Playing with DISASTER: A Blockchain-Enabled Supply Chain Simulation Platform for Studying Shortages and the Competition for Scarce Resources

Daniel Hellwig, Kai Wendt, Volodymyr Babich, and Arnd Huchzermeier

Abstract This chapter explores the potential of distributed ledger technology (DLT) in addressing supply chain shortages and competition for scarce resources. Specifically, we assess the effect of strategic information sharing on supply chain efficiency and the creation of virtual markets to improve supply chain performance. To facilitate this research, we designed a simulation platform called DISASTER (DLT In Sourcing And Strategic Trading Experimental Research), which hosts web-based, dynamic, and customizable supply chain simulations that leverage concepts of blockchain technology, and permit capturing of information regarding players' ordering strategies and behavioral traits.

In this chapter, we describe the DISASTER platform and discuss two selected DISASTER simulations that probe supply chain retailers' order behavior: the first investigates the role of information sharing among competing retailers; the second allows for the trading of tokens among competing retailers. In the first simulation, we find that decision makers act more strategically and closer to Nash equilibrium predictions as more information about historical orders of competitors is shared; however, the observed outcome is not invariably an improvement in efficiency as measured by profits across participants. In the second simulation, we observe that initial order quantities remain unchanged as compared to the baseline (non-trading) scenario, despite the possibility to trade on virtual markets; however, over time, more equitable distribution of inventory is achieved, and the supply chain efficiency as measured by profits increases.

Our findings highlight the value of empirical research and management games in shedding light on the role of decision makers' behavioral characteristics and inves-

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tigating real-life supply chain challenges and the potential of adopting blockchain-specific capabilities in that space.

Keywords Supply chain shortages · Blockchain technology · Information sharing · Virtual markets · Behavioral operations management

1 Introduction

In a business-as-usual state of the world, supply chains are not typically the center of top-management and popular media attention. However, a stream of recent crises has changed that. The scope, intensity, and duration of supply chain problems are unprecedented and pervasive: shortages, delays, higher prices, and panic buying have affected numerous industries. To list just a few examples, in 2020 and 2021, the world experienced shortages of medical ventilators, personal protective equipment, toilet paper, baker's yeast, pasta, lumber, furniture, pet food, and toys. Consequences of the global microchip shortage are still accruing, but the automotive industry estimates that 2–3 million fewer vehicles were produced in 2021—a total sales loss of $210 billion (AlixPartners 2021; WEF 2021).

Although the centrality of supply chain operations has become increasingly salient to the broader public only recently, the operations management (OM) academic community and practitioners have long argued that supply chain management constitutes a decisive factor in business success (Cohen and Lee 2020). In particular, understanding the value of information sharing has long been a focus of OM research. In the context of the bullwhip effect (BWE), or the demand distortion that travels upstream in supply chains, theoretical and empirical OM literature has shown that sharing demand information can be valuable in reducing the BWE stemming from signal processing causes and in improving supply chain performance (Cohen and Kouvelis 2020). In a similar context, Morris Cohen and colleagues Terwiesch et al. (2005) and Ren et al. (2009) explore the effects on supply chain performance of buyers and sellers being given unreliable information.

Extending ideas in Babich and Hilary (2019, 2020, 2022) and Hellwig et al. (2020), we argue that distributed ledger technology (DLT), specifically, blockchain, can facilitate both the trustless sharing of information in supply chains and the creation of virtual markets to enable a more efficient allocation of scarce supplies. First, blockchain is designed to allow for information sharing among multiple parties while ensuring both trustworthiness and (if needed) anonymity, thereby mitigating key concerns that have thus far limited the willingness of supply chain stakeholders to partake in information sharing. Second, blockchain enables the creation of digital tokens, which can represent unique and secure digital claims on assets and capacities in supply chains. Such tokens enable virtual markets in which supply chain resources can be traded. While the theory and practice of economics and finance highlight the role of markets in achieving efficient resource allocation, such markets have yet to be created and established for all products that flow through supply chains. Indeed, the volume for some products is not sufficient for traditional financial intermediaries to operate respective markets. By eliminating the need for financial intermediaries, blockchain technology can reduce the setup costs for such markets, thus helping to establish markets for less liquid assets. This will allow for the trading of supply chain inventory, thereby yielding a better match between demand and supply in dynamic systems.

To facilitate the investigation of the role of trustless information sharing in supply chains and the creation of virtual markets to improve supply chain performance, we designed a supply chain simulation platform called Distributed ledger technology In Sourcing And Strategic Trading Experience Research (DISASTER). In addition to behavioral experiments, the platform enables classroom and industry learning experiences about challenges arising in real-life supply chain and exploration of the benefits of adopting blockchain technology. Note that it is the concepts rather than the technology of blockchain and digital tokens that are applied in the simulation; nonetheless the functionalities embedded capture key features of how such markets could operate based on blockchain technology in a practical setting.

In this chapter, we describe the DISASTER platform and illustrate its use with two simulations: (i) information sharing among retailers competing for scarce supply and (ii) trading tokens on supplier's capacity between retailers when facing demand uncertainty. In the first simulation, we find that sharing selective competitive information may leave the supply chain worse off; this result is counterintuitive, as supply chain managers are expected to prefer more to less information. In the second simulation, our results demonstrate that initial orders to the supplier remain largely unchanged despite the possibility to trade on virtual markets. This is a surprising finding when compared to the empirical evidence provided by the transshipment literature, which shows that when inventory can be exchanged, post demand realization, orders tend to regress to the mean demand (Katok and Villa 2021). In addition, more than 30% improvement in the evenness of inventory distribution, namely fewer instances of shortages or excess inventory, is achieved, thereby increasing overall supply chain profit by over 20%.

Hereafter, the chapter is organized as follows: in Sect. 2, we introduce the BWE and the role of sharing information about competitors' past orders and blockchain technology in ameliorating supply chain disruptions. Section 3 describes how the virtual markets enabled by blockchain technology can mitigate mismatches between supply and demand. In Sect. 4, we introduce our newly developed platform and illustrate its use with results from two simulation games, and conclude in Sect. 5 with a summary of our contributions and main findings.

2 The Bullwhip Effect and Information Sharing

The BWE describes the phenomenon of greater variance in orders that a company places, as compared with the variance in demand that the company observes. Thus, uncertainty about orders tends to increase as one moves upstream in the supply chain (Lee et al. 1997), making it more difficult to manage supply chains and rising costs. Lee et al. (1997) authored a seminal paper that explains the causes of the BWE and proposes solutions. The authors identified four causes of the BWE: (i) demand signal processing, (ii) rationing games, (iii) order batching, and (iv) price variation. For instance, Baganha and Cohen (1998) discuss empirical observations and results from management games that illustrate the BWE and identify sufficient conditions for multi-echelon inventory policies to reduce this effect. An extensive literature follows this work; for a review, see Wang and Disney (2016).

