# Multi Period Contracts in Transport under Asymmetric Information and Prior Investments

Xavier Brusset

**Abstract** How does a carrier evaluate the transport contract he must offer a shipper under various assumptions of information about this shipper's other options and specific investments? A carrier can benefit from contract renegotiation when fully informed about the shippers' outside options, but the shipper can claim back some of the rent transfer when information is asymmetric. We compare the single-period contract case to the multi-period renegotiation one. This paper presents a way to link the interactions of shipper and carrier over multiple periods or contracts under several scenarios of information available to the carrier. The Nash equilibria contracts are presented in literal form. We conclude with some managerial insights.

## 1 Introduction

Carriers and shippers often do invest in specific assets to better mesh their operations and increase the efficiency and productivity of operators. For example, a logo painted on the sides of lorries working for a certain shipper, specific temperature control equipment, security controls are all specific investments to enhance some aspect of the service. 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. 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. The carrier may incur some of those investments even before the shipper has signed any contract (e.g., the regulatory requirements that the shipper stipulates as qualifiers to submit contractual offers). We wish to study here some effects of carrier

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information on the rent distribution between shipper and carrier when the contract linking them can be reopened or not. We present several information and negotiation scenarios. Information may be private and a contract may be binding or may be reopened at some future date if the partners agree to do so. We present several propositions regarding the generic contracts that the carrier and shipper may enter under each scenario and give some concluding remarks about managerial practice.

## 2 Literature Review

Game Theory is attractive in modeling the bargaining that goes inevitably on between shipper and carrier. The basis goes back at least to [13, p. 155] where the bargaining problem is defined as "two individuals who have the opportunity to collaborate for mutual benefits in more than one way.", but other sources more recently, such as [15] have brought interesting results. A guide to the history of bargaining theory is presented in [19]. 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.

The study in this paper wishes to bring forward the fact that both actors in a bargaining game must invest at some point in some relationship specific assets. This class of problems has not received much attention in game theoretic supply chain management literature. Most mentions trace their scientific basis to transaction cost economics [16, 17, 18], we mention [9] where the authors argue that the advent of the Internet leads to lower specific asset investments between players who use online auctions and other web-enabled technologies. In [10], the authors call for more research in how electronic marketplaces change the importance of specific assets and impact supply chain management. In the management of information technology literature, one finds a mention of relationship specific assets as not being wholly borne by the parties but rather by a community of parties [12]. In transaction cost economics, we mention [8] where trustworthiness is shown to induce lower specific asset investments by both parties in a relationship. In the same stream of literature, [14] provides evidence that a firm in the flower supply chain is able to gain competitive advantage by investing in relationship specific assets with her suppliers.

A more relevant reference is [20] which provides basis for the choice of long or short term contract by a buyer and this choice coupled with a lack of prior information about future production costs induces the seller into under investing in specific assets for fear of being held up by the buyer threatening to buy on the spot market. Other related works include several papers by Jacques Crémer who has studied the effect of information acquisition and asymmetry in principal-agent settings on the terms of trade and equilibrium strategies [5, 6, 7]. When a principal is confronted with several agents, [4] argues that information gathering by the agents enables the principal to select the best suited.

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 [19] 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 [15], 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 [19] specifies that the probability of the negotiation breakdown can be exogenous, in this paper we take into consideration only endogenous causes stemming from incentive incompatibility or rationality constraint violation.

## 3 Model of the Relationship between Shipper and Carrier over Several Periods

We are interested in the general case where a shipper $S$ (she) and a carrier $C$ (he)[1] set up a long term relationship and invest in specific assets with costs $A_{s1}$ and $A_{c1}$ 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 $C_s$ of doing so. The carrier's objective is to maximize his partial profit function $\Pi_c$ from working either for the shipper or some third party.

In time (see Figure 1), the sequence of events is the following: the shipper and carrier evaluate the required investments in specific assets that each is required to have to be able to work with the other. The carrier invests first in those specific assets. He then 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 1). If, on the other hand, the shipper finds the offer of the carrier interesting, a contract is agreed upon and the shipper invests in her turn 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.[2] 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).

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[1] In difference with the convention which considers the principal to be a "she", we shall term the shipper, even though an agent here, a "she" to remain coherent throughout the paper.

[2] This process is different from the commitment and renegotiation as defined in [11].

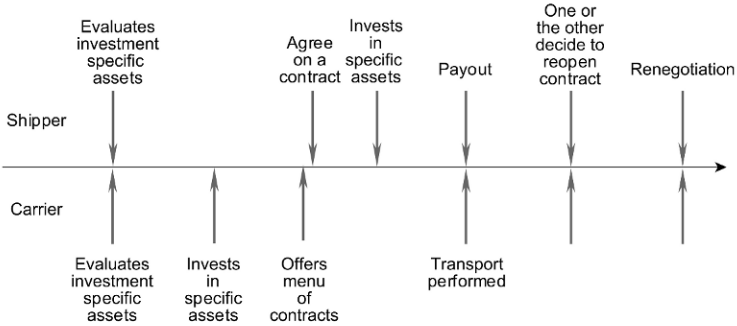


**Fig. 1** Timeline of events when shipper and carrier agree on a contract and to a new relationship. If the shipper does not agree to a contract, the timeline is stopped on this disagreement, each starts a new timeline (not represented here).

