline{X}} R'(x) = f(\overline{X})(\alpha - \overline{X}). \end{cases} \tag{B.15}$$

For both conditions in (B.14) to be true, we obtain the following conditions

$$\begin{cases} \underline{X} < \alpha + \frac{1}{f(\underline{X})} \\ \overline{X} > \alpha. \end{cases} \tag{B.16}$$

Note that the seller's belief about the range of expected buyer's willingness to pay includes both lower and higher values than that outside option revenue. If that were not the case, the seller's belief would have no bearing on his objective function. From Corollary 10, if $\alpha < \underline{X}$, the maximum revenue for the principal is achieved for him by choosing $\underline{X}$ as the offering price. Similarly, from the same corollary, if $\alpha > \overline{X}$, the principal chooses $\overline{X}$.

B.2 EVALUATING THE CARRIER'S OPTIMAL OFFER IN THE ASYMMETRIC INFORMATION AND COMMITMENT CONTRACT

In the following, we establish formally the way the carrier can optimally evaluate the thresholds for both A and a when this information is withheld by the shipper.

We provide here the demonstration for the proposition presented in §3.3.2 on page 35.

We spell out the carrier's objective function in terms of Z, the offer he makes.

$$\max_Z \left(\Pi_c(U^1, Z) | \delta_s^1\right) = U^1 \overline{F_Z}(Z) + (u_c - a_c) F_Z(Z). \tag{B.17}$$

Proof. This function yields as first differential in Z

$$\frac{\partial \Pi_c(Z)}{\partial Z} = f_Z(Z)\big(u_c - a_c - Z\big) - F_Z(Z) + 1. \tag{B.18}$$

For a threshold Z to be a maximizing one in terms of profit to the carrier, we must have

$$\begin{cases} \frac{\partial \Pi_c(Z^*)}{\partial Z} = 0, \; Z^* \in [\underline{Z}, \overline{Z}] \\ \frac{\partial^2 \Pi_c(Z^*)}{\partial Z^2} < 0, \; Z^* \in [\underline{Z}, \overline{Z}]. \end{cases} \tag{B.19}$$

The first order condition (F.O.C.) for an optimum means that

$$Z - \frac{\overline{F_Z}(Z)}{f_Z(Z)} = u_c - a_c. \tag{B.20}$$

This equation is similar to (B.7) in Appendix B.1.

We refer the reader to the demonstration in §B.1 earlier in this Appendix for the proof of the existence and uniqueness of a Z^* as threshold solving the above equation.

The unique value Z^* maximizing the carrier's profit is the solution to

$$Z^* - \frac{\overline{F_Z}(Z^*)}{f_Z(Z^*)} = u_c - a_c. \tag{B.21}$$

This contract $U = Z^*$ is accepted with probability $\overline{F_Z}(Z^*)$ and yields the following cost to the shipper

$$C_s = Z^* \overline{F_Z}(Z^*) + (u + a) F_Z(Z^*). \tag{B.22}$$

∎

B.3 ESTABLISHING THE EVALUATION OF THE INVESTMENT COSTS BY THE CARRIER

We first evaluate the strategies open to both players before presenting the calculations of those thresholds in the multi-period case.

Presenting the strategies and ensuing shipper's states...

The strategies which can now be applied by shipper and carrier can no longer be assumed to be leading to the same Nash Equilibirum as in the full-information multi-period game presented in section 3.3.3. If $A^{1*} < A$ or if $a^* > a$, the shipper will reject the carrier's offer. We must revisit the multi-period strategies in which the shipper finds herself according to the offers by the carrier.

STATE 1

Evaluated in period 1, the carrier's threshold $A^{1*} \geq A$, so given the sequential rationality of the shipper, she works with the carrier for this and all periods up to period $n-1$. In the last period, if the carrier's threshold $a^* \leq a$, the shipper also accepts to work with the carrier.

The carrier applies the same strategy as when he possessed all relevant information as seen in section 3.3.3. So

$$\begin{cases} U^1 = u - A^{1*}, \\ U^i = u, \qquad 1 < i < n, \\ U^n = u + a^*, \end{cases} \tag{B.23}$$

under the carrier's participation constraint

$$nu - A^{1*} + a^* \geq nu_c - a_c. \tag{B.24}$$

The shipper's cost and carrier's profit over the n periods are

$$\begin{aligned} C &= nu - A^{1*} + A + a^*, \\ \Pi_c &= nu - A^{1*} + a^*. \end{aligned} \tag{B.25}$$

When period n starts, the carrier must now show his offer using a^*. If $a^* > a$, the shipper rejects the offer, $\delta_s^n = 0$. The shipper's cost and carrier's profit become

$$\begin{aligned} C &= nu - A^{1*} + A + a, \\ \Pi_c &= (n-1)u - A^{1*} + u_c - a_c. \end{aligned} \tag{B.26}$$

STATE 2

In period 1, the carrier's threshold $A^{1*} < A$, the shipper rejects the offer. The carrier incurs a_c and the shipper incurs a in that period. In the second period, if $u \leq u_c$, the carrier is no longer interested in the shipper's custom and no further offer is made: the carrier turns to his outside option in all remaining $n-1$ periods.

If $u > u_c$, in the second period and in all posterior ones up to period $n - j$ such that the carrier's participation constraint and the shipper's incentive compatibility constraint

$$\begin{aligned} j+1 &\geq \frac{A^{(n-j)*}}{u - u_c}, && \text{(PC)} \\ A^{(n-j)*} &< A^{(n-j+1)*} && \text{(IC)} \end{aligned} \tag{B.27}$$

are satisfied, the carrier updates[1] his estimate of A .

If the shipper accepts, since in the final period the carrier can no longer capture any extra rent from the shipper, their respective results are

$$\begin{aligned} C &= nu - A^{j*} + A + a \\ \Pi_c &= (n-j)u - A^{j*} + ju_c - a_c. \end{aligned} \tag{B.28}$$

If the shipper refuses and the period is $n - j$, then the shipper is in state 3.

STATE 3

In State 3, all the carrier's offers in previous periods are such that $A^{j*} < A$. In period $n - j$, if

$$\begin{cases} j+1 < \frac{A^{(n-j)*}}{u-u_c}, & \text{(PC)} \\ A^{(n-j)*} \geq A^{(n-j-1)*}, & \text{(IC)} \end{cases} \tag{B.29}$$

he turns to his outside option till period n. The shipper and carrier *never* work together: the shipper's overall cost and carrier's overall profit can be written

$$\begin{aligned} C &= nu + a \\ \Pi_c &= nu_c - a_c. \end{aligned} \tag{B.30}$$

Figure 35 represents the three possible states and the shipper's decisions leading to them. The remaining leaves of the tree can not be populated because the shipper's decision tree and the carrier's offers would not lead to them.

Evaluating the thresholds...

We now present the evaluations of the thresholds that enable the carrier to calibrate his offers to the shipper. His objective is to maximize his profit given these thresholds and possible strategies and can be summarized as

$$\begin{aligned} &\max \Pi_c(A, a, A^j) = \\ &F_{A1}(A^1)\Big[(n-1)u - A^1 + \overline{F_a}(a)\Big(u + a\Big) + F_a(a)(u_c - a_c)\Big] + \\ &\overline{F_{A1}}(A^1)\Bigg[u_c - a_c + F_{A2}(A^2)\big\{(n-1)u - A^2\big\} + \\ &\qquad \overline{F_{A2}}(A^2)\Bigg(u_c + F_{A3}(A^3)\Big[(n-2)u - A^3\Big] + \dots \\ &\qquad\qquad F_{A(n-j)}(A^{n-j})\big((j+1)u - A^{n-j}\big) + \\ &\qquad\qquad u_c + \overline{F_{A(n-j)}}(A^{n-j})\big((j+1)u_c\big)\dots\Bigg)\Bigg], \end{aligned}$$

1 This evaluation is presented later.

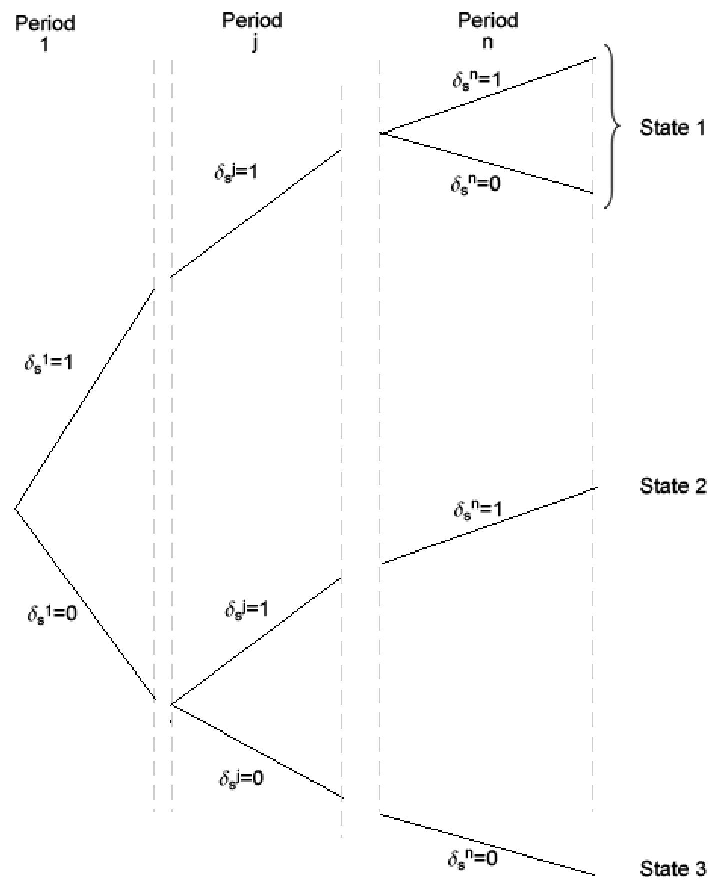

Figure 35: States of nature according to the carrier's thresholds A^{j*} and a^*.

Table 23: In a four-period game, the carrier's profit function in terms of the thresholds resulting from his updated estimates of A. The last line corresponds to the case where $3u - A^{2*} < 3u_c$.

1	2	3	4	State
$F_{A1}(A^1)\big[u - A^1$	$+u$	$+u$	$+\overline{F_a}(a)(u+a)+$	1
			$F_a(a)(u_c - a_c)\big]$	
$\overline{F_{A1}}(A^1)\big[u_c - a_c$	$+F_{A2}(A^2)(u - A^2$	$+u$	$+u)$	2
	$+\overline{F_{A2}}(A^2)\{u_c+$	$+F_{A3}(A^3)[u - A^3$	$+u]$	2
		$+\overline{F_{A3}}(A^3)[u_c$	$+u_c]\}$	3
$\overline{F_{A1}}(A^1)\big[u_c - a_c$	$+u_c$	$+u_c$	$+u_c\big]$	3

(B.31)

$$\text{s.t.} \begin{cases} (j+1)(u-u_c) \geq A^{(n-j)}, & \text{(PC)} \\ A^{(n-j)} \geq A^{(n-j+1)}, & \text{(IC)} \\ nu + a - A^1 \geq nu_c - a_c, & \text{(PC).} \end{cases}$$

We give in Table 23 an example of the carrier's profit function in the case of a four-period game. Note that the last line is the case where $A^{1*} < A$ and $3u - A^{2*} < 3u_c$: the carrier is not interested in offering a contract in period 2 because his expected profit given his threshold A^{2*} is lesser than turning to his outside option in the last three periods.

Belief about the shipper's relationship specific asset with her outside option a

We first turn to the belief about the shipper's investment into specific assets relative to her outside option a which the carrier has to make in period n.

The first differential of the profit function is written:

$$\frac{\partial \Pi_c(a)}{\partial a} = F_A(A)\Big[f_a(a)\big(u_c - a_c - u - a\big) + \overline{F_a}(a)\Big]. \tag{B.32}$$

This leads to the F.O.C.

$$(u+a) - (u_c - a_c) = \frac{\overline{F_a}(a)}{f_a(a)}. \tag{B.33}$$

The S.O.C. requires that the following inequality be true

$$f_a'(a^*)\big(u_c - a_c - u - a\big) - 2f_a(a^*) < 0. \tag{B.34}$$

Here again, assuming that f_a has an IFR and $f_a(a) \neq 0$, we can solve as a particular case of the problem defined in §B.1.1. So we have again one single optimal threshold.

There exists an interior value a^* such that

$$a^* - \frac{\overline{F_a}(a^*)}{f_a(a^*)} = u_c - a_c - u. \tag{B.35}$$

Updated belief about the shipper's relationship specific asset with the carrier A^{n-j}

In period $n-j$, the last period in which (B.27) are satisfied, the shipper is in state 2. The carrier makes a last update of A. The first differential of his profit function in terms of A^{n-j} is written

$$\frac{\partial \Pi_c^{(n-j)}(A^{n-j})}{\partial A^{n-j}} = f_{A(n-j)}(A^{n-j})\Big((j+1)(u-u_c) - A^{n-j}\Big) - F_{A(n-j)}(A^{n-j})\Big]. \tag{B.36}$$

The S.O.C. requires that

$$f'_{A(n-j)}(A^{(n-j)*})\Big((j+1)(u-u_c) - A^{(n-j)*}\Big) - 2f_{A(n-j)}(A^{(n-j)*}) < 0. \tag{B.37}$$

Once again, we recognize formulations which are of the form studied in §B.1.1.

So, from (B.36), and since (B.37) is true, we can deduct the optimal threshold $A^{(n-j)*}$ in period $n-j$ as solution to

$$A^{(n-j)*} + \frac{F_{A(n-j)}(A^{(n-j)*})}{f_{A(n-j)}(A^{(n-j)*})} = (j+1)(u-u_c), \tag{B.38}$$

Belief about the shipper's relationship specific asset with the carrier A

Using backward induction, we can now evaluate the threshold for A in the previous period starting with period $n-j-1$. The profit function in preceding periods i, $1 \le i \le n-j-1$, can be written as

$$L^i = F_{Ai}(A^i)\Big((n-i+1)u - A^i\Big) + \overline{F_{Ai}}(A_i)\Big(u_c + L^{i+1}\Big). \tag{B.39}$$

In period $n-j$, the last term of the series L is written as

$$L^{n-j} = F_{An-j}(A^{n-j})\Big((j+1)u - A^{n-j}\Big) + \overline{F_{An-j}}(A^{n-j})\Big((j+1)u_c\Big). \tag{B.40}$$

The optimal threshold in each period i is the result of evaluating the F.O.C. and S.O.C. of the expression L^i differentiated in A^i for $2 \le i < n-j$. By the same proof in appendix B.1 on page 141 as above, we obtain

$$A^{i*} + \frac{F_{Ai}(A^{i*})}{f_{Ai}(A^{i*})} = (n-i+1)u - u_c - L^{i+1}. \tag{B.41}$$

and proceeding in a bootstrapping iteration we evaluate all the preceding L^i back to L^2 and A^1:

$$A^{1*} + \frac{F_{A1}(A^{1*})}{f_{A1}(A^{1*})} = (n-2)u - u_c - L^2 \tag{B.42}$$

To be incorporated in contracts that can be offered to the shipper, the thresholds evaluated above must follow the strategy which we described when the shipper is in state 2 or 3, namely that $A^{i*} < A^{(i+1)*}$ for the first few periods.

By definition, L^i represents the expected profit to the carrier going forward in periods $i+1$ to n when he erred in his evaluation of A. As i increases, this expected profit decreases since each period's profit is not negative, even if it consists in taking his outside option. So

$$L^{i+1} < L^i. \tag{B.43}$$

Further, from (B.41), even if the distribution of the belief about A is not updated, in each period, the period's threshold is higher than the previous one's.

Moreover, since the carrier offers a sequence of monotonously increasing bids, we have

$$A^{*1} < A^{*2} < \ldots < A^{i*}. \tag{B.44}$$

We reach a point where A^i becomes large compared to $(n-i+1)u$ within L^i in (B.39). By construction, after that point A^i can no longer increase and in fact decreases as can be seen in the numerical illustration presented in Section 3.4. So the carrier cannot make an offer more enticing than the previous one to the shipper. Instead, the carrier turns to his outside option.

Armed with the results presented here we can formulate the best strategies for both shipper and carrier. Those are presented in Proposition 4 on page 44.

B.4 PROOF OF THE FULL ASYMMETRIC INFORMATION SCENARIO

We present here the relevant calculations to support the results presented in Proposition 5 of §3.3.6 on page 45.

Let us name the beliefs by the carrier of the shipper's cost of outside option and investment in relation specific assets as Z_1^j, Z_2 and Z_3^j in period j. We have

$$Z_1^j = u - A, \quad Z_2 = u + a, \quad Z_3^j = u. \tag{B.45}$$

As in the preceding Sections, the belief about Z_1^j is supported on $[\underline{Z_1^j}, \overline{Z_1^j}]$, with cumulative distribution function F_{Z1}^j. This distribution function is conditionally distributed according to the information revealed as Z_1^{i*}, $1 \le i < j$ have induced refusals from the shipper in previous periods. The belief about Z_3^j is supported on $[\underline{Z_3^j}, \overline{Z_3^j}]$ with distribution functions F_{Z3}^j, also conditionally distributed according to the previous periods' refusals by the shipper of contracts built upon the Z_3^{i*} with $2 \le i < j$. The belief about Z_2 is supported on $[\underline{Z_2}, \overline{Z_2}]$ with a cumulative distribution function F_{Z2}, itself conditionally distributed according to the information revealed by the acceptance of the contract based upon Z_1^{1*} in the first period and the acceptance of the contract in the second period based upon Z_3^{2*}. In all cases, the cumulative distribution functions have an IFR and $F_{Zi}^j(Z_i^j) < 1, i \in \{1, 2, 3\}$ but arbitrarily close to 1.

So the carrier decides upon the contracts he offers upon the thresholds Z_1^{j*}, Z_2^* and Z_3^{j*} in such a way as to maximize his profit.

We first present the different strategies that both players can deploy and later evaluate the required threshold values that the carrier needs to build his contractual offers. We conclude this section by evaluating the different strategies and presenting the Nash Equilibrium solution.

Once again, the shipper can find herself in one of three stages.

After the first period, the carrier is in a position of updating his prior using the answer provided by the shipper. Even if the carrier has obtained the agreement to work with him, he should be able to reevaluate the offer in the posterior periods using the confirmation that the shipper agrees with the offer and thus extract further rent from the shipper. In this model we take the simplifying assumption that once the carrier has obtained an agreement from the shipper, he does not take advantage of the shipper's acceptance to revise his prior on Z_1 or Z_3 and use this update as his new prior. This refinement has been left out for two reasons: it further complicates an already complex model and the solutions follow along the same path as the one presented here. This means that if Z_1^{i*} is acceptable, Z_2^* and Z_3^{i*} have been built using the information revealed by the acceptance of Z_1^{i*} in their respective periods but all offers U^j with $i < j < n$ are built using the same Z_3^{i*}.

STATE 1:
shipper has accepted the carrier's first period offer and invested A. If the

carrier also wins the second period contract and the final period contract, those are

$$\begin{cases} U^1 = Z_1^{1*}, \\ U^i = Z_3^{2*}, \quad \forall i, 2 \leq i \leq n-j, \\ U^n = Z_2^* \quad . \end{cases} \tag{B.46}$$

The corresponding profit over n periods to the carrier and cost to the shipper are

$$\begin{aligned} \Pi_c &= Z_1^{1*} + (n-2)Z_3^{2*} + Z_2^*, \\ C &= Z_1^{1*} + (n-2)Z_3^{2*} + Z_2^* + A, \end{aligned} \tag{B.47}$$

with Z_1^{1*} solution to (B.60), Z_3^{2*} solution to (B.69) and Z_2^* solution to (B.65). The participation constraints, as would be expected, are the following

$$\begin{cases} Z_1^{1*} \leq u - A, \\ Z_3^{2*} \leq u, \\ Z_2 \leq u + a, \\ Z_1^{1*} + (n-2)Z_3^{2*} + Z_2 \geq nu_c - a_c. \end{cases} \tag{B.48}$$

The shipper's strategy set is reduced to one vector $R_{s1} = \{v_{s1}\}$ with $v_{s1} = (1, 1, \ldots, 1)$. The carrier's strategy set is also reduced to one vector $R_{c1} = \{(Z_1^{1*}, Z_3^{2*}, \ldots, Z_2^*)\}$.

STATE 2:

In period 1, the carrier's threshold Z_1^{1*} and corresponding contract $U^1 > u - A$, so the shipper rejects the offer. The carrier incurs a_c and the shipper incurs a in that period. In posterior periods i such that

$$Z_1^{i*} + (n-i)Z_3^{i+1*} < (n-i+1)u_c, \qquad \forall i \,|\, 1 < i < n, \tag{B.49}$$

the carrier is no longer interested in the shipper's custom and no further offer is made: the carrier turns to his outside option in all remaining $n-i$ periods.

The participation and incentive compatibility constraints in this scenario are reworded as the following

$$\left.\begin{aligned} Z_1^{i*} + (n-i)Z_3^{i+1*} \geq (n-i+1)u_c, \quad & \text{(PC)} \\ Z_1^{i*} < Z_1^{(i-1)*}. \quad & \text{(IC)} \end{aligned}\right\} 1 < i < n. \tag{B.50}$$

In the period $i+1$, the carrier builds a new belief about Z_3 conditioned upon the acceptance of Z_1^i. If $Z_3^{(i+1)*} > u$, the shipper refuses. In the other case, The players' objective functions are written

$$\begin{aligned} \Pi_c^i &= (i-1)u_c - a_c + Z_1^{i*} + (n-i)Z_3^{(i+1)*}, \\ C^i &= (i-1)u + a + Z_1^{i*} + (n-i)Z_3^{(i+1)*} + A, \end{aligned} \quad 1 < i < n \tag{B.51}$$

with $Z_1^i \leq u - A$ and $Z_3^{i+1} \leq u$.

The shipper's strategy set is comprised of the following vectors $R_{s2} = \{v_{s2} = (\delta_s^1, \delta_s^2, \ldots, \delta_s^n) \,|\, \forall j, 1 \le j < i, \delta_s^j = 0, \delta_s^i = 1, \forall k, i < k \le n, \delta_s^k \in \{0,1\}\}$. The carrier's optimal strategy set is

$$R_{c2} = \{v_{c2} = (Z_1^{1*}, Z_2^{2*}, \ldots, Z_1^{i*}, Z_3^{(i+1)*}, \ldots)\},$$

with the Z_1^{j*} for $1 \le j \le i$ satisfying (B.60), Z_3^{k*} for $i+1 \le k \le n$ satisfying (B.69).

STATE 3:
shipper has rejected all earlier offers and only invested a in period 1. In period j, the carrier updates the belief about Z_1 and builds a distribution about Z_1^{j*} using the information revealed by the previous periods' refusals. However, one of the carrier's participation constraints in (B.50) is violated: the carrier turns to his outside option. The objective functions of carrier and shipper become

$$\begin{aligned} \Pi_c &= nu_c - a_c, \\ C &= nu + a. \end{aligned} \tag{B.52}$$

The shipper's strategy set is comprised of just one vector, the null vector: $R_{s3} = \{(0, \ldots, 0)\}$. The strategy set R_{c3} of the carrier includes all vectors $v_{c3} = (Z_1^{1*}, Z_1^{2*}, \ldots, Z_1^{(n-j)*}, 0, \ldots, 0)$ such that $\forall i \le n-j, Z_1^{i*} > u - A$ and all for all periods afterwards till the last, the carrier turns to his outside option, symbolized in the vector as an offer of 0 to the shipper.

Building the carrier's profit function...

We present in Figure 36 some of the profit functions in terms of the thresholds that the carrier sets in different periods.