The management game typically used to illustrate the BWE is the Beer Distribution Game, invented in 1960 by Jay Wright Forrester at MIT and analyzed in detail by Sterman (1989b). This game models operations of a serial supply chain in which, unlike the retailer, players representing other companies (wholesaler, manufacturer, and supplier) have no knowledge of final consumer demand and, moreover, are unable to coordinate their actions with each other—even though their objective is to minimize the total supply chain cost. The Beer Distribution Game is a popular teaching tool and exists in many incarnations; however, it does not permit the analysis of causes of the bullwhip effect that can arise only in non-serial supply chains, such as shortage gaming, which arises when a supplier must decide how to allocate scarce supply among buyers who attempt to manipulate the supplier's decision through their orders. Shortage gaming leads to irrational ordering and buying behaviors and has frequently been observed in global supply chains during the COVID-19 pandemic; the platform we created focuses on that aspect of the BWE.

2.1 Shortage Gaming

Supplier's allocation rules have been extensively researched from a theoretical perspective. For example, Cohen et al. (1986) analyze the optimal order and allocation policies for a multi-echelon inventory system; however, they do not directly link their results to shortages. In subsequent research, Cachon and Lariviere (1999) focus on shortages and show that, in equilibrium, if supply is scarce—and suppliers use the proportional allocation rule—then retailers inflate orders as much as possible.

Experimental research reports human behavior, which can contribute substantially to the BWE, that differs appreciably from theory (Chen et al. 2012; Cui and Zhang 2018). For instance, Croson and Donohue (2006) demonstrate that supply chain inefficiencies, such as the BWE, are present even when operational issues such as supply shortage, demand estimation, and price variation have been eliminated, the reason being that decision makers' suboptimal behavior can be a major driver of suboptimal supply chain performance. In this context, a wide range of behavioral characteristics—divergence in cultural norms, cognitive capacity, and risk preferences as well as biases such as anchoring—have been identified in the field of OM (for an overview, see, e.g., Katok et al. 2018; Fahimnia et al. 2019).

At the same time, managers tasked with decision-making, especially in crisis situations such as facing supply shortages, tend to favor the availability of information because it enables them to calibrate their actions more appropriately. Along these lines, the existing literature stresses that sharing information can facilitate both reducing the BWE and improving supply chain performance (Lotfi et al. 2013; Cohen and Kouvelis 2020). It is noteworthy that the behaviors inducing volatility across supply chains (e.g., decision bias and over-reaction to fluctuations) are also dampened via information-sharing initiatives (Croson and Donohue 2006).

Despite these advantages of information sharing that have been identified in the literature, most practical approaches to alleviating information distortion have been met with limited success, largely because of the desire to maintain a competitive advantage, confidentiality concerns, and questions about the reliability, accuracy, and timing of available information (Lotfi et al. 2013). We propose that blockchain technology can address these concerns and thus facilitate the sharing of information.

2.2 *How Blockchain Can Help*

It is common for organizations to operate their own information technology (IT) systems, which do not directly interface with the IT systems of other companies. Posting data on public outlets raises concerns about sharing strategic secrets, violating customers' privacy, and losing control over the use of that data. In addition, leveraging such data is complicated by reservations regarding their availability and validity, which can arise either from initially incorrect records or from hacking and data manipulation after the fact.

Blockchain technology facilitates the decentralized sharing of information with multiple parties (Hellwig et al. 2020). Tamper-proof permanent recording of data on the blockchain ensures trustworthiness: records cannot be altered, and participants can remain anonymous. The cryptographic mechanisms incorporated in the blockchain protocol help protect this anonymity while simultaneously allowing building a reputation based on participants' behaviors. In addition, fully homomorphic encryption (FHE), which can be added to blockchain solutions, makes it possible to perform computations on encrypted records. This feature enables the derivation of summary statistics from encrypted data which, when decrypted, will match the result as if they had been performed on the non-encrypted data in the first place (Hellwig and Huchzermeier 2022). For instance, the average aggregated data from a group of supply chain parties can be shared without revealing any information about the individual stakeholders to their competition.

These prospects have motivated scholars to investigate the potential of information sharing that leverages blockchain technology to improve supply chain performance (Babich and Hilary 2019). For instance, van Engelenburg et al. (2018) propose a conceptual blockchain architecture to reduce information asymmetry, thereby reducing the BWE while protecting sensitive data. Xue et al. (2020) similarly describe a decentralized blockchain-driven supply chain design to address those untimely and distorted information exchanges that can lead to increased order variance.

Given the advantages offered by blockchain, we hypothesize that using this technology to record and share selected information can improve supply chain performance and reduce the BWE's adverse consequences due to competition among retailers for scarce supply. To assess this proposal, we introduce the supply chain simulation game Information sharing among competitors, which is hosted on our DISASTER platform (Sect. 4.2.1).

3 Virtual Markets

3.1 Market Economics

Matching supply with demand is a challenge that prevails across industries. Even if ample supply is available upstream, stock-outs can occur at the local level because of demand variations and the unequal distribution of inventory. The significance of this issue is amplified when the supply shortages have severe implications. For example, pacemaker producers are scrambling for inventory and seeking priority over other industries in receiving microchips, amidst a global supply shortage of those components, to ensure continued production of their products (Roland 2021).

Markets that facilitate the efficient allocation of resources exist for only a select set of commodities; they do not exist for most goods in supply chains, although there are some approximate solutions: such as pooling inventory in one location and transshipments. Inventory pooling is however usually managed by a central planner in a supply chain, and transshipment strategies are typically restricted—vis-à-vis resolving the mismatch between demand and supply—by terms established prior to the realization of random shocks. Other disadvantages of transshipments, relative to inventory pooling are (i) inefficient operations due to double inventory handling and its accompanying risks, greater lead times, and higher costs; (ii) extensive coordination requirements between shipping and receiving parties; and (iii) the required disclosure of competitive information (e.g., inventory levels). OM research on both topics is voluminous (e.g., for inventory pooling, see Federgruen and Zipkin 1984; Cohen et al. 1986; Deshpande et al. 2003; for transshipments, see Tagaras and Cohen 1992; Rudi et al. 2001; Katok and Villa 2021).

