LVI SBPO SIMPÓSIO BRASILEIRO DE PESQUISA OPERACIONAL
DE 04 ATÉ 07 NOVEMBRO 2024
FORTALEZA | CEARÁ

Supply Chain Management in a Weak Dominance Coopetition Environment under Decision-Dependent Uncertainty

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RESUMO

O efeito chicote é bem estabelecido na literatura de gestão da cadeia de suprimentos como grande contribuinte para disrupção, portanto, estratégias para mitiga-lo, conferindo resiliência e robustez às cadeias de suprimentos, são relevantes. Apesar da natureza de tomada de decisão sequencial das cadeias de suprimentos, otimização robusta de incertezas dependente de decisões é uma técnica raramente aplicada. Neste artigo, uma nova abordagem para incerteza dependente a decisões foi aplicada, buscando derivar benefícios de resolver o problema pedido ótimo como um problema de decisão fracionada de expedição, em vez da abordagem clássica. Em duas variações do problema do jornaleiro, adicionando um fabricante e um extrator, o fabricante distorce a demanda, causando um pico. Usando comunicação com o fornecedor de segunda camada e incerteza dependente a decisão, o efeito chicote clássico e financeiro podem ser mitigados. Uma segunda variação do problema contemplou dois extratores com fraca dominação em um cenário de coopetition.

PALAVRAS CHAVE. Decisões em Dois Estágios, Incerteza Dependente da Decisão, Cadeia de Suprimentos, Coopetition.

Tópicos: L&T – Logística e Transportes, GF – Gestão Financeira e POI – PO na Indústria.

ABSTRACT

The bullwhip effect is well established within supply chain management literature as a major contributor to disruption. Therefore, strategies to mitigate its effects, granting more resilience and robustness to supply chains, are relevant to the field. Despite the sequential decision-making nature of supply chains, decision-dependent uncertainty robust optimization is a technique rarely applied to the field. In this paper a new approach to decision-dependent uncertainty, seeking to derive the benefits of solving the optimal order quantity problem as a fractional expedition decision problem, instead of the classic robust optimization approach. In the two variations of the Newsvendor problem, adding a manufacturer and an extractor, where the manufacturer distorts demand,

DOI: 10.59254/sbpo-2024-193870
https://proceedings.science/p/193870?lang=pt-br

causes an upwards spike. Using second-tier supplier communication and decision-dependent uncertainty, both the classic and financial bullwhip effects can be mitigated. The second variation contemplated two extractors with weak dominance in the competition.

KEYWORDS. Two Stage Decision, Decision Dependent Uncertainty (DDU), Supply Chain, and Coopetition.

Paper Topics: L&T – Logistics and Transport, GF – Financial Management, and POI – OR in Industry

DOI: 10.59254/sbpo-2024-193870
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1. Introduction

Since the advent of COVID-19, the study of resilience in supply chains has increased from multiple angles. A critical perspective is the so-called Bullwhip Effect (BWE), for which a set of proposals have been made aiming to prevent its propagation along the supply chain. Roughly speaking, the BWE is the phenomenon of a small fluctuation in demand at some retail level that induces progressively larger fluctuations in demand at the following wholesale, distributor, manufacturer, and raw material supplier levels. This phenomenon was first observed by Lee et al. [1997] as the variance of orders being larger than that of sales, and such distortion tends to increase as one moves upstream, i.e., for each agent involved in the supply chain, the chances of information distortion increases. A more recent definition for the BWE was coined by Sanders [2012] as the inaccurate and distorted information traveling up the chain like a *bullwhip uncoiling*. Therefore, the bullwhip effect is a major problem in supply chain logistics since it distorts the information flow and affects the subsequent entities' decision-making process as they tend to make sub-optimal decisions. In an approach similar to Forecast Value-Added analysis (FVA) [Goodwin et al., 2017], defined as the process of comparing relatively sophisticated forecasting methods with the accuracy of naive forecasts to investigate whether the extra costs and effort of implementing them are justified, the concept of Information Value Added (IVA) can be estimated, which consists in the comparison of a decision outcome when the agent has access to the demand of the previous tier member of the supply chain and when such information is lacking. The objective of this work is then to show how information sharing can be beneficial for the prevention of BWE and lead to better performance under a Decision Dependent Uncertainty (DDU) context [Goel and Grossmann, 2006]. A case study is presented based on the context of supply chains with a DDU point of view made by the access to instant information flow considering lead time variation between each step.