We have two iterative loops embedded one into the other. The first one is based upon the carrier's profit in period i if the shipper refused in period 1 to work with him but accepted in period $i-1$:

$$K^i = \overline{F_{Z3}^i}(Z_3^i)\big(Z_3^i(n-i+1)\big) + F_{Z3}^i(Z_3^i)\big(u_c + K^{i+1}\big), 2 < i < n. \tag{B.53}$$

The second one into which the fist appears is based upon the string of profits starting with the acceptance by the shipper of period i's contract –which satisfies constraints in (B.50)– after having rejected all earlier offers:

$$P^i = \overline{F_{Z1}^i}(Z_1^i)\big(Z_1^i + K^{i+1}\big) + F_{Z1}^i(Z_1^i)\big(u_c + P^{i+1}\big), 2 \le i < n. \tag{B.54}$$

The last period for which those K^i and P^i are evaluated is the one for which the constraints in (B.50) are satisfied. We have

$$K^{n-j+1} = ju_c, \tag{B.55}$$

since the carrier failed to have the shipper agree to his offer in period $n-j$ using his threshold Z_3^{n-j}. In the same way,

$$P^{n-j+1} = ju_c, \tag{B.56}$$

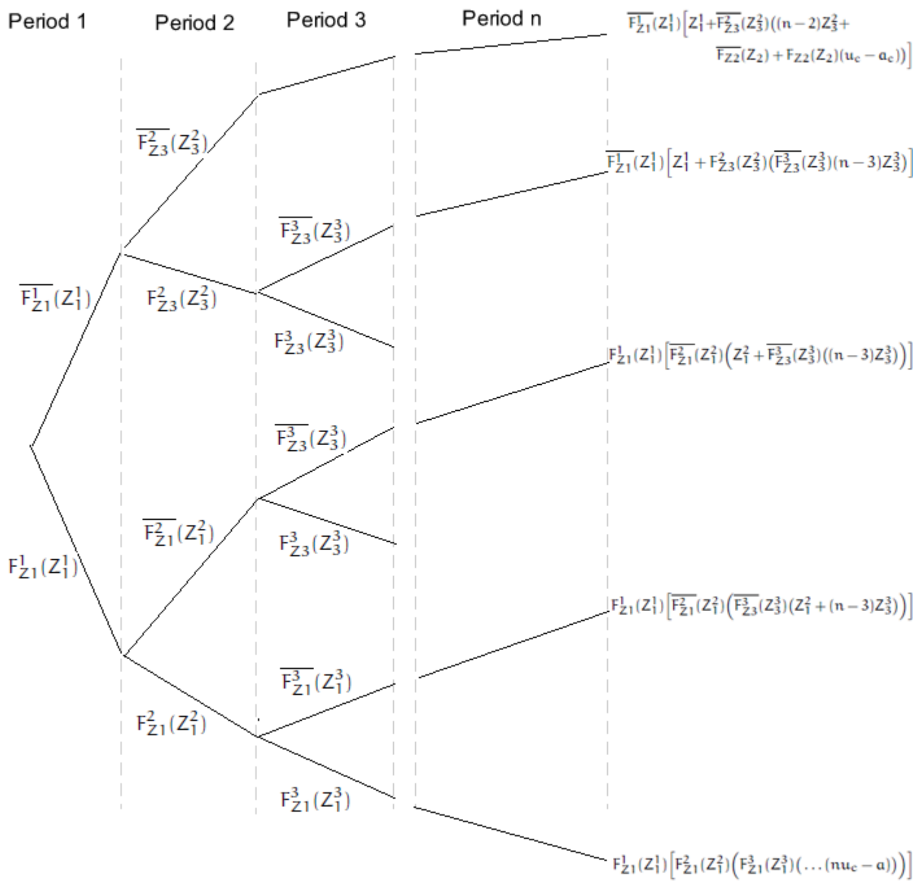

Figure 36: Some branches of the carrier's decision tree when information is fully asymmetric.

as in period $n-j$ the carrier erred in his revision of Z_1^{n-j} and so his profit will be larger if he turns to his outside option for the remaining j periods after already receiving u_c in period $n-j$.

We now rewrite the carrier's objective function fully

$$\begin{aligned}\max \Pi_c\left(Z_1^i, Z_2, Z_3^i\right) = \\ &\overline{F_{Z1}^1}(Z_1^1)\Big[Z_1^1 + \overline{F_{Z3}^2}(Z_3^2)\Big\{(n-2)Z_3^2 + \overline{F_{Z2}}(Z_2)Z_2 + \\ &F_{Z2}(Z_2)(u_c - a_c)\Big\} + F_{Z3}^2(Z_3^2)(u_c - a_c + K^3)\Big] + \\ &F_{Z1}^1(Z_1^1)\Big[u_c - a_c + P^2\Big],\end{aligned} \tag{B.57}$$

Evaluating the threshold Z_1^1...

We differentiate the above profit function in terms of Z_1^1 to obtain

$$\begin{aligned}\frac{\partial \Pi_c(Z_1^1)}{\partial Z_1^1} = f_{z1}^1(Z_1^1)\Big[u_c - a_c + P^2 - Z_1^1 - \\ &\overline{F_{Z3}^2}(Z_3^2)\{(n-2)Z_3^2 + \overline{F_{Z2}}(Z_2)Z_2 + F_{Z2}(Z_2)(u_c - a_c)\} - \\ &F_{Z3}^2(Z_3^2)(u_c - a_c + K^3)\Big] + \overline{F_{Z1}^1}(Z_1^1).\end{aligned} \tag{B.58}$$

In turn, this leads to the second differential

$$\begin{aligned}\frac{\partial^2 \Pi_c(x)}{\partial x^2} = &f_{Z1}^{1\prime}(x)\Big(u_c - a_c + P^2 - x - \\ &\overline{F_{Z3}^2}(Z_3^2)\{(n-2)Z_3^2 + \overline{F_Z2}(Z_2)Z_2 + F_{Z2}(Z_2)(u_c - a_c)\} - \\ &F_{Z3}^2(Z_3^2)(u_c - a_c + K^3)\Big) - 2f_{Z1}^1(x).\end{aligned} \tag{B.59}$$

We recognize here again the forms first presented in §B.1.1. As already demonstrated on that occasion, given that F_{Z1}^1 has an IFR, the solution to the F.O.C. exists and is a maximum.

So the optimal choice for Z_1^1 for the carrier must be solution to

$$\begin{aligned}Z_1^{1*} - \frac{\overline{F_{Z1}^1}(Z_1^{1*})}{f_{Z1}^1(Z_1^{1*})} = u_c - a_c + P^2 - \\ &\overline{F_{Z3}^2}(Z_3^2)\{(n-2)Z_3^2 + \overline{F_{Z2}}(Z_2)Z_2 + \\ &F_{Z2}(Z_2)(u_c - a_c)\} - F_{Z3}^2(Z_3^2)(u_c - a_c + K^3).\end{aligned} \tag{B.60}$$

Note that the threshold Z_1^{1*}, being written in terms of K depends upon the evaluation of A in subsequent periods.

Evaluating the threshold Z_3^2...

Observing the carrier's profit function in (B.57), we see that the threshold Z_3^2 is particular. The first differential of Π_c in Z_3^2 is

$$\frac{\partial \Pi_c(Z_3^2)}{\partial Z_3^2} = f_{Z3}^2(Z_3^2)\Big(u_c - a_c + K^3 - (n-2)Z_3^2 + \overline{F_{Z2}}(Z_2) + F_{Z2}(Z_2)(u_c - a_c)\Big) + (n-2)\overline{F_{Z3}^2}(Z_3^2). \tag{B.61}$$

We recognize here again the forms first presented in §B.1.1. Again, the solution to the F.O.C. exists and is a maximum.

$$Z_3^{2*} - \frac{\overline{F_{Z3}^2}(Z_3^{2*})}{f_{Z3}^2(Z_3^{2*})} = \frac{u_c - a_c + K^3 + \overline{F_{Z2}}(Z_2)Z_2 + F_{Z2}(Z_2)(u_c - a_c)}{n-2} \tag{B.62}$$

Evaluating the threshold Z_2...

Let us now turn to the belief Z_2. When we differentiate the carrier's profit function in Z_2, we find

$$\frac{\partial \Pi_c(Z_2)}{\partial Z_2} = \overline{F_{Z1}^1}(Z_1^1)\Big[\overline{F_{Z3}^2}(Z_3^2)\big(f_{Z2}(Z_2)(u_c - a_c - Z_2) + \overline{F_{Z2}}(Z_2)\big)\Big], \tag{B.63}$$

and the second differential is written

$$\frac{\partial^2 \Pi_c(Z_2)}{\partial Z_2^2} = \overline{F_{Z1}^1}(Z_1^1)\Big[\overline{F_{Z3}^2}(Z_3^2)\big(f'_{Z2}(Z_2)(u_c - a_c - Z_2) - 2f_{Z2}(Z_2)\big)\Big]. \tag{B.64}$$

Again, we find forms which are similar to the ones seen in §B.1.1. So there exist an optimal contract that the carrier can offer the shipper in period n, once $\delta_s^1 = 1$ such that

$$Z_2^* - \frac{\overline{F_{Z2}}(Z_2^*)}{f_{Z2}(Z_2^*)} = u_c - a_c. \tag{B.65}$$

Note that Z_2^* must be greater than $u_c - a_c$ or the carrier's participation constraint is not satisfied. Further, the reader will notice that the evaluation of Z_2 depends upon the success of both period one's and period two's offers. Even though the evaluation of Z_1^1 relied on a prior about Z_2, the last period's evaluation of Z_2 can fruitfully be re-evaluated using the posteriors of Z_1^1 and Z_3^2. An example of how this can be done is given in Section 3.4 on page 47.

Table 24: Decisions δ_s^i and corresponding states of shipper's investments in the full asymmetric information scenario.

Period						State
1	2	...	i	...	n	
1	1		1		1	1
1	1		1		0	2
1	0		1		1	2
0	0		0		0	3

Evaluating the thresholds Z_1^i...

We now turn to the threshold value for Z_1 in some period i, for which the constraints in (B.50) are satisfied. Using the carrier's objective function in (B.57) and the definition of P^i in (B.54), the F.O.C. is

$$f_{Z1}^i(Z_1^i)\left(u_c + P^{i+1} - Z_1^i - K^{i+1}\right) + \overline{F_{Z1}^i}(Z_1^i) = 0. \tag{B.66}$$

As before and for the same reasons, we can spell out the optimal threshold as being solution to

$$Z_1^{i*} - \frac{\overline{F_{Z1}^i}(Z_1^{i*})}{f_{Z1}^i}(Z_1^{i*}) = u_c + P^{i+1} - K^{i+1}, 2 \le i < n. \tag{B.67}$$

Evaluating the thresholds Z_3^i...

The threshold values of Z_3^i come by using the definition of K^i in (B.53) and the definition of the carrier's profit function defined in (B.57) for $1 < i < n$. The F.O.C. is written

$$f_{Z3}^i(Z_3^i)\left(u_c + K^{i+1} - (n-i+1)Z_3^i\right) + (n-i+1)\overline{F_{Z3}^i}(Z_3^i) = 0. \tag{B.68}$$

We again find the previously identified forms in §B.1.1 and thus conclude that it exists in each period i, $2 \le i < n$, a threshold Z_3^{i*} such that

$$Z_3^{i*} - \frac{\overline{F_{Z3}^i}(Z_3^{i*})}{f_{Z3}^i(Z_3^{i*})} = \frac{u_c + K^{i+1}}{n-i+1}, \tag{B.69}$$

which must also satisfy (B.50).

A slightly different calculation allows us to evaluate Z_3^n, the last threshold to be evaluated given that Z_1^{n-1} was the first contract to be accepted and the constraints in (B.50) are satisfied.

$$Z_3^{n*} - \frac{\overline{F_{Z3}^n}(Z_3^{n*})}{f_{Z3}^n(Z_3^{n*})} = u_c. \tag{B.70}$$

Evaluating the best strategy...

Which are the carrier's and shipper's best strategies across all three states?

We present the results according to the shipper's decisions in table 24.

By analogy with the reasoning in the proof of Proposition 3, we divide the strategy sets R_s among the states the shipper finds herself in.

A discussion is needed to show that the shipper is better off in state 1 and hence in agreeing with the carrier at every step of the way if her participation and incentive compatibility constraints are satisfied.

As opposed to the full information scenario in section 3.3.3, the shipper no longer can costlessly suffer from a "Trembling Hand" effect. In state 1, v_{s1} is the unity vector, she accepts all the contracts offered

$$\begin{cases} Z_1^{1*} \leq u - A, \\ Z_3^{i*} \leq u, \qquad\qquad \forall i,\ 2 \leq i < n, \\ Z_2^{*} \leq u + a. \end{cases} \tag{B.71}$$

The cost generated by this strategy is the lowest for the shipper as we proceed to prove.

Consider another strategy such that $v_s = (1, \ldots, 0, 1, \ldots, 1)$ with $\delta_s^i = 0$ when choosing in any period i her outside option. Her cost with such a strategy becomes

$$C = u + a + A + Z_1^{i*} + (n-2) Z_3^{(i+1)*}. \tag{B.72}$$

This cost is higher than the cost using v_{s1} unless

$$Z_1^{1*} + (n-2) Z_3^{2*} + Z_2 + A > u + a + A + Z_1^{i*} + (n-2) Z_3^{(i+1)*}. \tag{B.73}$$

But, naming

$$\begin{aligned} \varepsilon_1 &= Z_1^{i*} - (u - A), \\ \varepsilon_2 &= Z_3^{(i+1)*} - u, \end{aligned} \tag{B.74}$$

and replacing in (B.73), we come to

$$\varepsilon_1 + (n-2)\varepsilon_2 < 0, \tag{B.75}$$

a contradiction, since this expression is positive by construction.

So, the shipper's best strategy is the unity vector $v_{s1} = (1, \ldots, 1)$. Any mistake in the response generates higher costs to the shipper.

In the same way, if the carrier offers in any period a contract which does not satisfy the shipper's participation constraint, the shipper finds herself in state 2 or 3 and her cost is higher than her cost in state 1. The carrier's best profit in state 2 is the one given in (B.51). Since by construction, $Z_1^{1*} < Z_1^{i*}$ and $Z_3^{1*} < Z_3^{i*}$, then $\Pi_c(v_{c1}) > \Pi_c(v_{c2})$. In state 3, the carrier's profit is given in (B.52). Given that in state 1 the carrier's participation constraint is satisfied, $\Pi_c(v_{c3}) < \Pi_c(v_{c1})$. So

$$\forall v_c \in R_c,\ \Pi_c(v_{c1}) > \Pi_c(v_c), \tag{B.76}$$

and v_{c1} represents his dominant strategy. The state 1 contracts are the only ones which yield the carrier's best profit.

In conclusion, we have a unique Trembling-Hand pure Nash Equilibrium for the multi-period game.

APPENDIX TO CHAPTER 4

C

C.1 INFORMATION SCENARIO ANALYSIS

C.1.1 *Scenario 1 : Centralized decision-making*

The conditional expected cost to the shipper and expected revenue to the carrier as a function of the received demand X subject to P come to:

$$\begin{aligned}\mathbb{E}\left(O^1(u^{1*}|v^{1*})\right) = r + &\iint_{\Omega 1} (Xs)\, f\,(X,P)\, dXdP + \\ &\iint_{\Omega 2 \cup \Omega 3 \cup \Omega 4} (qc + (X-q)p_a) f(X,P) dXdP + \\ &\iint_{\Omega 5 \cup \Omega 6 \cup \Omega 7} (qc + q_a p_a + (X - q - q_a)P) f(X,P) dXdP,\end{aligned} \tag{C.1}$$

$$\begin{aligned}\mathbb{E}\left(R^1\left(v^{1*}|u^{1*}\right)\right) = r + &\iint_{\Omega 1} \big(Xs + (W-X)P\big)\big) f\,(X,P)\, dXdP + \\ &\iint_{\Omega 2 \cup \Omega 3 \cup \Omega 4} \big(sq + (X-q)\, p_a + (W-X)P\big) f\,(X,P)\, dXdP + \\ &\iint_{\Omega 5 \cup \Omega 6 \cup \Omega 7} \big(sq + q_a p_a + (W-q-q_a)P\big) f\,(X,P)\, dXdP.\end{aligned} \tag{C.2}$$

C.1.2 *Scenario 2: Common information, distinct profit centres*

We get the following revenue and cost functions:

$$\begin{aligned}\mathbb{E}\left(O^2\left(u^{2*}|v^{2*}\right)\right) = r + &\iint_{\Omega 1} (Xs)\, f\,(X,P)\, dXdP + \\ &\iint_{\Omega 2} (sq + (X-q)\,(P+\theta_s))\, f\,(X,P)\, dXdP + \\ &\iint_{\Omega 3} (sq + (X-q)\, p_a)\, f\,(X,P)\, dXdP + \\ &\iint_{\Omega 4} (sq + (X-q)\,(P-\theta_c))\, f\,(X,P)\, dXdP + \\ &\iint_{\Omega 5} (sq + q_a\,(P+\theta_s) + (X-q-q_a)\, P)\, f\,(X,P)\, dXdP + \\ &\iint_{\Omega 6} (sq + q_a p_{a+}\, (X-q-q_a)\, P)\, f\,(X,P)\, dXdP + \\ &\iint_{\Omega 7} (sq + q_a\,(P-\theta_c) + (X-q-q_a)\, P)\, f\,(X,P)\, dXdP,\end{aligned} \tag{C.3}$$

$$
\begin{aligned}
\mathbb{E}\big(R^2(u^{2*}|v^{2*})\big) = r + &\iint\limits_{\Omega 1} \big(Xs + (W - X)P\big) f(X,P)\, dXdP + \\
&\iint\limits_{\Omega 2} (sq + (X - q)(P + \theta_s) + (W - X)P) f(X,P)\, dXdP + \\
&\iint\limits_{\Omega 3} \big(sq + (X - q)p_a + (W - X)P\big) f(X,P)\, dXdP + \\
&\iint\limits_{\Omega 4} \big(sq + (X - q)(P - \theta_c) + (W - X)P\big) f(X,P)\, dXdP + \\
&\iint\limits_{\Omega 5} \big(sq + q_a(P + \theta_s) + (W - q - q_a)P\big) f(X,P)\, dXdP + \\
&\iint\limits_{\Omega 6} \big(sq + q_a p_{a+} (W - q - q_a)P\big) f(X,P)\, dXdP + \\
&\iint\limits_{\Omega 7} \big(sq + q_a(P - \theta_c) + (W - q - q_a)P\big) f(X,P)\, dXdP.
\end{aligned}
\tag{C.4}
$$

C.1.3 *Scenario 3 : private information of carrier*

This leads to the following cost function for S:

$$
O^3(u^*|v^*, X, P) =
\begin{cases}
r + Xs, & \forall (X,P) \in \Omega 1 \\
r + Xs + (X - q)(P + \theta_s), & \forall (X,P) \in \Omega 2 \\
r + sq + (X - q)\, p_a, & \forall (X,P) \in \Omega 3^3 \\
r + sq + (X - q)\, P, & \forall (X,P) \in \Omega 4^3 \\
r + sq + q_a(P + \theta_s) + (X - q - q_a)P, & \forall (X,P) \in \Omega 5 \\
r + sq + q_a p_a + (X - q - q_a)P, & \forall (X,P) \in \Omega 6^3;
\end{cases}
\tag{C.5}
$$

and to the following expected cost function:

$$
\begin{aligned}
\mathbb{E}\left(O^3\left(u^{3*}|v^{3*}\right)\right) = r + &\iint\limits_{\Omega 1} (Xs)\, f(X,P)\, dXdP + \\
&\iint_{\Omega 2} rsq + (X - q)(P + \theta_s) f(X,P) dXdP \\
&\iint\limits_{\Omega 3^3} (sq + (X - q)\, p_a)\, f(X,P)\, dXdP + \\
&\iint\limits_{\Omega 4^3} sq + (X - q)\, Pf(X,P)\, dXdP + \\
&\iint_{\Omega 5} \big(sq + q_a(P + \theta_s) + (X - q - q_a)P\big) f(X,P) dXdP + \\
&\iint\limits_{\Omega 6^3} (sq + q_a p_a + (X - q - q_a)P) f(X,P)\, dXdP.
\end{aligned}
\tag{C.6}
$$

In the same way, the expected revenue to the carrier is:

$$\begin{aligned}\mathbb{E}\left(R^3\left(v^{3*}|u^{3*}\right)\right) = r + &\iint\limits_{\Omega 1} (Xs + (W-X)P)\, f(X,P)\, dXdP + \\ &\iint_{\Omega 2}\big(sq + (X-q)(P+\theta_s) + (W-X)P\big) f(X,P) dXdP + \\ &\iint\limits_{\Omega 3^3} (sq + (X-q)\, p_a + (W-X)P)\, f(X,P)\, dXdP + \\ &\iint\limits_{\Omega 4^3} \big(sq + (X-q)\, P + (W-X)P\big) f(X,P)\, dXdP + \\ &\iint_{\Omega 5}\big(sq + q_a(P+\theta_s) + (W-q-q_a)P\big) f(X,P) dXdP + \\ &\iint\limits_{\Omega 6^3} (sq + q_a p_a + (X-q-q_a)\, P)\, f(X,P)\, dXdP.\end{aligned} \tag{C.7}$$

C.1.4 *Scenario 4 : carrier and shipper hide information*

Our expected cost and revenue functions become:

$$\begin{aligned}\mathbb{E}(O^4\left(u^{4*}|v^{4*}\right)) \;=\; r + &\iint\limits_{\Omega 1} (Xs)\, f(X,P)\, dXP + \\ &\iint\limits_{\Omega 2^4 \cup \Omega 3^4} \big(sq + (X-q)\, P\big) f(X,P)\, dXdP\end{aligned} \tag{C.8}$$

Expected revenue:

$$\begin{aligned}\mathbb{E}\left(R^4\left(v^{4*}|u^{4*}\right)\right) = r + &\iint\limits_{\Omega 1} (Xs + (W-X)P)\, f(X,P)\, dXdP + \\ &\iint\limits_{\Omega 2^4 \cup \Omega 3^4} (sq + (W-q)\, P)\, f(X,P)\, dXdP.\end{aligned} \tag{C.9}$$

C.1.5 *Scenario 5 : private information of shipper*

These equations can be contracted into the following cost function for S:

$$\begin{aligned}\mathbb{E}(O^5(u^{5*}|v^{5*})) = r + &\iint\limits_{\Omega 1} (Xs)\, f(X,P)\, dXdP + \\ &\iint\limits_{\Omega 2^5} (sq + (X-q)\, P)\, f(X,P)\, dXdP + \\ &\iint_{\Omega 4}\big(sq + (X-q)(P-\theta_c)\big) f(X,P) dXdP + \\ &\iint_{\Omega 5^5}\big(sq + q_a p_a + (X-q-q_a)P\big) f(X,P) dXdP + \\ &\iint_{\Omega 7}\big(sq + q_a(P-\theta_c) + (X-q-q_a)P\big) f(X,P) dXdP.\end{aligned} \tag{C.10}$$

Expected revenue to C:

$$\begin{aligned}\mathbb{E}\left(R^5\left(v^{5*}|u^{5*}\right)\right) = r + &\iint\limits_{\Omega 1} \big(Xs + (W - X)P\big) f(X,P) dXdP + \\ &\iint\limits_{\Omega 2^5} \big(sq + (W - q)P\big) f(X,P) dXdP + \\ &\iint_{\Omega 5^5} \big(sq + q_a p_a + (W - q - q_a)P\big) f(X,P) dXdP + \\ &\iint_{\Omega 4} \big(sq + (X - q_a)(P - \theta_c) + (W - X)P\big) f(X,P) dXdP + \\ &\iint_{\Omega 7} \big(sq + q_a(P - \theta_c) + (W - q - q_a)P\big) f(X,P) dXdP.\end{aligned} \tag{C.11}$$

C.2 COMPARING SCENARIO 2 AND 1

The expected difference for the shipper between the full information, single decision maker and the full information but two independent decision makers described in scenario 2 can be set up as a sum of double integrals over the probability regions:

$$\begin{aligned}&\mathbb{E}\left[O^2\left(u^{2*}|v^{2*}\right) - O^1\left(u^{1*}|v^{1*}\right)\right] = \\ &\iint\limits_{\Omega 2} \left(\left(X - q\right)\left(P + \theta_s - p_a\right)\right) f\left(X,P\right) dXdP + \\ &\iint\limits_{\Omega 4} \left(\left(X - q\right)\left(P - \theta_c - p_a\right)\right) f\left(X,P\right) dXdP + \\ &\iint\limits_{\Omega 5} \left(q_a\left(P + \theta_s - p_a\right)\right) f\left(X,P\right) dXdP + \\ &\iint\limits_{\Omega 7} \left(q_a\left(P - \theta_c - p_a\right)\right) f\left(X,P\right) dXdP \\ &\qquad = \mathbb{E}\left[R^2\left(v^{2*}|u^{2*}\right) - R^1\left(v^{1*}|u^{1*}\right)\right]\end{aligned} \tag{C.12}$$

Proof of Proposition 6.

