Playing with DISASTER: a Behavioral Simulation Platform of Supply Shortages, Competition for Supplier Capacity, Blockchain-enabled Strategic Information Sharing, and Markets for Capacity-Token Trading

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Sources

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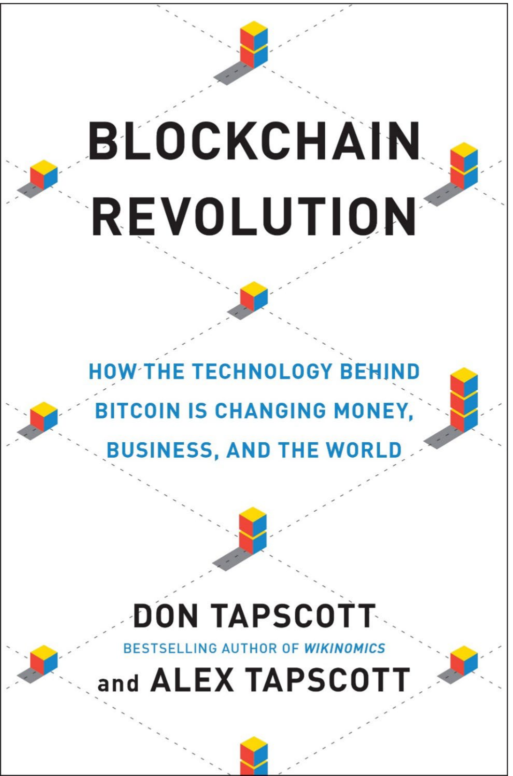
now
the essence of knowledge

Blockchain in SCM

Is it a revolution or hype?



Op-Ed

Blockchain: Is It All Hype?

Why we have not seen any major Blockchain uptake or usage.

Michel André | FinTech | Sunday, 27/12/2020 | 11:28 GMT+2

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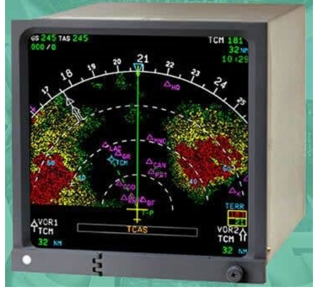
Blockchain in SCM

Current applications



1. Establish provenance and the chain of custody
   - Bumble Bee uses SAP blockchain to trace fish
   - Honeywell operates GoDirect marketplace for airplane parts, where part authenticity and ownership is recorded on blockchain
2. Provide proof of ethical and sustainable sourcing, fair trade practices
   - Everledger blockchain for diamonds stores image of Kimberley Process Certificates along with information about processes and chain of custody
   - Folger's FarmerConnect system for coffee. Verify ethical sourcing. Consumers can make donations that go directly to farmers (multi-tier financing)
3. Improve process efficiency, proof of ownership, asset tracking, and data generation
   - TradeLens---Joint venture between Maersk and IBM---hosts over 100 supply chain operators, accounting for almost ½ of all world ocean-freight data
   - The Tianjin Port blockchain pilot is used for confirmation of rights, certificates of bills, trading, finance, logistics, and supervision

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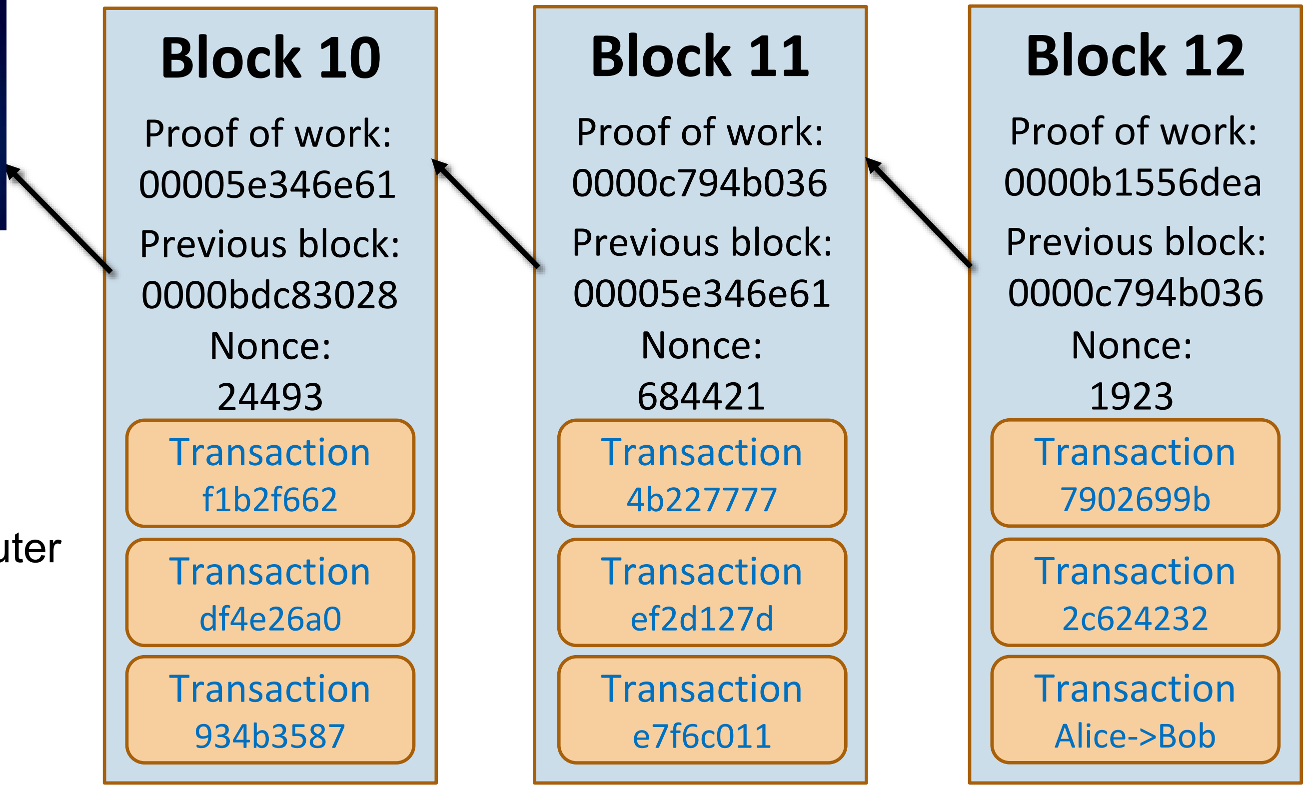
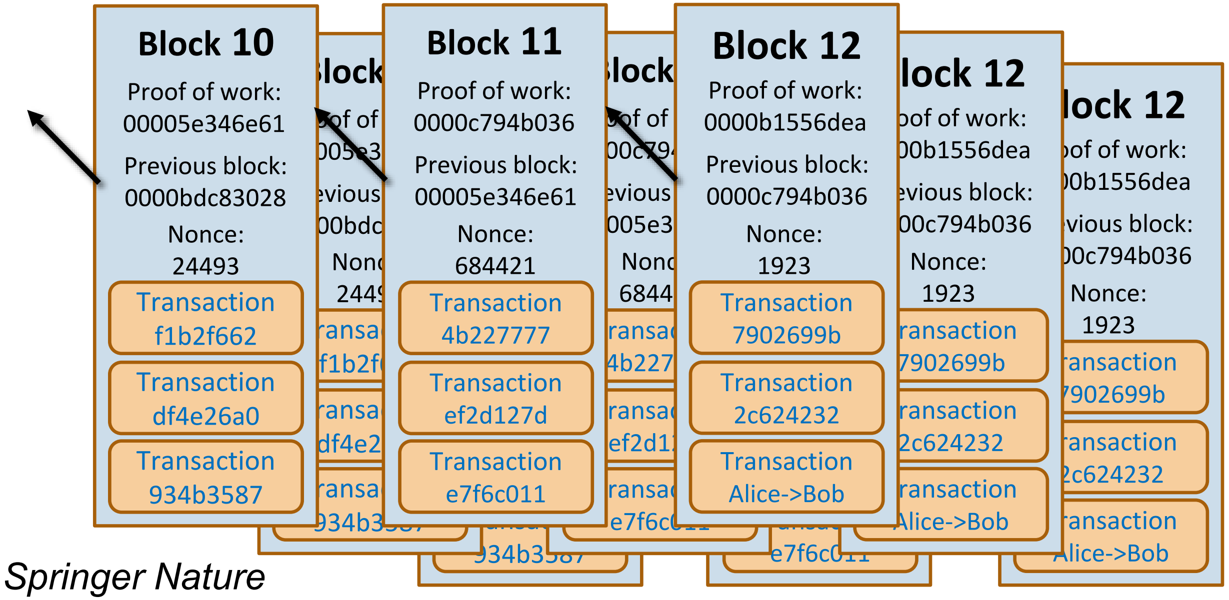
Blockchain core elements



What exactly is Blockchain?

- Distributed ledger
  - Database replicated on nodes of a peer-2-peer computer network
- Comprises cryptographically linked blocks
  - "Fingerprint" of a previous block is incorporated in a description of the current one
  - Information stored in blocks does not have to be encrypted
- Rules for appending, updating, and validating a ledger
- Consensus mechanism
  - Reconciling divergence between copies of the ledger across the network
- Incorruptible digital record of history



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Blockchain features for SCM

Many features. What is important?