Markets present an opportunity to inject the efficiency of centralized inventory pooling into decentralized supply chain systems. For some products, however, the financial intermediaries that organize commodity exchanges do not find the scale of supply chains large enough to justify the fixed costs of creating and operating such markets. This is where a technology solution, such as blockchain, may be of value. Key questions that arise in this context include how much value such markets can create within the confines of individual supply chains and how will these markets affect incentives and investments as well as physical, financial, and informational flows.

3.2 How Blockchain Can Help

Blockchain enables the creation of digital tokens, which can represent any asset (e.g., currencies, loyalty points, capacities) that are fungible and tradable. Blockchain tokens can be categorized into currencies and tokens. Whereas a currency (e.g., Bitcoin) is usually native to its blockchain, a token leverages an already existing blockchain (e.g., Ethereum) and is built on top of it. Tokens are created via a so-called smart contract, which is a self-executing computer protocol; the process of converting the rights to an asset (e.g., claims on a supplier's capacity) into a digital token is called tokenization.

The combination of blockchain technology's core elements, namely digital tokens paired with a distributed ledger; a decentralized consensus mechanism, which ensures that temporarily divergent versions of the database converge; and cryptographic security measures enable the creation of a decentralized, virtual marketplace. Such features can ensure symmetric information as well as trust in the data and the trading process by providing transparent and valid records of historical transactions (Babich and Hilary 2019). These unique features can be leveraged to create a virtual market for trading tokens, which represent claims on suppliers' capacities among (competing) retailers. The distribution of inventory can thus be optimized prior to physical shipments, thereby facilitating more efficient operations may be achieved as compared with traditional transshipments.

To assess this market's potential for improving supply chain performance and to understand the behavioral implications for decision makers who are exposed to such a market, we leverage the supply chain simulation game Trading tokens among competing retailers that is hosted on the DISASTER platform (Sect. 4.2.2).

4 DISASTER: A Research Platform for Advanced Supply Chain Simulations

Morris Cohen identifies the considerable gap between managers' knowledge and their decisions (INFORMS 2004). Empirical research can shed light on human decision-making behaviors in the context of supply chain management. We therefore introduce purpose-built experimental research and learning platform, DISASTER,[1] that facilitates analyses of how blockchain-enabled information sharing and virtual markets affect supply chains efficiency. Researchers can associate behavioral traits of participants with their performance, allowing these connections to be subsequently analyzed. The DISASTER platform also enables classroom experience that facilitates industry learning about real-life supply chain issues and the potential for blockchain technology applications.

[1] www.disaster-game.com.

This section proceeds as follows. We start by describing the purpose and features of the DISASTER platform. We then describe two simulation games hosted on the platform and conclude by offering an outlook on future developments.

4.1 Purpose

Several platforms and software tools are available in the context of supply chain simulations and games. These can be grouped into two main categories: (i) generic platforms (e.g., z-Tree, oTree, SoPHIELabs) and (ii) supply chain-focused platforms and games (e.g., the Beer Distribution Game, Hunger Chain Game, Flower Game, Fathomd, Newsvendor Game). Existing generic platforms provide an excellent framework for developing simulations, including extensive libraries and communities, and are widely used. However, creating new simulations or customizing existing ones for specific scenarios requires dedicated research resources, a substantial time investment, and coding knowledge. Supply chain-focused platforms and dedicated games cover a wide range of supply chain topics that are well suited to conveying basic concepts and can be easily used in classrooms, but they are limited in their flexibility to adjust for purposes different from those considered in the initial design. (See Appendix A for an overview and assessment of several prominent platforms.)

Although numerous supply chain-focused games exist, none incorporates the features required for our inquiry into the role of blockchain technology for information sharing in supply chains. We have consequently designed a new platform, which has the following functional advantages:

1. Web-based interface; usable from any device with an Internet connection and a browser.
2. Self-contained (e.g., participant links, instructions, quizzes, behavioral questionnaires).
3. Library of ready-to-use "personal traits" questionnaires, including evaluation of its use; this library[2] can be continuously updated and enhanced by all collaborators.
4. Stable and secure data capture; data is saved in real time.
5. Close to zero latency; real-time interactions occur across all user interfaces (UIs), which allows for dynamic and interactive games.

Moreover, the platform differs from existing platforms in terms of the following four attributes:

1. A suite of pre-defined, ready-to-play supply chain simulation games use concepts of blockchain combined with advanced encryption and decryption technologies.

[2] See Appendix C for a list of questions used to assess behavioral characteristics.

2. Plug-and-play approach; UI-based game configuration (e.g., behavioral traits questionnaires, game design, instructions, parameters).
3. Open access of underlying data structure; no alignment with providers is required.
4. No coding skills are needed for adjustments (spreadsheet-based backend).

In short, the DISASTER platform is a new tool with applications in academic research, classroom teaching, and industry learning. The platform has already been successfully used by the authors for research, as well as hundreds of students in courses on operations management and blockchain technology and industry practitioners in Europe and the USA.

4.2 Simulation Games

In what follows, we describe two selected DISASTER games that probe retailers' ordering behaviors. (See Appendix B for a comparison of simulation games that focus on the BWE.) We use these games to illustrate the platform interface and the process of using the platform.

4.2.1 Information Sharing Among Competing Retailers

Description This game aims to research and to demonstrate (i) how using concepts of blockchain technology to record and share select buyer information affects supply chain performance and (ii) the potential of this technology to reduce the BWE's adverse consequences in cases of competition for scarce supplies.

Participants act as retailers in a supply chain that consists of one supplier (played by the system) and multiple retailers (Fig. 1). All retailers have the same demand, cost, and sales price conditions. In every round, participants are randomly matched; all interactions occur through the simulation interface. In each simulation round, participants decide on how many units to order from the supplier, anticipating supply shortages due to the orders of competing retailers while attempting to maximize their own firm's cumulative profit over 30 rounds. (See Appendix D for an example of the simulation instructions.)

Four scenarios are pre-defined, as summarized in Table 1. In the baseline Scenario 1, participants have no information about the order history of other retailers against whom they are playing in each period; these conditions emulate the traditional supply chain set-ups found in today's industries. In the remaining three scenarios, participants observe different levels of information provision/sharing. In Scenario 2, participants observe the average order of both retailers in the previous round; in Scenario 3, they observe the individual orders of both retailers in the previous round; and in Scenario 4, they observe the individual orders of both retailers over all previous rounds.