In this model, to economize on notation, we shall consider initially two periods. The period number shall be presented in superscript form. The results are then extended to a finite number of periods $n$. We assume that both shipper and carrier hold as common information $n$, the number of times that the contract shall be reopened.

If they do not agree to work together in the first or second period, both have the outside option of working with another counterparty. Setting up a relationship with another counterparty also entails a cost in specific asset $A_{s2}$ for the shipper and $A_{c2}$ for the carrier. The counterparty number is indicated in subscript. For example, if the shipper decides to work with the carrier in period one but in period two turns to another carrier, she incurs the investment $A_{s2}$. 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.

The contract is named $\phi(\gamma^i)$ with $\gamma^i, i \in \{1,2\}$, as the vector of that contract's parameters and proper to period $i$. The contract which the shipper may sign with some third party is labeled $\phi_s(.)$. The carrier can also sign a contract $\phi_c(.)$ with a third party. The contracts are members of a finite set $\mathscr{P}$ which describes all relevant contracts. The vector $\gamma$ of parameters for the contract $\phi$ belongs to a finite set $\Gamma$ of possible vectors describing potentially available parameters for that contract. We call $\delta_s^i$ the shipper's participation decision variable in period $i$ which can take binary values. We present all the notation relative to this appendix in Table 1.

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. We shall consider four cases which are set along two dimensions. One is the dimension of renegotiation, the other is information (see Figure 2). 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 in-

**Table 1** Table of notations.

| Type | Notation | Definition |
|---|---|---|
| Shipper | $A_{s1}$ | specific asset investment by shipper with the carrier |
| | $A_{s2}$ | specific asset investment by shipper with outside option |
| | $\phi_s^i(.)$ | contract available to shipper from outside option |
| | $\phi(\gamma^i)$ | contract offered in period $i$ by carrier to shipper |
| | $C^i(.)$ | shipper's transport cost in period $i$ for the shipper |
| | $\delta_s^i$ | binary decision variable, 1 when agreeing with carrier |
| Carrier | $A_{c1}$ | specific investment by carrier for shipper |
| | $A_{c2}$ | specific investment by carrier in outside option |
| | $\phi_c^i(.)$ | outside option contract available in period $i$ to carrier |
| | $\Phi^i$ | $\phi_c^i(.) - A_{c2}$ |
| | $\Pi_c^i(.)$ | carrier's profit function in period $i$ |
| Carrier beliefs | $f_Z(A)$,$F_Z(Z)$ | pdf and cdf of belief about $Z = \phi_s(.) + A_{s2} - A_{s1}$ |
| | $f_{s1}(A_{s1}), F_{s1}(A_{s1})$ | pdf and cdf of belief of $A_{s1}$ |
| Time | $n$ | common information about the number of times a contract can be reopened in renegotiation scenario |

formation and both have the ability to renegotiate in the top righthand corner. In the right hand side of Figure 2, 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. In the top half of Figure 2, the shipper is private to the expected demand and rent derived between the transport cost and the revenue obtained from the delivery of the demand which she receives within the period. The carrier is private to his costs and opportunities. The cost of the specific assets are also private to the relevant investing party. We present in Section 3.2 the case where the carrier lacks the information about the relationship specific investment that the shipper has to make and about her outside option. At times, both agree to open negotiations on a new contract. This case requires substantial calculations to be fully covered. This

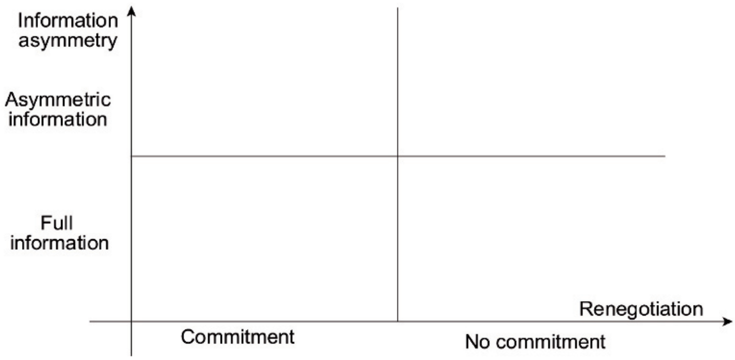


**Fig. 2** Dimensions of relationship between shipper and carrier: renegotiation and information.

paper will not cover it, it shall be broached in another communication. In the bottom half of Figure 2, the carrier and the shipper share the same information about specific asset costs, outside options and transport costs. These cases are discussed in Sections 3.1 and 3.3.

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. No negotiation takes place.