A key component of this paper is a *coopetition* (cooperative competition) approach to supply chain management since, as stated by Crick and Crick [2020], in a worldwide emergency, organizations are recommended to explore the potential mutual benefits of using competition strategies to yield higher levels of performance, meeting unprecedented demand, operating efficient supply chains, or indeed, simply surviving within a highly volatile market. Coopetition can be described as an environment where competitors act cooperatively, exerting weak dominance over one another and requiring compensation for the maintenance of the partnership. For the problem's formulation, agents can communicate information instantly, but the flow of products occurs between standard lead time intervals, therefore creating an artificial stage-like interval between supply chain members. In other words, to meet their respective demand, each agent would need to order at least double their expected consumption, thus compensating for the products still in transit.

There are two main methodological contributions of this work. Firstly, to adapt the Decision-Dependent Uncertainty (DDU) framework to better characterize the uncertainty modeling in a newsvendor problem in the context of Supply Chain Management (SCM). DDU consists of a class of problems where decisions are optimized over a time horizon under uncertainty, and such decisions influence the time of information discovery for a subset of the uncertain parameters Goel and Grossmann [2006]. In other words, it is akin to a robust optimization problem approach where a series of sequential decisions that affect not only one another but also the uncertainty surrounding the next decision. It has widespread use in energy planning problems such as in Ma et al. [2018]. However, it has been rarely used in SCM problems. The second contribution is the formulation of a "local DDU problem", i.e., the decision-dependency impacts the same agent, different to other applications of DDU in SCM, that each decision involves the following agent or is a decision of a different nature, as in Zhao and You [2019]. The referred local DDU is the formulation of the optimal order problem as a DDU solution of two fractional expedition decisions.

DOI: 10.59254/sbpo-2024-193870
https://proceedings.science/p/193870?lang=pt-br

2. Problem Description

The problem context considered in this work has a news-vendor problem is the last step of the supply chain, and the previous agents are providers to this vendor. More precisely, we consider a supply chain with 3 nodes: the news-vendor, a newspaper manufacturer, and a raw material extractor. In this context, the news-vendor is the final end of the chain selling to the end consumers, the manufacturer is an intermediary agent, having both a supplier and an intermediate consumer, and the extractor is the initial point, i.e., an agent without suppliers. For expository purposes, we assume that the latter agent extracts its own material instantaneously. Additionally, the conversion time of materials is instantaneous at each point in the supply chain.

To better capture the effects of BWE, we consider a manufacturer with an extremely high risk-averse profile regarding the level of service compared to the news-vendor, or, in other words, the manufacturer tends to overstock. Due to the ineffective communication between the news-vendor and the extractor agents, the latter only knows approximately the amount of newspapers the former will sell in the next period. However, the manufacturer, due to its risk aversion level, distorts the demand prediction, overestimating the actual demand, avoiding at all costs a context in which it fails to meet the news-vendor's demand.

It is worth highlighting that, as a supply chain, the risk aversion of the manufacturer has a significant impact on the extractor as well. More specifically, by overestimating the actual demand, the manufacturer ends up ordering a larger quantity of raw material than necessary from the extractor, thus holding a considerable amount of raw material in stock for the following period. Therefore, depending on the news-vendor's demand for this next period, there is a non-negligible possibility that the manufacturer may not need to place an order for replenishing its stock from the extractor, thereby generating unwanted volatility in revenue flow. To avoid this undesirable situation, the following restriction of cash-flow constraint will be instantiated in this work: the revenue from every expedition must be greater than a minimal value cash flow.

Given this context, a specific objective of this work is to determine, from the perspective of the extractor, the optimal amount to be extracted for the next period t, ensuring that the manufacturer's actual demand is met while also ensuring that it will be compelled to purchase new materials in the subsequent period $t + 1$. The flow of information and materials is illustrated in Figure 1. The process works as follows: the news-vendor places an order for the required quantity for the next period t to the manufacturer. Then, the manufacturer, knowing the quantity requested by the news-vendor and the amount of raw material in its inventory, places an (extrapolated) order to the extractor. Further on, the extractor, upon receiving the order from the manufacturer and having an approximate understanding of the news-vendor's actual demand and the amount of raw material in the manufacturer's inventory, sends a lower-than-ordered quantity of raw material to the manufacturer. This decision ensures that the manufacturer meets the news-vendor's demand while still guaranteeing a new order in the subsequent period. The manufacturer, despite receiving a lesser quantity than originally requested, still fulfills the news-vendor's demand as well as it can. If and only if the manufacturer's inventory falls below a certain level (SS), a new order is placed. The news-vendor receives its order from the newspaper manufacturer and fulfills its demand in $t + 2$. In this work, as the focus is on the extractor, this agent is the only one aiming to maintain balance in its cash flow for fixed expenses. The investment for ordering or producing always occurs in the first stage of the decision-making process for all entities. Since the news-vendor experiences a 2 step lead-time, it will always order twice as much as needed to ensure that its demand is met.