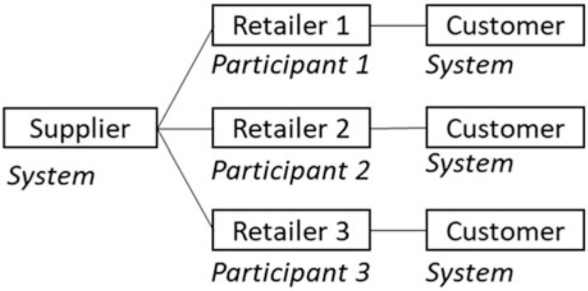


Fig. 1 Supply chain design of the Information sharing among competing retailers game

Table 1 Scenarios of the Information sharing among competing retailers game

Scenario	Information that participants observe	Blockchain application
1 (baseline)	No information about the order history of other retailers	• None (emulating traditional supply chain set-ups)
2	The average order of both retailers in the previous round	• Selected information is recorded on a distributed ledger, thereby building trust by design • Information is anonymized • Fully homomorphic encryption concepts are simulated by sharing aggregated statistics
3	The individual orders of both retailers in the previous round only	• Selected information is recorded on a distributed ledger, thereby building trust by design • Information is anonymized and traceable to individual actors, thereby a reputation is built
4	The individual orders of both retailers in all previous rounds	

This information is provided in a way that blockchain technology would enable in practice. Information is automatically recorded and anonymized, and it is always traceable to the individual entity (i.e., participants carry the history of their past decision even when matched with new players). In addition, features such as fully homographic encryption, which can be combined with blockchain technology—are simulated in the game by displaying the averages of past orders. This approach increases the individual firms' data protection as only aggregated and combined statistics are shown.

The results of each simulation run (e.g., average order per round, order variance, inventory shortages/excess, total profit) are automatically calculated and displayed to the game instructor. At this point, a discussion of how sharing past order information affects supply chain performance can be conducted based on participants' results.

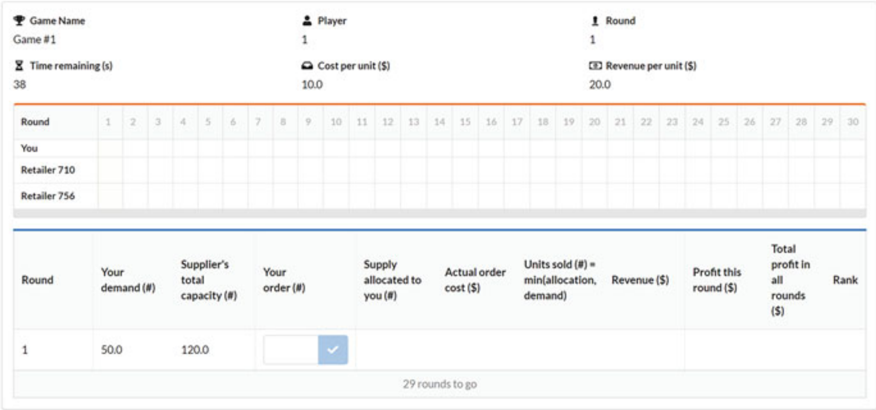


Fig. 2 Interface for order entry in the Information sharing among competing retailers game

User Interface Participants can access the game by clicking on the provided game link, which is automatically sent via a system-generated e-mail once the instructor has initiated the process. If activated, participants can be asked to read the game instructions and complete a readiness quiz prior to entering the simulation interface; following this procedure ensures that everyone understands the game and allows for a smooth simulation experience. Next, participants engage with an intuitive game interface that provides all the necessary information. Figure 2 depicts the scenario in which participants observe the individual orders of both competing retailers.

All displayed game parameters (e.g., number of rounds, time per round, number of players, cost, sales price) can be directly adjusted on the instructor's screen. After completing the game, participants can be asked to fill out a post-game questionnaire for the purpose of gathering additional feedback on the simulation—explicitly asking about the strategies participants applied during the game, testing their understanding of supply chain dynamics, and/or assessing behavioral characteristics through a pre-defined list of well-established questionnaires.

Results We used the DISASTER platform in several OM and blockchain technology courses and collected responses from hundreds of student participants, who were divided into four groups based on the type of historical information available to them when making ordering decisions. Results of these simulation games are shown in Fig. 3, which plots the average order per round placed by the participants. There are four scenarios, as described in Table 1. The control/baseline group (blue line), which has no information about competing retailers' behavior, namely, emulating the traditional supply chain set-ups without the application of blockchain technology demonstrates by far the slowest order inflation over time. When the average order of both retailers in the last round (orange line) or the entire order history (yellow line) is known (simulating the blockchain application in which past order behaviors are automatically recorded, anonymized, and traceable), the graph reveals that orders