Proof. By construction of the regions, in Ω_2 and Ω_5, $P + \theta_s - p_a < 0$ and in regions Ω_5 and Ω_7, $P - \theta_c - p_a > 0$. So,

$$\mathbb{E}\left[O^2\left(u^{2*}|v^{2*}\right) - O^1\left(u^{1*}|v^{1*}\right)\right] = 0 \tag{C.13}$$

when

$$\begin{aligned}&\iint\limits_{\Omega 2} (X - q)(P + \theta_s - p_a) f(X,P) dXdP = \\ &\qquad \iint_{\Omega 4} (X - q)(P - \theta_c - p_a) f(X,P) dXdP,\end{aligned} \tag{C.14}$$

and

$$\begin{aligned}&\iint_{\Omega 5} (q_a\left(P + \theta_s - p_a\right)) f(X,P) dXdP = \\ &\qquad \iint_{\Omega 7} (q_a(P - \theta_c - p_a)) f(X,P) dXdP.\end{aligned} \tag{C.15}$$

This can be the case when $\theta_s = \theta_c$ jointly with $p_a = \mu_x$ and the distribution of the spot price when it is above q is symmetric around the mean. This last condition is given when the spot market price is independent from demand.

■

C.3 COMPARING SCENARIO 3 AND 2

In table 25 we tabulate the relevant differences in revenue for the carrier and in cost for the shipper between both scenarios.

Table 25: Differences between scenario 3 and scenario 2 for both players, region per region

	Differences scenario 3 – scenario 2
Region	Carrier/Shipper
$\Omega 3^3$	0
$\Omega 4^3 \cap \Omega 3$	$(X-q)(P-p_a)$
$\Omega 4^3 \cap \Omega 4$	$(X-q)\theta_c$
$\Omega 5$	0
$\Omega 6^3 \cap \Omega 6$	0
$\Omega 4^3 \cap \Omega 6$	$(P-p_a)q_a$
$\Omega 4^3 \cap \Omega 7$	$q_a\theta_c$

If we now place ourselves in the players' shoes, our job is to decide upon the contract parameters so as to minimize for the shipper S or maximize for the carrier the following:

$$\begin{aligned} EC_{3-2}(q, q_a, p_a, \theta_c) = &\iint_{\Omega 4^3 \cap \Omega 3} (X-q)(P-p_a) f(X,P)\, dXdP + \\ &\iint_{\Omega 4} (X-q)\theta_c f(X,P) dXdP + \\ &\iint_{\Omega 4^3 \cap \Omega 6} q_a (P-p_a) f(X,P) dXdP + \\ &\iint_{\Omega 7} q_a \theta_c f(X,P) dXdP. \end{aligned} \tag{C.16}$$

Proof of Proposition 7:

Proof. The first differential of this difference in terms of q_a is

$$\frac{\partial EC_{3-2}(q, q_a, p_a, \theta_c)}{\partial q_a} = \iint_{\Omega 7} \theta_c f(X,P) dXdP + \iint_{\Omega 4^3 \cap \Omega 6} (P-p_a) f(X,P) dXdP. \tag{C.17}$$

This differential increases directly in θ_c but decreases in the second order in both p_a and q_a. It is independent of penalty θ_s.

The first differential in terms of p_a is

$$\frac{\partial EC_{3-2}(q, q_a, p_a, \theta_c)}{\partial p_a} = -\iint_{\Omega 6 \cap \Omega 4^3} q_a f(X, P) dX dP + \iint_{\Omega 3 \cap \Omega 4^3} (q - X) f(X, P) dX dP. \tag{C.18}$$

This differential is negative and directly decreases in q_a. ■

C.4 DIFFERENCE BETWEEN SCENARIO 3 AND SCENARIO 2 ALWAYS POSITIVE

We see from the structure of the double integrals in (C.16) in Appendix C.3 that each separately will be positive if the bivariate probability density function is positive or null over these domains. This is obviously the case by construction of the bivariate probability density function as presented in the model in section 4.3.1.

C.5 PROOF OF THE INCREASED VARIANCE OF SCENARIO 3 COMPARED TO SCENARIO 2

Proof. Using the properties of variance whereby $Var(X) = E(X^2) - E(X)^2$ and rearranging the terms in the double integrals of equation (C.16) in Appendix C.3 for all the domains, it can be shown that the variance increases: both shipper and carrier suffer increased volatility of their revenue or cost. ■

C.6 COMPARING SCENARIO 4 AND 2

In table 26 we tabulate the relevant differences in revenue for the carrier and in cost for the shipper between both scenarios.

Table 26: Differences between scenario 4 and scenario 2 for both players, region per region

	Differences scenario 4 – scenario 2
Region	Carrier/Shipper
$\Omega 2^4 \cap \Omega 2$	$-(X-q)\theta_s$
$\Omega 2^4 \cap \Omega 3$	$(X-q)(P-p_a)$
$\Omega 3^4 \cap \Omega 3$	$(X-q)(P-p_a)$
$\Omega 3^4 \cap \Omega 4$	$(X-q)\theta_c$
$\Omega 2^4 \cap \Omega 5$	$-q_a\theta_s$
$\Omega 2^4 \cap \Omega 6$	$(P-p_a)q_a$
$\Omega 3^4 \cap \Omega 6$	$(P-p_a)q_a$
$\Omega 3^4 \cap \Omega 7$	$q_a\theta_c$

We write the difference as

$$EC_{4-2}(q, q_a, p_a, \theta_s, \theta_c) = \iint_{\Omega 2} -(X-q)\theta_s f(X,P)\, dXdP + \iint_{\Omega 3} (X-q)(P-p_a) f(X,P)\, dXdP + \iint_{\Omega 4} (X-q)\theta_c f(X,P)\, dXdP + \iint_{\Omega 5} -q_a\theta_s f(X,P)\, dXdP + \iint_{\Omega 6} q_a(P-p_a) f(X,P)\, dXdP + \iint_{\Omega 7} q_a\theta_c f(X,P)\, dXdP. \tag{C.19}$$

C.7 EVALUATING THE BEST PARAMETERS FOR THE SHIPPER IN SCENARIO 4

Proof of Proposition 10

Proof. Given that the penalties do not get paid in scenario 4, the interesting parameters are p_a and q_a. To see whether they have an influence over the difference, we can differentiate this expression in terms of p_a.

$$\frac{\partial EC_{4-2}(q, q_a, p_a, \theta_s, \theta_c)}{\partial p_a} = \iint_{\Omega 6} q_a f(X,P) dXdP + \iint_{\Omega 3} (q-X) f(X,P) dXdP. \tag{C.20}$$

This differential is minimized if $q >> \mu_x$ and $q_a = p_a = 0$, because this reduces Ω_3 and Ω_6 and the importance of the cumulative density function F over both regions.

In the same way, when differentiating in q_a, we obtain

$$\frac{\partial EC_{4-2}(q, q_a, p_a, \theta_s, \theta_c)}{\partial q_a} = \iint_{\Omega 5} -\theta_s f(X,P) dXdP + \iint_{\Omega 7} \theta_c f(X,P) dXdP + \iint_{\Omega 6} (P-p_a) f(X,P) dXdP. \tag{C.21}$$

■

C.8 EVALUATING THE VARIANCE OF OUTCOMES IN SCENARIO 4 VS SCENARIO 2

Proof of Proposition 11.

Proof. We observe in (C.19) in Appendix C.6 that, as in the proof of proposition 8, this sum of double integrals will always be positive for strictly positive parameters q_a, p_a, θ_s, θ_c. Further, as in the proof of 9 presented in C.5, the variance of the difference will also always be positive when those parameters are strictly positive. ■

C.9 COMPARING SCENARIO 5 AND 2

In table 27 we tabulate the relevant differences in revenue for the carrier and in cost for the shipper between both scenarios.

Table 27: Differences between scenario 5 and scenario 2 for both players, region per region

	Differences scenario 5 – scenario 2
Region	Carrier/Shipper
$\Omega 2^5 \cap \Omega 2$	$-(X-q)\theta_s$
$\Omega 2^5 \cap \Omega 3$	$(X-q)(P-p_a)$
$\Omega 3^5 \cap \Omega 3$	0
$\Omega 4$	0
$\Omega 2^5 \cap \Omega 5$	$-q_a\theta_s$
$\Omega 2^5 \cap \Omega 6$	$(P-p_a)q_a$
$\Omega 5^5 \cap \Omega 6$	0
$\Omega 7$	0

Proof of proposition 12:

Proof. The cost difference between both scenarios is written

$$\begin{aligned} EC_{5-2}(q,q_a,p_a,\theta_s) = &\iint\limits_{\Omega 2} -(X-q)\theta_s f(X,P)\,dXdP+ \\ &\iint\limits_{\Omega 2^5\cap\Omega 3} (X-q)(P-p_a)f(X,P)\,dXdP+ \\ &\iint\limits_{\Omega 2^5\cap\Omega 6} q_a(P-p_a)f(X,P)\,dXdP+ \\ &\iint\limits_{\Omega 5} -q_a\theta_s f(X,P)\,dXdP. \end{aligned} \tag{C.22}$$

Let us present the first differential of EC_{5-2} in terms of q_a.

$$\begin{aligned} \frac{\partial EC_{5-2}(q,q_a,p_a,\theta_s)}{\partial q_a} = &-\int_0^{p_a-\theta_s}\int_{q+q_a}^{Q_{Hi}} \theta_s f(X,P)dXdP+ \\ &\int_{p_a-\theta_s}^{p_a}\int_{q+q_a}^{Q_{Hi}} (P-p_a)f(X,P)dXdP. \end{aligned} \tag{C.23}$$

This differential is always negative and always becomes larger in p_a and q_a. It also becomes larger in θ_s. Looking at it from the angle of the distribution of the spot market price versus demand, setting $p_a << \mu_P$ together with a low penalty θ_s will reduce the importance of the probability region in which the shipper will be tempted to take recourse in the spot market. The carrier will reduce the shipper's rent advantage by choosing a low price p_a and no penalty θ_s.

Let us present the first differential in terms of p_a.

$$\frac{\partial EC_{5-2}(q, q_a, p_a, \theta_s)}{\partial p_a} = \iint_{\Omega 2^5 \cap \Omega 6} -q_a f(X, P) dXdP - \iint_{\Omega 2^5 \cap \Omega 3} (X - q) f(X, P) dXdP. \tag{C.24}$$

The sign of the differential is also negative: the difference will always grow in the additional price p_a.

Finally, we present the differential in terms of the penalty θ_s:

$$\frac{\partial EC_{5-2}(q, q_a, p_a, \theta_s)}{\partial \theta_s} = \iint_{\Omega 5} q_a f(X, P) dXdP + \iint_{\Omega 2} (q - x) f(X, P) dXdP. \tag{C.25}$$

In this last case, the differential can take positive or negative values: a differential which is equal to 0 requires additional information on the bivariate distribution of demand and spot market prices. ∎

C.10 EVALUATING THE VARIANCE OF OUTCOMES IN SCENARIO 5 VS SCENARIO 2

Proof of Proposition 13.

Proof. We observe in (C.22) in Appendix C.9 that, as in the proof of proposition 8, this sum of double integrals will always be strictly negative for strictly positive parameters q_a, p_a and θ_s. So, as in the proof of 9 presented in C.5, the variance of the difference will also always be positive when those parameters are strictly positive. ∎

C.11 NUMERICAL INSTANCE

We first note that all the differences of objective functions between scenarios in equations (C.16) presented in Appendix C.3, (C.19) presented in Appendix C.6 and (C.22) presented in Appendix C.9 can also be written in a general way as sums of double integrals of the form

$$C(x, y|q, p) = \int_0^y \int_0^x C(x, y) f(q, p) dq dp, \tag{C.26}$$

with $C(x, y)$ as a function over x and y and q and p as the random variables over domains which also depend upon x and y and can be represented as in figure 37.

The functions C can be written in the form of sums of double integrals of the form

$$A^k_{ij} = \iint\limits_{\Omega k} x^i y^j f(x, y, \lambda_1, \lambda_2, \rho)\, dx\, dy. \tag{C.27}$$

When we replace $f(q, p)$ by the Downton distribution, we have a formulation as represented in equation (2.5) in Brusset and Temme (2007) which leads to the expressions as represented in (C.31), a model and its solution developed specifically for this purpose. Using the results established in Brusset and Temme (2007), our functions can now all be expressed as some combinations of functions which do not include double integrals. We moreover have very fast mathematical algorithms to evaluate the corresponding numerical results. We have the Ωk, $k \in \{2, 3, 4, 5\}$, the regions of probability space, as described in Figure 1 of Brusset and Temme (2007) and reproduced in figure 37. These regions do not cover the same spaces as the ones in our case, but they can be represented as combinations of regions. In table 28 are given the relevant combinations so that we can proceed with the numeric evaluation.

In the following, the numeric instance will use the normalized exponential distribution functions with $\lambda_1 = \lambda_2 = 1$, for which both the means and the variances are equal to 1.

Let us focus on the first double integral in EC_{3-2} in (C.16) of Appendix C.3. Using the terms as defined in (C.27), this double integral is a combination of regions:

$$\begin{aligned}
&\iint_{\Omega 4^3 \cap \Omega 3} (X-q)\,(P-p_a)\,f\,(X,P)\,dXdP = \\
&\int_0^{p_a+\theta_c}\int_0^{q+q_a}(XP - qP - Xp_a + qp_a)f(X,P)dXdP - \\
&\int_0^{p_a}\int_0^{q+q_a}(XP - qP - Xp_a + qp_a)f(X,P)dXdP - \\
&\int_0^{p_a+\theta_c}\int_0^{q}(XP - qP - Xp_a + qp_a)f(X,P)dXdP + \\
&\qquad\int_0^{p_a}\int_0^{q}(XP - qP - Xp_a + qp_a)f(X,P)dXdP. \qquad (C.28)
\end{aligned}$$

Each of these double integrals can be represented as

$$A_{11}^2 - qA_{01}^2 - p_a A_{10}^2 + qp_a A_{00}^2,$$

with Ω^2 taking different boundaries. Specifically: $\Omega^2 = [0; p_a + \theta_c] \times [0, q + q_a]$ for the first, $\Omega^2 = [0; p_a] \times [0; q + q_a]$ for the second, $\Omega^2 = [0; p_a + \theta_c] \times [0; q]$ for the third and $\Omega^2 = [0; p_a] \times [0; q]$ for the last.

The calculations are not presented in this work but are available from the author upon request.

Table 28: Correspondence with regions in Brusset and Temme (2007)

	Regions		Corresponding region		
	objective	to be subtracted	Ω	x	y
Scenario 3-2	$\Omega 4^3 \cap \Omega 3$	$[0; q] \times [0; p_a + \theta_c]$ $+[0; q + q_a] \times [0; p_a]$ $-[0; q] \times [0; p_a]$	$\Omega 2$	$q + q_a$	$p_a + \theta_c$
	$\Omega 4$	$[0; q] \times [p_a + \theta_c; Q_{Hi}]$	$\Omega 4$	$q + q_a$	$p_a + \theta_c$
	$\Omega 4^3 \cap \Omega 6$	$[0; p_a] \times [q + q_a; Q_{Hi}]$	$\Omega 3$	$q + q_a$	$p_a + \theta_c$
	$\Omega 7$	$- - . - -$	$\Omega 5$	$q + q_a$	$p_a + \theta_c$
Scenario 4-2	$\Omega 2$	$[0; q] \times [0; p_a - \theta_s]$	$\Omega 2$	$q + q_a$	$p_a - \theta_s$
	$\Omega 3$	$[0; q] \times [0; p_a + \theta_c]$ $+[0; q + q_a] \times [0; p_a - \theta_s]$ $-[0; q] \times [0; p_a - \theta_s]$	$\Omega 2$	$q + q_a$	$p_a + \theta_c$
	$\Omega 4$	$[0; q] \times [p_a + \theta_c; P_{Hi}$	$\Omega 4$	$q + q_a$	$p_a + \theta_c$
	$\Omega 5$	$- - . - -$	$\Omega 3$	$q + q_a$	$p_a - \theta_s$
	$\Omega 6$	$\Omega 5$	$\Omega 3$	$q + q_a$	$p_a + \theta_c$
	$\Omega 7$	$- - . - -$	$\Omega 5$	$q + q_a$	$p_a + \theta_c$
Scenario 5-2	$\Omega 2$	$[0; q] \times [0; p_a - \theta_s]$	$\Omega 2$	$q + q_a$	$p_a - \theta_s$
	$\Omega 2^5 \cap \Omega 3$	$[0; q] \times [0; p_a]$ $+[0; q + q_a] \times [0; p_a - \theta_s]$ $-[0; q] \times [0; p_a - \theta_s]$	$\Omega 2$	$q + q_a$	p_a
	$\Omega 2^5 \cap \Omega 6$	$[0; q + q_a] \times [0; p_a]$ $+[q + q_a; Q_{Hi}] \times [0; p_a - \theta_s]$	$\Omega 3$	$q + q_a$	p_a
	$\Omega 5$	$- - . - -$	$\Omega 3$	$q + q_a$	$p_a - \theta_s$

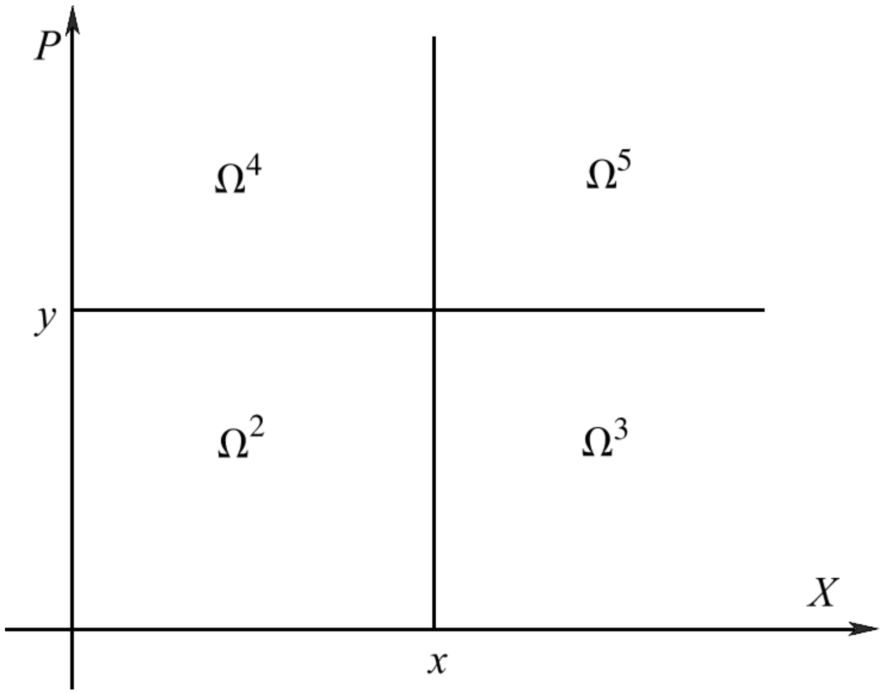

Figure 37: Domains of probability Ω^k, $k = 2, 3, 4, 5$; Ω^1 is the complete quarter plane

We have chosen Downton's bivariate exponential distribution as described in Kotz et al. (2000) with the joint density function (pdf):

$$f(q,p,\lambda_1,\lambda_2,\rho) = \frac{\lambda_1\lambda_2}{1-\rho}\exp\left(-\frac{\lambda_1 q+\lambda_2 p}{1-\rho}\right) I_0\left(\frac{2(\rho\lambda_1\lambda_2 qp)^{1/2}}{1-\rho}\right) \tag{C.29}$$

where, to simplify, $q = Q$, $p = P$, λ_1 and $\lambda_2 > 0$ and

$$I_0(z) = \sum_{k=0}^{\infty}(z/2)^{2k}/k!^2 \tag{C.30}$$

is the modified Bessel function of the first kind of order zero.

Let it be clear that here we restrict our attention to the case of non-negative imperfect correlation between P and Q, ie $0 < \rho < 1$. We study the cases where spot market prices for freight transport and demands addressed to the shipper are *positively correlated*.

The above density function was initially derived by Moran (1967). The marginal distributions of both Q and P are exponential with means $1/\lambda_1$ and $1/\lambda_2$ respectively. Since $I_0(0) = 1$, it is clear that Q and P are independent if and only if $\rho = 0$. Downton (1970) showed that ρ is the correlation coefficient of the two variates (see Brusset and Temme, 2007, for further discussion of parameters and other functions) .

For the evaluation of the double integrals defined in (C.16) presented in Appendix C.3, (C.19) presented in Appendix C.6 and (C.22) presented in Appendix C.9 we need the following functions presented in Brusset and Temme (2007):

$$\begin{aligned}
A_{00}^k &= \iint_{\Omega^k} f(x,y,\lambda_1,\lambda_2,\rho)\,dxdy,\\
A_{10}^k &= \iint_{\Omega^k} xf(x,y,\lambda_1,\lambda_2,\rho)\,dxdy,\\
A_{01}^k &= \iint_{\Omega^k} yf(x,y,\lambda_1,\lambda_2,\rho)\,dxdy,\\
A_{11}^k &= \iint_{\Omega^k} xyf(x,y,\lambda_1,\lambda_2,\rho)\,dxdy,\\
A_{20}^k &= \iint_{\Omega^k} x^2f(x,y,\lambda_1,\lambda_2,\rho)\,dxdy.
\end{aligned} \tag{C.31}$$

We also need the new formulation for A_{11}:

$$\begin{aligned}
A_{11}^5 &= \int_y^\infty\int_x^\infty qp\,f(q,p)\,dq\,dp\\
&= \frac{1}{(1-\rho)^2}\{e^{-x-y}[(c_0+\kappa_1+\kappa_2)I_0(\xi)+c_1I_1(\xi)]\\
&\qquad +\kappa_1e^{-w}K(\rho x,y)+\kappa_2e^{-z}K(\rho y,x)\},
\end{aligned} \tag{C.32}$$

Armed with these results, we can now proceed to study the particular expressions resulting from differences between scenarios which are all of the form presented in (C.26) of Appendix C.11 and come to conclusions.

D

APPENDIX TO CHAPTER 5

We present here some proofs regarding Price Only Relational Contract (PRC), Minimum Purchase Commitment (MPC) and Quantity Flexibility Clause (QFC).

D.1 PROOF OF PROPOSITION

Proof. Proof of Proposition 14 on page 105
There is an optimal commitment for the shipper or the carrier if the shipper's or the carrier's objective function are concave. For the shipper, this is the case iff

$$\frac{\partial^2 E_s^2(q,s,r,n)}{\partial q^2} = sf_X(q) + If_X'(q) - \frac{\partial^2 \varphi_s(q)}{\partial q^2} \leq 0 \tag{D.1}$$

We look for the optimal quantity q which should satisfy both players.

$$\frac{\partial E_s^2(q,s,r)}{\partial q} = -s\overline{F_X}(q) + If_X(q) - \frac{\partial \varphi^s(q)}{\partial q} \tag{D.2}$$

$$\tag{D.3}$$

The F.O.C. requires that

$$s = \frac{If_X(q) - \varphi^{s\prime}(q)}{\overline{F_X}(q)}, \tag{D.4}$$

subject to $0 < F_X(q) < 1$ and the shipper's objective function being concave.