3. Methodology

Solving the problem described in Section 2 requires handling three optimization problems: the news-vendor, the manufacturer, and, finally, the extractor. Firstly, the news-vendor decision

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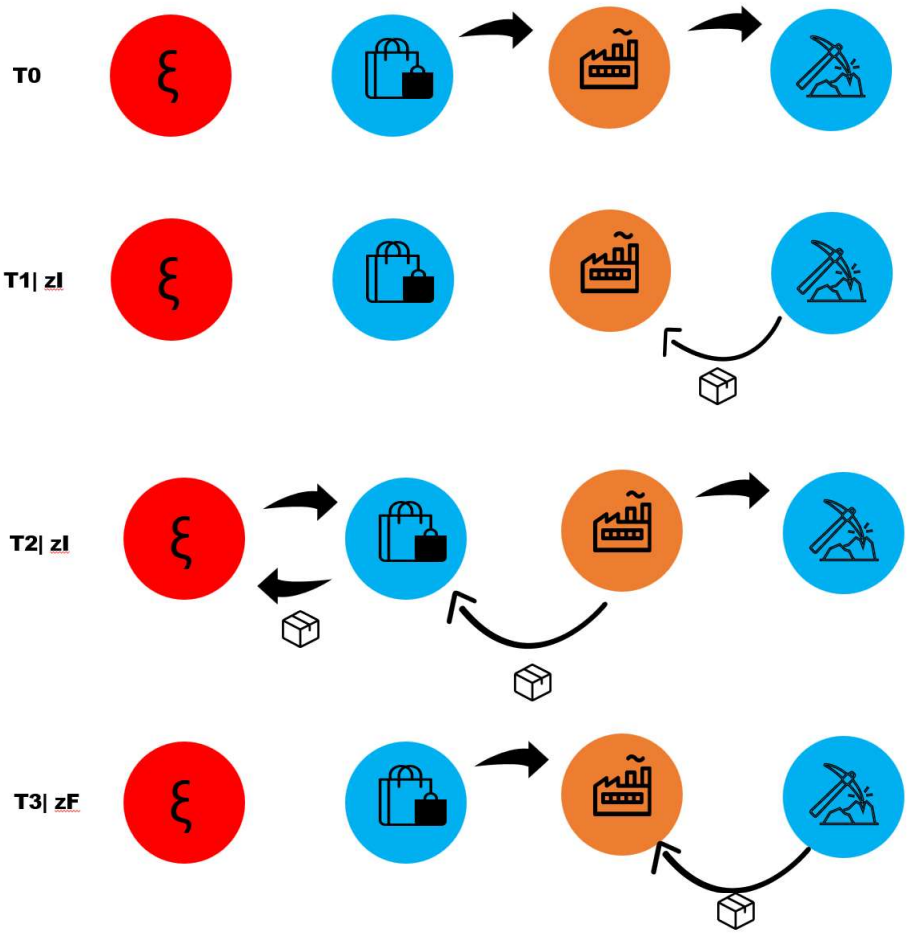


Figure 1: T_0 : The orders are made in preparation of demand; $T_1|z_I$: The z_I^E quantity is delivered; $T_2|z_I$: The manufacturer has to deliver to the news-vendor, suffering the impact of demand, thus placing a z_F order for the extractor; $T_3|z_F$: The news-vendor reveals his z_F order to the manufacturer, a step similar to T_2 would ensue and the cycle restarts.

problem is, essentially, to define the quantity to be ordered from the manufacturer. Formally, the optimization problem is presented in (1)–(7):

$$\max_{x^N} \; P^N \tag{1}$$

subject to

$$P^N = P_I^N + P_F^N; \tag{2}$$

$$P_I^N = q^N \cdot z_I^N - c^N \cdot x^N; \tag{3}$$

$$P_F^N = q^N \cdot z_F^N; \tag{4}$$

$$0 \leq z_F^N \leq \hat{\xi}; \tag{5}$$

$$0 \leq z_I^N \leq \hat{\xi}; \tag{6}$$

$$z_I^N + z_F^N \leq x^N. \tag{7}$$

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In (1)–(7), P^N is the total profit of the news-vendor, P_I^N is the profit obtained by the news-vendor in the first interaction, P_F^N is the profit obtained by the news-vendor in the second interaction, x^N is the quantity of ordered by the news-vendor. Therefore, x^N is limited by the sum of z_I^N and z_F^N, where each term represents the number of newspapers sold in the first and second interactions, respectively. The selling price of a newspaper is represented by q^N, c^N is the cost of acquiring the products, and $\hat{\xi} = \mathbb{E}[\tilde{\xi}]$ is the expected demand for newspapers by the news-vendor. Note that since the cost of the order is paid in full in the first stage, and a cash-flow stability constraint was not implemented, P_I^N is susceptible to negative profit levels, compensated in the second delivery stage z_F^N.