- Tokens
  - Right to an asset (like NFTs but useful)
  - MyPower will issue tokens to investors based on the amount of solar power generated
- Smart contracts—pieces of executable software
  - Skuchain automates trade, financing, and other supply chain transactions

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5 + 5 strengths + weaknesses of BC in SCM

Neither a revolution nor hype

Strengths:

1. Trust in information

   Information is resistant to tempering

2. Increased visibility

   Observe transactions across multiple tiers/participants

3. Information aggregation

   Information from multiple sources, types, times

4. Process automation

   Execute transactions automatically

5. System resiliency

   System can continue to operate even if some nodes fail

Weaknesses:

1. Garbage in, garbage out

   Incorrect information may be entered, physical reality may change after information has been entered

2. Lack of privacy

   Personal records can be visible, competitive info leaks

3. Lack of standardization

   Myriad of different protocols, technological uncertainty

4. Black box effect

   Users must trust the integrity of the process without understanding technology

5. Inefficiency

   Transactions can be slow record and process, requiring greater computing power

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Blockchain future applications and research opportunities

Research Themes

- Information
- Tokenization
- Automation

- Tokenizing and trading of supply chain assets
- Managing the Bullwhip Effect
- Consumer choices with granular SC data
- SC automation and commitments
- Supply Chain Risk Management
- Ethical, sustainable, and responsible (ESR) operations
- Crisis management
- Supply Chain Finance
- Economics of information, contracts, and governance
- Industrial organization of Blockchain

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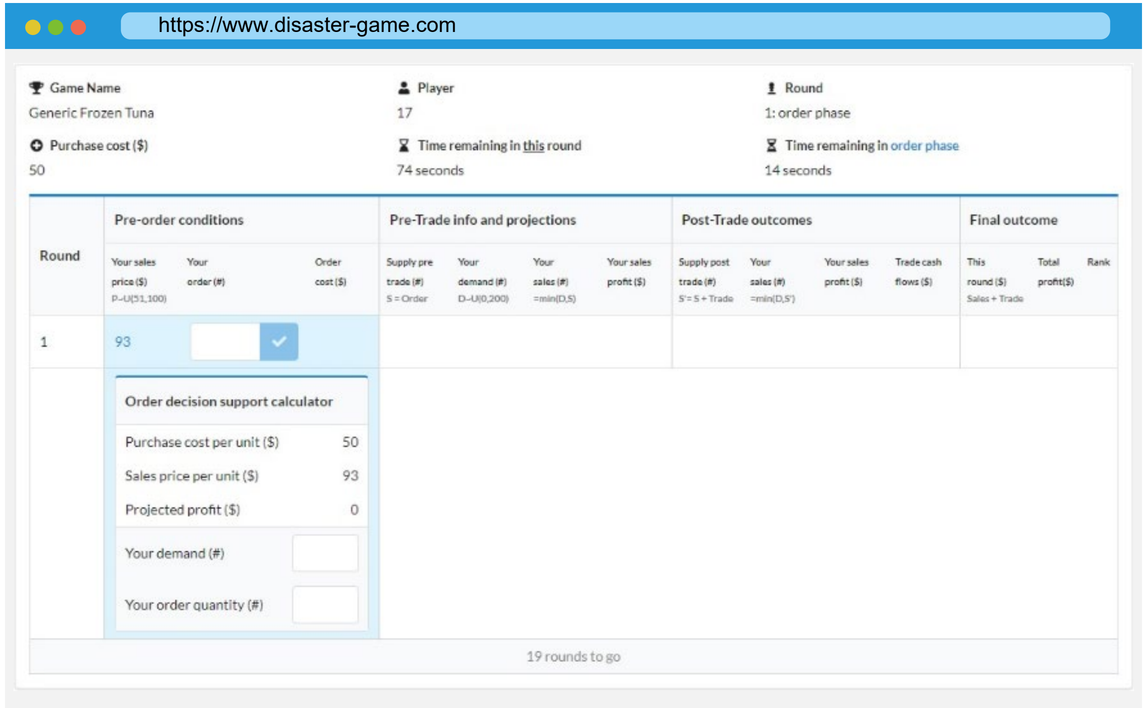
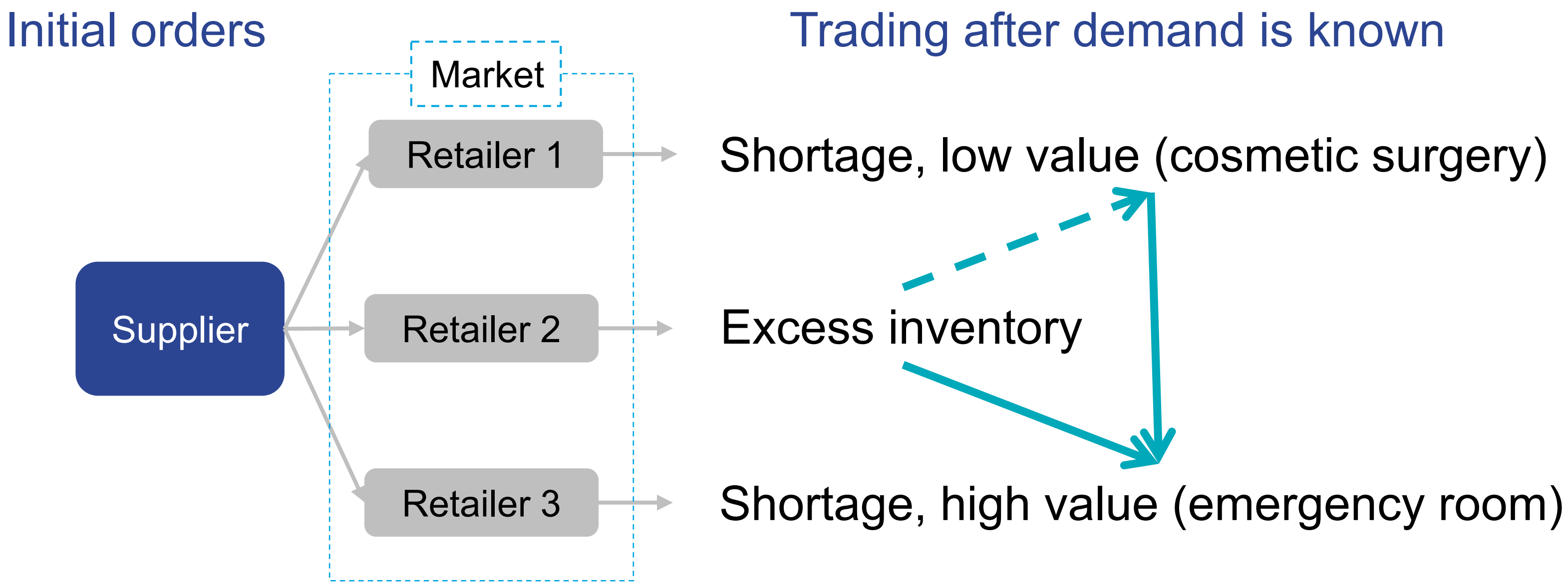
DISASTER platform

Description

- **A web-based platform for advanced supply chain simulation games** which uses concepts of **blockchain combined with advanced encryption technologies** for information sharing and token-based trading
- **DISASTER enables research and engaging learning experiences** about real-life supply chain issues and the potential of adopting blockchain technology
- **DISASTER facilitates the collection of players' behavioral traits** as well as information regarding their ordering and trading strategies

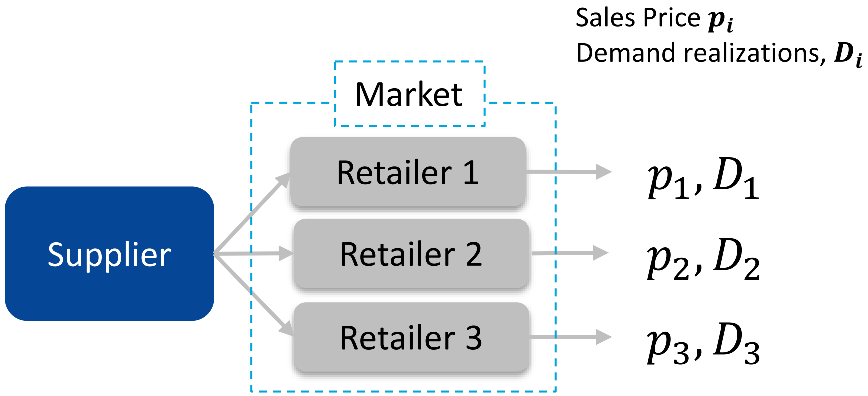


Behavioral Simulation of Blockchain-enabled Market for Supplier Capacity Trading among Retailers



Sources: disaster-game.com
Hellwig D, Wendt K, Babich V, Huchzermeier A (2022)

Markets



Markets promise

- Efficient allocation
- Signal of value through prices

Wheat Futures (Sept 2022), CBOT

Markets are costly to setup and operate

- Verify ownership claims
- Operate an exchange for trading claims
- Manage participants and counterparty risk

Most goods in supply chains do not have sufficient volume to justify trading on large exchanges

Transshipments in supply chains serve similar function, but come with logistics costs and may have restrictions on trades

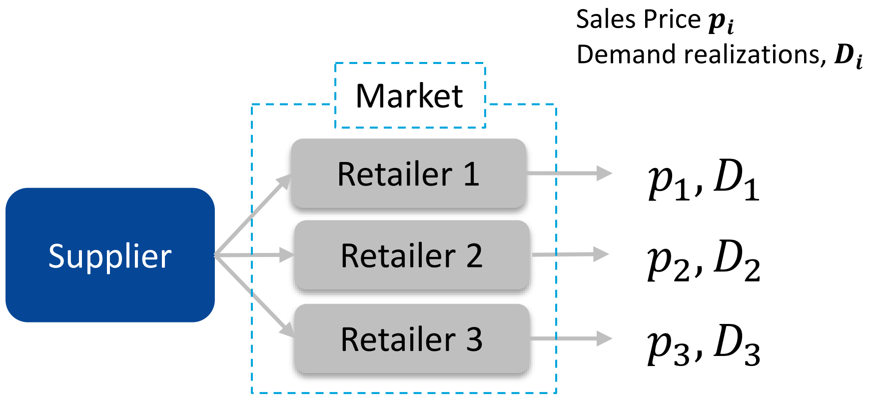
Blockchain facilitates trading digital claims (tokens) on SC assets

- Reduces some of the market costs
- More flexibility than transshipments

Questions

If a market for trading claims on supplier's capacity were available

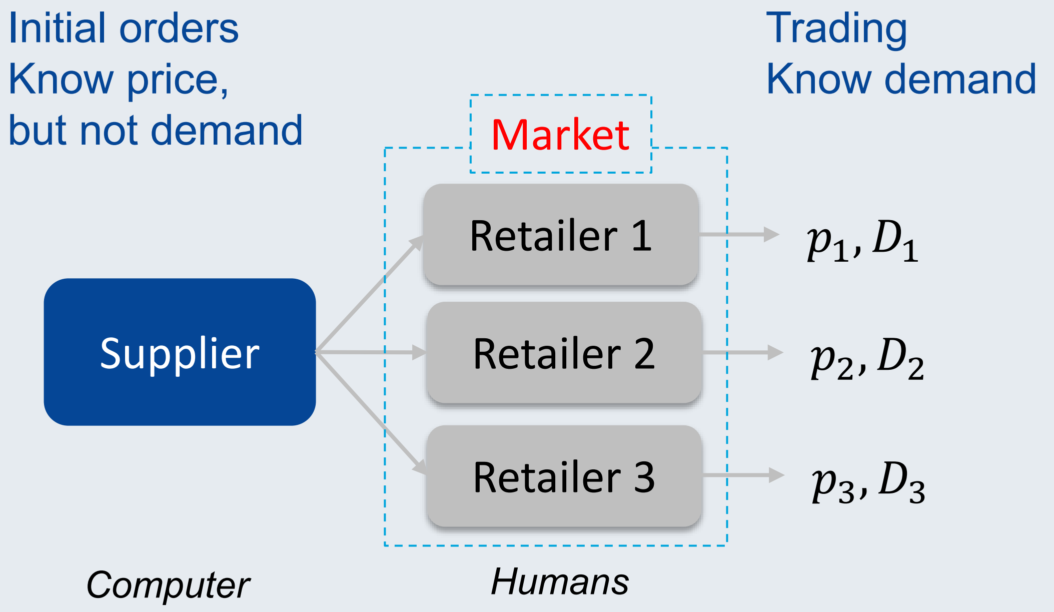
1. Would this reduce excess inventory and shortages?
2. What would be the market clearing price?
3. Would the clearing price signal the value of the goods?
4. What trading strategies would retailers use?
5. How would initial orders of retailers change?
6. How would they affect the supplier?