For the carrier, the first and second differentials in q of his profit function are written

$$\frac{\partial E_c^2(q,s,r)}{\partial q} = (s-c)\overline{F_X}(q) + \frac{\partial \varphi^c(q)}{\partial q}. \tag{D.5}$$

$$\frac{\partial^2 E_c^2(q,s,r)}{\partial q^2} = -(s-c)f_X(q) + \frac{\partial^2 \varphi^c(q)}{\partial q^2}. \tag{D.6}$$

The second derivative of $\varphi(q)$ may not be always negative for all q so that no conclusion can be drawn as to whether the extremum in q for the carrier is actually an optimum. In point of fact, in the bivariate example presented here, the values of q which mark local extrema are minima.

Depending on the bargaining power of both players, the final commitment on which both agree may be equal to the optimum of the shipper or higher.

■

D.2 DEFINITION OF A QFC'S OBJECTIVE FUNCTIONS.

Proof of the definition of the shipper's and carrier's objective functions when the QFC is chosen.

Proof. Given that all periods of the game are symmetric: each demand outcome is i.i.d. with respect to the others and the spot prices are also i.i.d. with respect to the other spot prices. We can reorder the realized demands within the overall sum in each of the objective functions of the buyer and supplier irrespective of what demand occurs exactly in which period.

The objective functions take different forms whether the sum of outcome demands is higher than β or not: if the shipper has overestimated her demand, she has to pay a penalty.

$$\beta \geq \sum_{i=1}^{i} x_i, \quad \begin{cases} V_3(X,P) = & \alpha \sum_{i=1}^{n} x_i + \theta(\beta - \sum_{i=1}^{n} x_i) \\ \pi_3(X,P) = & \alpha \sum_{i=1}^{n} x_i + \theta(\beta - \sum_{i=1}^{n} x_i) - c \sum_{t=1}^{n} x_i - nK \end{cases}$$

$$\beta < \sum_{i=1}^{n} x_i, \quad \exists j \,|\, j \leq n \quad \wedge \sum_{i=1}^{n-j-1} x_i \leq \beta \quad \wedge \quad \sum_{i=1}^{n-j} x_i > \beta,$$

$$\begin{cases} V_3(X,P) = & \alpha\beta + \left(\sum_{i=1}^{n-j} x_i - \beta\right) p_{n-j} + \mu_P \sum_{i=n-j+1}^{n} x_i \\ \pi_3(X,P) = & \alpha\beta + \left(\sum_{i=1}^{n-j} x_i - \beta\right) p_{n-j} + \mu_P \sum_{i=n-j+1}^{t} x_i - c \sum_{i=1}^{n} x_i - nK. \end{cases}$$

To evaluate the dispersion of demands around β, we need to calculate the variance of the sum of expected demands within a game. Because expected demand is a stationary stochastic process, its sum over n periods is also a stationary process, and its variance is finite. Remember that $Y_n = \sum_{i=1}^{n} x_i$. By the central limit theorem, *for a large n*,

$$Y_n \sim \mathcal{N}(n\mu_X, \sqrt{n}\sigma_X). \tag{D.7}$$

Let us call $f_Y(.)$ and $F_Y(.)$ the Probability Density Function (pdf) and Cumulated Density function (cdf) of this normal distribution.

■

In the following, we shall assume that n is sufficiently large as to render the Central Limit Theorem applicable.

D.3 EXPECTED OPTIMAL PARAMETERS IN THE QFC'S OBJECTIVE FUNCTIONS.

The parameters of the contract α, β, θ and n presented in Condition 3 on page 107 are discussed and evaluated.

The shipper is interested in minimizing the impact of both the spot market when she underestimates the demand she has to satisfy and the penalty she has to pay when she overestimates the demand.

Optimal θ in QFC:

$$\frac{\partial E_s^3(\alpha, \beta, \theta, n)}{\partial \theta} = -\Big(\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta, n)\Big) \leq 0 \tag{D.8}$$

So the shipper is always looking to minimize the penalty. By the same token, the carrier is always looking to increase it.

The shipper would not accept a contract in which the penalty for not forecasting correctly the demand to be carried over the length of the contract is equal to the whole budget she has identified for transport. The carrier would not countenance a penalty where he would have to actually *pay* for a forecasting error imputable to the shipper.

So, the range for this parameter is

$$0 \leq \theta \leq \frac{B - n\alpha\mu_X - \mu_P\big(g_2(\beta, n) - \beta/\overline{F_{Y_n}}(\beta)\big)}{\beta/F_{Y_n}(\beta) - g_1(\beta, n)}. \tag{D.9}$$

The higher the penalty, the higher the confidence that the shipper has in her forecasts (meaning she has a pretty good notion that she won't have to pay up), or the higher the carrier's bargaining power, or both. This commitment by the shipper resembles the commitment presented in the model in Cachon and Lariviere (2001). A large penalty clearly signals that the shipper expects to *exceed* her transport commitment.

Optimal β:

Observing the shipper's and carrier's objective functions, we see that the differential in terms of β are only different in sign.

$$\frac{\partial E_3^c(\alpha, \beta, \theta, n)}{\partial \beta} = \frac{\partial \Psi(\beta, \theta, n)}{\partial \beta}. \tag{D.10}$$

Let us look at the differential of $\Psi(\beta, \theta, n)$ more closely.

$$\begin{aligned} \frac{\partial \Psi(\beta, \theta, n)}{\partial \beta} &= \theta\Big(\frac{1}{F_{Y_n}(\beta)} - \frac{\beta f_{Y_n}(\beta)}{F_{Y_n}(\beta)^2} - \frac{\partial g_1(\beta, n)}{\partial \beta}\Big) + \\ &\quad + \mu_P\Big(\frac{\partial g_2(\beta, n)}{\partial \beta} - \frac{1}{\overline{F_{Y_n}}(\beta)} - \frac{\beta f_{Y_n}(\beta)}{\overline{F_{Y_n}}(\beta)^2}\Big). \end{aligned} \tag{D.11}$$

The first differential of $g_1(\beta, n)$ in terms of β is

$$\frac{\partial g_1(\beta, n)}{\partial \beta} = \frac{e^{-\frac{n^2\mu_x^2 - n\beta\mu_x + \beta^2}{n\sigma_x^2}}}{2\pi\sigma_x}\Bigg[\sqrt{2\pi}(2\beta - n\mu_x)F_Y(\beta, n)e^{\frac{n^2\mu_x^2 + \beta^2}{2n\sigma_x^2}} - \tag{D.12}$$

$$2\sqrt{n}\sigma_x\Big(e^{\frac{\beta^2}{2n\sigma_x^2}} - e^{\frac{\beta\mu x}{\sigma_x^2}}\Big)\Bigg]. \tag{D.13}$$

In the same way, the first differential of $g_2(\beta, n)$ in β is

$$\frac{\partial g_2(\beta, n)}{\partial \beta} = \frac{1}{2\pi\overline{F_Y}(\beta, n)}\Big[e^{-\frac{(\beta - n\mu_x)^2}{n\sigma_x^2}} + e^{-\frac{(Q_{Hi} + \beta - n\mu_x)^2 + n^2\mu_x^2 - 2Q_{Hi}\beta}{2n\sigma_x^2}}\Big] - \tag{D.14}$$

$$\frac{\partial f_Y(\beta, n)}{\partial \beta}\Big(1 - \frac{n\mu_x}{\beta}\Big). \tag{D.15}$$

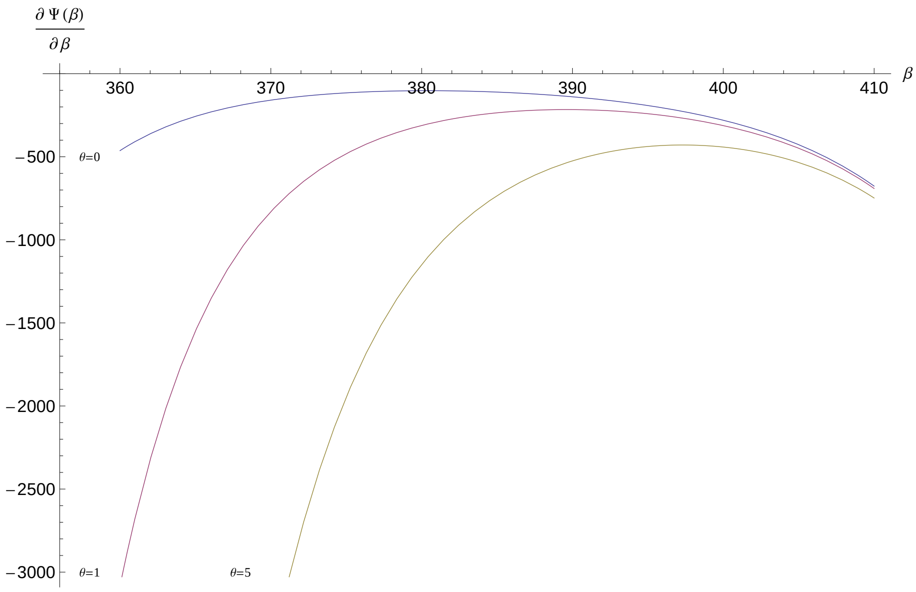

Figure 38: Graph of first differential of $\Psi(\beta, \theta, n)$ in β when $\theta = 0, 1, 5$ in the bivariate normal distribution: the maximum tends towards $n\mu_x$ when θ increases ($n = 40$, $\mu_x = 10$, $\sigma_x = 3$).

The evaluation of the β which will nullify the first differential of the Ψ function is not easily tractable. As can be seen in figure 38, when taking a numerical instance like the one presented in the subsection 5.5.1 of the numerical example in section 5.5, this value is approximated by $n\mu_x$ as θ increases: a maximum for the shipper and a minimum for the carrier.

Whatever the type of distribution of demands, g_1, g_2 are always continuous on the domain of interest, $\theta \geq 0$ so $\Psi(\beta, \theta, n)$ is also continuous and may admit an extremum over the domain. However, by construction, this will be a maximum for one party when it is a minimum for the other party.

The shipper will be looking for a *low* β when the carrier looks for a *high* one: we have no way of telling how the bargaining will turn.

Optimal n:

As an initial remark, the reader is reminded that both carrier and shipper are involved in a transaction setting which requires an initial investment which has yet to run its full economic life. This life is a function of the number of games that both participants play but not of the length of each game. Both are motivated to increase the lifetime of the investments because at the end of the useful life of those investments, they will have to incur new ones. So *both are inclined to choose n as large as possible*.

To evaluate the optimal number of periods, we *linearize n*, using the notation $\tilde{n}$, and differentiate according to it. We obtain

$$\frac{\partial E_s^3(\alpha, \beta, \theta, \tilde{n})}{\partial \tilde{n}} = \frac{\partial B(\tilde{n})}{\partial \tilde{n}} - \alpha\mu_X - \frac{\partial \Psi(\beta, \theta, \tilde{n})}{\partial \tilde{n}} \qquad \text{(D.16)}$$

The optimal $\tilde{n}$ to the shipper is when the First Order Condition (F.O.C.) is satisfied, meaning that

$$\alpha = \frac{1}{\mu_X}\Big[\frac{\partial B(\tilde{n})}{\partial \tilde{n}} - \frac{\partial \Psi(\beta,\theta,\tilde{n})}{\partial \tilde{n}}\Big]. \tag{D.17}$$

To the carrier, the optimal $\tilde{n}$ is when

$$\alpha = c + \frac{K}{\mu_X} - \frac{1}{\mu_X}\frac{\partial \Psi(\beta,\theta,\tilde{n})}{\partial \tilde{n}}. \tag{D.18}$$

This parameter α for the carrier is different from the shipper's unless $\partial B(n)/\partial n = K + c\mu_X$. This case is the trivial situation where the shipper's budget per period is equal to the carrier's cost per period for the expected demand over one period.

As we stated in 5.3 on page 99, we are interested in the non-trivial case where $\partial B(n)/\partial n > K + c\mu_X$ and hence the shipper's and carrier's individual rationality constraints can be satisfied simultaneously. For all these cases, there exist a non-empty set of values for α for which both carrier and shipper are interested in increasing n.

The parameter α, result of the bargaining, will fall within a range defined by the regions in which both partners wish to *extend* the number of periods[1].

The ensuing α is such that

$$\begin{aligned}\alpha &\leq \frac{1}{\mu_X}\Big[\frac{\partial B(\tilde{n})}{\partial \tilde{n}} - \frac{\partial \Psi(\beta,\theta,\tilde{n})}{\partial \tilde{n}}\Big] \\ \alpha &\geq c + \frac{K}{\mu_X} - \frac{1}{\mu_X}\frac{\partial \Psi(\beta,\theta,\tilde{n})}{\partial \tilde{n}}.\end{aligned} \tag{D.19}$$

Along the way we obtain a *"desirable"* range for α, something which is not given from the F.O.C. in α of the players' objective functions since the carrier's and shipper's first differential in α of their objective functions are of opposite signs. However, this range is not mandatory: choosing a value outside this range does not impede the players from reaching an agreement, so we shall only mention it here but not include it in the set of conditions for the eligibility of the contract.

To illustrate the range, we evaluate the high and low bounds on α in the case of the bivariate normal distribution presented in 5.5.1 on page 112. The results are presented in figure 39. As can be seen, α would be ranging within negative values. The shipper and carrier would be willing to extend the number of periods in a contract if $\alpha < 0$! When n ranges between 10 and 1000, no occurrence has been found in this numeric instance where α would take positive values.

We have earlier set α to be positive or null: the shipper pays the carrier to carry her loads. We have not found literature to support the fact that a contract of this nature coordinates the dyad and proving this is not within the remit we have set ourselves here. So, in this particular numerical instance, both shipper and carrier are better off by restricting the length of their contract. Shipper and carrier might be interested in lengthening

1 i.e. where both differentials in terms of n are positive.

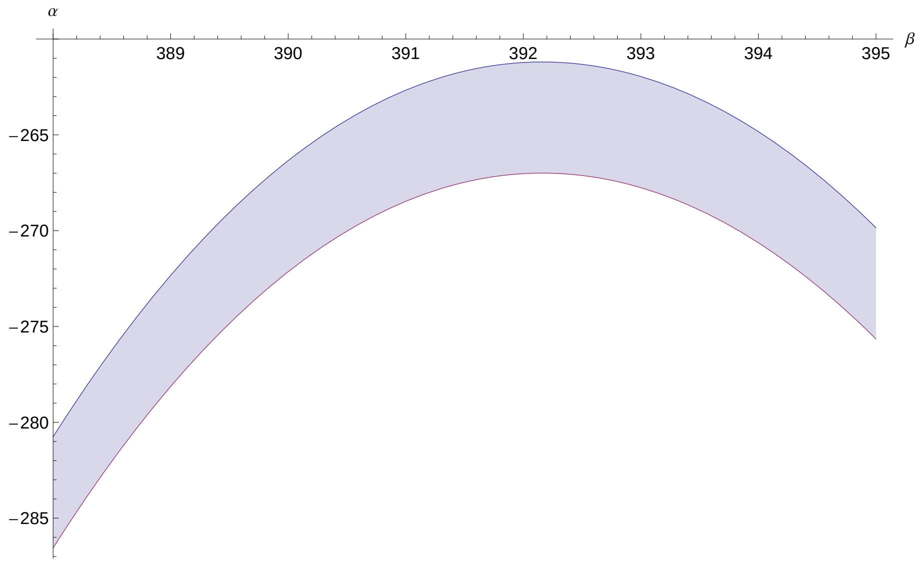

Figure 39: Part of the set of negative values for α where the shipper and carrier would be willing to extend the number of periods ($\theta = 2$, $n = 40$, $\mu_x = 10$, $\sigma_x = 3$).

the contract given the relationship-specific investments they made but the present model does not include them. We have no way of deriving the equilibrium number of periods which might balance this effect.

Participation constraints

The participation constraints on the players also require that

$$\begin{cases} E_3^s(\alpha,\beta,\theta,n) \geq 0, \\ E_3^c(\alpha,\beta,\theta,n) \geq 0. \end{cases} \tag{D.20}$$

with

$$\begin{aligned} E_3^s(\alpha,\beta,\theta,n) &= B(n) - n\alpha\mu_X - \Psi(\beta,\theta,n) \\ E_3^c(\alpha,\beta,\theta,n) &= n[\alpha\mu_X - c\mu_X - K] + \Psi(\beta,\theta,n). \end{aligned} \tag{D.21}$$

By replacing function Ψ by its definition in (5.17) from page 106, the participation constraints can now be written

$$\begin{aligned} \theta\Big(\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta,n)\Big) &\leq \quad B(n) - n\alpha\mu_X - \mu_P\Big(g_2(\beta,n) - \frac{\beta}{\overline{F_{Y_n}}(\beta)}\Big) \\ \theta\Big(\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta,n)\Big) &\geq \; nK + nc\mu_X - n\alpha\mu_X - \mu_P\Big(g_2(\beta,n) - \frac{\beta}{\overline{F_{Y_n}}(\beta)}\Big). \end{aligned}$$

The figure 40 on the facing page represents the area where the tuples $\{\alpha,\beta\}$ with both α and β positive enable a positive penalty θ to exist in the numerical example of a bivariate demand and price. Another way of looking at the same reality is through figure 44: in that figure the upper and lower bounds on θ are presented in terms of β and α. All parameters must be positive for this contract to coordinate shipper and carrier.

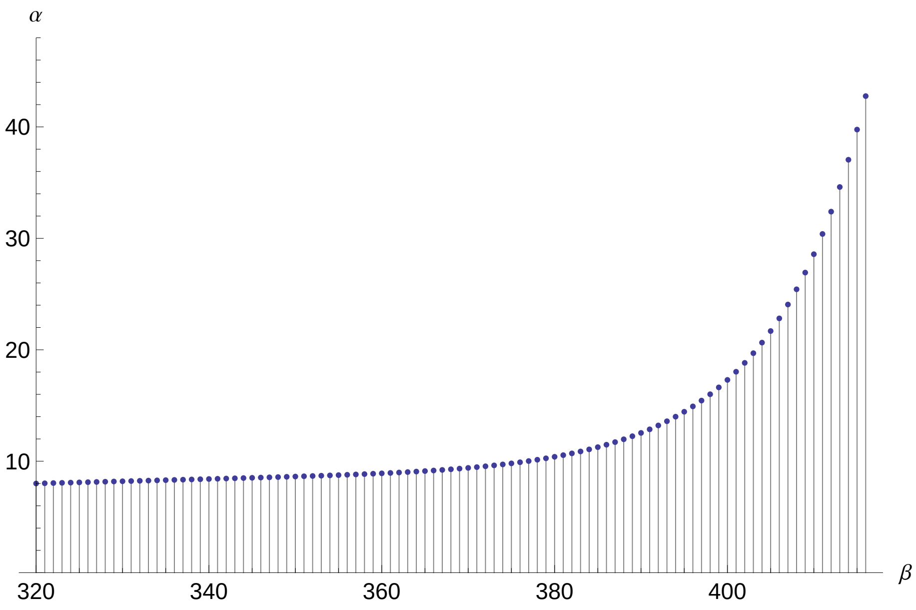

Figure 40: The grey segments represent the possible tuples $\{\beta, \alpha\}$ for which $\theta \geq 0$ and a coordinating QFC can be chosen in the bivariate numerical example developed later ($n = 40$, $\mu_x = 10$, $\sigma_x = 3$).

Because all the above functions and expressions are continuous and do not change when we consider integer values for n, in the following we shall drop the tilde over the n and consider that we are using whole periods only.

We can now enunciate the conditions of existence of the QFC:

$$\begin{cases} \alpha \geq 0, \wedge\ \theta \geq 0, \wedge\ \beta > 0 \\ \theta \leq \frac{1}{\beta/F_{Y_n}(\beta) - g_1(\beta,n)} \left[B(n) - n\alpha\mu_X - \mu_P\big(g_2(\beta,n) - \beta\big)\right] \\ \theta \geq \frac{1}{\beta/F_{Y_n}(\beta) - g_1(\beta,n)} \left[nK + nc\mu_X - n\alpha\mu_X - \mu_P\big(g_2(\beta,n) - \beta\big)\right]. \end{cases} \tag{D.22}$$

D.4 PROOF OF CONDITION 6

Proof. From (5.28) on page 110 and for both players to choose a QFC it must generate more reward than the MPC to each player. Since $n > 0$, we must have

$$\begin{cases} r + s\mu_X(q) + I\overline{F_X}(q) + \varphi^s(q) \geq \Psi(\beta,\theta,n)/n + \mu_X\alpha \\ c\mu_X + r + (s-c)\mu_X(q) + \varphi^c(q) \leq \Psi(\beta,\theta,n)/n + \mu_X\alpha. \end{cases} \tag{D.23}$$

Further, the parameters r, s and q have to satisfy Condition 2 and β, θ and n must satisfy Condition 3.

∎

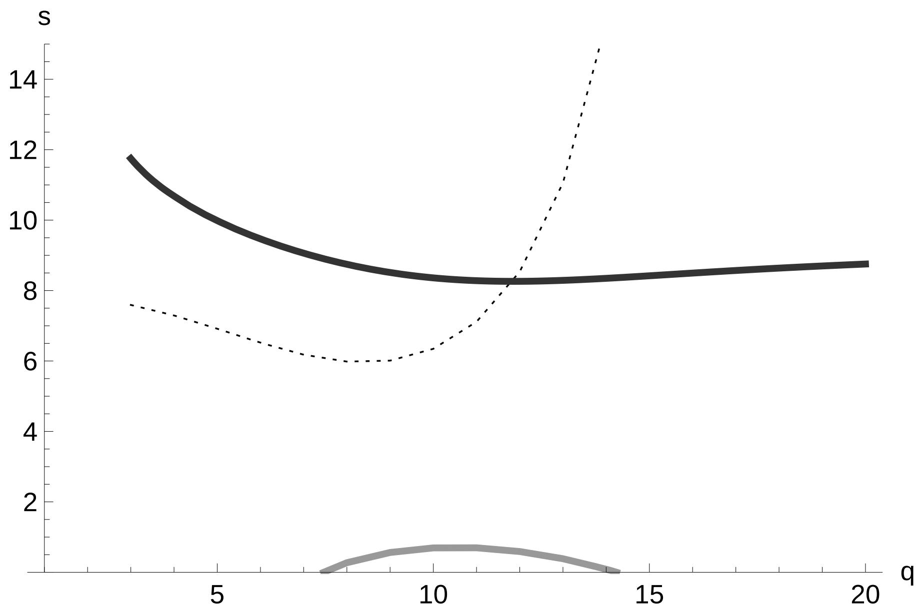

Figure 41: The thick lines are the upper and lower limits on s for shipper and carrier to participate, the thin dotted line is the values of s satisfying Theorem 14.

D.5 NUMERIC EXAMPLE WITH BIVARIATE VARIABLES

D.5.1 *Conditions for a PRC to exist*

We first start by determining the conditions for a PRC from Condition 1 to be eligible, p_r has to satisfy

$$3.80 \leq p_r \leq 9.6. \tag{D.24}$$

D.5.2 *Condition for a MPC to exist (Condition 2)*

To know the MPC to be satisfactory *per se* for both players, let us look at how to satisfy Proposition 14, that is to say, which values of q enable an optimal s to satisfy both players simultaneously.

We notice that the shipper's objective function is not concave: the second differential in q of the objective function of the shipper is not always negative, so we cannot apply here the Proposition 14 for the shipper. The same is true of the carrier's objective function, which precludes using a simple unique function to calculate the parameter s. We plot in figure 41 the curves of values of s in terms of q: (a) the maximum values of s over which the shipper will have eaten her budget, even if $r = 0$, (b) the minimum value of s for the carrier under which he cannot make a profit when $r = 0$, (c) the curve under which the second differential of the shipper's objective function is negative, (d) the curve of $s(q)$.