Following the supply chain, the amount the news-vendor is willing to order (x_N) is passed to the manufacturer as a "demand". However, we highlight that such information is uncertain to the manufacturer and dependent on the response of the news-vendor facing newspaper demand uncertainty $(\tilde{\xi})$. Assuming that the uncertain factor $\tilde{\xi}$ can be appropriately characterized by a Normal Distribution with a mean μ and a standard deviation σ, $\tilde{\xi} \sim \mathcal{N}(\mu, \sigma)$, and highlighting that it is highly sub-optimal for the news-vendor to actually order more than the optimal quantity $(x_N^\star)$ to avoid eventual overstocking induced by variations of the newspaper demand process, the uncertain demand for the manufacturer (i.e., the total order from the news-vendor) has the following dependence

$$\tilde{\xi}^M(x_N^\star) = \min\{x_N^\star, N(\mu, \sigma)\} \tag{8}$$

Note that (8) explicitly highlights the decision-dependent uncertainty of the supply chain problem. More specifically, the uncertain realization is bounded by the optimal decision of problem (1)–(7), re-shaping the dynamic of the uncertain variable $\tilde{\xi}^M$. In (9)–(15), the decision-making problem for the manufacturer is presented:

$$\max_{x^M} \; P^M \tag{9}$$

s.t.

$$P^M = P_I^M + P_F^M; \tag{10}$$

$$P_I^M = q^T \cdot z_I^M - c^M \cdot x^M; \tag{11}$$

$$P_F^M = q^M \cdot z_F^M; \tag{12}$$

$$0 \leq z_F^M \leq \hat{\xi}^M; \tag{13}$$

$$0 \leq z_I^M \leq \hat{\xi}^M; \tag{14}$$

$$z_I^M + z_F^M \leq x^M. \tag{15}$$

Similarly to the news-vendor problem (1)–(7), P^M represent the total profit of the manufacturer, P_I^M is the profit obtained by the manufacturer in the first interaction, P_F^M is the profit obtained by the manufacturer in the second interaction, x^M is the quantity of ink ordered by the manufacturer. Therefore, x^M is limited by the sum of z_I^M and z_F^M, where each represents the number of newspapers sold in the first and second interactions. In (1)–(7), q^M is the selling price of newspaper, c^M the cost of acquiring the products and $\hat{\xi}^M = \mathbb{E}[\tilde{\xi}^M(x_N^\star)]$ is the expected demand for the manufacturer.

Finally, the last agent in the supply chain, the extractor agent, responsible for providing raw material to the manufacturer, has the following decision problem:

$$\max_{x^E} \; P^E \tag{16}$$

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s.t

$$P^E = P_I^E + P_F^E; \tag{17}$$
$$P_I^E = q^E \cdot z_I^E - c^E \cdot x^E - f_I^E; \tag{18}$$
$$P_F^E = q^E \cdot z_F^E - f_F^E; \tag{19}$$
$$f_I^E = f^E \cdot \left(\xi^M - z_I^E\right); \tag{20}$$
$$f_F^E = f^E \cdot \left(\xi^M - S_{int}^M - z_F^E\right); \tag{21}$$
$$S_{int}^M = S_0^M + z_I^E - \xi; \tag{22}$$
$$0 \leq z_I^E \leq \xi; \tag{23}$$
$$0 \leq z_F^E \leq \xi - z_I^E; \tag{24}$$
$$z_I^E + z_F^E \leq x^E; \tag{25}$$
$$z_I^E - \xi \leq SS^M; \tag{26}$$
$$P_I^E \geq FC^E; \tag{27}$$
$$P_F^E \geq FC^E; \tag{28}$$
$$S_{int}^M, f_I^E, f_F^E \geq 0. \tag{29}$$

In (16)–(29), P^E is the total profit of the extractor, P_I^E is the profit obtained by the extractor in the first interaction, P_F^E is the profit obtained by the extractor in the second interaction, x^E is the quantity of raw material ordered by the manufacturer. Therefore x^E is limited by the sum of z_I^E and z_F^E, where each represents the quantity of raw material sold in the first and second interactions and S_{int}^M is the intermediary stock of the manufacturer between iterations, after receiving z_I^E but before ordering z_F^E. The selling price of the raw material is given by q^E, c^E is the cost of extracting the material, $\hat{\xi}^M$ and $\hat{\xi}$ are the same as in (1)–(7) and (1)–(7), respectively. It should be highlighted that, in the 2$^{\text{nd}}$ tier, the supplier information exchange is established by the news-vendor relaying the information to the extractor.