Experimental Setup | Supply Chain Events

Behavioral simulation of markets for claims on capacity

Game Setup



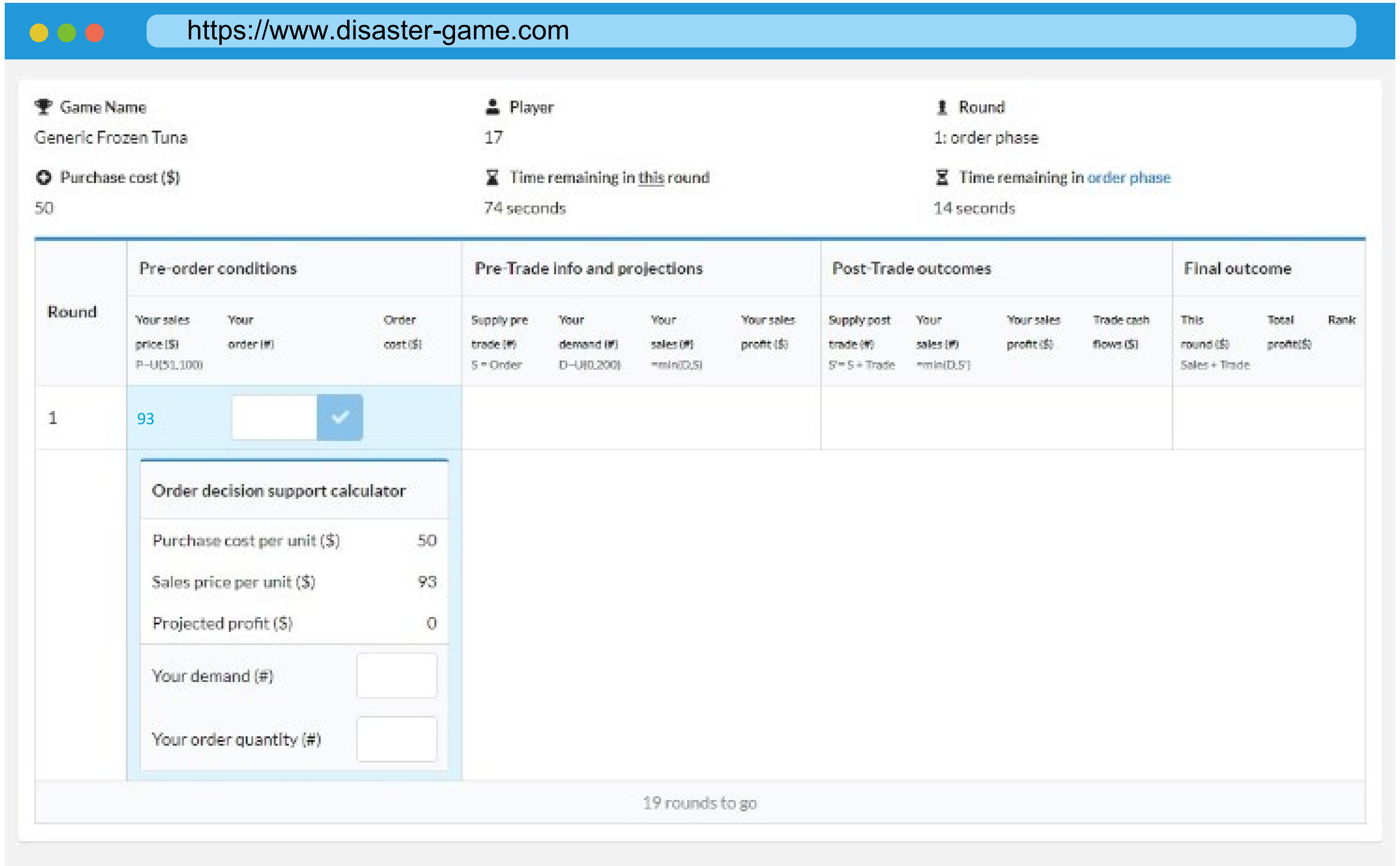
Experiment Design

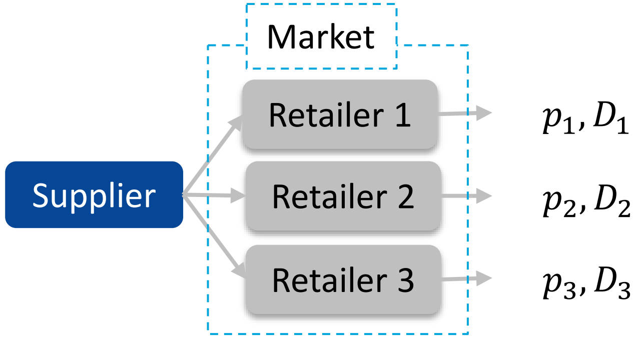
- **6 Treatments** (~30 subjects each)
  - Newsvendor, Small Market (3), Large Market (all)
  - High- and Low- wholesale price (i.e., for each scenario)
- **Common Parameters**
  - Demands: ~ U[0,200],
  - Retail prices: ~ U[51,100]
  - Supply: unlimited
  - Duration: 15 rounds
  - No backlogging or inventory carry over between rounds

Both demand and retail price vary across retailers.

Experimental Setup | DISASTER Platform

Participants follow the same sequence of activities during each round of the simulation





https://www.disaster-game.com

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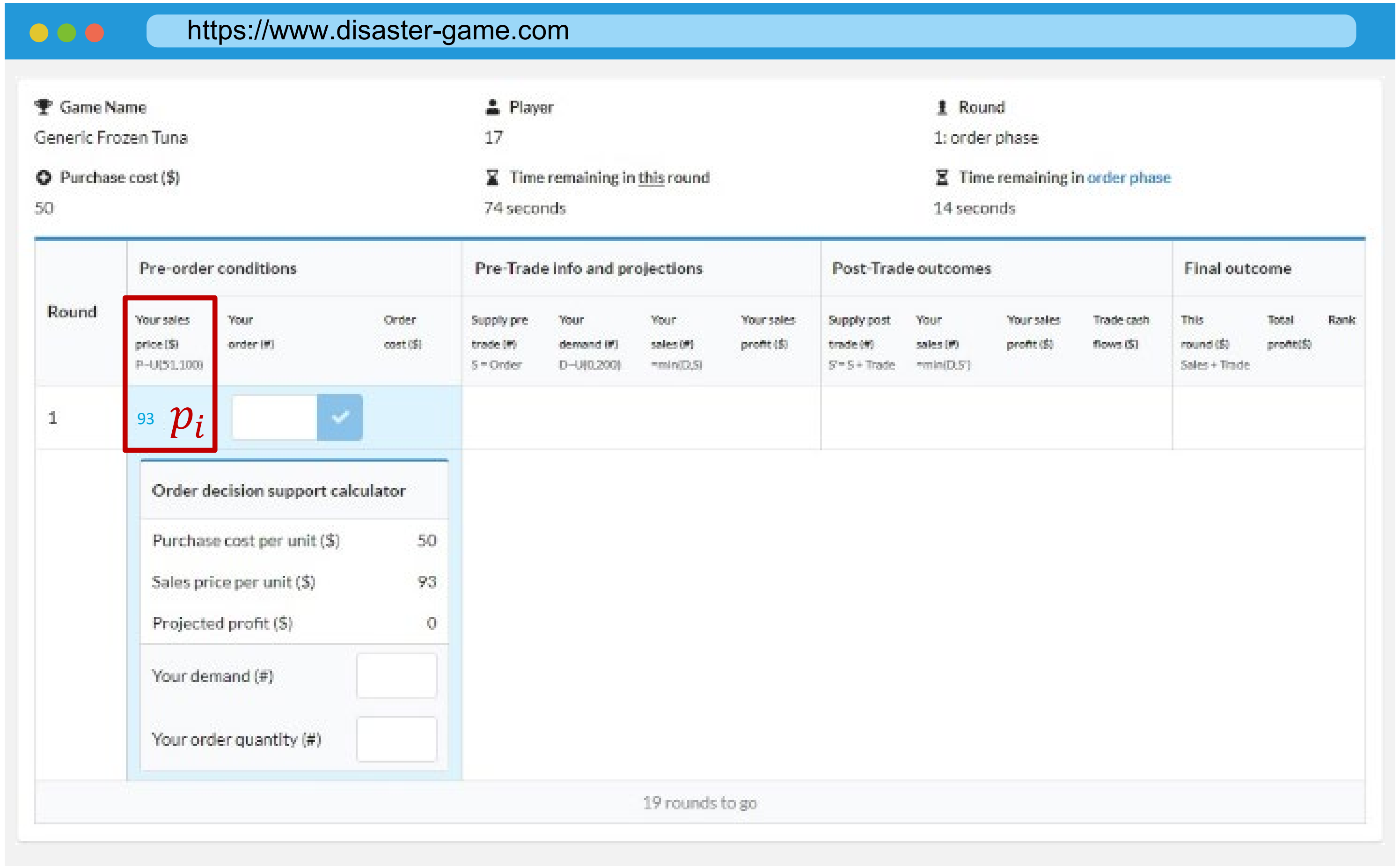