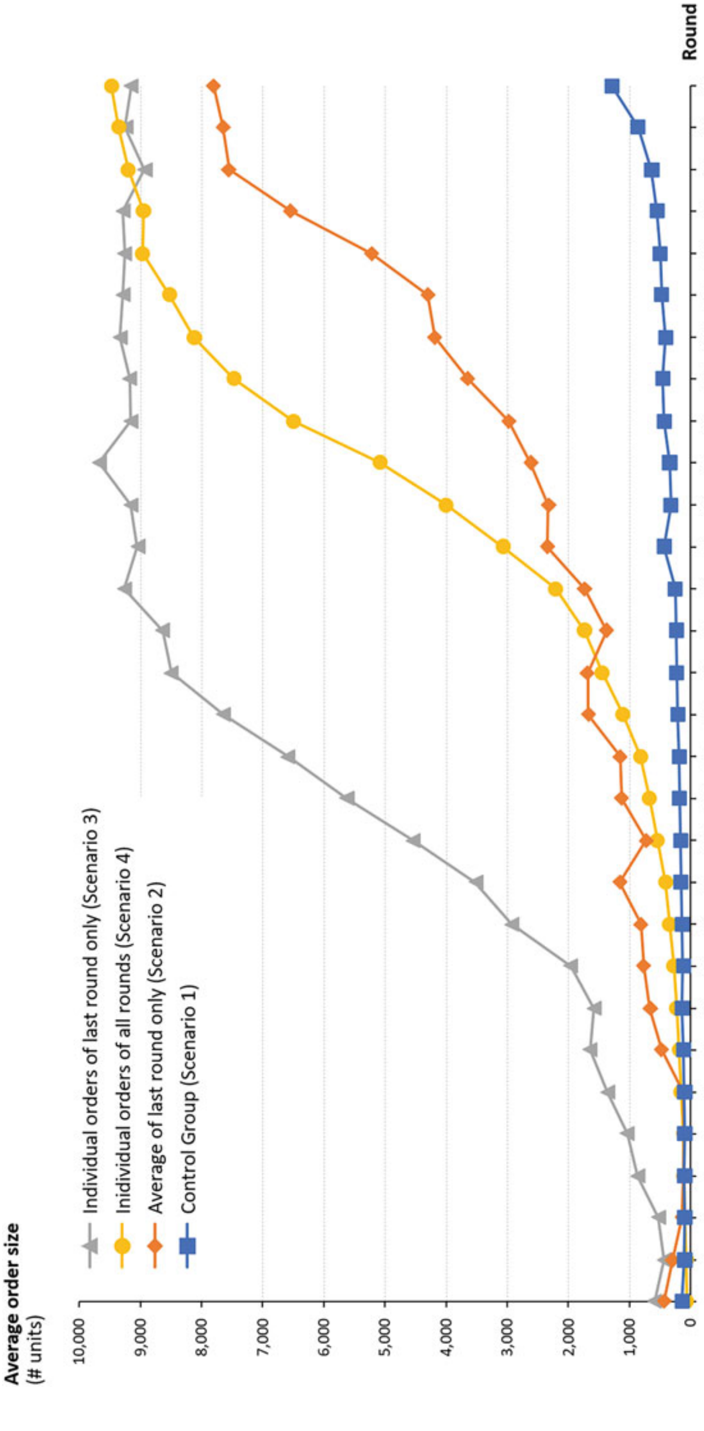


Fig. 3 Simulation results of the Information sharing among competing retailers game

inflate more rapidly. It is interesting that the fastest order inflation converging toward the Nash equilibrium is seen in the scenario under which the two competing retailers' individual orders are shared for only the last round (gray line).

In case of significant order inflation, as observed in scenarios 2–4, there is a disconnect between demand and orders. This is problematic because one would hope that orders not only convey important information to suppliers about downstream demand but also enable them to plan their capacities and resources appropriately. Suppliers often use received orders to allocate their available scarce supplies between customers.

When orders carry no demand information, suppliers are forced to rely on their own (often less accurate) market knowledge and must allocate supplies to customers based on historical and thus potentially outdated metrics. A detailed discussion of the drivers (e.g., behavioral characteristics) leading to such results is beyond the scope of this chapter. Yet the results and implications for academics, practitioners, and policymakers are surprising. The severe consequences of order inflation have been observed in many industries amid the COVID-19 pandemic.

In the absence of concerns such as the reliability, accuracy, and timing of available information, it seems reasonable at first sight to increase information sharing, since managers nearly always prefer more information to less (or no) information. Our results however demonstrate that opposite outcomes can occur: more information sharing does not invariably result in an improvement in efficiency as measured by profits across participants. These insights are relevant for academics, practitioners, and policy makers when designing DLT-based information sharing systems to anticipate potential downsides of sharing information among competing supply chain entities.

4.2.2 Trading Tokens Among Competing Retailers

Description The purpose of this game is to research to what extent demand–supply mismatches can be reduced, and supply chain performance improved, by creating a virtual market among retailers for trading tokens of a supplier's capacity. The tokens represent digital claims on assets and can be enabled by blockchain technology.

Much as in the game described in Sect. 4.2.1, participants act as retailers in a supply chain that consists of one supplier (played by the system) and multiple retailers. All interactions occur through the simulation interface. Two experimental scenarios were played. (For teaching purposes, scenarios can be played consecutively with the same group of participants.) In the baseline Scenario 1, participants must decide how many units to order from the supplier while anticipating uncertain demand and trying to maximize their firm's total profit (i.e., they solve the standard newsvendor problem). In Scenario 2, a virtual market is implemented whose design is based on features offered by blockchain technology. Namely, retailers order tokens of the supplier's capacity (as opposed to units of the product) and then have an opportunity to trade these tokens with each other anonymously while symmetric information as well as trust in the data and the trading process by providing transparent and valid records of historical transactions is ensured. This set-up guarantees that competitive information (e.g., a requested quantity, which may indicate the severeness of a shortage) is not disclosed.

The sequence of events is as follows. At the start, participants decide how many tokens to order from the supplier. All participants know the purchase cost of \$10 and the sales price, which is uniformly distributed between \$51 and \$100. Participants must anticipate uncertain demand, which is uniformly distributed between 0 units and 200 units. All retailers observe identical parameters, but the demand and sales price realizations are independent between retailers and across rounds. That is, retailers act in geographically distant/different markets and have different valuations for goods—a situation commonly observed across industries (as evidenced by different US states' willingness to pay for ventilators depending on the shortage severeness). Once demand has been realized, participants can perform trades with other retailers to buy or sell tokens by specifying the quantity and price; thus, they seek to maximize their respective firm's profits. The simulation lasts for 20 rounds. (See Appendix E for an example of the simulation instructions.)

The results of each simulation run (e.g., supply–demand match, total profits) are automatically calculated and displayed for the instructor. To illustrate the impact of adding the virtual market for trading tokens, results of the two scenarios can be plotted on the same graph.

User Interface This game is embedded in the same framework as the first one. Hence the instructor can again easily adjust game parameters, flexibly modify the game instructions, schedule a readiness quiz, and add post-game questions. The scenario that allows for trading tokens is split into three phases, as we shall describe from the participant's perspective. In the baseline scenario (i.e., standard newsvendor problem), only the first phase is played. The screen for the ordering phase (see Fig. 4) presents an intuitive interface providing all necessary information to place the order to the supplier; it also offers a "decision support calculator."

After placing their initial orders, players enter the trading phase (Fig. 5). In this phase, they submit trade orders to the system.

Finally, in the evaluation phase (Fig. 6), players can observe the outcome of their trading orders and the resulting cash flow.

Results Results from the baseline scenario are in line with the standard newsvendor literature, e.g., Bolton and Katok (2008). More specifically, we observe that (i) orders deviate from optimal solution and exhibit a significant pull-to-center effect and (ii) 30% of participants demonstrate demand-chasing behavior. In the trading scenario, initial orders to the supplier are similar to the baseline (non-trading) scenario. This is surprising given the empirical evidence provided by the transshipment literature indicating that when transshipments are allowed, orders tend to move toward the mean demand (Katok and Villa 2021). Players actively undertake trades with the other participants to increase their own profit, which yields a more than 30% improvement in the evenness of inventory distribution (i.e.,