Some new variables were introduced for this problem. The manufacturer has, established in contracts, the following service level-oriented fines for each delivery that fails to meet the requested demand: m_I^E, the total penalty in the 1$^{\text{st}}$ interaction between the extractor and the manufacturer and m_F^E, the total penalty in the 2$^{\text{nd}}$ interaction between the extractor and the manufacturer. As a benefit of agreeing to the fine policy, the manufacturer is obliged to inform its current stock and reordering policy, adding the variables: S_{int}^M is the raw material stock of the manufacturer between its interactions with the extractor, that is, the current stock after z_I^E is delivered and the manufacturer suffers the demand. S_0^M is the initial stock of the manufacturer at each cycle, and SS^M is the reorder point of the manufacturer, the minimum value its stock can reach before a new order is placed.

Concerned with the financial bullwhip effect that the previous supply chain nodes are susceptible to, the extractor opts for a cash-flow constraint in the following form: the profit of both deliveries must always be greater than the corresponding fixed cost FC^E.

3.1. Ideal Context

Since the manufacturer needs to wait for the arrival of the extractor's delivery, similar to the news-vendor's agent, a quantity sufficient for two periods must be ordered, therefore compensating for the lead time and having the products ready for expedition. Before delving into the solution, a simpler sub-problem can be addressed where the Manufacturer behaves appropriately. In other words, the supply chain would be in perfect harmony, resulting in the best possible outcome for the

DOI: 10.59254/sbpo-2024-193870
https://proceedings.science/p/193870?lang=pt-br

extractor. This provides a point of reference to the effectiveness of the DDU formulation for both financial performance and reduction of the BWE.

3.2. Real Context

The real context consists on the aforementioned situation, where the manufacturer, acts irrationally risk averse, causing a demand distortion.// Note that the new manufacturer resolution will be given by equations of the same modeling, excluding the demand extrapolation (represented by a uniform distribution $U(A, B)$ for the news-vendor's demand to the manufacturer). This way, the information distortion can be appropriately represented by the increase in the expected demand by the manufacturer.

$$\max_{x^M} \; P^M \tag{30}$$

s.t.

$$P^M = P_I^M + P_F^M \tag{31}$$
$$P_I^M = q^T \cdot z_I^M - c^M \cdot x^M \tag{32}$$
$$P_F^M = q^M \cdot z_F^M \tag{33}$$
$$0 \leq z_F^M \leq \xi^M \tag{34}$$
$$0 \leq z_I^M \leq \xi^M \tag{35}$$
$$z_I^M + z_F^M \leq x^M \tag{36}$$
$$U(A, B) + \tilde{\xi}^M\left(x_N^\star\right) = \xi^M \tag{37}$$

3.3. Competition Context

By introducing a new raw material extractor as a competitor, hereinafter referred to *Extractor B*, the manufacturer can choose where to source its raw materials. By hypothesis, we assume that the price of Extractor B is higher than its competitor, *Extractor A*, so that Extractor A has a preference over ordering and will be offered the supply opportunity first. Figure 2 illustrates this context. Formally, both Extractor B and Extractor A decision problems are displayed in (38)–(51) and (52)–(65), respectively.

Extractor B Decision-Making Problem:

$$\max_{x^B} \; P^B \tag{38}$$

s.t

$$P^B = P_I^B + P_F^B; \tag{39}$$
$$R_I^B = q^B \cdot z_I^B - c^B \cdot x^B - m_I^B; \tag{40}$$
$$R_F^B = q^B \cdot z_F^B - m_F^B; \tag{41}$$
$$m_I^B = m^B \cdot \left(\xi^M - z_I^B - z_I^{A*}\right); \tag{42}$$
$$m_F^B = m^B \cdot \left(\xi^M - S_{int}^T z_F^{A*} - z_F^B\right); \tag{43}$$
$$S_{int}^M = S_0^M + z_I^{A*} + z_I^B - \xi; \tag{44}$$
$$0 \leq z_I^B \leq \xi^M - z_I^{A*}; \tag{45}$$
$$0 \leq z_F^B \leq \xi^M - z_I^{A*} - z_I^B - z_F^{A*}; \tag{46}$$
$$z_I^B + z_F^B \leq x^B; \tag{47}$$