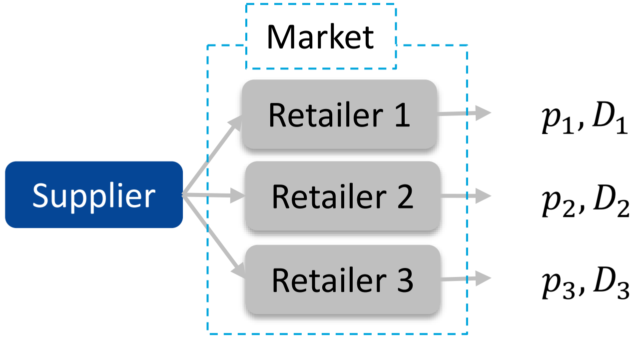

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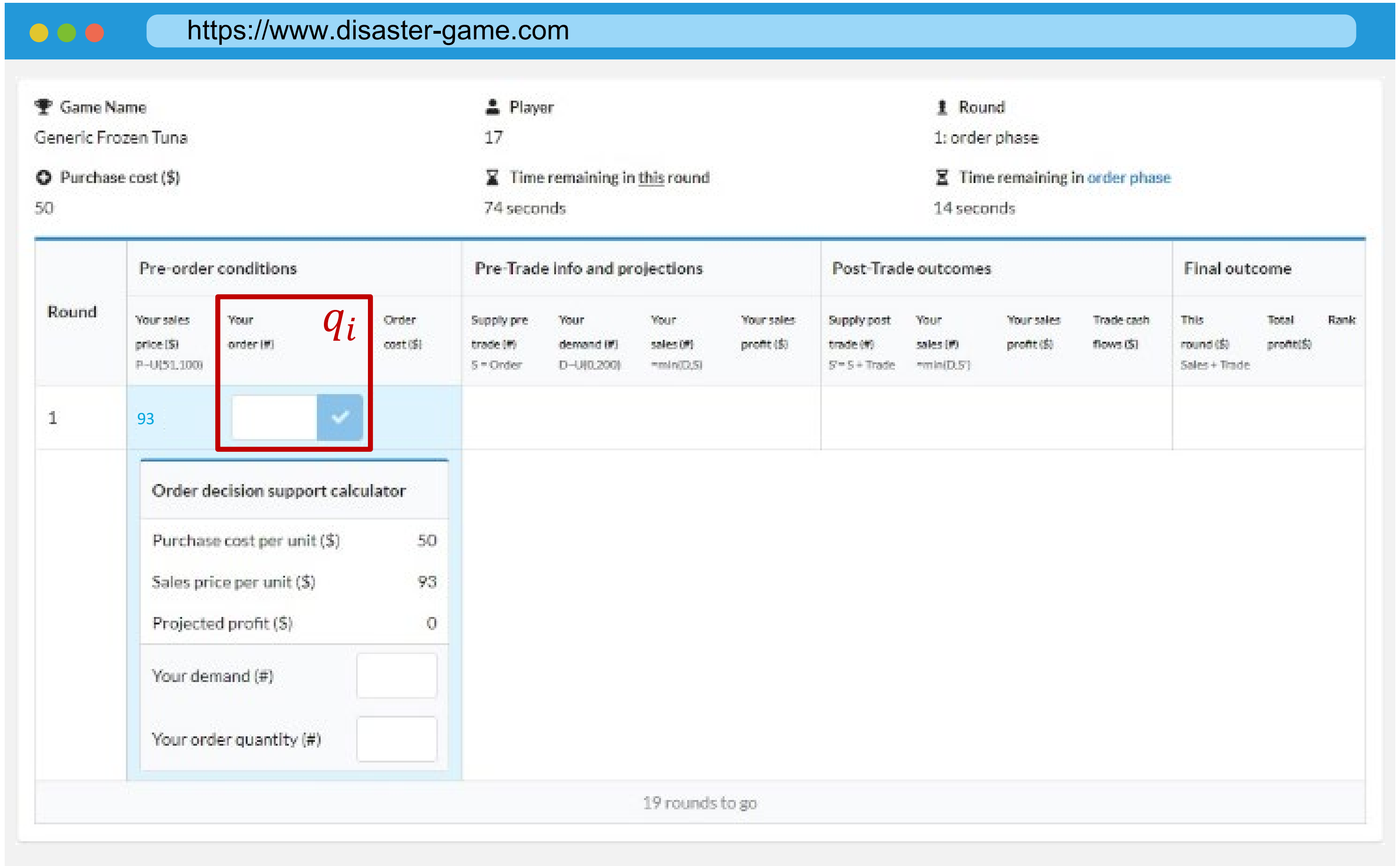

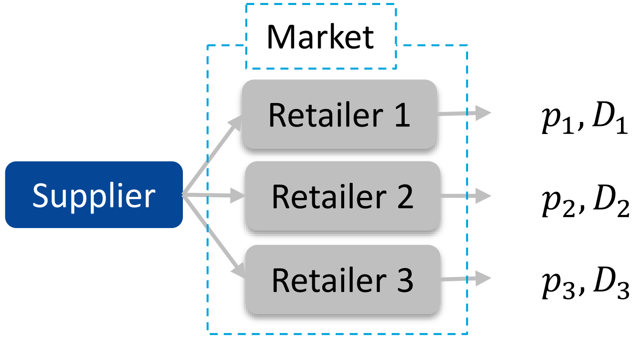

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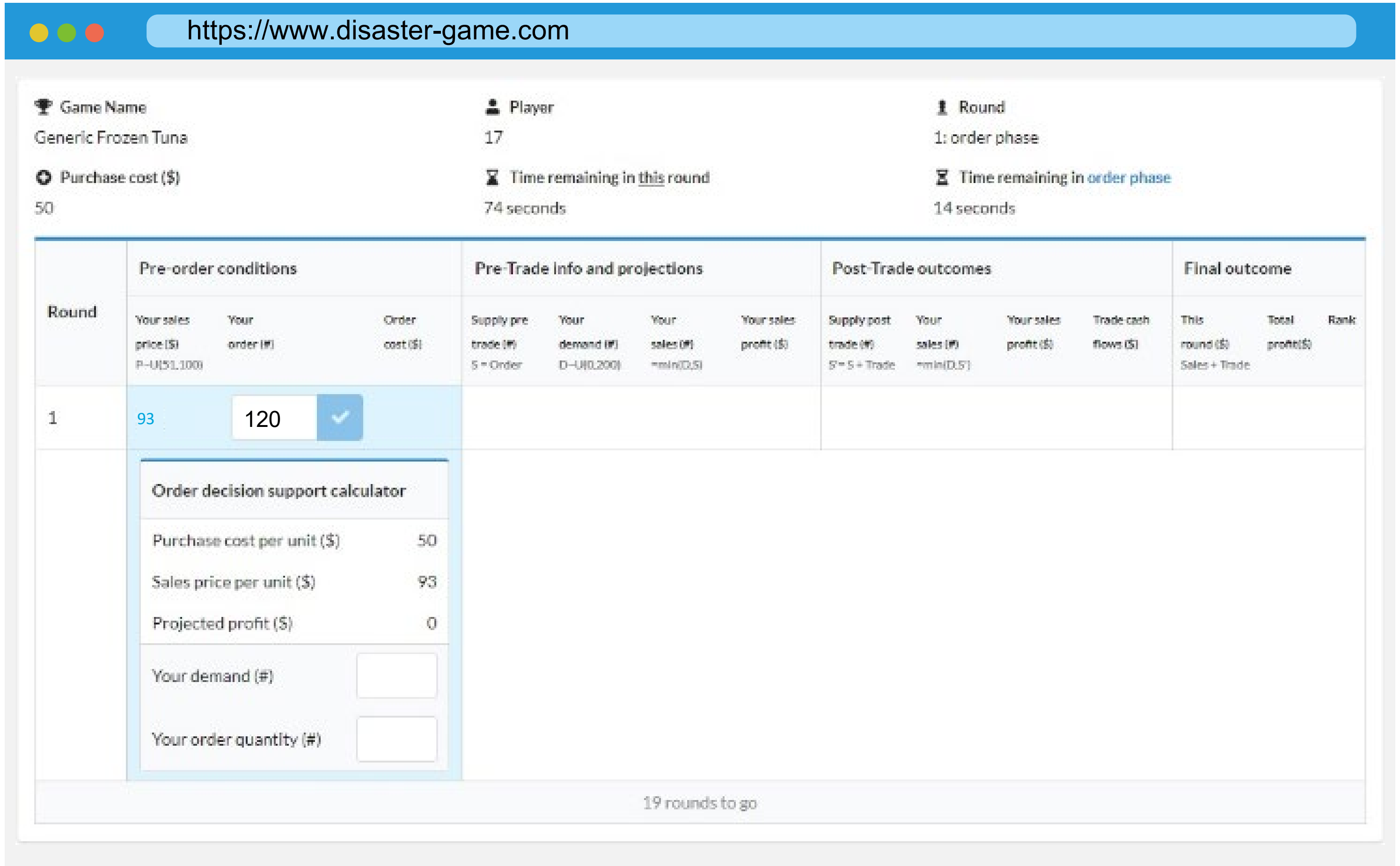

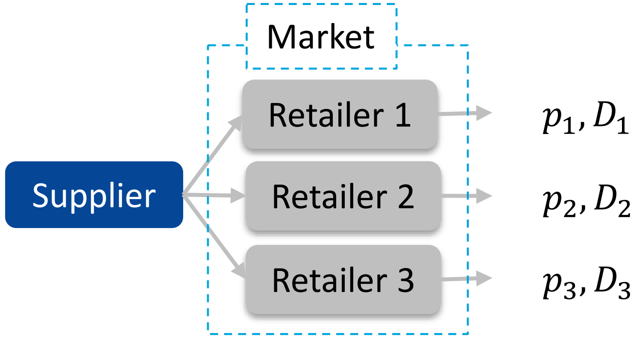

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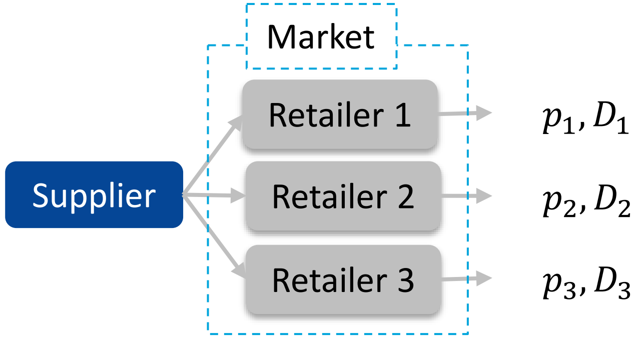