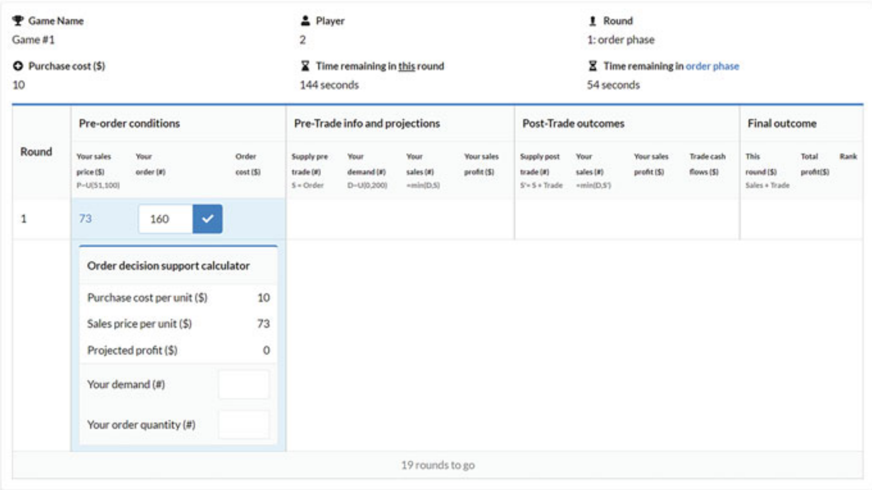


Fig. 4 Interface for initial orders of tokens in the Trading tokens among competing retailers game

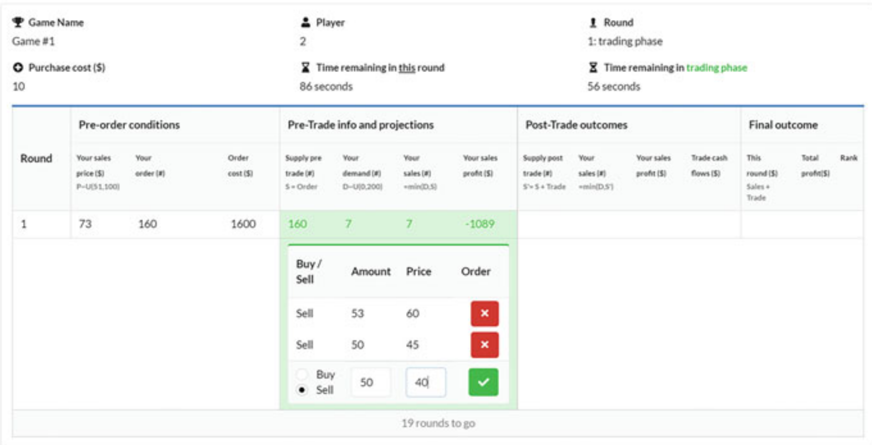


Fig. 5 Interface for trade submissions in the Trading tokens among competing retailers game

fewer instances of shortages or excess inventory) and an overall supply chain profit increase by over 20%. Over time, participants appear to improve their understanding of the market setup; thus, more successful trades tend to be placed toward the end of the simulation.

Our results demonstrate that via blockchain-enabled virtual market, which allows anonymous trading of tokens on supplier's capacity while ensuring symmetric information, trust in the data and transparency can be created and successfully harness the efficiency of centralized inventory pooling.

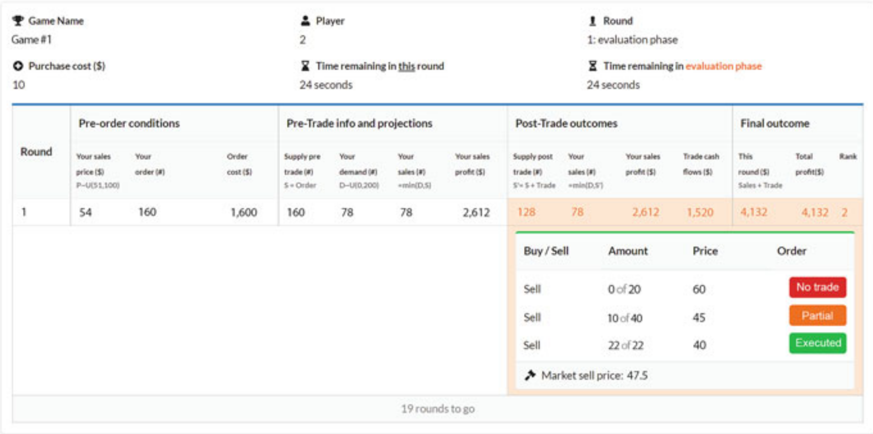


Fig. 6 Interface for review and evaluation in the Trading tokens among competing retailers game

4.3 *Ongoing and Planned Enhancements*

Two main development streams are ongoing to advance this platform further. First, additional games and scenarios are being developed to increase the number of use cases while leveraging concepts of blockchain and advanced encryption and decryption technologies in supply chains. For example: although the two games described here utilize different blockchain strengths (i.e., advanced information sharing and creation of virtual markets), a combination of both would yield additional intriguing research opportunities.

Second, we are developing the platform's backend. We are working on a blockchain-based data-handling solution (i.e., smart contract) to automate secure user data management and the collection and storage of data for research. This is a common concern for behavioral research simulations. The goal is to create a global, collaborative, and ever-growing simulation data pool that aggregates data from multiple simulations while fully complying with regulations on research on human subjects. That is, we intend to deploy blockchain to collect simulation data, ensuring anonymity and limiting access to participants' identifying information (according to IRB[3] requirements) while allowing participants to withdraw their consent to use the data they generate for research purposes, even after the data have been recorded to comply with GDPR, see GDPR (2022). Such a collaborative approach across institutions will create a powerful database, enabling novel insights for the OM community and beyond.

[3] Institutional Review Board, a committee responsible for the review of research involving human subjects.

A transparent, verifiably anonymous process for collecting user performance data on a blockchain ledger will allow analyses of larger samples than any single researcher can collect, and it will benefit the process of knowledge creation while preserving participants' anonymity and complying with applicable laws and regulations. To facilitate the distribution of rewards for participation in the simulation, an automated reward process is being developed to anonymously pay subjects in cryptocurrency via blockchain. All features are developed to ease usage of the platform by researchers and instructors and to improve the experience of all participants.

5 Conclusion

This chapter describes the potential roles of DLT for addressing supply chain shortages and competition for scarce resources via enhanced information sharing capabilities and controls. We introduce a novel blockchain-enabled supply chain simulation platform called DISASTER that compares favorably with existing solutions owing to several attractive features; these include ready-to-use and highly customizable supply chain simulations that leverage concepts of blockchain and encryption technologies.