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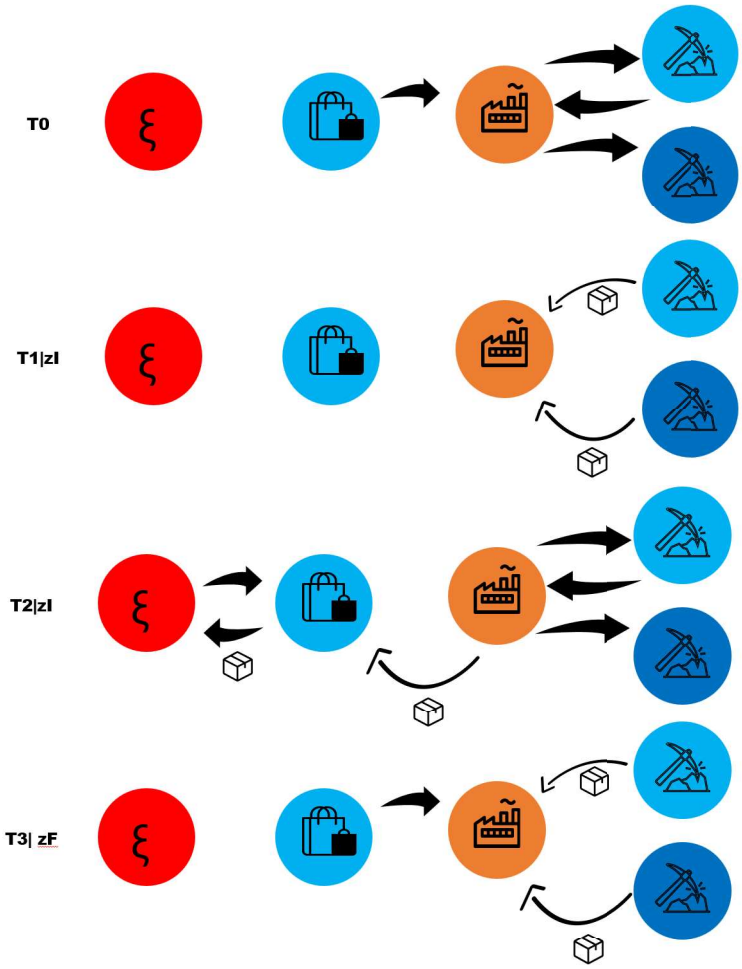


Figure 2: T_0The orders are made in preparation of demand first the value of z_I^A is informed by extractor A, so the manufacturer's order can then be relayed to extractor B, $T_1|z_I$: The $z_I^A + z_I^B$ quantity is delivered. $T_2|z_I$: The manufacturer can deliver to the news-vendor, that suffers the impact of the demand and place the z_F order for the extractor. $T_3|z_F$: The News-vendor reveals his z_F order to the manufacturer, a step similar to T_2 would ensue and the cycle restarts.

$$z_I^{A*} + z_I^B - \xi \leq SS^M; \tag{48}$$
$$P_I^B \geq FC^B; \tag{49}$$
$$P_F^B \geq FC^B; \tag{50}$$
$$S_{int}^M, m_I^B, m_F^B \geq 0. \tag{51}$$

Extractor A Decision-Making Problem:

$$\max_{x^A} \quad P^A \tag{52}$$

s.t

$$P^A = P_I^A + P_F^A; \tag{53}$$
$$P_I^A = q^A \cdot z_I^A - c^A \cdot x^A - m_I^A; \tag{54}$$
$$P_F^A = q^A \cdot z_F^A - m_F^A; \tag{55}$$

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$$m_I^A = m^A \cdot \left(\xi^M - z_I^A\right); \tag{56}$$
$$m_F^A = m^A \cdot \left(\xi^M - S_{int}^T - z_I^{B*} - z_F^A\right); \tag{57}$$
$$S_{int}^M = S_0^M + z_I^{B*} + z_I^A - \xi; \tag{58}$$
$$0 \leq z_I^A \leq \xi^M; \tag{59}$$
$$0 \leq z_F^A \leq \xi^M - z_I^A; \tag{60}$$
$$z_I^A + z_F^A \leq x^A; \tag{61}$$
$$z_I^{B*} + z_I^A - \xi \leq SS^M; \tag{62}$$
$$P_I^A \geq FC^A; \tag{63}$$
$$P_F^A \geq FC^A; \tag{64}$$
$$S_{int}^M, m_I^A, m_F^A \geq 0. \tag{65}$$