## 3.1 Full Information and Commitment

In this case both parties set up a contract which governs their relationship for the first and only period because they agree to commit to the terms of this contract for any future period in the same way. The carrier's objective is to maximize his profit function $\Pi_c$ in terms of the decision he takes and the contract he offers under constraint of the shipper's choice of carrier and his own participation constraint. So, we have

$$\max_{\delta_c^1,\gamma^1} \mathbb{E}\Big(\Pi_c\big(\delta_c^1,\phi(\gamma^1)\big)\,|\,\delta_s^1\Big)$$

$$\text{s.t.}\begin{cases}\mathbb{E}\Big(C_s\big(1,\phi(\gamma^1)\big)\Big)\leqslant \mathbb{E}\Big(C_s(0,.)\Big),\\ \mathbb{E}\Big(\Pi_c\big(1,\phi(\gamma^1)\big)\Big)\geqslant \mathbb{E}\Big(\Pi_c\big(0,\phi_c(.)\big)\Big),\end{cases} \tag{1}$$

with $\delta_c^1\in\{0,1\}$, $\delta_s^1\in\{0,1\}$, $\gamma^1\in\Gamma$, $\phi\in\mathscr{P}$, 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. So, more simply, we must have

$$\max_{\delta_c^1,\gamma^1} \Pi_c(\delta_c^1,\phi(\gamma^1))\,|\,\delta_s^1$$

$$\text{s.t.}\begin{cases}\phi(\gamma^1)+A_{s1}\leqslant \phi_s(.)+A_{s2},\\ \phi(\gamma^1)\geqslant \phi_c(.)-A_{c2},\end{cases} \tag{2}$$

with $\delta_s^1\in\{0,1\}$, $\delta_c^1\in\{0,1\}$, $\gamma^1\in\Gamma$, $\phi\in\mathscr{P}$.

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 $\phi_c(.)$ less the investment in relationship specific assets $A_{c2}$. If his return from the contract with the shipper is higher than $\Phi^1=\phi_c^1(.)-A_{c2}$, he will bear to work for the shipper.

The contract is hence written as

$$\phi(\gamma^1)=\phi_s(.)+A_{s2}-A_{s1}, \tag{3}$$

subject to

$$\phi(\gamma^1) \geqslant \Phi^1, \tag{4}$$

the carrier's individual rationality constraint.

**Proposition 1** *Full information and commitment contract*
*When shipper and carrier are fully informed about each other's outside opportunities, relationship specific investment costs, the optimal full commitment contract and corresponding parameters for the carrier is*

$$\phi(\gamma^1) = \phi_s(.) + A_{s2} - A_{s1}, \tag{5}$$

$$\text{s.t.}\, \phi(\gamma^1) \geqslant \Phi^1,\, \gamma^1 \in \Gamma, \phi \in \mathscr{P}. \tag{6}$$

## 3.2 Asymmetric Information and Commitment

In this case, the carrier and shipper also negotiate for just one period since renegotiation is not available. Their first choice of contract and parameters are set once and for all, whatever the length of the relationship. The carrier forms a belief about the shipper's reservation contract and investment in relationship specific levels.

Let us name $Z$ as this estimate. We have, from equation (3),

$$Z = \phi_s(.) + A_{s2} - A_{s1}. \tag{7}$$

The carrier holds a belief about $Z$ which can go from $\underline{Z}$ to $\overline{Z}$. The carrier also forms a belief about the estimated distribution of $Z$. This belief has a distribution law which follows a density function $f_Z(.)$ and a cumulated density function $F_Z(.)$ which we shall assume to be IFR (Increasing Failure Rate) as defined in [1]. These functions include quite a large variety of classical statistical distributions such as the exponential, the gamma, the Weibull, the modified extreme value distribution and the truncated normal for most types of common parameter sets as characterized in [1].[3] We can write the *expected* profit function of the carrier in terms of the belief of the threshold $Z$ (written $\widehat{Z}$) as:

$$\max_{\delta_c^1,\gamma^1,\widehat{Z}} \left(\Pi_c(\delta_c^1, \phi(\gamma^1), \widehat{Z}) |\, \delta_s^1\right) = \phi(\gamma^1)\overline{F_Z}(\widehat{Z}) + \Phi^1 F_Z(\widehat{Z})$$

$$\text{s.t.} \begin{cases} \phi(\gamma^1) \leqslant \widehat{Z} \\ \phi(\gamma^1) \geqslant \Phi^1, \end{cases} \tag{8}$$

with $\delta_c^1 \in \{0,1\}$, $\delta_s^1 \in \{0,1\}$, $\gamma^1 \in \Gamma$, $\phi \in \mathscr{P}$, $\widehat{Z} \in [\underline{Z}, \overline{Z}]$ and $\overline{F_Z}(\widehat{Z}) = 1 - F_Z(\widehat{Z})$.

The parameter over which the carrier must maximize his profit is here the estimate of $Z$.

[3] Note that in an IFR distribution $\overline{F_{s1}}(Z) \neq 0$ which leads to the notion that $F_Z(\overline{Z}) < 1$ but can be defined chosen such that it is arbitrarily close to 1.