For the sake of clarity, we assume here that the shipper and carrier will agree on a value of s which satisfies Proposition 14 as long as s does

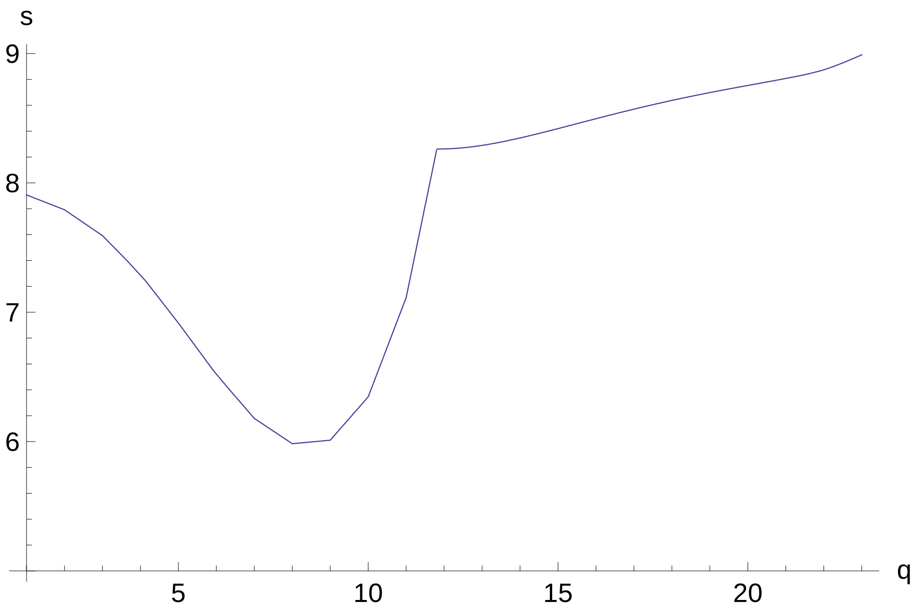

Figure 42: The values of s in q which satisfy Theorem 14 and respect the participation constraints.

not violate the shipper's participation constraint and then follows the participation constraint limit.

The plot of the corresponding values of s are given in figure 42.

From the first two inequalities in condition 2, we obtain as the grey segments in figure 43 on the next page the tuples $\{q, r\}$ with a *strictly positive* fixed fee, meaning a fee that the shipper *pays* to the carrier. This limits q to $1 \leq q \leq 11$.

Why does the fixed fee have to be strictly positive? We observe that the results presented in Cachon and Lariviere (2001) condition the coordination of the shipper and the carrier to the fact that the shipper signals her demand forecast credibly by *paying* ex ante the carrier a fixed fee. Only promising a higher per unit fee s does not signal *credibly* the required capacity by the shipper, as shown in Cachon and Lariviere (2001).

D.5.3 *Conditions for a QFC to exist (Condition 3)*

We first start by determining the conditions for a QFC alone. We then shall submit those to the comparison with conditions of the QFC dominating the other contracts.

How do we evaluate the number of periods which will satisfy both players? As we have seen in the considerations over the optimal n in appendix D.3, the conditions for both to agree on one value depend on their relative bargaining powers. So that the Central Limit theorem can apply and without loss of generality, we assume that they agree on $n = 40$.

The important constraints are the ones which determine θ as solution to the participation constraints expressed in terms of β, α and n in Condition 3.

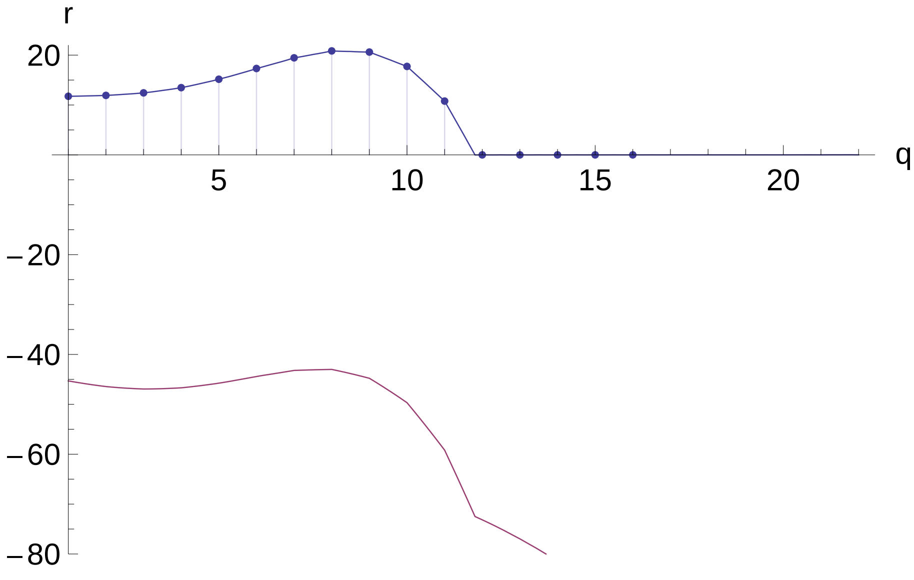

Figure 43: The segments represent the possible tuples $\{q, r\}$ for which a MPC which coordinates the shipper and carrier can be chosen. Parameter r ranges between 0 (excluded) and 20.84.

In figure 44 on the facing page the possible values for parameter θ are the positive values between the two envelopes which represent the upper and lower participation constraints, expressed in terms of α and β. As can be seen, there are upper limits on α which, whatever the value of β within the domain, do not enable a contract to fulfill the participation constraints because the corresponding penalty would have to be set at a negative value. We shall consider only the vectors of parameters $\{\alpha, \beta, \theta\}$ for which the participation constraints are satisfied.

The corresponding solutions are an equilibrium in which the QFC is chosen in isolation, what would the outcome be if the shipper and carrier could compare it to the PRC?

D.5.4 *Condition for the QFC to be equivalent to the PRC (Condition 5)*

We join the constraints from Condition 3 and from 5. We evaluate p_r when function $\Psi(\alpha, \beta, n)$ is replaced by its upper and lower bounds.

In figure 45 on the next page we represent the upper and lower envelopes within which the value of p_r evolves given tuples of $\{\beta, \alpha\}$ when θ is at or slightly higher than its low bound. When this is the case, the vectors α, β, p_r describe the volume between both grey envelopes. When θ takes on its high bound no values of β and α can make a QFC compatible with a PRC.

However, we also have to satisfy the conditions of existence of the QFC in the first place. This is given by Condition 3 and as seen earlier (see figure 44 on the facing page), not all tuples $\{\beta, \alpha\}$ comply. The limit on the combination of β and α values are the same as the one for existence of a QFC in the first place.

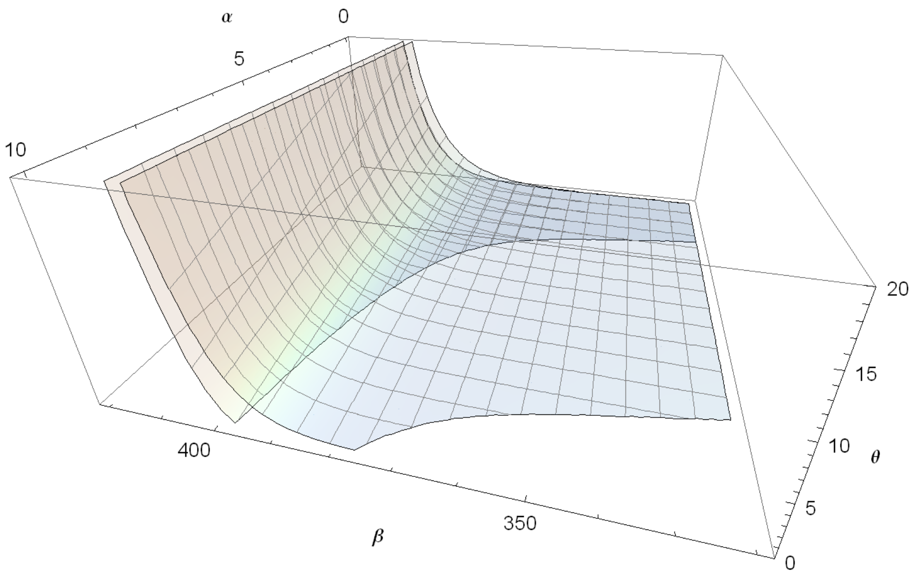

Figure 44: The valid values of the parameter θ are the positive ones between the two envelopes in β and α for Condition 3 to be fulfilled when $n = 40$.

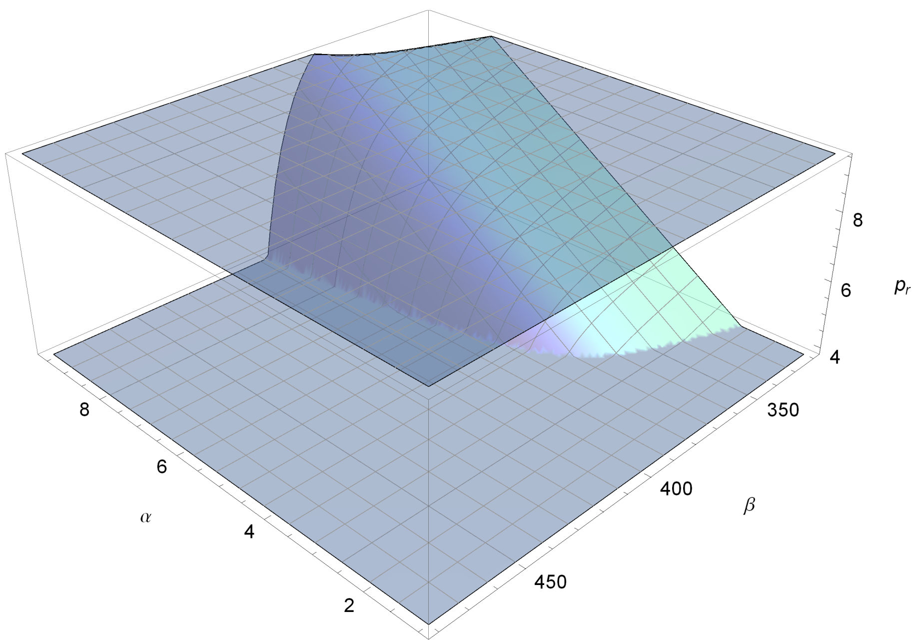

Figure 45: Between the envelopes which limit the value of p_r are given vectors $\{\beta, \alpha, \theta\}$ for a QFC to be comparable to the PRC: the highest envelope is the one when θ assumes its high bound, the lower one is for the low bound on θ, which at times may be equal to 0.

Let us now look at the conditions of existence and dominance of a MPC over a PRC before submitting them to the comparison with the QFC.

D.5.5 *Condition for a MPC to dominate a PRC (Condition 4)*

Let us consider how Condition 4 on the dominance of the MPC over the PRC can be met. We represent this set of inequalities as two functions in q and p_r, as the high and low boundaries for r in (5.22) on page 109:

$$\begin{aligned} \rho_{Hi}(q, p_r) &= 10p_r - 2\overline{F_X}(q) - \varphi^s(q) - s(q)\mu_X(q), \\ \rho_{Lo}(q, p_r) &= 10p_r - \varphi^c(q) + 1.8(\mu_X(q) - 10) - s(q)\mu_X(q), \end{aligned} \tag{D.25}$$

with $s(q)$ as the function which generates s from the values of q as defined in D.5.2. We observe that

$$2 \geq q < 12 \Rightarrow \rho_{Hi}(q, p_r) > \rho_{Lo}(q, p_r), \forall p_r. \tag{D.26}$$

which satisfies the condition of preeminence of the MPC as set in (5.22) of Condition 4, so the MPC prevails for all $2 \leq q < 12$. When

$$q = 1, r > 0, \Rightarrow \rho_{Hi}(q, p_r) < \rho_{Lo}(q, p_r), \tag{D.27}$$

which means that the PRC is preferred to the MPC insofar as $r \geq 0$, as the inequality set (5.23) in Condition 4 is satisfied.

By inspection of the lower limits on p_r when $2 \leq q \leq 11$, this means that we must have at least $p_r \geq 7.51$, otherwise we would have $r < \rho_{Lo}(1, p_r) \leq 0$: the MPC under comparison would not be a coordinating one. Even though the players will not retain it, the outcome must be based on contracts which respect the constraints set up.

When $q \geq 12$, we observe that no possible positive value of r can satisfy Condition 4: for those values of q, the MPC is no longer coordinating shipper and carrier so shall be discarded in this setting as of limited interest. Figure 46 presents the case of lower and higher limits for r in terms of p_r when $q = 8$: not all values of p_r can enable both players to be coordinated by a lump sum payment that the shipper makes to the carrier. When $p_r \leq 7.51$, the shipper would actually receive a payment from the carrier!

D.5.6 *Condition for a QFC to dominate a MPC (Condition 6)*

We now look at the requirements so that the QFC dominate the MPC given in the set of inequalities (5.29) on page 110 of Condition 6. Given that previous conditions of existence of the QFC also have to be satisfied, we obtain

$$\begin{cases} r + s\mu_X(q) + I\overline{F_X}(q) + \varphi^s(q) > \Psi_{Hi}(\alpha, \beta, n)/n + \mu_X\alpha \\ c\mu_X + r + (s - c)\mu_X(q) + \varphi^c(q) < \Psi_{Lo}(\alpha, \beta, n)/n + \mu_X\alpha. \end{cases} \tag{D.28}$$

Let

$$\begin{aligned} rhs_{Hi}(\alpha, \beta, n) &= \Psi_{Hi}(\alpha, \beta, n)/n + \mu_X\alpha, \\ rhs_{Lo}(\alpha, \beta, n) &= \Psi_{Lo}(\alpha, \beta, n)/n + \mu_X\alpha, \end{aligned} \tag{D.29}$$

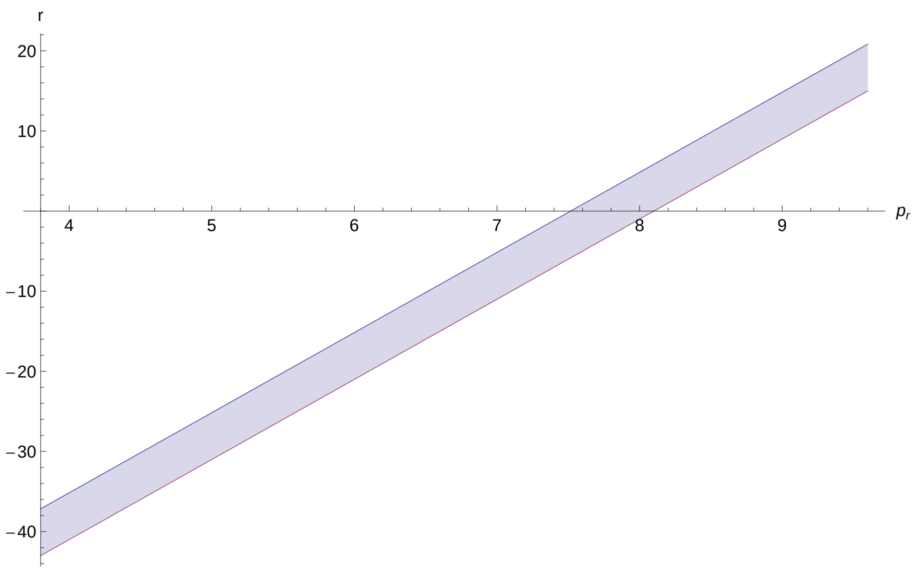

Figure 46: The shaded band above the abscissa represents the possible r for the corresponding values of p_r when $q = 8$. The band widens progressively as q increases from 2 to 12, but its higher bound is progressively lower. when $q \geq 12$, no positive value of r can be found which satisfies Condition 4.

as the right hand side of the constraint when the function Ψ has been replaced by its high and low bounds.

We first set up four functions for the left hand side of the inequalities: two with the upper limit on r for the shipper and carrier and two using the lower limits on r for both players. The lower limit on r comply with the condition of a positive or null fixed fee r so that the MPC is a coordinating contract in the sense established by Cachon and Lariviere (2001) (in the present numerical instance, this low limit is $r = 0$).

$$\begin{aligned} lhs^s_{Lo}(q) &= r_{Lo}(q) + s(q)\mu_X(q) + 2\overline{F_X}(q) + \varphi^s(q) \\ lhs^s_{Hi}(q) &= r_{Hi}(q) + s(q)\mu_X(q) + 2\overline{F_X}(q) + \varphi^s(q) \\ lhs^c_{Hi}(q) &= r_{Hi}(q) + 18 + (s(q) - 1.8)\mu_X(q) + \varphi^c(q) \\ lhs^c_{Lo}(q) &= r_{Lo}(q) + 18 + (s(q) - 1.8)\mu_X(q) + \varphi^c(q) \end{aligned} \quad \text{(D.30)}$$

These four functions are represented in figure 48 on page 187. The left plot represents the left hand side set of inequalities when r takes the high value (the lower curve plots the carrier's constraint and the higher one the shipper's). The right plot represents the carrier's and the shipper's constraints when r takes the lower possible bound. We observe that

$$\begin{aligned} &\forall r, |r > 0, \forall q, |1 < q < 12, \quad lhs^s_{Lo}(q) < lhs^c_{Lo}(q), \\ &\forall r, |r > 0, \forall q, |1 < q < 12, \quad lhs^s_{Hi}(q) < lhs^c_{Hi}(q), \end{aligned} \quad \text{(D.31)}$$

which means that the set of inequalities in (D.28) are never satisfied and hence that the QFC cannot dominate the MPC when $q > 1$.

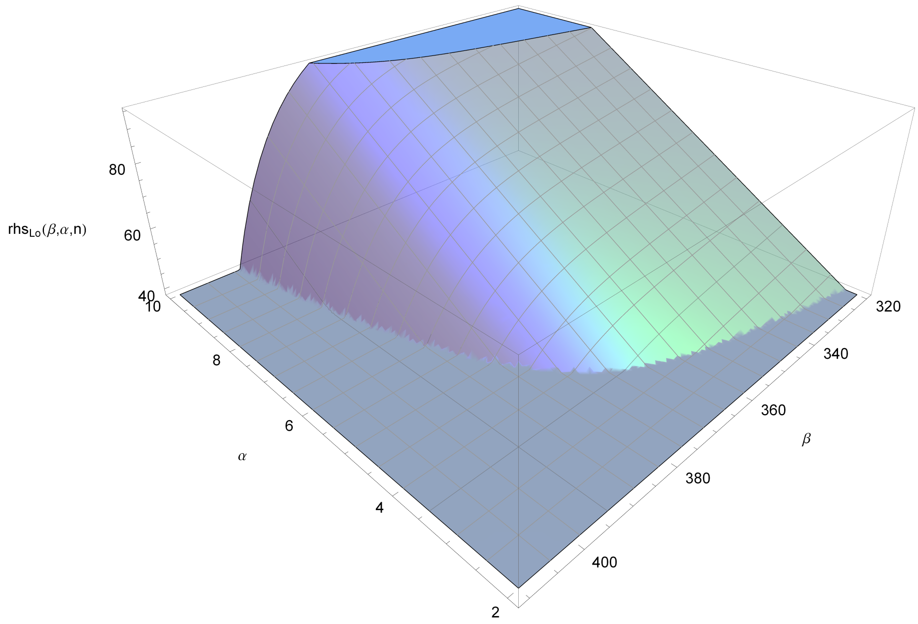

Figure 47: The right hand side function $rhs_{Lo}(\beta, \alpha, n)$ evolves between 38 and 96 for all tuples $\{\alpha, \beta\}$ which satisfy to the existence of a mutually acceptable QFC.

The only case when a QFC dominates a MPC is when $q = 1$, in which case we have $lhs^s_{Lo} = 84.25$ and $lhs^c_{Lo} = 83.31$. This leads to writing for example that

$$83.31 < rhs_{Lo}(\alpha, \beta, 40) < 84.25, \qquad \text{(D.32)}$$

if one considers the case when θ takes its lower bound. Hence, we can express the commitment β in terms of high and low bound on α. A solution to these inequalities is, among others,

$$\beta = 380, \quad 9.13 < \alpha < 9.22, \quad \theta = 0, \quad n = 40. \qquad \text{(D.33)}$$

This contract has parameters which enable it to beat the MPC when the MPC has $q = 1$. It yields a profit to the carrier between 1812.3 and 1850.1 according to the level of α but for any β such that $320 < \beta < 430$ and when θ is at its lower bound.

Let us now see when $q > 1$ if the MPC is chosen simultaneously by both partners over the QFC.

We have $rhs_{Hi}(\alpha, \beta, n) = 96$ a constant when θ is set at its high bound. On the other hand, by inspection we see that $38.00 < rhs_{Lo}(\beta, \alpha, n) \leq 96$ for all tuples $\{\beta, \alpha\}$ which satisfy the conditions of existence of a QFC (see figure 47).

So, for any value of θ, the right hand side of the constraint is always bounded from below by 38 and from above by 96. We can now look at the behaviour of the left hand side.

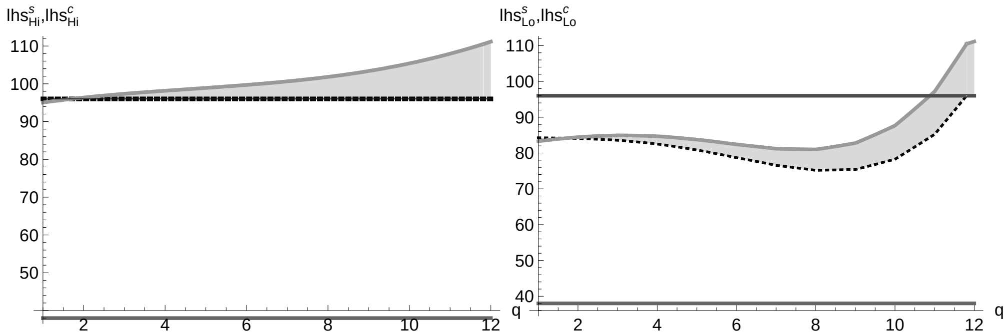

Figure 48: The horizontal lines on levels 38 and 96 represent the top and lower limits on the rhs described in (D.29). The boundaries on the grey areas are the lhs from (D.30).

If the MPC dominates strictly the QFC, we can rephrase (5.30) of Condition 6 into the following:

$$\begin{cases} lhs^c_{Hi}(q) > rhs_{Hi}(\alpha,\beta,n) > lhs^s_{Hi}(q) \\ lhs^c_{Lo}(q) > rhs_{Lo}(\alpha,\beta,n) > lhs^s_{Lo}(q). \end{cases} \tag{D.34}$$

What can be observed from the left-hand graph in figure 48 for the upper limit of r is that

$$\begin{cases} lhs^s_{Hi}(q) > rhs_{Hi}(\alpha,\beta,40), \\ lhs^c_{Hi}(q) = rhs_{Hi}(\alpha,\beta,40), \end{cases} \tag{D.35}$$

so that neither contract dominates. Whereas, in the right-hand graph, when $r = 0$ and $2 \le q \le 11$, inequalities (D.34) are satisfied: the MPC effectively dominates the QFC. When $q \ge 12$, we see that no contract can be chosen simultaneously by both players because the required conditions spelled out in Condition 6 for a QFC are not satisfied either.

We conclude that a set of parameters of a MPC which dominates the QFC exist which satisfy both players.

The MPC which yields the highest return to the shipper when taken in isolation has $q = 8$ and $r = 0$, ie its low bound. In the same way, the MPC which yields the highest profit to the carrier is when $q = 11$.

Without knowing the balance of power between both, we have no way of pinpointing the set of parameters of the MPC on which both will agree: $8 \le q \le 11$ and $0 \le r \le r_{Hi}(8)$ (as presented in figure 43).

D.5.7 *Condition for a contract to dominate both other contracts (Condition 9)*

The conditions for the emergence of a contract over both other contracts means that Condition 9 must be satisfied for one of the three contracts. As seen in the previous subsections, the MPC dominates the PRC when $q \ge 2$ and is preferred to the QFC when $2 \le q \le 11$. So, the MPC is preferred overall and no other contract can be preferred in the present numeric instance over 40 periods.