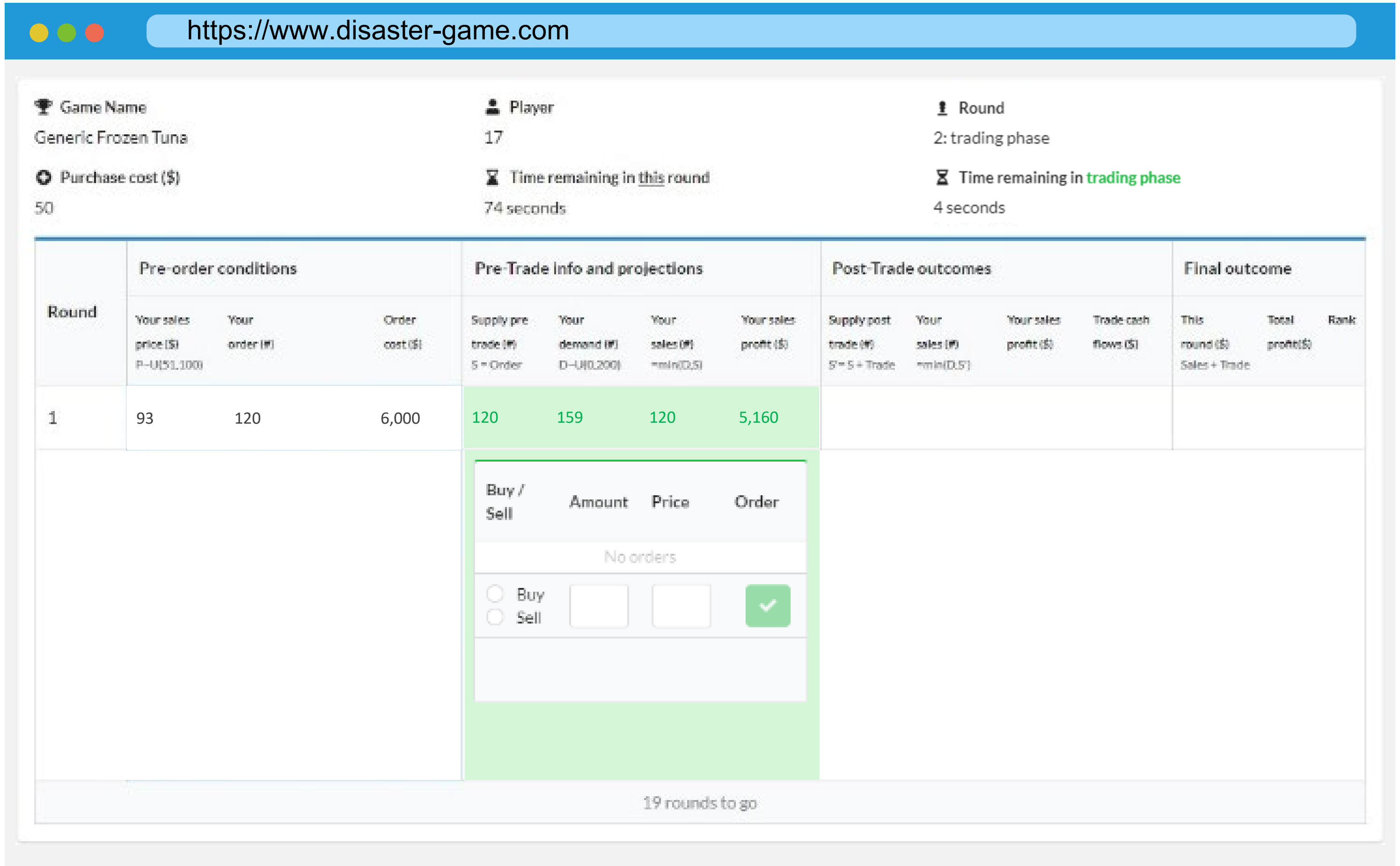

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T=1 Retailers order q_i tokens from the supplier

T=2 Retailers privately observe demand realizations for the current round, D_i

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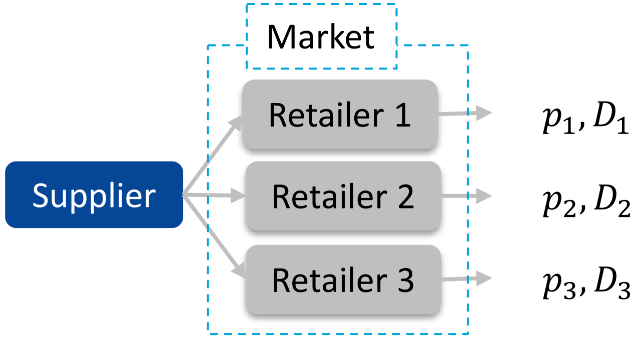

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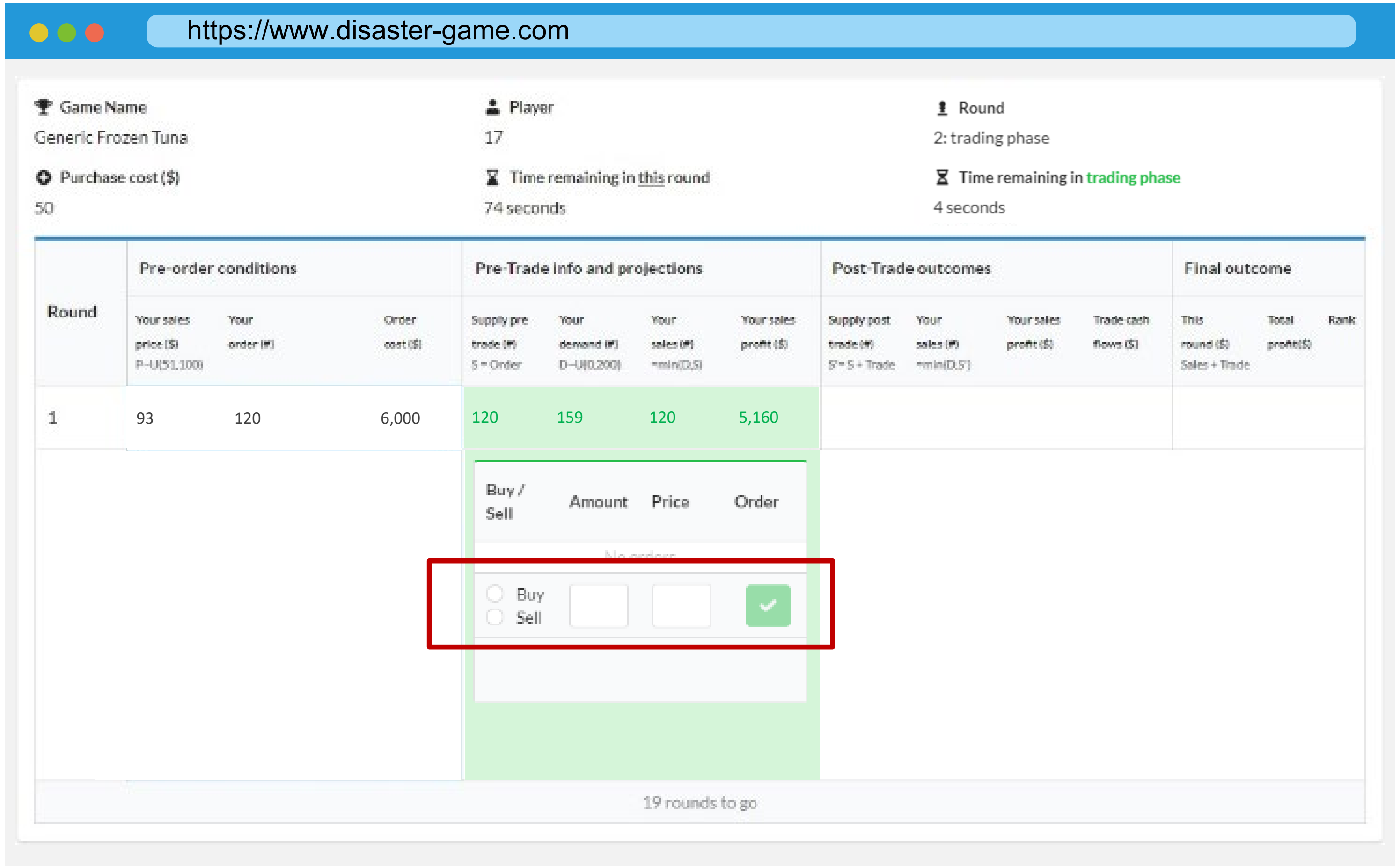

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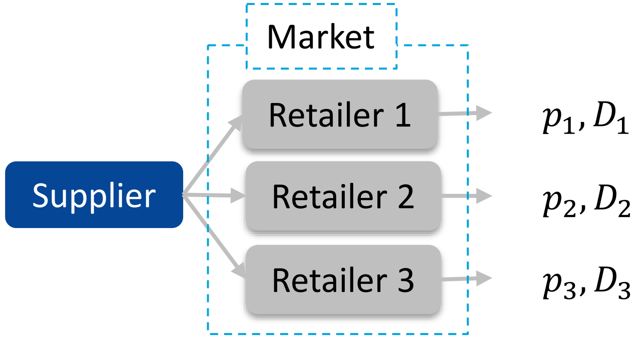

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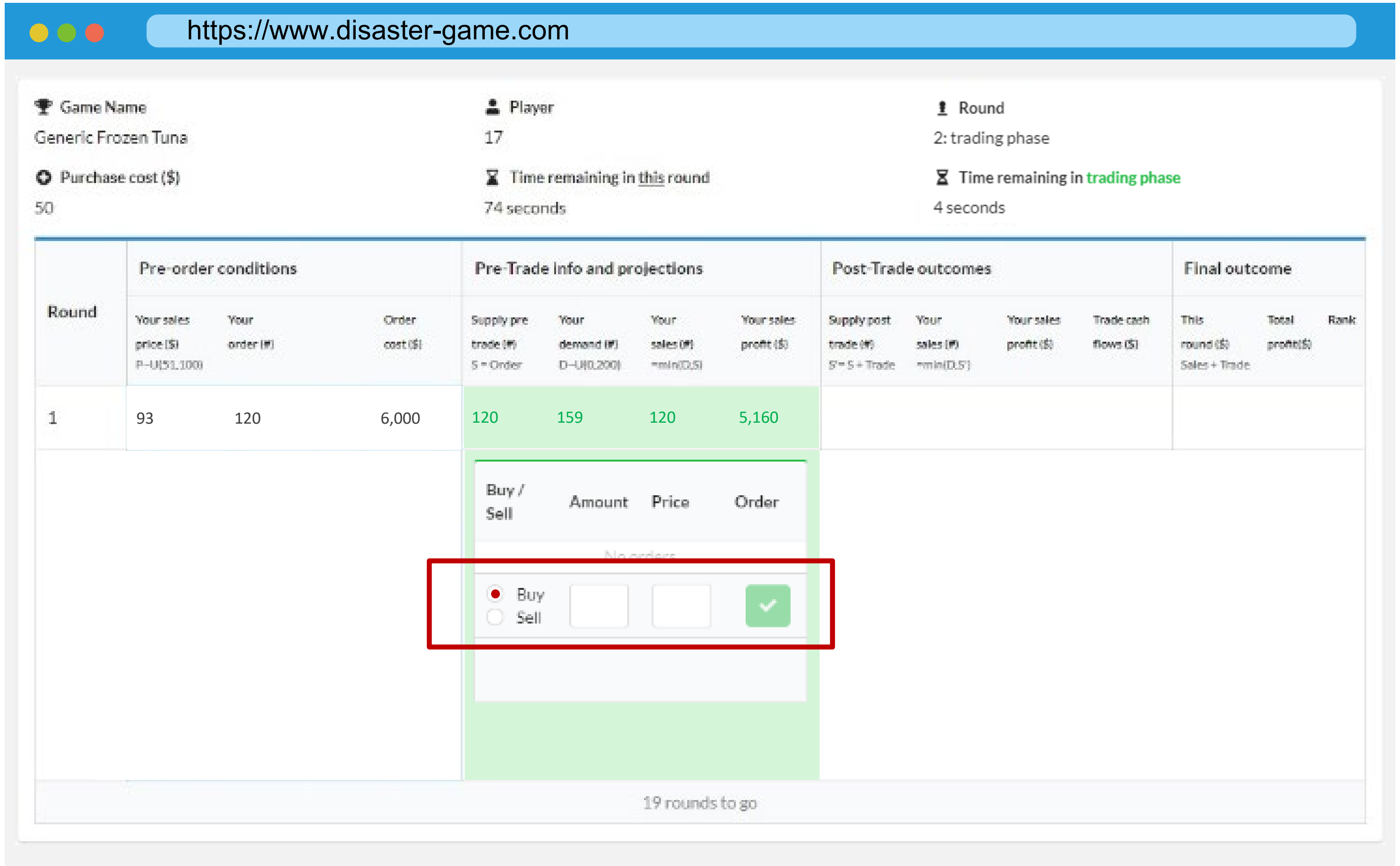