The carrier wishes to maximize his profit: hence he will want to offer the most expensive contract at his disposal, this is the case when $\phi(\gamma^1) = \widehat{Z}$. He offers the contract which he believes the shipper will accept, given his belief about $Z$. So, from (8), the first differential in $Z$ is written

$$\frac{\partial \Pi_c(Z)}{\partial Z} = f_Z(Z)\big(\boldsymbol{\Phi}^1 - Z\big) - F_Z(Z) + 1. \tag{9}$$

For this optimal contract to be a maximizing one in terms of profit to the carrier, we must have

$$\begin{cases} \frac{\partial \Pi_c(Z^*)}{\partial Z} = 0, Z^* \in [\underline{Z}, \overline{Z}] \\ \frac{\partial^2 \Pi_c(Z^*)}{\partial Z^2} < 0, Z^* \in [\underline{Z}, \overline{Z}]. \end{cases} \tag{10}$$

The first order condition for an optimum means that

$$Z - \frac{\overline{F_Z}(Z)}{f_Z(Z)} = \boldsymbol{\Phi}^1. \tag{11}$$

The second differential is written, under the restriction that $f_Z(Z) \neq 0$,

$$\frac{\partial^2 \Pi_c(Z)}{\partial Z^2} = (\boldsymbol{\Phi}^1 - Z) f'_Z(Z) - 2 f_Z(Z). \tag{12}$$

If both conditions have to be realized, then, replacing $\boldsymbol{\Phi}^1 - Z$ by its value in (11) in (12), we can write

$$f'_Z(Z) \frac{F_Z(Z) - 1}{f_Z(Z)} - 2 f_Z(Z) < 0. \tag{13}$$

Since $f_Z(Z)$ is positive for all $Z$ in the range $[\underline{Z}, \overline{Z}]$, we can restate this inequality as

$$f'_Z(Z)(F_Z(Z) - 1) - 2 f_Z(Z)^2 < 0. \tag{14}$$

However, we have assumed that the distribution of $Z$ is IFR which means that the failure rate $r(Z) = f_Z(Z)/\overline{F_Z}(Z)$ is weakly increasing for those values of $Z$ for which $F_Z(Z) < 1$. Then the first differential of the function $r$, which is written

$$\frac{\partial r(Z)}{\partial Z} = \frac{f'_Z(Z)(1 - F_Z(Z)) + f_Z(Z)^2}{(1 - F_Z(Z))^2} \tag{15}$$

must be positive or null, so that

$$\frac{\partial r(Z)}{\partial Z} \geqslant 0 \Rightarrow f'_Z(Z)(F_Z(Z) - 1) - f_Z(Z)^2 \leqslant 0. \tag{16}$$

This last condition is stronger than the one spelt in (14) because $f_Z(Z)^2 > 0$. So if the carrier holds a belief about the distribution of the estimate of $Z$ which is IFR and if we confine ourselves to the cases when $f_Z(Z) \neq 0$, then inequality (14) holds and we have a unique optimal solution $\widehat{Z}$ to the optimization problem of the carrier if the FOC is satisfied.

Evidently, the carrier can not second guess the actual levels of $A_{s1}$, $A_{s2}$ nor of $\phi_s(0,.)$. He is bound by this initial estimate.

Does this contract satisfy the shipper? For that, we must have $\phi(\gamma^1) \leqslant \phi_s(0,.) + A_{s2} - A_{s1}$. The solution is very similar to the one spelt out in Proposition 1, except that this time the shipper may have some rent left. Using the optimal $Z^*$ which solves equation (11) as the optimal contract for the carrier, we can spell out the following proposition.

**Proposition 2** *Asymmetric information and commitment contract*
*When the carrier is not informed about the shipper's outside opportunities, relationship specific investment costs, the optimal full commitment optimal contract and corresponding optimal parameters for the carrier are characterized by the following conditions*

$$\begin{cases} \phi(\gamma^1) = Z^*, \\ \phi(\gamma^1) \geqslant \Phi^1, \\ Z^* - \frac{\overline{F_Z}(Z^*)}{f_Z(Z^*)} = \Phi^1. \end{cases} \tag{17}$$

It is clear that such commitment appears as overly rigid and impracticable. In the upcoming scenario presented in Section 3.3, we study the case where the carrier (and the shipper) can reopen the contract.

## 3.3 Full Information and Renegotiation

In this case, the parties may decide periodically to renegotiate the contract and they possess all relevant information to do so. In a way, this corresponds to a decentralized group with entities working together. Here, since the carrier and shipper know each other's relationship specific investment costs, if there was a negotiation, its outcome and the terms of the contract are straightforward [15].

In the first period, the shipper can decide to work with the carrier or not, in the second period, the shipper can again decide to work with the carrier or not, whether she has done so in the first period or not. This is a decision tree with two levels and two branches at each level and investments that depend upon the decisions. 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 bottom right hand corner in Table 2). In the same way, we assume that the carrier also has to work, either with the shipper or some other party, as mentioned earlier. The corresponding outcomes in terms of the relationship specific investments which he incurs are presented in Table 3.

The model will evaluate all the shipper's possible strategies.