In the unlikely case where a commitment of $q = 1$ is preferred, then both the PRC and QFC come back into play as possible choices. Either can be retained because sufficient domains exist for the economic result for each player to be equal. Note however that the conditions are tighter than when both are compared on their own merits without comparing them to the MPC: we need to have $p_r \geq 8.425$ as observed in D.5.5.

D.6 NUMERIC EXAMPLE WITH FIXED SPOT PRICE

In this instance, we consider that the spot market price for transport does not fluctuate. Due to the fact that the only random variable now is demand, the functions $\varphi()$ in (B.8), $s(q)$ in (5.15) change and we can write, adding a superscript 1 to indicate that they represent a univariate state of the world and naming P the *fixed* spot price,

$$\begin{aligned}
\varphi^{s1}(q) &= \frac{1}{\overline{F_X(q)}} \int_q^{Q_{Hi}} (x-q) P f_X(x) dx, \\
\varphi^{c1}(q) &= \frac{1}{F_X(q)} \int_0^q (q-x)(P-c) f_X(x) dx + \\
&\qquad \frac{1}{\overline{F_X(q)}} \int_q^{Q_{Hi}} (x-q)(P-c) f_X(x) dx \\
s^1(q) &= \frac{I f_X(q) - \varphi^{s1'}(q)}{1 - F_X(q)}.
\end{aligned} \tag{D.36}$$

Regarding the functions which intervene in the calculations of the QFC, the definitions of functions $g_1(\beta, n)$ and $g_2(\beta, n)$ are the same in both the bivariate and univariate cases. So, we also have the same definition for $\Psi(\beta, \theta, n)$.

The condition of emergence of the PRC are the same in the univariate case as in the bivariate one so shall not be covered here.

D.6.1 *Condition of existence of a MPC in the univariate case*

We first want to see what conditions for the parameters of the MPC would make this contract eligible. From Condition 2, when adapted to the case at hand, we can present the constraints on r in the figure 49. Since, to be a coordinating contract, we need the parameter r to be positive, the resulting possible tuples $\{q, r\}$ are restricted to the grey vertical segments in that figure.

The corresponding objective functions of the players can be presented in the figure 50 on the next page. Because the fixed fee is at least equal to 0 and cannot take negative values, the shipper makes the most of her budget by choosing $q = 8$ and $r = 0$. If we had left r take negative values, the shipper would have had an increasing objective function in terms of q. As the carrier is also motivated by a high commitment, they would have settled for a commitment as high as possible (like $q = 22$, or 4 standard deviations above the expected demand): a contract which is clearly not a coordinating one as the shipper would fail to fill the capacity put at her disposition, negating the benefit of this type of contract. Moreover, and, in our view convincingly, the carrier would have had to pay the shipper a fixed fee which defeats the coordinating characteristics of the MPC.

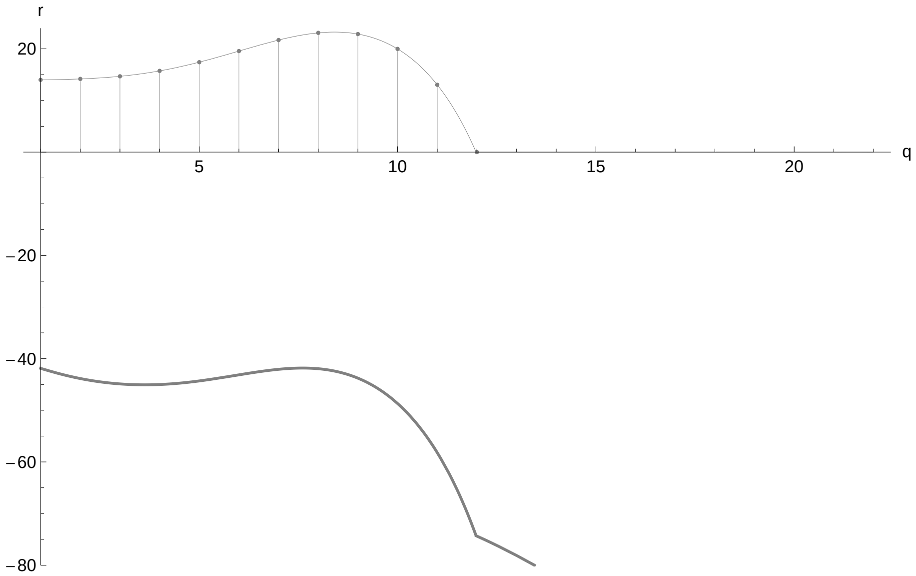

Figure 49: Fixed spot price: the parameter r in terms of q, the segments are the tuples $\{q, r\}$ that enable the MPC to coordinate the players.

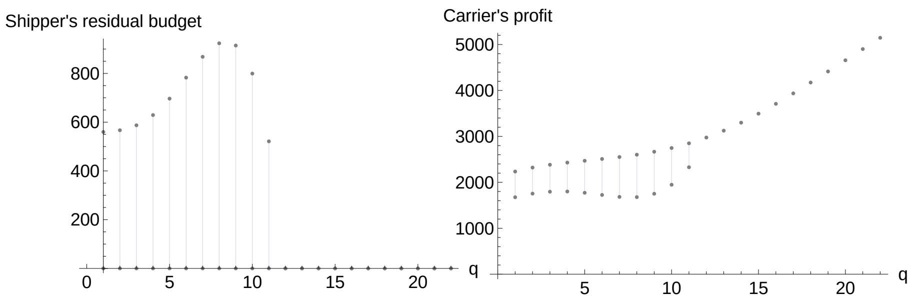

Figure 50: Fixed spot price: objective functions of shipper and carrier: the objective functions show that the carrier is better off when extending q, whereas the shipper's maximum retained budget is achieved when $q = 8$ and is null when $q = 12$.

As in the bivariate case, we must have $1 \leq q \leq 12$ and $r > 0$. The price s must also comply with the rationality constraints of both players (see figure 42 for an idea of the plot of s in terms of q).

D.6.2 *Condition of existence of a QFC in the univariate case*

We now turn to the QFC. The participation constraints from Condition 3 on θ are the same as in the bivariate case.

The envelopes in the volume $\{\alpha, \beta, \theta\}$ which represent the boundaries of existence of the penalty θ are also the same as the ones presented in section D.5.3 in figure 44 on page 183. The vectors of values which describe this volume constitute the mutually agreeable sets of parameters for a QFC to be eligible in the univariate case also.

We now compare the MPC and the PRC.

D.6.3 *Condition of dominance of a MPC over a PRC*

Which parameters of the MPC would make it superior to the PRC for both players to adopt it? From Condition 4 adapted to the univariate case, we have

$$\begin{aligned} r &\leq 10p_r - 2\overline{F_X}(q) - \varphi^{s1}(q) - s^1(q)\mu_X(q) \\ r &\geq 10p_r - \varphi^{c1}(q) - 1.8\big(10 - \mu_X(q)\big) - s^1(q)\mu_X(q). \end{aligned} \tag{D.37}$$

We present in figure 51 on the next page the resulting envelopes. We see that the lower bound (topmost envelope in the figure) crosses the higher one when $q = 1.985$, which means that the conditions for the dominance of a MPC can only be fulfilled when $2 \leq q \leq 12$. Within those limits, the MPC dominates the PRC for both players. The PRC is preferred when $q = 1$, as the inequalities 5.23 in Condition 4 would be satisfied. In other cases, either r would be negative or p_r would have to exceed 9.6, the shipper's participation constraint. Such solutions in terms of r and of p_r are presented as the shaded area in figure 52.

D.6.4 *Comparing the QFC and PRC in the univariate case*

Since Condition 5 which presents the cases of dominance of one contract over the other on page 109 can be applied to the univariate case in the same way as in the bivariate one, and by replacing θ by its upper and lower bounds (expressed in terms of α and β) in the definition of function $\Psi_{Hi}(\beta, \theta, n)$, we obtain a set of constraints on p_r in Condition 1 which can be written in the following way

$$\begin{cases} 3.8 \leq \alpha + \frac{\Psi_{Hi}(\alpha,\beta,n)}{n\mu_X} \leq 9.6, \\ 3.8 \leq \alpha + \frac{\Psi_{Lo}(\alpha,\beta,n)}{n\mu_X} \leq 9.6. \end{cases} \tag{D.38}$$

If these inequalities were not true, the QFC and PRC would not be equivalent, so none could be retained simultaneously by both players.

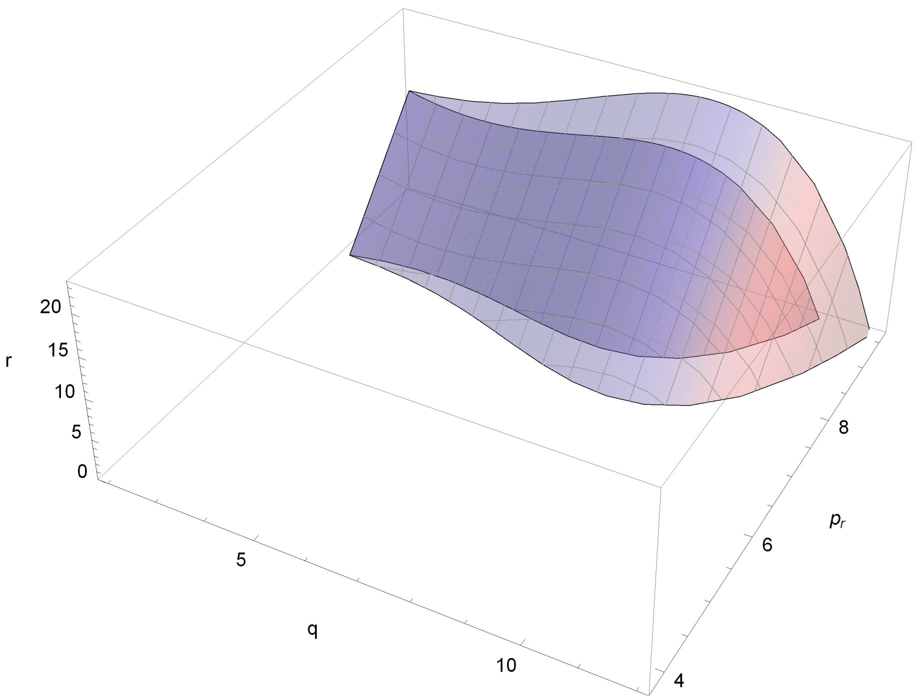

Figure 51: Fixed spot price: The available values of r lie between both envelopes. Not all values of p_r are compatible.

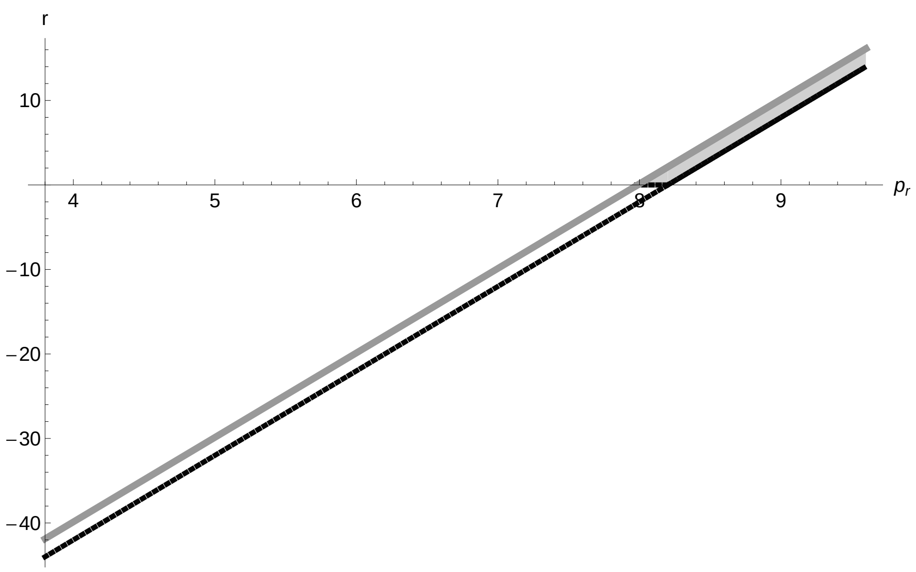

Figure 52: Fixed spot price: The shaded area represents the available values of r given p_r for a PRC to dominate a MPC, when $q = 1$.

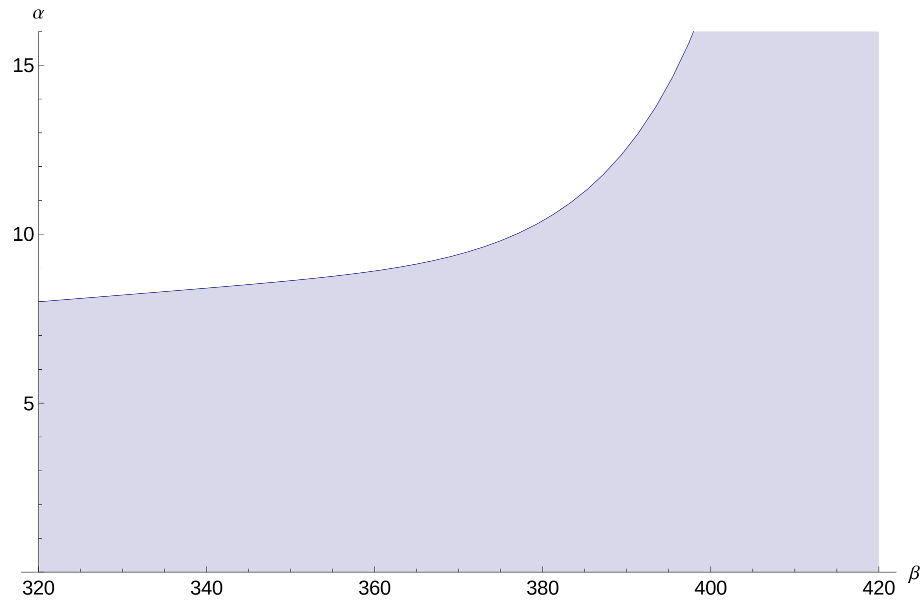

Figure 53: The shaded surface represents the possible tuples $\{\alpha, \beta\}$ for which a QFC and a PRC can be equivalent. The penalty θ can take any of the possible values that are allowed under Condition 3.

When one plots the expressions $\alpha + \frac{\Psi_{Hi}(\alpha,\beta,n)}{n\mu_X}$ and $\alpha + \frac{\Psi_{Lo}(\alpha,\beta,n)}{n\mu_X}$, one sees that the first has a minimum of 3.8 and a maximum of 9.6, except for those tuples $\{\alpha, \beta\}$ which in any case do not satisfy the participation constraints of the shipper. In the same way, the second expression has a minimum of 9.6 except for those tuples in $\{\alpha, \beta\}$ which do not satisfy the participation constraints of the shipper. The possible tuples $\{\alpha, \beta\}$ which satisfy all requirements for equivalence between either contract are represented as the shaded area in figure 53.

D.6.5 *Condition of dominance of a QFC over a MPC*

Let us evaluate the conditions in which the QFC dominates the MPC. Adapting Condition 6 from the bivariate case by replacing functions $\varphi^s(q)$ and $\varphi^c(q)$ by their equivalents in the univariate case, we correspondingly change the functions presented in (D.30) and rename them with an added superscript 1: lhs^{c1}_{Hi}, lhs^{s1}_{Hi}, lhs^{c1}_{Lo} and lhs^{c1}_{Lo}.

As in the bivariate case, the right hand side of the inequalities are the same as in the bivariate instance.

The functions lhs describe the segments within which r can be set in terms of q, as can be seen in figure 54 on the facing page: the left hand graph represents the high and low bounds when r is at its high bound, the right hand graph represents the same high and low limits taken by $lhs^i_{Lo}(q)$, $i \in \{s, c\}$ when r is at its low bound (in the present case: $r = 0$). The higher and lower limits of $rhs(\alpha, \beta, n)$ are also presented.

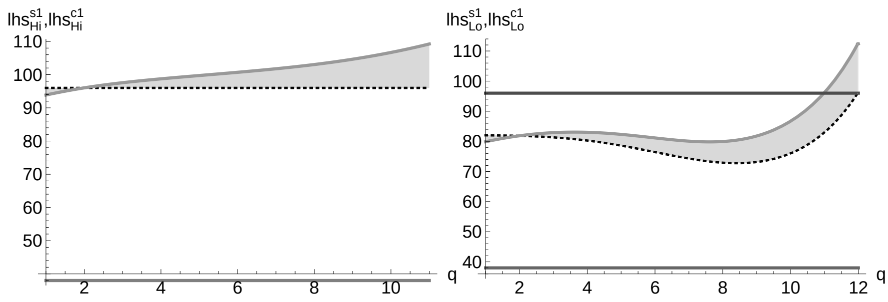

Figure 54: The left hand side of inequalities in (D.30) suitably adapted to the univariate case are presented together with the upper and lower limits on $rhs(\alpha, \beta, n)$: left-hand graph when r is at its highest, right-hand graph, when $r = 0$.

If the QFC dominates the MPC, by Condition 6, we must have

$$\begin{cases} lhs^{c1}_{Hi}(q) < rhs_{Hi}(\alpha, \beta, n) < lhs^{s1}_{Hi}(q) \\ lhs^{c1}_{Lo}(q) < rhs_{Lo}(\alpha, \beta, n) < lhs^{s1}_{Lo}(q). \end{cases} \tag{D.39}$$

By inspection, $lhs^{c1}_{Lo} > lhs^{s1}_{Lo}$ and $lhs^{c1}_{Hi} > lhs^{s1}_{Hi}$, $\forall q \geq 2$ so that the QFC cannot dominate the MPC.

We further observe that in two other situations:

$$q \geq 12 \Rightarrow \ lhs^{c1}_{Lo} > rhs_{Hi}, \tag{D.40}$$

and

$$r = r_{Hi}(q), \wedge q \geq 2, \Rightarrow \ lhs^{s1}_{Hi} = rhs_{Hi}, \tag{D.41}$$

the players would choose different contracts.

If, when $2 \leq q \leq 12$ and $0 \leq r \leq r_{Hi}(q)$, there are values of α, θ and β which enable the inequalities 5.30 in Condition 6 to be satisfied, then there exist MPC contracts which dominate the QFC and if no values of $\{\alpha, \beta, \theta\}$ can be found neither contract can be chosen simultaneously. When we select a MPC with $q = 1$, we see that

$$\begin{cases} 79.87 < rhs_{Hi}(\alpha, \beta, n) < 82.00 \\ 79.87 < rhs_{Lo}(\alpha, \beta, n) < 82.00, \end{cases} \tag{D.42}$$

admits values for α and β, given that $n = 40$ for rhs_{Lo}. For example, when $\beta = 380$, we have $8.78 \leq \alpha \leq 9$ and $0 \leq \theta \leq 0.29$, which lead to a retained budget for the shipper between 560 and 645 when $\theta = 0$ and 0 when the penalty θ is set at its high bound. In the same case, the carrier's profit is equal to 2320 when the penalty is set at its high bound and is bounded between 1675 and 1760 when $\theta = 0$.

When $q = 8$, $r = 0$, $s = 5.983$, we have $lhs^{c1}_{Lo}(8) = 79.9489$ and $lhs^{s1}_{Lo}(8) = 72.909$. We ask ourselves which suitable sets of $\{\alpha, \beta, \theta\}$ allow

$$72.909 < \Psi(\beta, \theta, 40)/40 + \mu_x \alpha. \tag{D.43}$$

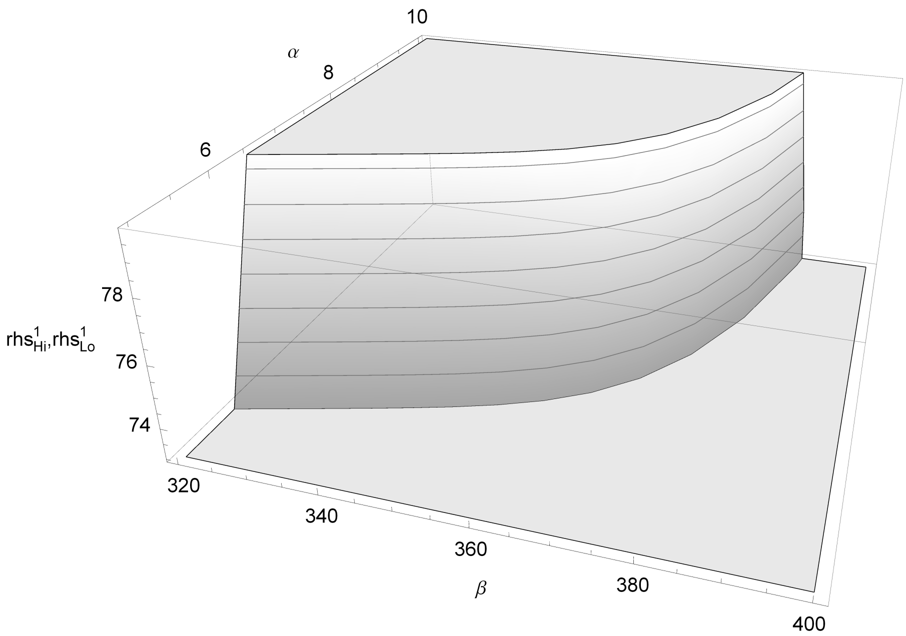

Figure 55: Fixed spot price: The upper and lower bounds of $rhs^1(\alpha, \beta, 40)$ are 72.909 and 79.9489. The graph represents a volume containing the possible tuples $\{\alpha, \beta\}$ when θ is at its low bound: the point $\{5, 380\}$ is in the solution set, $\{8, 340\}$ is not.

For example, as can be gathered from figure 55, once $\{\alpha, \beta\}$ have been determined, the available penalties are the ones for which $72.909 < \Psi(\beta, \theta, 40) + \mu_x \alpha < 79.9489$, so for example, if $\alpha = 5$, $\beta = 380$, then $0 < \theta < 0.9663$.

D.6.6 *Condition of dominance of a PRC over a MPC and equivalent to a QFC*

As seen above for the preeminence of the PRC over the MPC, this means that we need $q = 1$ for a PRC to dominate. If this is so, the required values of p_r are as presented in figure 52, ie $7.99 < p_r \leq 9.6$.

Since we also need an equivalent QFC, we must have Condition 5 satisfied. This is true when

$$\begin{cases} \theta < \left[3840 - n\mu_X\alpha - \mu_P\left(g_2(\beta, n) - \frac{\beta}{F_{Y_n}(\beta)}\right)\right]\frac{1}{\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta)}, \\ \theta > \left[3280 - n\mu_X\alpha - \mu_P\left(g_2(\beta) - \frac{\beta}{F_{Y_n}(\beta)}\right)\right]\frac{1}{\frac{\beta}{F_{Y_n}(\beta)} - g_1(\beta)}. \end{cases} \tag{D.44}$$

This set of conditions is reminiscent of the ones encountered in D.6.5. The lower and upper limits to the possible values of θ are very close. As an example, when $\alpha = 5$, $\beta = 405$ and $n = 40$, we have $21.62 < \theta < 23.60$. The set of available QFC parameters $\{\alpha, \beta, \theta\}$ are presented in figure 56.