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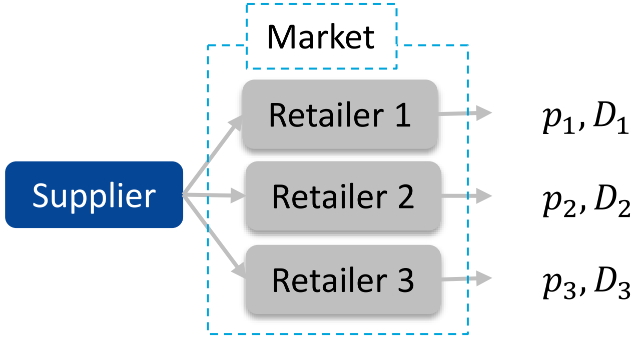

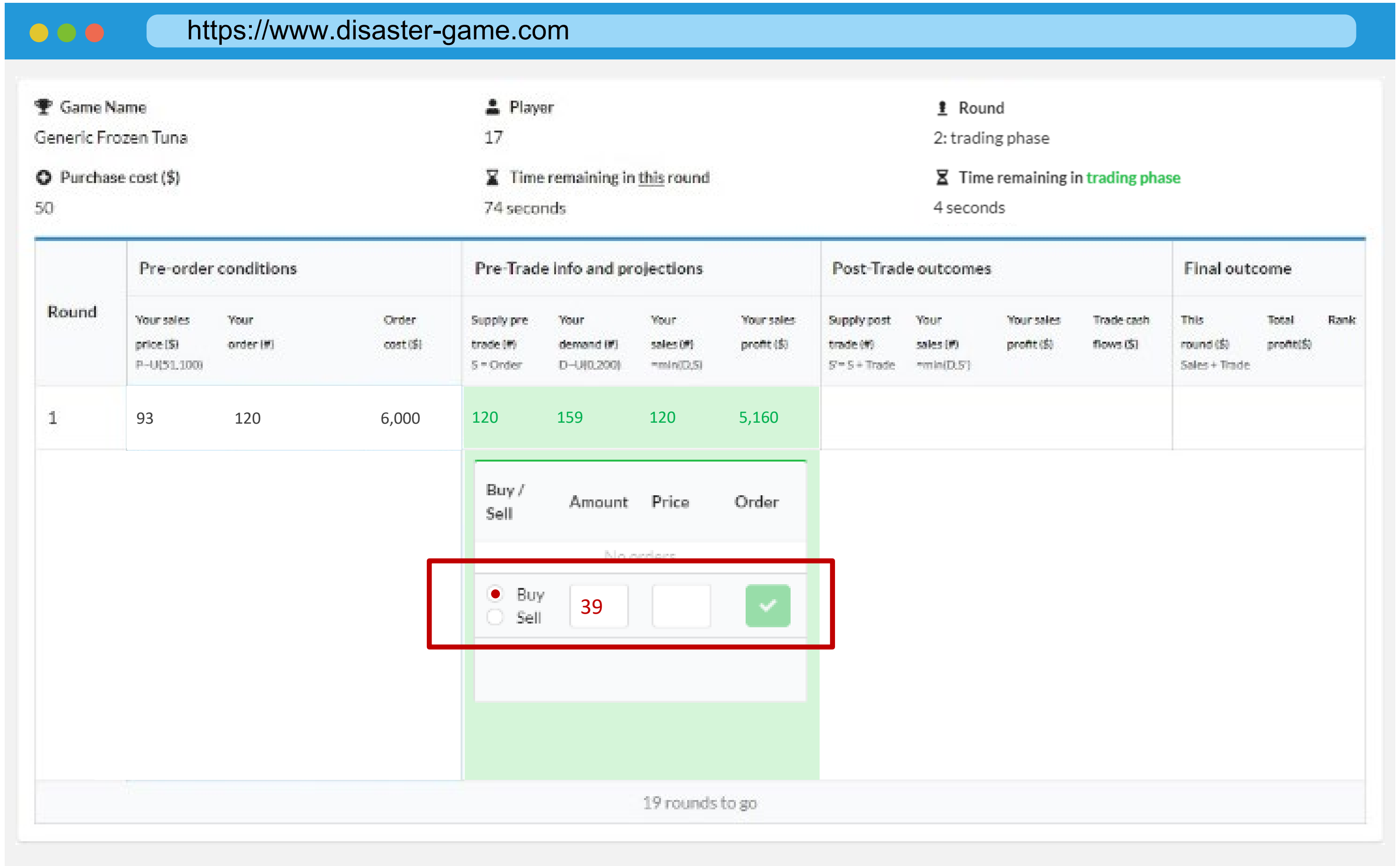

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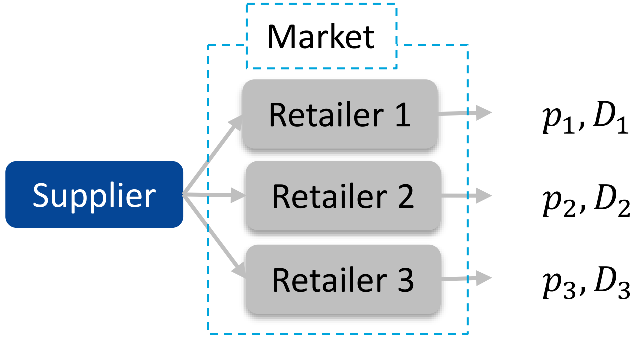

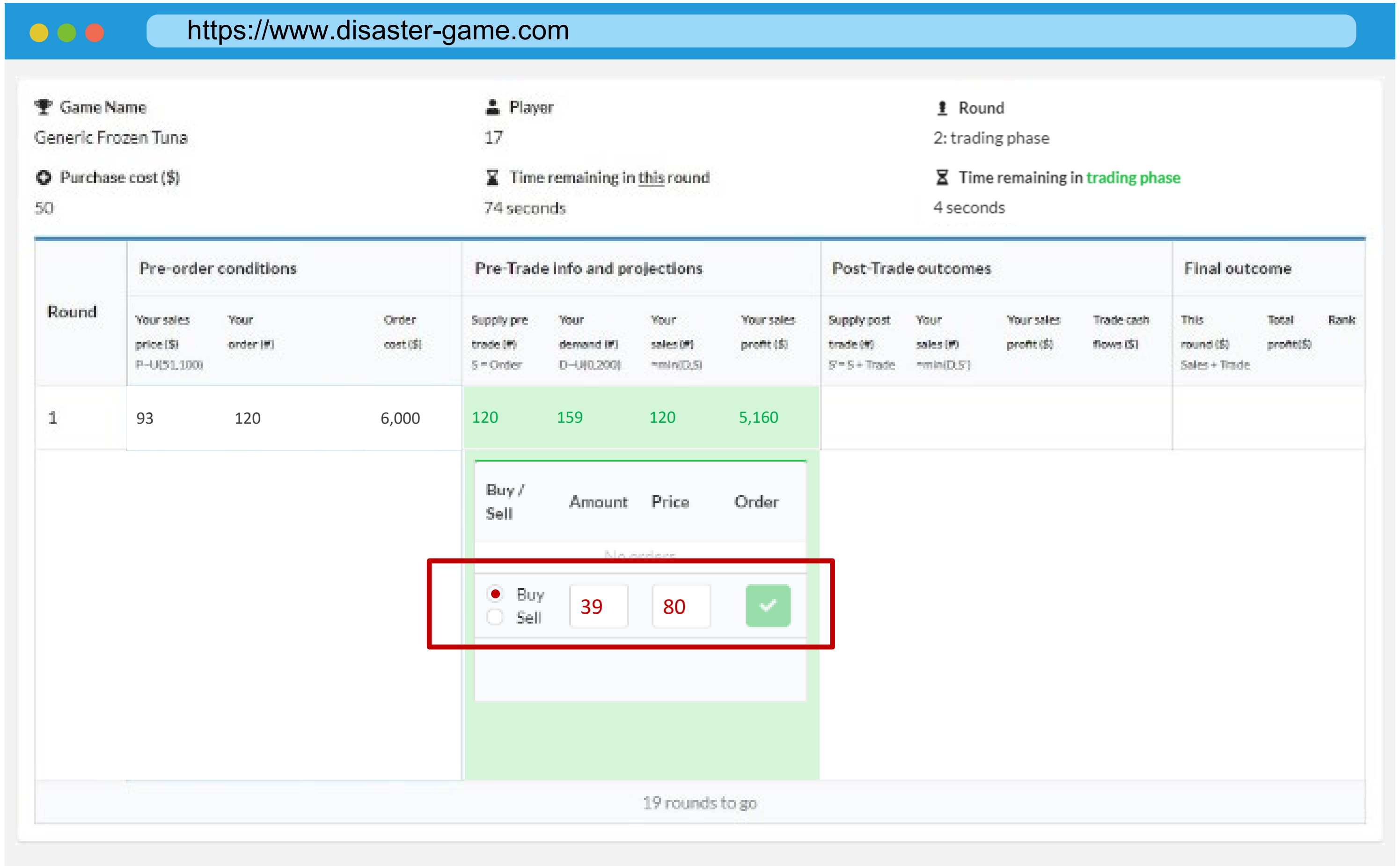

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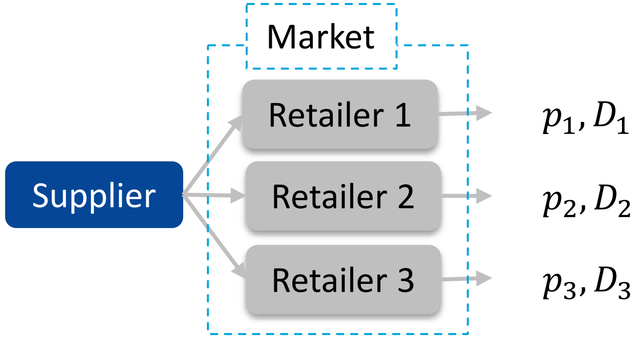