To solve this problem, we enumerate all cases. We start with the decisions to be taken at the leaves of the decision tree, in our case after the outcome of the first period (Figure 3).

**Table 2** The shipper's investment in relationship specific assets according to her decisions in first (horizontal) and second (vertical) period.

| $\delta_s^2$ \ $\delta_s^1$ | 0 | 1 |
|---|---|---|
| 1 | $A_{s1}+A_{s2}$ | $A_{s1}$ |
| 0 | $A_{s2}$ | $A_{s1}+A_{s2}$ |

**Table 3** The carrier's investment in relationship specific assets according to the shipper's decisions in first (horizontal) and second (vertical) period.

| $\delta_s^2$ \ $\delta_s^1$ | 0 | 1 |
|---|---|---|
| 1 | $A_{c2}$ | 0 |
| 0 | $A_{c2}$ | $A_{c2}$ |

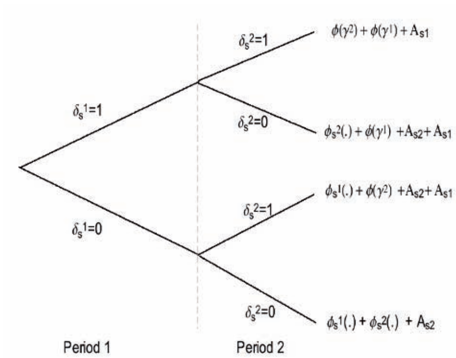


**Fig. 3** Shipper's decision tree in the two periods according to the possible decisions of the carrier.

$$\begin{cases} \delta_s^1 = 1 \begin{cases} \delta_s^2 = 1, C_s = C_s^1 + \phi(\gamma^2) \\ \delta_s^2 = 0, C_s = C_s^1 + \phi_s^2(.) + A_{s2} \end{cases} \\ \delta_s^1 = 0 \begin{cases} \delta_s^2 = 1, C_s = C_s^1 + \phi(\gamma^2) + A_{s1} \\ \delta_s^2 = 0, C_s = C_s^1 + \phi_s^2(.), \end{cases} \end{cases} \tag{18}$$

where $C_s^1$ is the cost incurred in the first period by the shipper. Working backwards, this first period cost can be written depending upon the decision of the shipper to work with the carrier or not as

$$\begin{cases} \delta_s^1 = 1, C_s^1 = \phi(\gamma^1) + A_{s1} \\ \delta_s^1 = 0, C_s^1 = \phi_s^1(.) + A_{s2}. \end{cases} \tag{19}$$

Since both players know that the other is a profit maximizer, the shipper knows that if she decides in the first period to work with the carrier, she will be offered in the second period the contract which equates both working with the carrier and taking her outside option. That is, when

$$C_s(\phi,\gamma|\,\delta_s^1=1,\delta_s^2=1)=\phi(\gamma^1)+\phi(\gamma^2)+A_{s1}. \tag{20}$$

Whereas if she does not work with the carrier in the second period, her cost function becomes

$$C_s(\phi,\gamma`|\,\delta_s^1=1,\delta_s^2=0)=\phi(\gamma^1)+\phi_s^2(.)+A_{s1}+A_{s2}. \tag{21}$$

So she knows that, in the second period, the carrier will maximize his profit by offering

$$\phi(\gamma^2|\delta_s^1=1)=\phi_s^2(.)+A_{s2}. \tag{22}$$

Hence, once the decision in the first period is to work with the carrier, the shipper's cost function across both periods can be fully written as

$$C_s(\phi,\gamma|\delta_s^1=1)=\phi(\gamma^1)+\phi_s^2(.)+A_{s1}+A_{s2}, \tag{23}$$

whether $\delta_s^2=0$ or $\delta_s^2=1$, when $\delta_s^1=1$.

The other branch of the alternative to the shipper is to go for her outside option in the first period. In this case, the carrier is willing to offer in the second period a contract such that

$$\phi(\gamma^2|\delta_s^1=0)=\phi_s^2(.)-A_{s1}, \tag{24}$$

insofar as

$$\phi(\gamma^2|\delta_s^1=0)\geqslant\phi_c(.), \tag{25}$$

the carrier's participation constraint.[4]

So, replacing in (18) the second period contract $\phi(\gamma^2)$ by the maximum offers that the carrier is bound to make, the shipper's cost is the same whether she chooses to work with the carrier in the second period or not:

$$C_s(\phi,\gamma|\delta_s^1=0)=\phi_s^1(.)+\phi_s^2(.)+A_{s2}. \tag{26}$$

Which is the dominant strategy for the shipper? In other words, how does she decide whether to accept or reject the contract in the *first* period given that she now knows what contracts the carrier will offer her in the *second* period?

The carrier's best course is to offer contracts to the shipper in such a way as to obtain positive decisions from her in both periods, as can be seen in Table 3. The carrier must offer a contract in the first period such that $\delta_s^1=1$, which means that the shipper's cost as evaluated in (23) must be lower than the cost evaluated in (26).

$$\phi(\gamma^1)+\phi_s^2(.)+A_{s1}+A_{s2}\leqslant\phi_s^1(.)+\phi_s^2(.)+A_{s2} \tag{27}$$

[4] Note that the carrier has had to invest $A_{c2}$ in the first period, since he could not work with the shipper.