The solutions of the extractors interfere with one another, but they have no communication and would attempt to solve the problem, ignoring the competitor. For the particular numerical experiment presented in this work, both would have the incentive to fulfill as much of the demand as they could in the first step, by fear of not having another opportunity in the future, leading to a weak dominance of Extractor A over Extractor B, as long as the prices charged by the latter remain lower than the former. Finally, note that the cash-flow constraint may not be met in this context since no profit is obtained by Extractor A.

3.4. Coopetition Context

The coopetition (cooperative competition) formulation follows the same logic previously stated, counting only with the addition of b^A as a bonus that Extractor B pays to Extractor A not to exert its optimal order quantity. This value is lower than the fine payed from the extractors to the manufacturer. Therefore, there is an incentive for Extractor B to comply, and Extractor A makes a profit without spending any resources. The dominance is weak and price-dependent; note that Extractor B could exert dominance over Extractor A if $q^B \leq q^A$. However, this would imply a lesser total profit scenario. The mathematical formulation for the coopetition context is presented in (66)–(90).

$$\max_{x^{coop}} \; P^{coop} \tag{66}$$

s.t

$$P^{coop} = P^A + P^B; \tag{67}$$
$$P^A = P_I^A + P_F^A; \tag{68}$$
$$P_I^A = q^A \cdot z_I^A - c^A \cdot x^A - f_I^A + z_I^B \cdot b^A); \tag{69}$$
$$P_F^A = q^A \cdot z_F^A - f_F^A + z_I^B \cdot b^A); \tag{70}$$
$$P_F^A \geq CF^A; \tag{71}$$
$$P_I^A \geq CF^A; \tag{72}$$
$$z_F^A \leq \xi^M - z_I^B - z_I^A; \tag{73}$$
$$z_I^A \leq \xi^M; \tag{74}$$
$$z_I^A + z_F^A \leq x^A; \tag{75}$$
$$m_I^A = m \cdot (\xi^M - z_I^A); \tag{76}$$
$$m_F^A = m \cdot (\xi^M - \xi - z_I^A - z_I^B); \tag{77}$$

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$$z_I^A + z_I^B \leq \xi + SS^M; \tag{78}$$
$$z_F^A + z_F^B \leq \xi; \tag{79}$$
$$z_F^B \leq \xi^M - z_I^A - z_I^B - z_F^A; \tag{80}$$
$$z_I^B \leq \xi - z_I^A; \tag{81}$$
$$z_I^B + z_F^B \leq x^B; \tag{82}$$
$$P_I^B = q^A \cdot z_I^B - c^B \cdot x^B - m_I^B - b^A \cdot z_I^B; \tag{83}$$
$$P_F^B = q^A \cdot z_F^B - m_F^B - b^A \cdot z_F^B; \tag{84}$$
$$P^B = P_I^B + P_F^B; \tag{85}$$
$$P_I^B \geq CF^B; \tag{86}$$
$$P_F^B \geq CF^B; \tag{87}$$
$$m_I^B = m \cdot (\xi^M - z_I^A - z_I^B); \tag{88}$$
$$m_F^B = m \cdot (\xi^M - z_F^B - z_I^A - z_F^A); \tag{89}$$
$$x^A, z_I^A, z_F^A, m_I^A, m_F^A, b^A, x^B, z_I^B, z_F^B, m_I^B, m_F^B \geq 0. \tag{90}$$

4. Results

4.1. Single supplier formulation

4.1.1. Ideal Context Analysis

For this ideal context analysis, we assume $\tilde{\xi} \sim N(40, 8)$, $q^J = 130$ and $c^J = 80$, $q^T = 80$ and $c^T = 45$ and for solving the main optimization problem, $q^E = 45$, $c^E = 10$, $FC_E = 250$ and $m^E = 0.10q^E$. Table 1 showcases the main results for this ideal context.

DDU Ideal Scenario	News-vendor	Manufacturer	Extractor
Total profit expectation	3,198	4,730	4,801
Profit I expectation	-801	-627	1,503
Profit F expectation	3,999	5,357	3,298
Order quantity	73	147	147
zI*	37	73	73
zF*	37	73	73
Expected stock remainder	0	0	0

Table 1: Results table in the ideal context

Considering Table 1, it is interesting to note that in the stock-out ideal scenario, there is no overstocking, which would theoretically perpetuate the cycle in a steady flow of demand in the upstream supply chain. The addition of the S30 scenario creates a small overstock in the extractor agent since, despite receiving the exact information, there is an incentive to have a higher-than-necessary stock to compensate for the risk of receiving a fine.