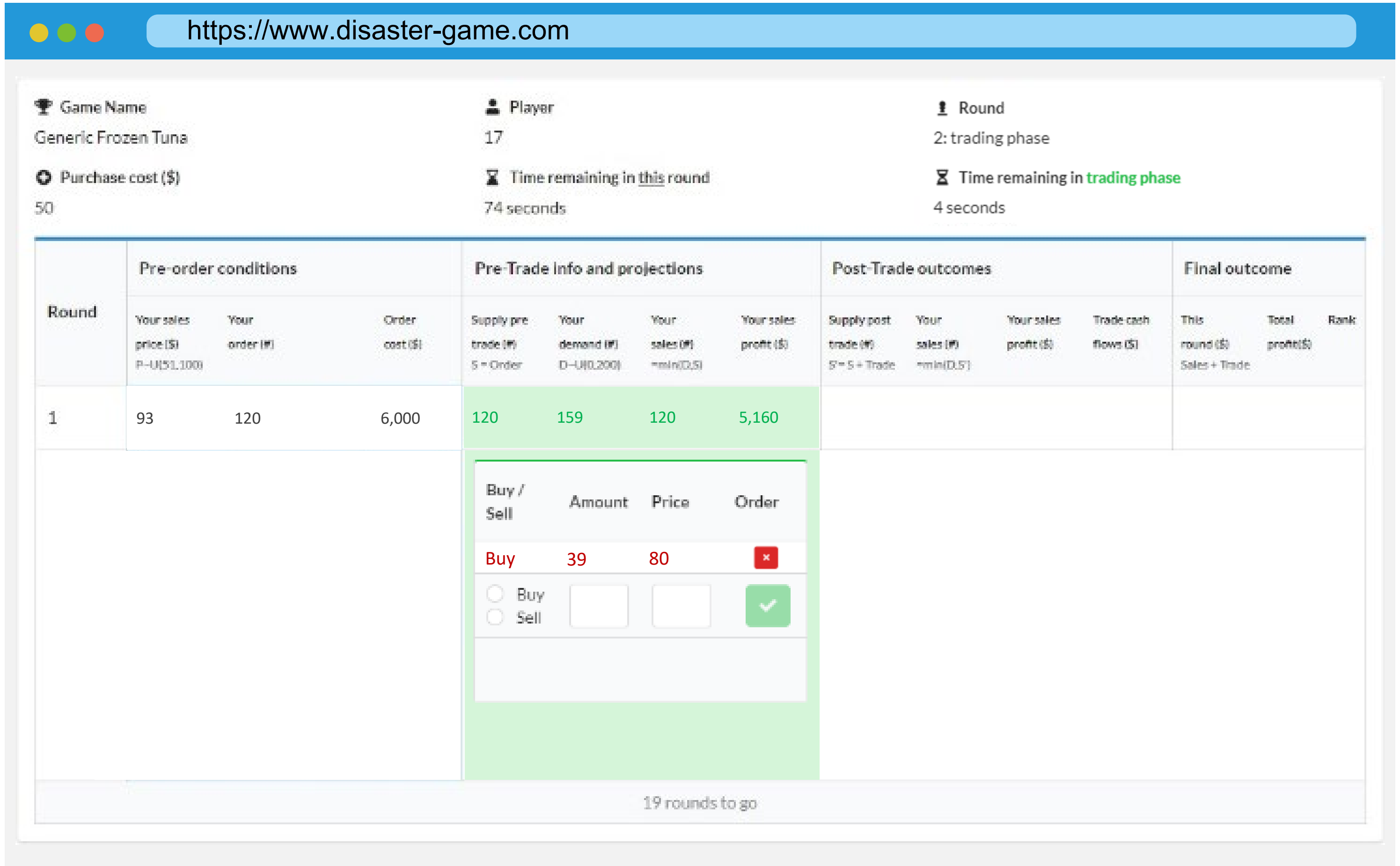

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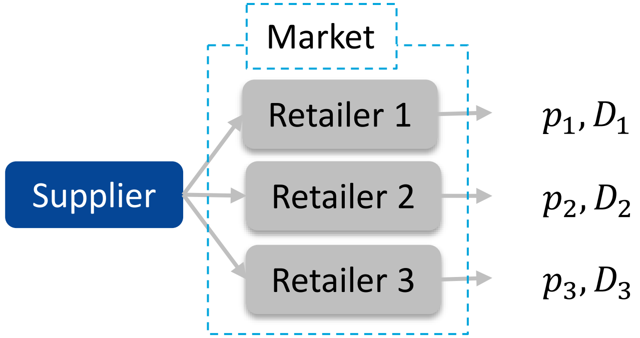

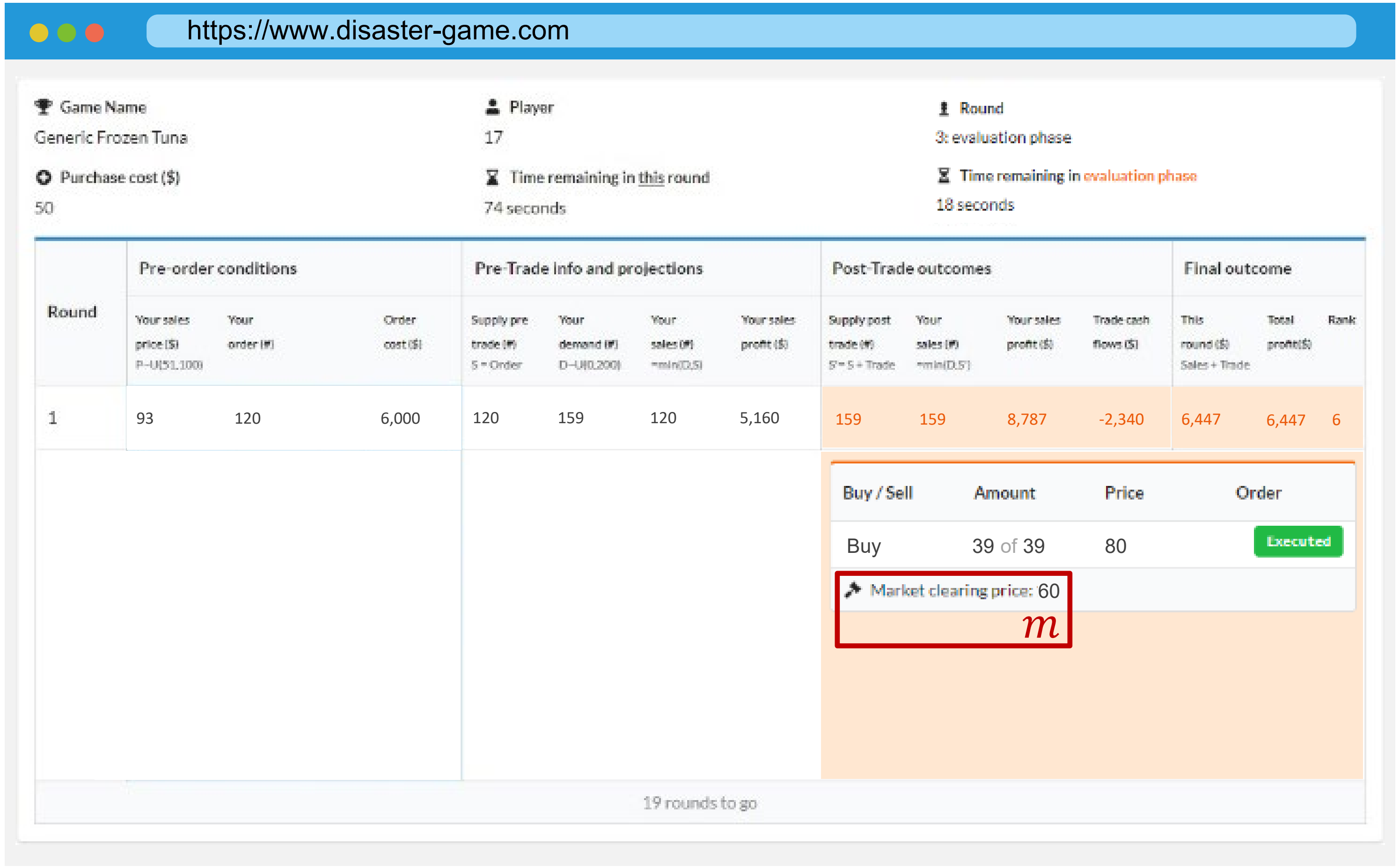

https://www.disaster-game.com

Game Name
Generic Frozen Tuna

Player
17

Round
3: evaluation phase

Purchase cost ($)
50

Time remaining in this round
74 seconds

Time remaining in evaluation phase
18 seconds

Round	Pre-order conditions			Pre-Trade info and projections				Post-Trade outcomes				Final outcome		
	Your sales price ($) P~U(51,100)	Your order (#)	Order cost ($)	Supply pre trade (#) S = Order	Your demand (#) D~U(0,200)	Your sales (#) =min(D,S)	Your sales profit ($)	Supply post trade (#) S' = S + Trade	Your sales (#) =min(D,S')	Your sales profit ($)	Trade cash flows ($)	This round ($) Sales + Trade	Total profit($)	Rank
1	93	120	6,000	120	159	120	5,160	159	159	8,787	-2,340	6,447	6,447	6

Buy / Sell	Amount	Price	Order
Buy	39 of 39	80	Executed

Market clearing price: 60

m

19 rounds to go

T=0	Retailers (players) privately observe values p_i
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T=2	Retailers privately observe demand realizations for the current round, D_i
T=3	Retailers submit buy and/or sell trades (quantity, price)
T=4	Market clears at price m, trades are executed, retailers redeem tokens for supplier capacity, customer demand is satisfied

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Experimental Setup | Market Clearing Mechanism

- Each player can submit up to five, sealed buy and sell orders: (quantity, price)
- Single market-clearing price determined at the end of trading stage
  - Prevent "front running" and other market manipulation due to low liquidity
- Market-clearing price calculation