When the second period contract is replaced by the expression computed in (22), this inequality becomes

$$\phi(\gamma^1) \leqslant \phi_s^1(.) - A_{s1}. \tag{28}$$

To maximize his profit in the first period, the carrier will offer the shipper a contract such that

$$\phi(\gamma^1) = \phi_s^1(.) - A_{s1}. \tag{29}$$

We now evaluate the carrier's participation constraints. The carrier makes the offer and is tied by it: he is forced to accept the shipper's decision. To participate in the first period, he offers a contract such that $\phi_s^1(.) - A_{s1} \geqslant \phi_c^1(.) - A_{c2}$. The worst case for him is when $\delta_s^1 = 0$ since he has to make the further investment $A_{c2}$ in the first period and to offer in the second period $\phi(\gamma^2|\delta_s^1 = 0) = \phi_s^2(.) - A_{s1}$. However, the carrier would only offer such a contract if $\phi_s^2(.) - A_{s1} \geqslant \phi_c^2(.)$. If that were not the case, he would prefer going for his outside option, given that he has already made the outside investment $A_{c2}$.

The carrier's participation can be summed up as the following:

$$\begin{cases} \phi_s^2(.) - A_{s1} \geqslant \phi_c^i(.), i \in \{1,2\} \\ \phi_s^1(.) - A_{s1} \geqslant \phi_c^1(.) - A_{c2}, \\ \phi_s^2(.) + A_{s2} \geqslant \phi_c^2(.) - A_{c2}. \end{cases} \tag{30}$$

Does this dominant strategy for the shipper satisfy the carrier's participation constraint? And would it also be a dominant strategy for the carrier? The shipper's dominant strategy will also be the carrier's dominant one if we have

$$\phi_s^2(.) + A_{s2} \geqslant \phi_c^1(.) - A_{c2}, \tag{31}$$

which is the same as the last participation constraint of the carrier iff $\phi_c^1(.) = \phi_c^2(.)$.

*Proof.* When $\delta_s^1 = 1$, $\delta_s^2 = 1$, $\Pi_c = \phi_s^1(.) - A_{s1} + \phi_s^2(.) + A_{s2}$. Whereas, when $\delta_s^1 = 0$, $\delta_s^2 = 1$ or when $\delta_s^1 = 1$ and $\delta_s^2 = 0$, $\Pi_c = \phi_s^1(.) - A_{s1} - A_{c2} + \phi_c^1(.)$, so, prior to his first offer to the shipper, the carrier must have

$$\phi_s^2(.) + A_{s2} \geqslant \phi_c^1(.) - A_{c2}, \tag{32}$$

or he would not make an offer to the shipper in the first place.

### 3.3.1 Extending the Results to Three Periods or More…

Let us investigate the results and policies when instead of two periods, the shipper and carrier wish to reopen negotiations $n-1$ times, at the beginning of $n-1$ periods.

In any future period $j$, with $j \geqslant 3$, the shipper can only be in three different states of relationship specific investments. She either has only invested in the relationship specific assets required to work with the carrier, or she has incurred also the investment in order to work with her outside option, or, third, she has never incurred the investment $A_{s1}$ but instead has incurred $A_{s2}$. Note that, initially, the period in which the investment occurs, or, alternatively, the first time in which $\delta_s = 0$, is irrelevant. Since the carrier knows the state the shipper is in, he tailors the contract he offers so as to match that state.

The following demonstration is in two steps: we initially extend the results of a two-period game and then reflect on the outcome before offering a new optimal strategy for both shipper and carrier.

STATE 1: shipper has only invested $A_{s1}$, the cost in period one is

$$C^1 = \phi_s(.), \tag{33}$$

since the carrier induces the shipper into working with him by refunding the relationship specific investment $A_{s1}$. At this stage of our reasoning, we consider that the carrier just extends the result of the two-period game to the following periods. We shall see later that is not optimal. In any posterior period

$$\phi(\gamma^j) = \phi_s^j(.) + A_{s2}, \qquad \text{if} \, \forall i \in \{1, \dots, j-1\}, \delta_s^i = 1. \tag{34}$$

The participation constraints for the shipper and carrier are respectively

$$\begin{cases} \phi(\gamma^j) < \phi_s^j(.) + A_{s2} \\ \phi(\gamma^j) > \phi_c^j(.) - A_{c2}. \end{cases} \tag{35}$$

The flow of profits to the carrier over $n$ periods can now be evaluated as

$$\Pi_c = \sum_{i=2}^{n} \left(\phi_s^i(.) + A_{s2}\right) + \phi_s^1(.) - A_{s1}. \tag{36}$$

And the shipper's total cost over $n$ periods is

$$C = \sum_{i=1}^{n} \phi_s^i(.) + (n-1)A_{s2} \tag{37}$$

STATE 2: shipper has invested both $A_{s1}$ and $A_{s2}$, carrier has invested $A_{c2}$: the carrier does not enjoy any particular advantage over the shipper's outside option, so he must match this outside party's proposition.