By way of demonstration, we describe two simulation games hosted on the DISASTER platform that probe supply chain retailers' order behavior: the first investigates the role of information sharing among competing retailers, specifically during supply chain shortages such as those observed during the COVID-19 pandemic. We find that decision makers act more strategically and more closely to Nash equilibrium predictions when information about historical orders of competitors is shared. The attendant increased order inflation has adverse consequences, such as suppliers' inability to plan capacities or allocate resources appropriately. Whereas more information sharing is commonly desired by managers, especially when concerns such as the reliability, accuracy, and timing of available information are eliminated by a technology such as blockchain, our results demonstrate its potential downsides. The second game enables the study of a virtual market on which tokens of supplier's capacity can be traded among competing retailers. These tokens can be enabled by blockchain technology in practice. We observe that initial order quantities are similar irrespectively of the possibility to trade as well as a markedly more equitable distribution of inventory, resulting in an increase in supply chain efficiency as measured by an increase in total profit across retailers.

Given its easy-to-adjust game set-up and the inclusion of behavioral assessments, the DISASTER platform enables classroom and industry learning experiences about real-life supply chain issues and blockchain technology. More generally, this platform provides insight into how blockchain technology can affect supply chain performance and on the role of decision makers' behavioral characteristics via enhanced information sharing capabilities.

Appendix

A. Comparison of Existing Platforms

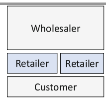
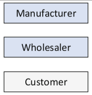
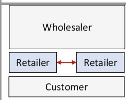
	Generic platforms			Supply chain-focused platforms	
	z-Tree	oTree	SoPHIELabs	Fathomd	DISASTER
Description	Software package for programming experiments	Online software for programming experiments	Experiment platform focusing on economic and psychology experiments	Game platform in operations management	Experiment and research platform focusing on advanced supply chain simulations
Offering	Software package to program own experiment	Software platform to develop experiments	Modular-based platform to develop own games	Off-the-shelf operations management games	Off-the-shelf advanced supply chain games leveraging concepts of blockchain and encryption technologies
Access	On request; software to be downloaded	Open source	On request	On request; game usage only	On request; game usage only
Fee model	Free of charge; academia to cite paper, others on request	Free of charge; cite paper	Pay for usage	Subscription fee per student for academia; others on request	Free of charge; cite paper
Data	Self-generated data only	Self-generated data only	Self-generated data only	Self-generated data only	Self-generated data and anonymized data pool
Customization	Requires coding knowledge (C++)	Requires coding knowledge (Python)	Requires coding knowledge (Python)	In collaboration with developers	Freely customizable Excel-based backend; UI changes in collaboration with developers
Features	Library of example games and code snips	Library of basic games and source code; Integration with Amazon Turk	Modular; add-ons and lab management solutions	Library of basic supply chain games	Library of ready-to-use personal traits questionnaires

(continued)

	Generic platforms			Supply chain-focused platforms	
	z-Tree	oTree	SoPHIELabs	Fathomd	DISASTER
Features	Library of example games and code snips	Library of basic games and source code; Integration with Amazon Turk	Modular; add-ons and lab management solutions	Library of basic supply chain games	Library of ready-to-use personal traits questionnaires
Advantages	Widely used; community and manuals available	Large online community (GitHub)	Technical support and training available	Basic supply chain games are ready to play	Advanced supply chain games are ready to play and easy to customize; flexible adjustments of parameters

Note. Information regarding z-Tree is from *Zurich Toolbox for Readymade Economic Experiments*, by z-Tree—Zurich Toolbox for Readymade Economic Experiments (2022) (https://www.ztree.uzh.ch/en.html). Copyright 2021 by University of Zurich. Information regarding oTree is from *oTree*, by oTree (2022) (http://www.otree.org/). Copyright 2022 by oTree team. Information regarding SoPHIELabs is from *SoPHIELabs*, by SoPHIELabs GmbH (2022) (https://www.sophielabs.com/). Copyright 2022 by SoPHIELabs team. Information regarding Fathomd is from *Fathomd*, by Fathomd, Inc. (2022) (https://www.fathomd.com/). Copyright 2022 by Fathomd, Inc.

B. Comparison of BWE Simulation Games

	Beer distribution game	Hunger chain game	Forecast sharing game	DISASTER Game I: Information sharing among competitors	DISASTER Game II: Trading tokens among competing retailers
Concept	Information sharing in serial supply chain	Competition for limited supply	Sharing forecast information between two parties	Information sharing among retailers competing for limited supply	Trading of tokens to match supply and demand under uncertainty
Supply chain design					
Learning objectives	Experience and understand how lack of information and limited visibility of orders leads to the BWE; learn mitigation strategies for reducing the BWE	Experience and understand the impact of competition for limited supply (panic ordering, hoarding); learn how scarce supply can be allocated fairly	Understand the role of forecast sharing, incentives, contracts, and trust in supply chains	Understand the role, importance, and impact of blockchain-enabled information sharing on supply chain performance when supply is scarce	Understand how the trading of tokens of suppliers' capacity, as enabled by blockchain, can affect supply chain performance under demand uncertainty
Outcomes	Over-reaction to small demand fluctuations, reduced supply chain performance, higher costs	Order inflation and uncoordinated supply chain	Trust and trustworthiness (i.e., limited forecast inflation and limited discounting) lead to improved supply chain performance	Faster order inflation toward Nash equilibrium as information is shared	If trading is enabled, then initial order quantities are reduced and supply chain performance improves

(continued)

	Beer distribution game	Hunger chain game	Forecast sharing game	DISASTER Game I: Information sharing among competitors	DISASTER Game II: Trading tokens among competing retailers
Duration	ca. 1–5 h	ca. 1–2 h	ca. 1–2 h	ca. 1–2 h	ca. 1–2 h
Providers	Multiple	Rutgers Business School	Fathomd	Authors	Authors

Note. Information regarding Beer Distribution Game is from *Flight Simulators for Management Education "The Beer Game,"* by Sterman (1989a) (https://web.mit.edu/jsterman/www/SDG/beergame.html). Information regarding Hunger Chain Game is from *Games and Experiential Learning in Supply Chain Management*, by Zhao (2022) (http://zhao.rutgers.edu/Games-Hunger-Chain.pdf). Information regarding Forecast Sharing Game is from *Fathomd*, by Fathomd, Inc. (2022) (https://www.fathomd.com/). Copyright 2022 by Fathomd, Inc.