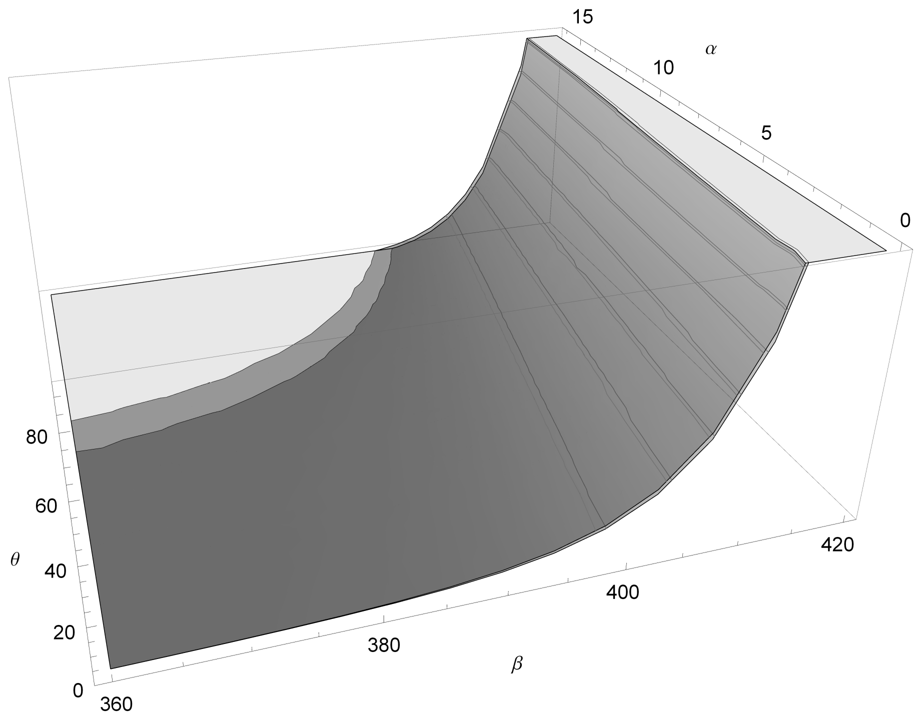

Figure 56: Fixed spot price: the figure represents two envelopes which nearly coincide : the lower and upper limits of the value of θ in terms of the tuples $\{\alpha, \beta\}$ solution to D.44 and which describe the QFC which is equivalent to the dominant PRC.

D.6.7 *Condition of dominance of a MPC over both a QFC and a PRC*

Since we already have established the conditions for a MPC to dominate both a PRC and a QFC separately, we just have to ensure that the PRC and QFC are equivalent to obtain the necessary and sufficient conditions for a MPC to dominate both others.

We have seen earlier that the only remaining commitment q which enables the satisfaction of theses conditions is when $2 \leq q < 12$, and the parameters of the QFC allow it to be equivalent to the PRC. Further, the inequality set (D.39) has to be satisfied.

We represent in figure 57 one set of tuples which enable a QFC to exist and be comparable to a MPC when $q = 8$. It has been chosen after setting θ at its low boundary. A similar graph could have been drawn for other values of θ and q.

D.6.8 *Condition of dominance of a QFC over both a MPC and a PRC*

We have seen earlier that the set of values which enable a QFC to be chosen preferentially require that the MPC be first dominated; this means that $q = 1$, further the penalty must satisfy the inequality set (D.44).

This leads to profit functions which are plotted in figure 58: the result is independent of the commitment as both α and θ are in fact the coordinating factors. This graph leads us to believe that the variance of demand

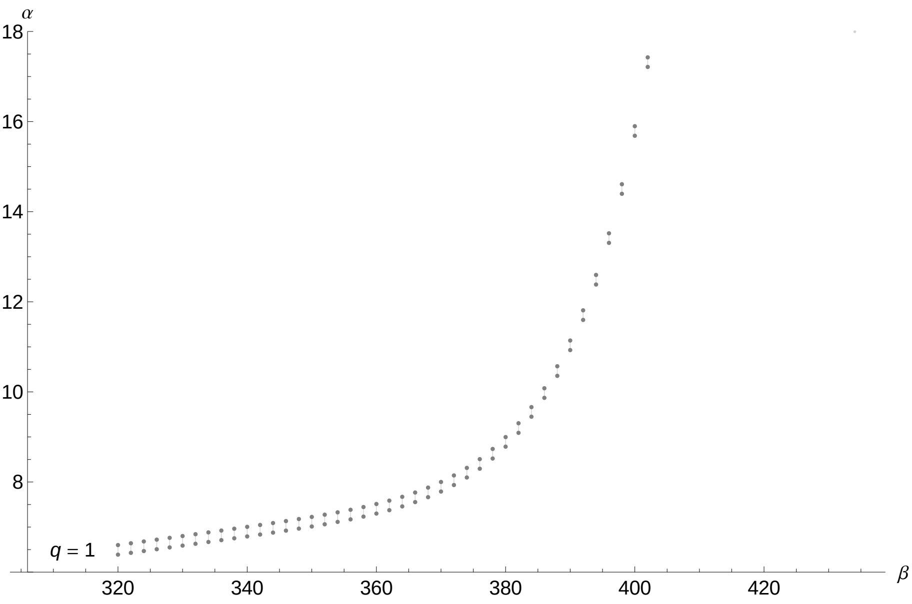

Figure 57: Fixed spot price: the figure represents the lower and higher limits of the tuples $\{\alpha, \beta\}$ which enable the right hand side of the inequalities in (5.30) to be between lhs^{c1}_{Lo} and lhs^{s1}_{Lo} and hence a compatible QFC to exist. The case where $q = 8$ is represented, the other values of q would be similar.

must have a high impact on the final result both for the shipper and carrier when a high commitment β is agreed upon: if the realized demand does not meet the expected one, the result must be very different from the ones plotted here given that both α and θ are relatively expensive (when $\beta = 436$, $\alpha = 300.3$ and $7.128 < \theta < 18.27$).

We investigate now this variance.

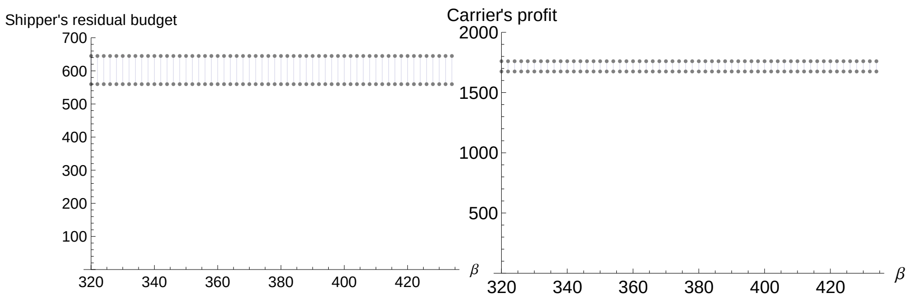

Figure 58: Fixed spot price: the figure represents the lower and higher limits of the objective functions of the shipper and carrier in the case that the dominated MPC has $q = 1$ for all capacity commitments.

D.7 VARIANCE OF RESULTS FOR ALL STRATEGIES

We proceed to evaluate the variance of each contract. We start with the variance of the profit or retained budget for carrier and shipper in the case where they both rely in the spot market for their needs.

D.7.1 *Variance of residual budget to the shipper when buying from the spot market*

The expected cost of going to the spot market every period to buy the required capacity to the shipper is the result of the product of the two random variables X and P, demand and spot market price. By definition,

$$E(XY) = Cov(X, P) + \mu_X \mu_P = 82.25. \tag{D.45}$$

Hence, the expected residual budget is over 40 periods:

$$\Pi_{spot} = B(40) - 40(2 + 82.25) = 470. \tag{D.46}$$

The variance is by definition over one period

$$Var(XP) = E(X^2P^2) - E(XP)^2 = 1186.3. \tag{D.47}$$

Let us assume that the spot market price in each period are iid, then, the variance of a procurement strategy using only the spot market over 40 periods is 40 times the preceding result:

$$V_{spot} = 47451. \tag{D.48}$$

Let us now evaluate the variance for the contracts.

Variance of the cost of the PRC

The only risk affecting the shipper in this contract is the demand risk, hence the variance of the cost to her of using this contract is reduced to the variance of demand times the number of periods and the square of the per-unit price:

$$Var_{PRC}(p_r) = np_r^2\sigma_X^2 \tag{D.49}$$

In our bivariate numerical instance this can be represented in terms of p_r in figure 59 on the next page. As can be seen, $5198 < Var_{PRC} < 33178$.

D.7.2 *Variance of the cost to the shipper of the MPC*

Since the contract does not use the spot market when demand is less than q, we can distinguish, for the purpose of evaluating the covariance, between the case when demand is less than q and when it is higher. Let us define

$$\begin{aligned} v(q) &= Var(X|X < q) \\ z(q) &= Var\Big((X - q)P|X > q\Big). \end{aligned} \tag{D.50}$$

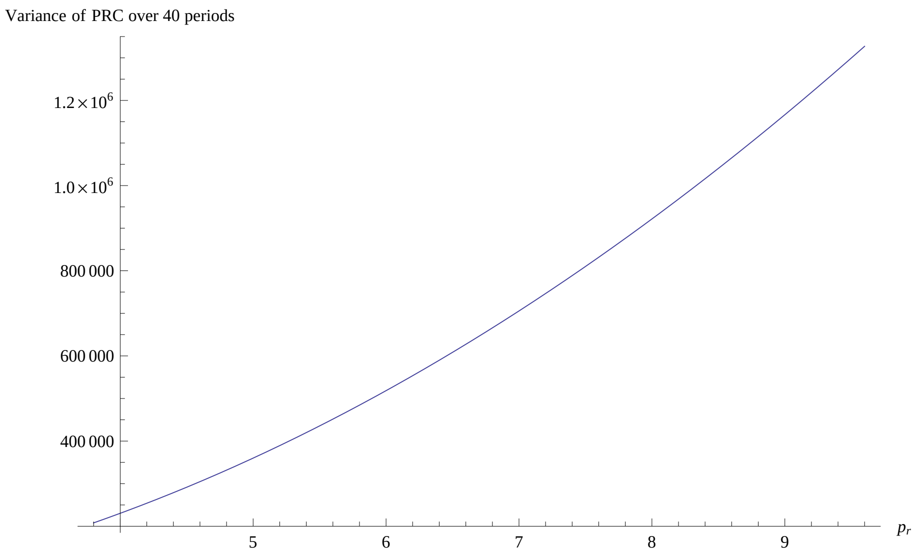

Figure 59: Variance of a PRC according to p_r over 40 periods.

We can write the conditional variance of the demand when it is less than the committed capacity as

$$\begin{aligned} v(q) &= E(X^2|X < q) - E(X|X < q)^2 \\ &= \frac{1}{F_X(q)} \int_0^q x^2 f_X(x)dx - \\ & \quad \frac{1}{F_X(q)^2}\Big(\int_0^q x f_X(x)dx\Big)^2. \end{aligned} \tag{D.51}$$

However, the covariance of demand and spot market price when demand exceeds the committed capacity must be written

$$\begin{aligned} z(q) &= E\Big([(X-q)P]^2|X > q\Big) - E\Big((X-q)P|X > q\Big)^2 \\ &= e_X(q) - q_X(q)^2, \end{aligned} \tag{D.52}$$

with

$$\begin{aligned} e_X(q) &= \frac{1}{1-F_X(q)} \int_v^{P_{Hi}} \int_q^{Q_{Hi}} (x-q)^2 y^2 f(x,y)dxdy \\ q_X(q) &= \frac{1}{1-F_X(q)} \int_v^{P_{Hi}} \int_q^{Q_{Hi}} (x-q) y f(x,y)dxdy. \end{aligned} \tag{D.53}$$

The total variance of the MPC to the shipper is the sum of both variances since they occur in distinct domains:

$$Var(V_2) = s(q)^2 v(q) + z(q) \tag{D.54}$$

So total variance of the MPC decreases to a minimum when the capacity commitment equals expected demand as can be seen in figure 60 on the facing page before increasing again in terms of q. At the minimum, it is lower than the variance of the spot market procurement (topmost line in figure 60).

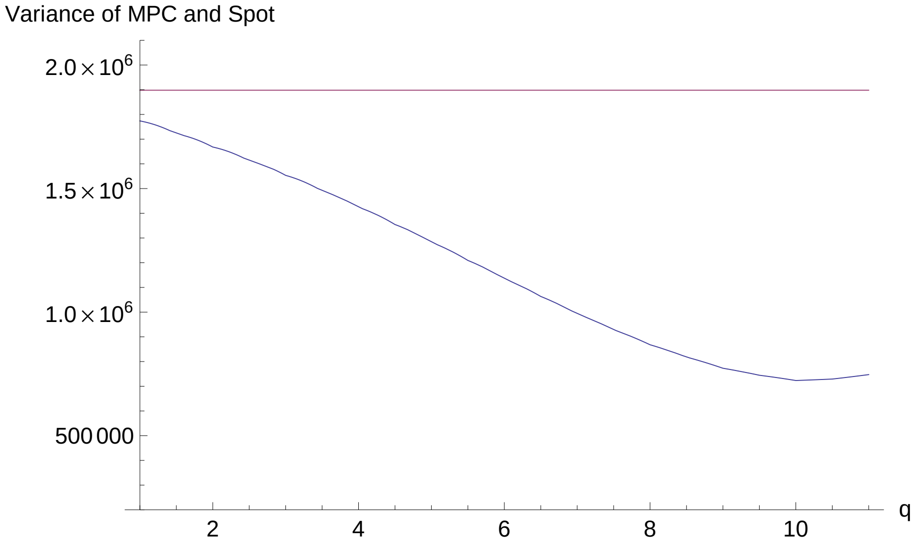

Figure 60: Variance of a MPC and spot market buying strategy according to q when taken in isolation.

D.7.3 *Variance of the cost of the QFC to the shipper*

We first need the variance of the sum of demands when they sum less than the commitment β:

$$\begin{aligned} V_{g1}(\beta, n) &= E(X^2 | \sum_{i=1}^{n} x_i \leq \beta) - E(X | \sum_{i=1}^{n} x_i \leq \beta)^2 \\ &= \frac{1}{F_{Y_n}(\beta)} \int_0^{\beta} u^2 f_{Y_n}(u) du - \frac{1}{F_{Y_n}(\beta)^2} \Big[\int_0^{\beta} u f_{Y_n}(u) du \Big]^2. \end{aligned} \tag{D.55}$$

When the sum of demands is higher than commitment β, the spot price comes into play and its variance has to be taken into account. The variance is that of a product of random variables, which is $Var(XY) = \mathbb{E}(X^2Y^2) - \mathbb{E}^2(XY)$. We also know that $\mathbb{E}(X^2Y^2) = \mathbb{E}(X^2)\mathbb{E}(Y^2) + 2\mathbb{E}^2(XY)$. Hence, the variance of the price for transport when the sum of demands exceeds β is written as

$$\begin{aligned} Var(P(\sum_{i=1}^{n} X_i - \beta) | \sum_{i=1}^{n} > \beta) = &\mathbb{E}(P^2)\mathbb{E}\big((Y_n - \beta)^2 | Y_n > \beta\big) + \\ &\mathbb{E}^2\big(P(Y_n - \beta) | Y_n > \beta\big). \end{aligned} \tag{D.56}$$

So we can write

$$V_{g2}(\beta, n) = \frac{1}{\overline{F_{Y_n}}(\beta)} \int_{\beta}^{QY_{Hi}} (u - \beta)^2 f_{Y_n}(u) du + \tag{D.57}$$

$$\Big[\frac{1}{\overline{F_{Y_n}}(\beta)} \int_{\beta}^{QY_{Hi}} 8(u - \beta) f_{Y_n}(u) du \Big]^2, \tag{D.58}$$

naming V_{g1} and V_{g2} the functions of the variance when demand is lower and higher than β respectively.

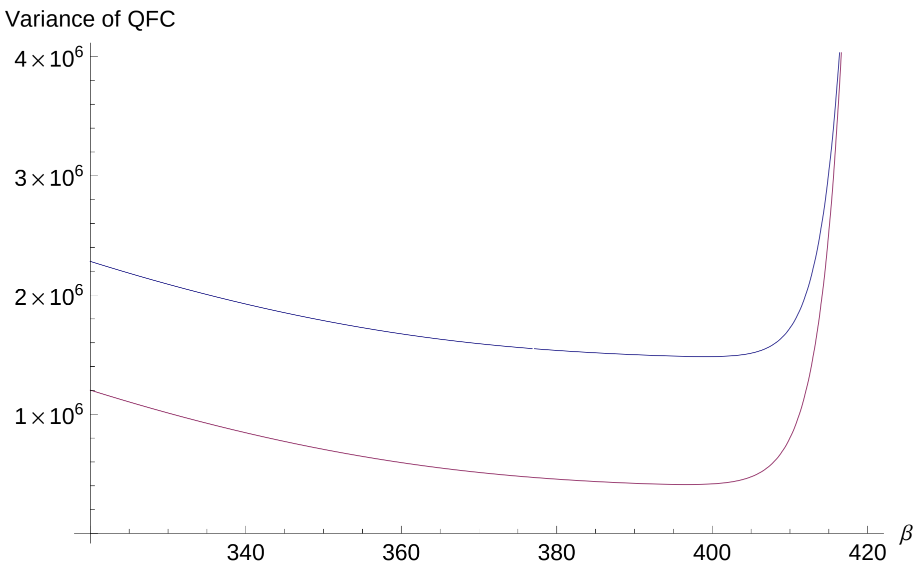

Figure 61: Variance of a QFC according to β, with $n = 40$, $\alpha = 5$ (bottom curve), and $\alpha = 10$ (top curve) when taken in isolation. θ has been set here at its high bound and is a function of β and α as described in the inequality set(D.22).

The variance of the residual budget of the shipper with this contract can be resumed to

$$Var(V_3(\alpha, \beta, n)) = 3^2\alpha^2 n^2 + \theta^2 V_{g1}(\beta, n) + \mu_P^2 V_{g_2}(\beta, n). \quad \text{(D.59)}$$

We present in figure 61 the resulting variance when $\theta = 0.1$, two values of $\alpha = 10$ and $\alpha = 5$ when β ranges between 320 and 420. As the penalty increases with β it also induces higher volatility, especially when exceeding 400, which represents $n\mu_x$. When α is low, the variance drops when $\beta \leq n\mu_x$ but increases sharply afterwards as the influence of the penalty θ becomes felt. In figure 62, we have plotted the variances of a QFC when $\alpha = 2$ and the penalty takes its high bound (top curve) or its low bound (bottom curve).

The variance of such a contract is clearly lower than the ones resulting from the use of either the MPC or pure spot procurement when β approaches $n\mu_x$.

The results have been tabulated in table 21 on page 117.

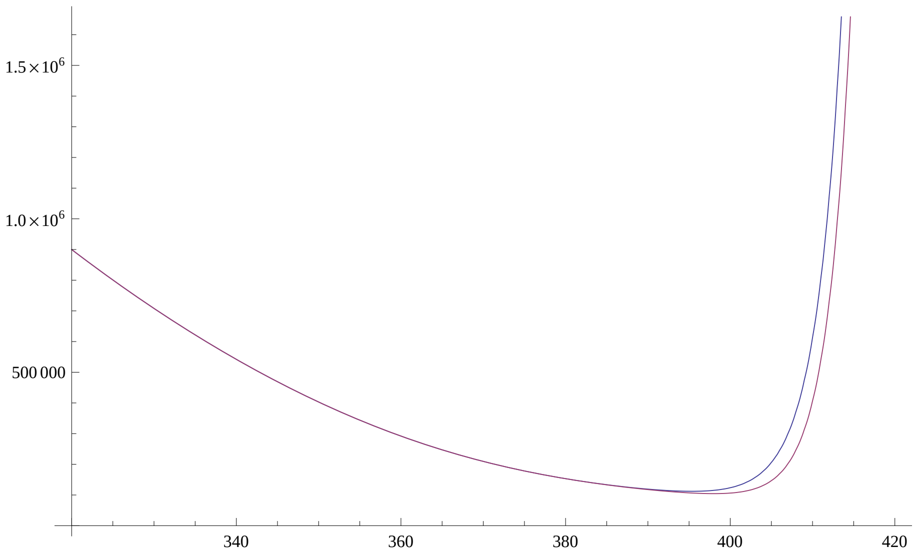

Figure 62: Variance of a QFC according to β, with $n = 40$, $\alpha = 2$ and $\theta_{\min}$ (bottom curve), and $\theta_{\max}$ (top curve) when taken in isolation.

Allen, Franklin, Douglas Gale. 1992. Measurement distortion and missing contingencies in optimal contracts. *Economic Theory* **2**(1) 1–26.

Anderlini, Luca, Leonardo Felli. 1994. Incomplete written contracts: Undescribable states of nature. *The Quarterly Journal of Economics* **109**(4) 1085–1124.

Anupindi, Ravi, Ram Akella. 1993. An inventory model with commitments. Working Paper, Nothwestern University.

Anupindi, Ravi, Yehuda Bassok. 1998. Supply contracts with quantity commitments and stochastic demand. S. Tayur, R. Ganeshan, M. Magazine, eds., *Quantitative models for Supply Chain Management*, chap. 7. Kluwer Academic, Dordrecht, Holland, 197–232.

Azoury, Katy. 1985. Bayes solution to dynamic inventory models under unknown demand distribution. *Management Science* **31** 1150–1160.

Azoury, Katy, Bruce Miller. 1984. A comparison of the optimal ordering levels of bayesian and non-bayesian inventory models. *Management Science* **30** 993–1003.

Baker, George, Robert Gibbons, Kevin Murphy. 2001. Bringing the market inside the firm? *American Economic Review* **91**(2) 212–218.

Baker, George, Robert Gibbons, Kevin Murphy. 2002. Relational contracts and the theory of the firm. *Quarterly journal of economics* **117**(1) 39–83.

Barlow, Richard E., Frank Proschan. 1965. *Mathematical theory of reliability*. John Wiley & Sons, 9–18.

Baron, David, David Besanko. 1984. Regulation and information in a continuing relationship. *Information Economics and Policy* **1** 267–302.

Bassok, Yehuda, Ravi Anupindi. 1997. Analysis of supply contracts with total minimum commitment. *IIE Transactions* **29**(5) 373–381.

Beil, Damian, Lawrence M. Wein. 2003. An inverse-optimization-based auction mechanism to support a multiattribute rfq process. *Management Science* **49**(11) 1529–1545.

Bonser, Jewel S., S. David Wu. 2001. Procuremebt planning to maintain both short-term adaptiveness and long-term perspective. *Management Science* **47**(6) 769–786.

Boyaci, Tamer. 2005. Competitive stocking and coordination in a multiple-channel distribution system. *IIE Transactions* **37** 407–427.

Brown, Martin, Armin Falk, Ernst Fehr. 2004. Relational contracts and the nature of market interactions. *Econometrica* **72**(3) 747–780.

Brusset, Xavier. 2005. Road transport at Imerys: a logistics report. Confidential report, Centre of Excellence in Supply Chain Management, Université Catholique de Louvain.

Brusset, Xavier. 2006. Logistique kruidvat. Confidential report, Centre of Excellence in Supply Chain Management, Université Catholique de Louvain.

Brusset, Xavier. 2009a. Choosing a transport contract over multiple periods. *International Journal Logistics Systems and Management* **5**(2-3) 273–322.

Brusset, Xavier. 2009b. Multi period contracts in transport under asymmetric information and prior investments. Stefan Voß, Julia Pahl, Silvia Schwarze, eds., *Logistik Management, Systeme, Methoden, Integration*. Business and Economics, Springer-Verlag Berlin, Heidelberg, 37–54. doi:10.1007/978-3-7908-2362-2.

Brusset, Xavier, Nico Temme. 2007. Optimizing an objective function under a bivariate probability model. *European Journal of Operational Research* **179**(2) 444–458. doi:http://dx.doi.org/10.1016/j.ejor.2006.02.034.

Brusset, Xavier, Nico M. Temme. 2005. *Supply Chain Management – European Perspectives*, chap. 12 - Impact of information and coordination on transport procurement. 1st ed. Copenhagen Business School Press, Copenhagen, Denmark, 239–261.

Busch, Lutz-Alexander, Ignatius Horstmann. 1999. Endogenous incomplete contracts: a bargaining approach. *The Canadian Journal of Economics* **32**(4) 956–975.

Cachon, Gérard. 2004a. The allocation of inventory risk in a supply chain: Push, pull, and advance-purchase discount contracts. *Management Science* **50**(2) 222–238.

Cachon, Gérard. 2004b. Supply chain coordination with contracts. Ton de Kok, Stephen Graves, eds., *Handbooks in Operations Research and Management Science: Supply Chain Management*, vol. 11, chap. 6. Elsevier, 229–340.

Cachon, Gérard, Martin Lariviere. 1999. Capacity choice and allocation: Strategic behaviour and supply chain performance. *Management Science* **45**(8).