$$\phi(\gamma^j) = \phi_s^j(.), \qquad \text{if} \, \exists \{i,k\} \in \{1, \dots, j-1\}^2, i \neq k, \, \delta_s^i = 0, \delta_s^k = 1. \tag{38}$$

As in period 2, $\phi(\gamma^j) \geqslant \phi_c(.)$ or the carrier would prefer his outside option. For the shipper, the participation constraint is basically $\phi(\gamma^j) \leqslant \phi_s^j(.)$ since she has already borne the cost of the investment $A_{s2}$ in previous periods. In effect, there is no link between period $i$ and previous periods in terms of the participation constraints because in those earlier periods the shipper could not anticipate the carrier's actions, so she had to "amortize" the investment $A_{s2}$ over the first period in which she chose to work with her outside option. The flow of profits to the carrier is now written

$$\Pi_c = \sum_{i=1}^{j-1} \left(\phi_s^i(.) + A_{s2}\right) + \sum_{i=j+1}^{n} \left(\phi_s^j(.)\right) - A_{c2} - A_{s1}. \tag{39}$$

All costs to the shipper after period $j$ are equal to the outside contract cost $\phi_s^i(.)$, so we can write the total cost over the $n$ periods as

$$C = \sum_{i=1}^{n} \phi_s^i(.) + (j-1)A_{s2}. \tag{40}$$

The lowest possible outcome in this case is for the shipper to refuse to work with the carrier in the second period, so that

$$C^2 = \phi_s^2(.) + A_{s2}, \tag{41}$$

whether or not the carrier offers $\phi_s^2(.) + A_{s2}$ as his contract. The overall cost becomes

$$C = \sum_{i=1}^{n} \phi_s^i(.) + A_{s2}. \tag{42}$$

STATE 3: shipper has not yet invested $A_{s1}$, so the carrier offers

$$\phi(\gamma^j) = \phi_s^j(.) - A_{s1}, \qquad \text{if} \forall i \in \{1,\ldots,j-1\}, \delta_s^i = 0, \tag{43}$$

under the participation constraints: $\phi(\gamma^j) \geqslant \phi_c(.)$ or the carrier would simply walk away; $\phi(\gamma^j) \leqslant \phi_s^j(.) + A_{s2}$ or the shipper would choose her outside option. Now the stream of profits to the carrier over $n$ periods is even less:

$$\Pi_c = \sum_{i=1}^{n} \phi_c(.) - A_{s1}. \tag{44}$$

Reciprocally, the stream of costs to the shipper becomes

$$C = \sum_{i=1}^{n} \phi_s(.) + A_{s2}. \tag{45}$$

In the second state, since the shipper has invested in relationship specific assets with both her counterparties, the carrier cannot exploit the incumbent's advantage of the relationship specific investment with the shipper's outside option. This explains why he simply matches the shipper's outside option.

When comparing the streams of costs for the three states of reputation specific assets for the shipper, we see that the worst state for her is to have accepted to deal only with the carrier all along.

Hence the shipper's best strategy is to refuse to work with the carrier in period two: $\delta_s^2 = 0$ after $\delta_s^1 = 1$ and again to accept to work with him in all posterior periods $i > 2$, $\delta_s^i = 1$. Note that we suppose that the shipper accepts to work with the carrier rather than with her outside option all other conditions being equal because we assume that she has chosen the carrier in the first place for reasons which escape the present model but which can be related to the relative quality advantage of the carrier over her outside option.

How can the carrier yet change this strategy to reflect this predictable decision on the shipper's part in the second period?

As we have assumed in the preamble that both know $n$, the carrier can tailor his second period and all posterior period contracts so as to equal the terms that the shipper obtains in states 2 and 3. Thus, his best offer is

$$\phi(\gamma^i) = \phi_s^i(.) + \frac{A_{s2}}{n-1}, \quad \forall i, i \geqslant 2, \tag{46}$$

under the participation constraint

$$\phi_s^i(.) + \frac{A_{s2}}{n-1} \geqslant \phi_c^i(.) - A_{c2}. \tag{47}$$

Given this offer, the shipper's total cost over $n$ periods in state 1 becomes

$$C = \sum_{i=1}^{n} \phi_s^i(.) + A_{s2}, \tag{48}$$

and his participation constraint becomes

$$\sum_{i=1}^{n} \phi_s^i(.) + A_{s2} - A_{s1} \geqslant \sum_{i=1}^{n} \phi_c^i(.) - A_{c2}. \tag{49}$$

To the carrier, the profit flow over the $n$ periods is obviously larger than what he would have in either state 2 or 3.