Trade System Player

C. List of Pre-defined Questions[4] for Eliciting Behavioral Characteristics

Characteristic	Measurement instrument	Reference
Ambiguity aversion	Willingness to pay (WTP) game	Fox and Tversky (1995) and Halevy (2007)
Cognitive abilities	Cognitive Reflection Test (CRT)	Frederick (2005)
Fairness (inequality aversion)	(Hypothetical) Dictator game questionnaire	Forsythe et al. (1994), Fehr and Schmidt (1999) and van Damme et al. (2014)
Loss aversion	Lottery choice task Willingness to accept (WTA) game Willingness to purchase (WTP) game	Kahneman and Tversky (1979), Fehr and Goette (2007) and Gächter et al. (2021)
Positive reciprocity	(Hypothetical) Investment game questionnaire	Berg et al. (1995), Cox (2004), Cooper and Kagel (2016) and Falk et al. (2016)
Negative reciprocity	(Hypothetical) Ultimatum game questionnaire	Forsythe et al. (1994), van Damme et al. (2014) and Falk et al. (2016)
Overconfidence	Questionnaire	Russo and Schoemaker (1992)
Risk preferences	Multiple price list method DOSPERT questionnaire	Holt and Laury (2002) and Blais and Weber (2006)
Trust and trustworthiness	Questionnaire Investment game	Berg et al. (1995), Mayer and Davis (1999) and Falk et al. (2016)

D. Simulation Instructions for the Information Sharing Among Competing Retailers Game (Scenarios 2–4)

Step 1: Past order observation

You can observe the past order(s) of the other two players against whom you are playing in the current round. Similarly, your past order(s) is (are) visible to the players in your group.

Step 2: Order submission

[4] Questions can be added to the underlying spreadsheet with a fast and easy plug-and-play approach

For your order, you can choose an integer number between 0 and 10,000 units.

Once you have submitted your order, you cannot change it.

Step 3: Supplier stock allocation and cost

The supplier has 120 units available in total, which are divided among all three retailers in your group.

The allocation is determined as follows.

(a) The system calculates the total order received from the retailers (i.e., the sum of your order and the orders from the other two retailers).
(b) If the total order is less than or equal to 120, you will receive the number of units you ordered.
(c) If the total order is greater than 120, you will receive:
Your allocation = (your order/total order) $\times$ 120

Please note that you may receive fractions (decimals) of units.

For example,

- If you order 60 units and the total order from all retailers in your group is 110, then you will receive 60 units. The other two retailers will receive 50 units in total.
- If you order 60 units and the total order from all retailers in your group is 150, then you will receive 48 units [=(60 $\div$ 150) $\times$ 120]. The other two retailers will receive 72 units in total.

The order cost is $10 per unit. The order cost applies only to units you receive. So, for example, if you receive 60 units then your order cost would be $600 but if you receive just 48 units then your order cost would be $480.

Step 4: Sales and revenues

The number of units you sell is equal to the minimum of (i) the demand from your customers (50 units) and (ii) your supply, or the number of units allocated to you by the supplier (as described in Step 3).

Unsold items are discarded at the end of the round; they are not carried over to the next round. Unsatisfied demand is lost and cannot be backlogged to the next round.

For example,

- if the supplier allocated 40 units to you, then your sales are 40 units (=min(40, 50)) and the unsatisfied demand for 10 units is lost at the end of the round;
- if the supplier allocated 52 units to you, then your sales are 50 units (=min(52, 50)) and the leftover 2 units are lost at the end of the round.

Revenue amounts to $20 per unit. Therefore, if your sales are 40 units then your revenue is $800.

Step 5: Profit

Your profit per round = revenue per round – cost per round.

Your total profit over the entire simulation is the sum of profits per round.

E. Simulation Instructions for the Trading Tokens Among Competing Retailers Game

Step 1: Observation of your sales price for the current round

Observe the realization of your sales price, which is randomly drawn from the range of \$51 to \$100 per unit and with an equal likelihood of every integer value (a number without any decimals, such as \$51, \$63, \$95).

The sales price of other retailers is also randomly drawn from the range of \$51 to \$100 per unit.

Sales prices are independent between rounds and across retailers.

Step 2: Submit your order to the supplier

For your order, choose an integer number between 0 and 400 units.

You can use the simulation tool to support your decision on how many tokens to order from the supplier. This tool will provide you with the expected pre-trade profit after you enter your estimated demand and specified order quantity.

Step 3: Demand realization

Your customer demand is randomly drawn from the range of 0 to 200 units, with an equal likelihood of every integer value (a number without any decimals, e.g., 13, 105, 186).

Other players face their own levels of customer demand (i.e., you are not competing for the same customers), which is also randomly drawn from the range of 0 to 200 units.

Customer demands are independent between rounds and across retailers.

Step 4: Cost, sales, and revenue

You can observe your pre-trade profit projection. If you do not submit any trading orders, then that projection would be your final profit in this round. The following text describes how the projected pre-trade profit is calculated.

The order cost is \$10 per token. For instance, if you order 130 tokens then your cost is \$1300.

The number of units you can sell to your customers is equal to the minimum of (i) the demand from your customers (see Step 3) and (ii) how many tokens of the supplier's capacity that you hold (see Step 2). Suppose, for example, that you hold 130 tokens and that your customer demand is 90 units; in that case, your potential sales quantity is 90 units (=min(130, 90)).

Your projected pre-trade revenue is equal to the sales price multiplied by the sales quantity. So if your sales price is \$60 and you sell 90 units, then your projected pre-trade revenue is \$5400.

Finally: Projected pre-trade profit = projected pre-trade revenue – order cost.

Step 5: Perform trades with other retailers in your group

You can change how many tokens you hold by trading with other retailers.

To trade, you specify whether you want to buy or sell tokens, the quantity, and the price. You can sell all tokens that you hold (even if you can then not fulfill your customer demand as the result). You can submit multiple trade orders per round, up to a maximum of five.

At the end of the trading period, the market clears given all orders that the retailers in your group have submitted.

Trading and market-clearing processes (see table below)

A. Sell orders are ranked in price from lowest to highest and buy orders in price from highest to lowest.
B. Units are matched in buy and sell orders whenever the buy price is greater than the sell price of the matched units.
C. The average of the lowest buy price and the highest sell price at which the last match happens is the market-clearing price: all buy orders pay this price and all sell orders receive this price.

Consider the following example. The steps just described are marked by A, B, and C in the table.

	Sell orders					Buy orders				
	Player	Time	Price per unit		Number of units	Player	Time	Price per unit		Number of units
	1	10:30:23	$51	A	14	2	10:30:40	$76	A	19
B	1	10:30:40	$53		21	3	10:30:23	$55		16
	1	10:30:15	$56		13	2	10:30:00	$54		21
	1	10:30:00	$60		6	3	10:30:15	$49		9

C Market clearing price = $54 = ($53 + $55) / 2

After the trading phase is completed, you sell to your customers using the new number of tokens you have.

This marks the end of the round, and the final profits for this round are then calculated. Your total profit over the entire simulation is the sum of profits per round.

Any unsold tokens are voided at the end of the round; they are not carried over to the next round.

Unsatisfied customer demand is lost, and it cannot be backlogged to the next round.

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