Cachon, Gérard, Martin Lariviere. 2001. Contracting to assure supply: how to share demand forecasts in a supply chain. *Management Science* **47**(5) 629–646.

Cachon, Gérard, Martin Lariviere. 2005. Supply chain coordination with revenue-sharing contracts: strengths and limitations. *Management Science* **51**(1) 30–44.

Cachon, Gérard, Serguei Netessine. 2004. *Handbook of Quantitative Supply Chain Analysis - Modeling in the eBusiness Era*, chap. 2 – Game theory in supply chain analysis. 1st ed. International Series in Operations Research & Management Science, Springer Science, New York, NY, 13–66.

Cachon, Gérard, Fuqiang Zhang. 2006. Procuring fast delivery: sole sourcing with information asymmetry. *Management Science* **52**(6) 881–896.

Chen, Fangruo. 2001. Market segmentation, advanced demand information and supply chain performance. *Manufacturing & Service Operations Management* **3**(1) 53–67.

Chen, Fangruo. 2004. Information sharing and supply chain coordination. Ton de Kok, Stephen Graves, eds., *Handbooks in Operations Research and Management Science: Supply chain Management*, vol. 11, chap. 7. Elsevier, 341–421.

Chen, Fangruo. 2007. Auctioning supply contracts. *Management Science* **53**(10) 1562–1576.

Chen, Fangruo, Bin Yu. 2005. Quantifying the value of lead-time information in a single-location inventory system. *Manufacturing & Service Operations Management* **7**(2) 144–151.

Christopher, Martin. 1998. *Logistics and Supply Chain Management*. 2nd ed. Pearson Education Ltd, London, UK.

Coase, Ronald H. 1937. The nature of the firm. *Economica* **4**(16) 386–405.

Corbett, Charles, Deming Zhou, Christopher Tang. 2004. Designing supply contracts: a contract type and information asymmetry. *Management Science* **50**(4) 550–559.

Danielis, Romeo, Edoardo Marcucci, Lucia Rotaris. 2005. Logistics managers' stated preferences for freight service attributes. *Transportation Research Part E* **41** 201–215.

Díaz, Sergio Jara. 1982. Transportation product, transportation function and cost functions. *Transportation Science* **16**(4) 522–539.

Díaz, Sergio Jara. 1983. Freight transportation multi-output analysis. *Transportation Research* **17A**(6) 429–438.

Díaz, Sergio Jara. 1988. Multi-output analysis of trucking operations using spatially disaggregated flows. *Transportation Research* **22B**(3) 159–171.

Díaz, Sergio Jara. 2000. *Analytical Transport Economics, An International Perspective*, chap. Transport production and the analysis of industry structure. Elgar, Cheltenham, UK, 27–50.

Díaz, Sergio Jara, Leonardo Basso. 2003. Transport cost functions, network expansion and economies of scope. *Transportation Research Part E* **39** 271–288.

Díaz, Sergio Jara, C. Cortés. 1996. On the calculation of scale economies from transport cost functions. *Journal of Transport Economics and Policy* **30**(157-170).

Dong, Lingxiu, Hong Liu. 2007. Equilibrium forward contracts on non-storable commodities in the presence of market power. *Operations Research* **55**(1) 128–145.

Dorer, Klaus, Monique Calisti. 2005. An adaptive solution to dynamic transport optimization. Proceedings of the fourth international joint conference on Autonomous agents and multiagent systems, Utrecht, The Netherlands.

Downton, F. 1970. Bivariate exponential distributions in reliability theory. *Journal of Royal Statistical Society* **B 32** 408–417.

Dye, Roanld A. 1985. Costly contract contingencies. *International Economic Review* **26** 233–250.

Dyer, Jeffrey H. 1996. Does governance matter? keiretsu alliances and asset specificity as sources of japanese competitive advantage. *Organization Science* **7**(3) 649–666.

Dyer, Jeffrey H., Wujin Chu. 2003. The role of trustworthiness in reducing transaction costs and improving performance: empirical evidence from the united states, japan, and korea. *Organization Science* **14**(1) 57–68.

Edlin, Aaron, Stefan Reichelstein. 1996. Holdups, standard breach remedies, and optimal investment. *American Economic Review* **86**(3) 478–501.

Eisenhardt, K.M. 1989. Agency theory: an assessment and review. *Academy of Management Review* **14**(1) 57–74.

Elmaghraby, Wedad, Pinar Keskinocak. 2004. Technology for transportation at the home depot. Teaching case, Georgia Institute of Technology, Atlanta, GA.

Elmaghraby, Wedad J. 2000. Supply contract competition and sourcing policies. *Manufacturing & Service and Operations Management* **2**(4) 350–371.

Erkoc, Murat, S. David Wu. 2005. Managing high-tech capacity expansion via reservation contracts. *Production and Operations Management* **14**(2) 232–242.

Ertogral, Kadir, S. David Wu. 2002. A bargaining game for supply chain contracting. URL http://www.lehigh.edu/~sdw1/ertogral3.pdf.

EUROSTAT. 2005. Road transport freight - report. URL http://epp.eurostat.ec.europa.eu.

Evans-Pritchard, Ambrose. 2009. Shipping rates hit zero as trade sinks. *Telegraph* **January 14th**. URL http://www.telegraph.co.uk/finance/4229198/Shipping-rates-hit-zero-as-trade-sinks.html.

Fama, E.F., M.C. Jensen. 1983. Separation of ownership and control. *Journal of Law and Economics* **26** 301–326.

Favereau, Olivier. 1989. Marchés internes, marchés externes. *Revue Economique* **40**(2) 273–328.

Fudenberg, Drew, Bengt Holmstrom, Paul Milstrom. 1990. Short-term contracts and long-term agency relationships. *Journal of Economic Theory* **51**(1) 1–31.

Fudenberg, Drew, David K. Levine, Jean Tirole. 1985. *Game-Theoretic Models of Bargaining*, chap. Infinite-horizon models of bargaining with one-sided incomplete information. Cambridge University Press.

Fudenberg, Drew, Jean Tirole. 1983. Sequential bargaining with incomplete information. *Review of Economic Studies* **50** 221–247.

Fudenberg, Drew, Jean Tirole. 1991. *Game Theory*. MIT Press, Cambridge, MA.

Gallien, Jérémie, Lawrence Wein. 2005. A smart market for industrial procurement with capacity constraints. *Management Science* **51**(1) 76–91.

Ganeshan, Ram, Eric Jack, Michael Magazine, Paul Stephens. 1999. *Quantitative Models for Supply Chain Management*, chap. 27 - A taxonomic review of supply chain management research. International Series in Operations Research & Management Science, Kluwer Academc Publisher, 839–879.

Gavirneni, Srinagesh, Roman Kapuscinski, Sridhar Tayur. 1999. Value of information in capacitated supply chains. *Managment Science* **45**(1) 16–24.

Geanakoplos, John, Heraklis Polemarchakis. 1982. We can't disagree forever. *Journal of Economic Theory* **28** 192–200.

Gibson, Brian, Ray Mundy, Harry Sink. 1995. Supplier certification: application to the purchase of industrial transportation services. *Logistics and Transportation Review* **31**(1) 75–93.

Gibson, Brian, Harry Sink, Ray Mundy. 1993. Shipper-carrier relationships and carrier selection criteria. *Logistics and Transportation Review* **29**(4) 371–383.

Goeree, Jacob K., Charles A. Holt. 2004. Models of noisy introspection. *Games and Economic Behavior* **46**(2) 365–382.

Grey, W., T. Olvason, D. Shi. 2005. The role of e-marketplaces in relationship-based supply chains. *International Business Machines systems journal* **44**(1) 109–123.

Grieger, Martin. 2003. Electronic marketplaces 2003: A literature review and a call for supply chain management research. *European Journal of Operational Research* (144) 280–294.

Harsanyi, John. 1967. Games with incomplete information played by bayesian players. *Management Science* **14** 159–182, 320–334, 486–502.

Hart, Oliver, Jean Tirole. 1988. Contract renegotiation and coasian dynamics. *The Review of Economic Studies* **55** 509–540.

Hubbard, Thomas N. 2001. Contractual forma and market thickness in trucking. *The Rand Journal of Economics* **32**(2) 369–386.

Jackson, Matthew O., Simon Wilkie. 2005. Endogenous games and mechanisms: side payments among players. *Review of Economic Studies* **72** 543–566.

Jansen, Jos. 2003. Coexistence of strategic vertical separation and integration. *International Journal of Industrial Organization* **21**(5) 699–716.

Jin, M., S. David Wu. 2004. Coordinating supplier competition via auctions. Technical report, Lehigh University. URL http://www.lehigh.edu/~sdw1/jin1.pdf.

Jing, Lu, Peter Marlow, Wang Hui. 2008. An analysis of freight rate volatility in dry bulk shipping markets. *Maritime Policy & Management* **35**(1) 10–39.

Kalashnikov, Vyacheslav, Roger Rios-Mercado. 2006. A natural gas cash-out problem: A bilevel programming framework and a penalty function method. *Optimization and Engineering* **7**(4) 403–420. doi:10.1007/s11081-006-0347-z.

Kavussanos, Manolis G., Nikos K. Nomikos. 2001. Discovery, causality and forecasting in the freight futures market. doi:http://papers.ssrn.com/sol3/papers.cfm?abstract_id=271072.

Keller, Scott B., Katrina Savitskie, Theodore P. Stank, Daniel F. Lynch, Alexander E. Ellinger. 2002. A summary and analysis of multi-item scales used in logistics research. *Journal of Business Logistics* **23**(2) 83–275.

Klein, Benjamin, Robert A. Crawford, Armen A. Alchian. 1978. Vertical integration, appropriate rents , and the competitive contracting process. *Journal of Law and Economics* **21** 297–326.

Kleindorfer, Paul R., D.J. Wu. 2003. Integrating long- and short-term contracting via business-to-business exchanges for capital-intensive industries. *Management Science* **49**(11) 1597–1615.

Knemeyer, A. Michael, Thomas Corsi, Paul R. Murphy. 2003. Logistics outsourcing relationships: customer perspectives. *Journal of Business Logistics* **24**(1) 77–109.

Kœnig, G. 1993. Production de la connaissance et pratiques organisationnelles. *Revue de Gestion des Ressources Humaines* **9** 4–17.

Kotz, S., N. Balakrishnan, N.L. Johnson. 2000. *Continuous multi-variate distributions*, vol. 1. 2nd ed. John Wiley & Sons, New York, NY.

Kreps, David M., Robert Wilson. 1982. Reputation and imperfect information. *Journal of Economic Theory* **27** 253–279.

Laffont, Jean Jacques, Jean Tirole. 1988. The dynamics of incentive contracts. *Econometrica* **56**(5) 1153–1175.

Laffont, Jean Jacques, Jean Tirole. 1993a. *A Theory of Incentives in Procurement and Regulation*. MIT Press, Cambridge, Mass., 111.

Laffont, Jean Jacques, Jean Tirole. 1993b. *A Theory of Incentives in Procurement and Regulation*, chap. 10. MIT Press, Cambridge, Mass., 437–438.

Lagunoff, Roger. 1992. Fully endogenous mechanism selection: An essay on endogenous institutional choice. *Economic Theory* **2**(4) 465–480. URL http://ideas.repec.org/a/spr/joecth/v2y1992i4p465-80.html.

Lahno, Bernd. 2002. Is trust the result of bayesian learning? URL http://www.uni-duisburg.de/FB1/PHILO/index/Bayes.PDF. Working Paper.

Lariviere, Martin. 2006. A note on probability distributions with increasing generalized failure rates. *Operations Research* **54**(3) 602–604.

Lariviere, Martin A., Evan L. Porteus. 2001. Selling to the newsvendor: an analysis of price-only contracts. *Manufacturing & Service Operations Management* **3**(4) 293–305.

Le Moigne, J-L. 1990. *Epistémologies et Sciences de Gestion*, chap. Epistémologies constructivistes et sciences de l'organisation. Economica, Paris, 81–140.

Lee, Hau, S. Whang. 2000. Information sharing in supply chain. *International Journal of Technology Management* (20).

Lee, Hau L., Meir Rosenblatt. 1986. A generalized quantity discount pricing to increase suupplier's profits. *Management Science* **32**(9) 1177–1185.

Levin, Jonahtan. 2003. Relational incentive contracts. *American Economic Review* **93**(3) 835–857.

Li, Chung-Lun, Panos Kouvelis. 1999. Flexible and risk sharing supply contracts under price uncertainty. *Management Science* **45**(10) 1378–1398.

Lipman, Barton L. 1992. Limited rationality and endogenously incomplete contracts. Working Papers 858, Queen's University, Department of Economics. URL http://ideas.repec.org/p/qed/wpaper/858.html.

Lovejoy, William S. 2006. Optimal mechanisms with finite agent types. *Management Science* **52**(5) 788–803.

Macauley, S. 1963. Non-conctractual relations in business. *American Sociological review* **28**(1) 55–67.

MacGinnis, Michael A. 1990. The relative importance of cost and service in freight transportation choice: Before and after deregulation. *Transportation Journal* **30**(1) 12–20.

MacLeod, W. Bentley. 2002. *The Economics of Contracts: Theories and Applications*, chap. 13 – Complexity and contract. Cambridge University Press, Cambridge, UK, 213–240.

Malcolmson, James, Frans Spinnewyn. 1988. The multi-period principal-agent problem. *Review of Economic Studies* **55**(3) 391–407.

Mangina, Eleni, Ilias P. Vlachos. 2005. The changing role of information technology in food and beverage logistics management: beverage network optimisation using intelligent agent technology. *Journal of Food Engineering* **70**(3) 403–420.

Martínez-de-Albéniz, Victor, David Simchi-Levi. 2005. A portfolio approach to procurement contracts. *Production and Operations Management* **14**(1) 90–114.

Maskin, Eric. 1999. Nash equilibrium and welfare optimality. *The Review of Economic Studies* **66** 23–39.

Maskin, Eric, John Moore. 1999. Implementation and renegotiation. *The Review of Economic Studies* **66** 39–57.

Milner, Joseph, Panos Kouvelis. 2005. Order quantity and timing flexibility in supply chains: the role of demand charactiristics. *Management Science* **51**(6) 970–985.

Moe, Terry. 1984. The new economics of organization. *American Journal of Political Science* **28**(4) 755.

Moinzadeh, Kamran, Steven Nahmias. 2000. Adjustment strategies for a fixed delivery contract. *Operations Research* **48**(3) 408–423.

Moran, P.A.P. 1967. Testing for correlation between non-negatie variates. *Biometrika* **54** 385–394.

Muthoo, Abhinay. 1995. On the strategic role of outside options in bilateral bargaining. *Operations Research* **43**(2) 292–297.

Myerson, Roger B. 1979. Incentive compatibility and the bargaining problem. *Econometrica* **47**(1) 61–73.

Nash, John. 1950. The bargaining problem. *Econometrica* **18** 155–162.

Orléan, André. 1994. *Analyse Economique des Conventions*. PUF, Paris, France.

Özalp Özer, Wei Wei. 2006. Strategic commitment for optimal capacity decision under asymmetric forecast information. *Management Science* **52**(8) 1238–1257.

Peters, Michael. 2001. Common agency and the revelation principle. *Econometrica* **69**(5) 1349–1372.

Plambeck, Erica L., Terry A. Taylor. 2004. Partnership in a dynamic production system with unobservable actions and non-contractible output. *Management Science* **52**(10) 1509–1527.

Plambeck, Erica L., Terry A. Taylor. 2005. Sell the plant? the impact of contract manufacturing on innovation, capacity, and profitability. *Management Science* **51**(1) 133–150.

Plambeck, Erica L., Terry A. Taylor. 2007. Supply chain relationships and contracts: the impact of repeated interaction on capacity investment and procurement. *Management Science* **53**(10) 1577–1593.

Porteus, Evan. 1990. *Stochastic Models*, *Handbook in Operations Research and Management Science*, vol. 2, chap. Stochastic Inventory Theory. Elsevier Science Publishers B.V., 605–652.

Porteus, Evan. 2002. *Foundations of Stochastic Inventory Theory*, chap. 10. Stanford Business Books, 151–163.

Porteus, Evan, Seungjin Whang. 1991. On manufacturing / marketing incentives. *Management Science* **37**(9) 1166–1181.

Rasmusen, E. 1989. *Games and information: An introduction to the theory of games*. Basil blackwell, Oxford, UK.

Razzaque, Mohammed Abdur, Chen Sheng Chang. 1998. Outsourcing of logistics functions: a literature survey. *International Journal of Physical Distribution & Logistics Management* **28**(2) 89–107.

Remmert, Jan, Kornelia Reifenberg. 2004. Escaping the air cargo bazaar how to enforce price structures. White Paper 030604, Simon Kucher & Partners, Haydnstraße 36,D-53115 Bonn, Germany.

Rubinstein, Ariel. 1982. Perfect equilibrium in a bargaining model. *Econometrica* **54** 97–109.

Sankaran, Jay, David Mun, Zane Charman. 2002. Effective logistics outsourcing in new zealand. *International Journal of Physical Distribution & Logistics Management* **32**(8) 682–702.

Scarf, H. 1959. Bayes solution of the statistical inventory problem. *Annals of Mathematical Statistics* **30** 490–508.

Scarf, H. 1960. Some remarks on Bayes solution to the inventory problem. *Naval Research Logistics Quarterly* **7** 591–596.

Schwarz, L.B., Z.K. Weng. 2000. The design of a jit supply chain: the effect of lead time uncertainty on safety stock. *Journal of Business Logistics* **20**(1) 141–163.

Sebestyén, Zoltan, Viktor Juhász. 2003. The impact of the cost of unused capacity on production planning of flexible manufacturing systems. *Periodica Polytechnica Ser. Management Science* **11**(2) 185–200.

Seifert, Ralf, Ulrich Thonemann, Warren Hausman. 2004. Optimal procurement strategies for online spot markets. *European Journal of Operational Research* **152**(3) 781–799.

Selten, Reinhard. 1965. Spieltheoretische behandlung eines oligopolmodells mit nachtfrageträgheit. *Zeitschrift für die gesamte Staatswissenschaft* **12** 301–324.

Selten, Reinhard. 1975. Reexamination of the perfectness concept for equilibrium points in extensive games. *International Journal of Game Theory* **4** 25–55.

Sethi, Suresh P., Houmin Yan, Hanqin Zhang. 2005. *Inventory and Supply Chain Management with Forecast Updates*, *International Series in Operational Research and Management Science*, vol. 81, chap. 6 – Multi period Quantity-Flexibility Contracts. Springer, New York, NY, 165–221.

Sink, Harry L., C.John Langley Jr. 1997. A managerial framework for the acquisition of third-party logistics. *Journal of Business Logistics* **18**(2) 163–189.

Spengler, Joseph. 1950. Vertical integration and antitrust policy. *Journal of Political Economy* **58** 347–352.

Spinler, Stefan, Arnd Huchzermeier. 2006. The valuation of options on capacity with cost and demand uncertainty. *European Journal of Operational Research* **171**(3) 915–934.

Ståhl, Ingolf. 1972. *Bargaining Theory*. Economics Research Institute, Stockholm School of Economics.

Thonemann, Ulrich. 2002. Improving supply chain performance by sharing advance demand information. *European Journal of Operational Research* **142**(1) 81–107.

Tirole, Jean. 1986. Procurement and renegotiation. *Journal of Political Economy* **94**(2) 235–259.

Tirole, Jean. 1988. *The Theory of Industrial Organization*. The MIT Press, Cambridge, MA.

Tomlin, Brian. 2003. Capacity investments in supply chains: Sharing the gain rather than sharing the pain. *Manufacturing & Service Operations Management* **5**(4) 317–333.

Tsay, Andy. 1999. Quantity flexibility contract and supplier-customer incentives. *Management Science* **45**(10) 1339–1358.

Tsay, Andy, W. Lovejoy. 1999. Quantity flexibility contracts and supply chain performance. *Manufacturing & Service Operations Management* **1**(2) 89–111.

Tsay, Andy, Steven Nahmias, Narendra Agrawal. 1999. *Quantitative Models for Supply Chain Management*, chap. 10 – Modeling supply chain contracts: A review. 1st ed. International Series in Operations Research & Management Science, Kluwer Academic, 299–336.

TUB. 2002. Analysis of the transport decision making process. Deliverable Report D2, D3 Work Package 2, SULOGTRA, Technical University of Berlin, Heriot Wat University, Zentrum fur Logistik Untenehmenplanung, Research Center of the University of Athens.

Tunca, Tunay, Stefanos A. Zenios. 2006. Supply auctions and relational contracts for procurement. *Manufacturing & Service Operations Management* **8**(1) 43–67.

Tvedt, Jostein. 2003. A new perspective on price dynamics of the dry bulk market. *Maritime Policy & Management* **30**(3) 221–230.

von Neumann, John, Oskar Morgenstern. 1944. *Theory of games and economic behavior*. Princeton University Press.

Wang, Susheng, Tian Zhu. 2004. Contract law and the boundaries of the firm. *Journal of Economic Research* **9**(1) 93–113.

Watson, Joel. 2002. *Strategy: An Introduction to Game Theory*. W.W. Norton, 139.

Watson, Joel. 2006. Contract and mechanism design in settings with multi-period trade. URL http://repositories.cdlib.org/cgi/viewcontent.cgi?article=1058&context=ucsdecon. Dept of Economics, University of California, San Diego, USA.

Weitzman, Martin. 1976. The new soviet incentive model. *Bell Journal of Economics* **7** 251–257.

Weitzman, Martin. 1980. The ratchet principle and performance incentives. *Bell Journal of Economics* **11**(1) 302–308.

Williamson, Oliver E. 1975. *Markets and Hierarchies: Analysis and antitrust implications*. Free Press, New York, NY, USA.

Williamson, Oliver E. 1985. *The Economic Institutions of Capitalism*. Free Press, New York, NY, USA.

Williamson, Oliver E. 1996. *The Mechanisms of Governance*. Oxford University Press, New York, NY, 115–116.

Williamson, Oliver E. 2002. The theory of the firm as governance structure: from choice to contract. *Journal of Economic Perspectives* **16**(3) 171–195.

Wright, Robert. 2009. Shipping insolvencies threat grows in wake of defaults. *Financial Times* **January 19th**. URL http://www.ft.com/cms/s/19aa2214-e5c8-11dd-afe4-0000779fd2ac.html.

Wu, D.J., Paul Kleindorfer. 2005. Competitive options, supply contracting and electronic markets. *Management Science* **51**(3) 452–466.

Wu, D.J., Paul R. Kleindorfer, J.E. Zhang. 2001. Optimal bidding and contracting strategies in the deregulated electric power marketplace: Part ii. R.H. Sprague Jr, ed., *Proceedings of the 34th Annual Hawaii International Conference on Systems Sciences*. IEEE Computer Society Press, Los Alamitos, California, USA, 2033–2043. doi:http://doi.ieeecomputersociety.org/10.1109/HICSS.2001.926291.

Wu, D.J., Paul R. Kleindorfer, Jin E. Zhang. 2002. Optimal bidding and contracting strategies for capital-intensive goods. *European Journal of Operational Research* **137**(3) 657–676.

Wu, S. David. 2004. *Handbook of Quantitative Supply Chain Analysis: Modeling in the E-Business Era*, chap. 3 – Supply chain intermediation, a bargaining theoretic framework. International Series in Operations Research & Management Science, Springer, New York, NY, USA, 67–115.

Wu, S. David, Murat Erkoc, Suleyman Karabuk. 2005. Managing capacity in the high-tech industry: a review of literature. *The Engineering Economist* **50** 125–158. Online.

Yu, Tun-Hsiang (Edward), David A. Bessler, Stephen W. Fuller. 2007. Price dynamics in u.s. grain and freight markets. *Canadian Journal of Agricultural Economics* **55** 381–397.

Zhao, Xiande, Jinxing Xie, W.J. Zhang. 2002. The impact of information sharing and ordering on supply chain performance. *Supply Chain Management: an International Journal* **7**(1) 24–40.

Zhu, Tian. 2000. Holdups, simple contracts and information acquisition. *Journal of Economic Behaviour & Organization* **42** 549–560.

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