*Proof.* When the shipper is in state 1, the carrier's profit is

$$\Pi_c = \sum_{i=1}^{n} \phi_s^i(.) + A_{s2} - A_{s1}. \tag{50}$$

This is compared to

$$\Pi_c = \sum_{i=1}^{j} \phi_s^i(.) + \frac{j}{n-1} A_{s2} + \sum_{k=j+1}^{n} \phi_c^k(.) - A_{s1} - A_{c2} \tag{51}$$

in state 2 and

$$\pi_c = \sum_{i=1}^{n} \phi_c^i(.) - A_{c2} \tag{52}$$

in state 3. Both these strategies yield inferior outcomes if the participation constraint in inequalities (47) and (49) are satisfied.

This is a Nash equilibrium because if, in any posterior period $j$, $j > 2$, the shipper decides to diverge from this strategy, her cost becomes

$$C = \sum_{i=1}^{n} \phi_s^i(.) + A_{s2} + \frac{j-1}{n-1} A_{s2}. \tag{53}$$

The cost of such a strategy is minimized when $j = 2$. This strategy is clearly inferior to the other strategy: the shipper is not better off than accepting the Nash equilibrium strategy.

Now we have a dominant strategy for the carrier which is also a dominant strategy for the shipper.

We can now bring together the conditions of the emergence of common dominant strategies for both carrier and shipper. When the carrier knows exactly the outside option and relationship specific investments, the offers he makes can be spelt in the following proposition.

**Proposition 3** *Full information and renegotiation*
*When the carrier is informed of the outside opportunities and relationship specific investments that the shipper has and when the shipper and carrier have the ability to reopen negotiations after an initial period, then the carrier will offer contracts over the n periods such that*

$$\begin{cases} \phi(\gamma^1) = \phi_s^1(.) - A_{s1}, \\ \phi(\gamma^i) = \phi_s^i(.) + \frac{A_{s2}}{n-1}, \forall i, i \geqslant 2. \end{cases} \tag{54}$$

*The previous are subject to the following participation constraints*

$$\begin{cases} \phi_s^i(.) - A_{s1} \geqslant \phi_c^1(.) - A_{c2}, & \text{(PC)} \\ \phi_s^i(.) + \frac{A_{s2}}{n-1} \geqslant \phi_c^i(.) - A_{c2}, & \text{(PC)} \\ \sum_{i=1}^n \phi_s^i(.) + A_{s2} - A_{s1} \geqslant \sum_{i=1}^n \phi_c^i(.) - A_{c2}. & \text{(PC)} \end{cases} \tag{55}$$

*This strategy represents a Nash equilibrium.*

It is interesting to note that the optimal contract to the carrier, if the shipper's outside option relies on a price-only relational contract, is a minimum purchase commitment (MPC). If, for example, the shipper relies for her outside option on the spot market, the fixed cost $A_{s2}$ is her information cost of finding counterparties in the spot market and the contract $\phi_s^i(.), i \in \{1,2\}$ is in fact the expected spot market price times the expected demand.

## 4 Conclusion

The single most remarkable result for a practitioner is the fact that the first period contract costs so much less to the shipper than the second period one. If the relationship specific investment is important relative to the cost of the outside opportunity open to the shipper, the carrier may well be offering a contract which may not yield more than the economic profit. He does so in the knowledge that the second period contract will be so much more profitable. It will in fact be in proportion to the relationship specific investment that the shipper would have to incur to work with her outside option.

In all the preceding, we show how the carrier must take into account his competition when pricing his contracts. Even if the competition is reduced to the spot market, he can tailor his contract so as to be preferred by taking into account the fixed costs that the shipper incurs when gathering information about available spot market capacity. We explain in this way how even large shippers who may have good information about conditions in the spot market still turn to carriers with whom they have worked before. We show that a shipper must at least once refuse to work with the carrier so that he knows that the relationship specific investment with a third party has been incurred and so the first carrier can no longer extract an extra rent but simply match the outside option's best offer in the remaining periods.

We have shown in the above how a carrier can tailor the contract according to his knowledge of the shipper's relationship specific investments in the first and eventual posterior periods. This situation is seen in practice when new entrants in a market wish to conquer market share and offer to subsidize a shipper to work with them. As we have shown, this practice does not make shippers change suppliers unless the subsidy over just one contract or period is equal or superior to the corresponding cost of the relationship investment. The present model, however, does not take into account the differing quality or reliability of the transport service suppliers and hence remains mute as to the other possible causes that hinder shippers from changing suppliers. We may conjecture about the inclusion of quality and reliability issues as specific costs to the other relationship specific investment that the shipper is to make but this would require further research.

In the present paper we have chosen to limit the carrier to just one final take-it-or-leave-it offer to the shipper. In real life, the carrier would very likely be able to make several offers in successive bargaining rounds [2].

We show how the shipper and carrier can be linked in their relationship over several periods and hence how both can try to obtain an advantage over the other even without considering the exact contractual mechanism which can link them. The present work extends and enriches previous work on the multi-period contractual relationship between shipper and carrier in [3] by offering new modeling instruments to explain the behaviour of shipper and carrier which often continue working together even when neither is satisfied with the other.

In this paper, we have not examined the renegotiation case where the carrier has no information about the shipper's exact investment in relationship specific assets and so must estimate it. Further research is ongoing in this area.

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