4.1.2. Real Context Analysis

Table 2 displays the main results for the real context. By adding uncertainty modeling for the choice of the second value to be delivered z_F^E subject to the delivery of z_I^E, a better solution can be achieved despite the inappropriate behavior of the Manufacturer. In this context, the modeling becomes robust to the adverse effects of imprecise information flow in the supply chain. This situation derives from the opportunity for the extractor to sell more than the manufacturer needs.

DOI: 10.59254/sbpo-2024-193870
https://proceedings.science/p/193870?lang=pt-br

DDU Real Scenario	News-vendor	Manufacturer	Extractor
Total profit expectation	3,212	6,662	6,137
Profit I expectation	-804	-866	2,730
Profit F expectation	4,016	7,529	3,407
Order quantity	75	210	180
zI*	37	105	105
zF*	37	105	75
Expected stock remainder	0	60	0

Table 2: Results table in the real context

Based on the work of Zanddizari et al. [2019] where the relation between overstocking and the bullwhip effect was demonstrated as causation of overstocking, it can be stated by analyzing Tables 1 & 2 that by reducing the variation of order quantity and the overall stocking of the supply chain from 60 ordered by the manufacturer to 0, the bullwhip effect is mitigated. Therefore, communication between the second-tier suppliers is an effective strategy to reduce the BWE, even without the collaboration of intermediate agents, since without the information, the manufacturer would have overstocked. Another interesting observation regarding the results is the increase in profit originated from the increase in demand ordered by the manufacturer. Furthermore, note that the newspaper demand is constant, implying that the expected profit of the Manufacturer is inflated. In reality, the manufacturer will not realize the expected gains once the first cycle is implemented. Due to the DDU strategy, the manufacturer will not suffer the ill effects of the overestimation of demand. This way, the supply chain as a whole is more resilient. If the cash-flow constraint were ignored or the extractor complied with the manufacturer's order, the supply chain would suffer from a financial bullwhip effect and propagate the demand distortion.

5. Two supplier formulation

5.0.1. Competition Context Analysis

As previously stated, the competition problem is infeasible due to the cash-flow constraint imposed on the extractor problem since Extractor A is motivated to realize as much demand as possible in z_I^A frustrating the steady cash-flow of resources and also condemning Extractor B to realize the overestimated demand of the manufacturer to survive, leading to an order skip in the next cycle.

5.0.2. Coopetition Context Analysis

For the coopetition context, we assume the following setup: $q^A = 45$, $c^A = 10$, $S_0^T = 0$, $CF^A = 250$, $q^B = 60$, $c^B = 10$, $CF^B = 250$, $m = 4.5$, $b^A = 4$. The main results are displayed in Table 3.

Coopetition	News-vendor	Manufacturer	Extractor-A	Extractor B
Total profit expectation	3,212	6,662	4363	765
Profit I expectation	-804	-866	1983	250
Profit F expectation	3,999	5,357	2,380	515
Order quantity	75	210	144	36
zI*	37	105	86	19
zF*	37	105	58	17
Expected stock remainder	0	60	0	0

Table 3: Results table in the coopetition context

DOI: 10.59254/sbpo-2024-193870
https://proceedings.science/p/193870?lang=pt-br

Note that the manufacturer's expected outcome will not be realized since the delivery of raw material is the sum of the extractors. Thus, it was demonstrated that by modeling the supply chain using a 4-stage DDU framework, with information sharing from the News Vendor, a coopetition context not only dissipates the bullwhip effect but also finds a stable equilibrium, maintaining a stable cash flow and induces higher resilience to the supply chain.

6. Conclusion and future works

This work successfully:

- Proposed a local DDU formulation of a fractional delivery order quantity problem.
- Showed the effectiveness of DDU in mitigating the bullwhip effect through second-tier supplier communication.
- Used DDU as a multi-stage formulation for coopetition problems, enabling an equilibrium solution, otherwise impossible in traditional order quantity problems.

As future works develop, the development of price decisions before each round and more agents to allow for different possibilities of collaboration throughout the supply chain would be an interesting development. A cash-flow threshold variable would also be interesting. This way, it would simulate the capacity of agents to sustain iterative unprofitable rounds before going bankrupt and how this factor impacts competitors and overall resilience.

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