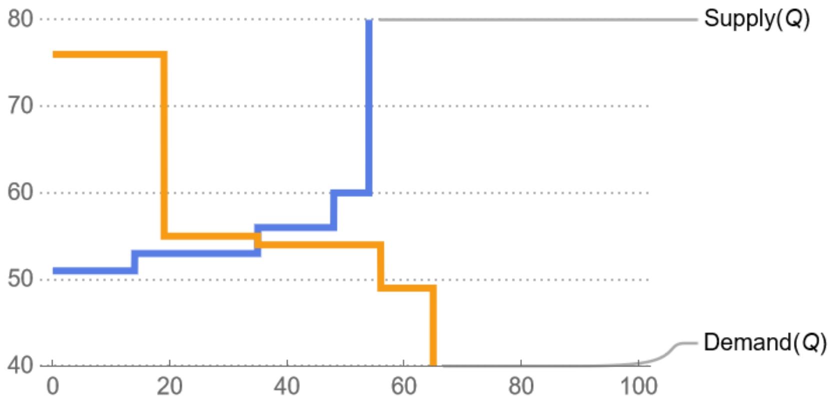
Sell orders

	Player	Time	Price per unit	Number of units
	1	10:30:23	$51 (A)	14
B	1	10:30:40	$53	21
	1	10:30:15	$56	13
	1	10:30:00	$60	6

Buy orders

Player	Time	Price per unit	Number of units
2	10:30:40	$76 (A)	19
3	10:30:23	$55	16
2	10:30:00	$54	21
3	10:30:15	$49	9

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



Markets reduce excess and shortage

Markets reduce excess and shortage

Large markets are better than small ones for low wholesale price

	G3-50 vs **NV-50**	**GA-50** vs **NV-50**	**G3-10** vs **NV-10**	**GA-10** vs **NV-10**
Average Excess (per round and player)	34.4% (0.002)	-18.6% (0.213)	40.7% (<0.001)	64.7% (<0.001)
Average Shortage (per round and player)	21.3% (0.005)	51.6% (<0.001)	6.8% (0.511)	52.6% (<0.001)
Total (Excess + Shortage)	35.4% (<0.001)	27.0% (<0.001)	32.3% (<0.001)	61.6% (<0.001)

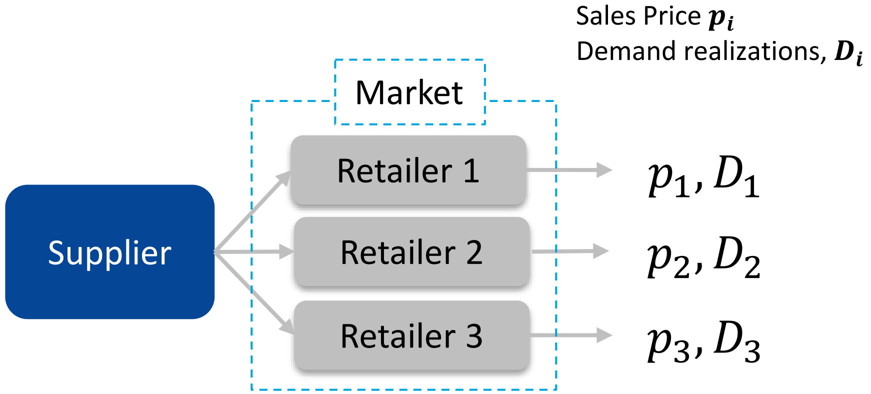
P-values are in parentheses

NV-10: Newsvendor; Low Cost (*$10*)
NV-50: Newsvendor; High Cost (*$50*)

G3-10: Small Market; Low Cost (*$10*)
G3-50: Small Market; High Cost (*$50*)

GA-10: Large Market; Low Cost (*$10*)
GA-50: Large Market, High Cost (*$50*)

Market Clearing Price (MCP)

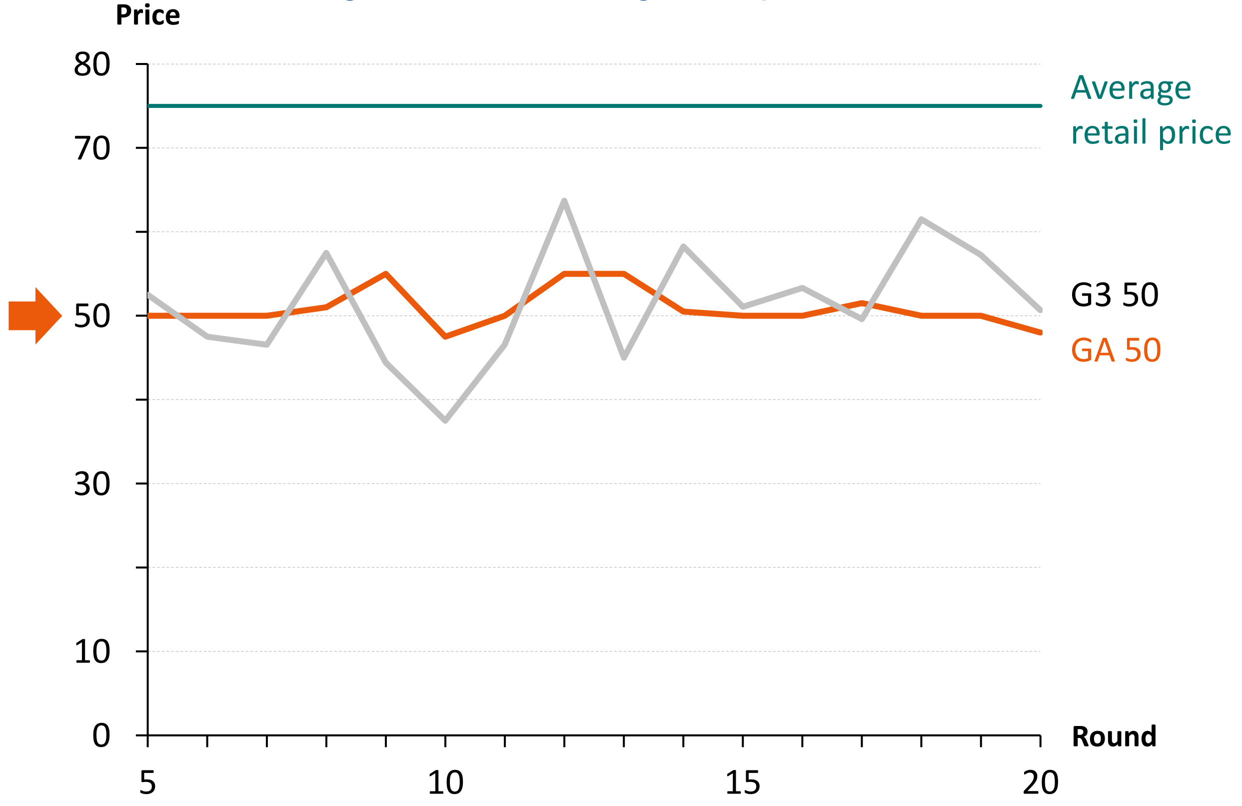


- MCP should not be a function of the wholesale price
- MCP should depend on the realized net supply and demand and on sales prices

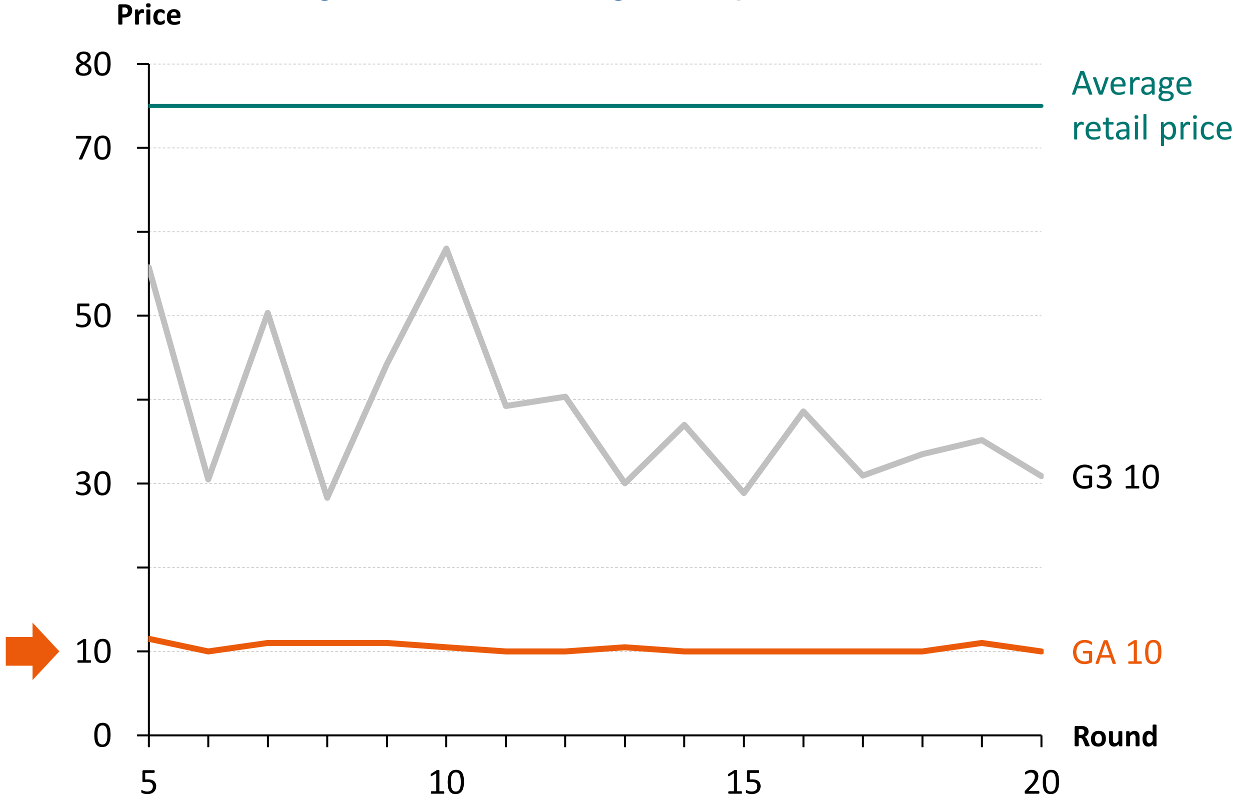
Market Clearing Price

MCP is anchored to the supplier's wholesale price. Behavioral effect. Does not reflect the value of goods in large markets

High wholesale-price experiments (price = 50):
Average Market Clearing Price per Round



Low wholesale-price experiments (price = 10):
Average Market Clearing Price per Round



Market Clearing Price | Signal of Value

In small markets, clearing prices are correlated with the value to retailers and net demand; not so in large markets

MCP	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
Avg. Sales Price	.299	.144	2.08	.04	.014	.585	**
Net Demand	.029	.012	2.46	.016	.006	.053	**
Constant	27.321	10.682	2.56	.012	6.071	48.57	**

Mean dependent var	50.518	SD dependent var	11.301
R-squared	0.117	Number of obs	85
F-test	5.417	Prob > F	0.006
Akaike crit. (AIC)	647.903	Bayesian crit. (BIC)	655.231

**** p<.01, ** p<.05, * p<.1*

Low wholesale-price experiment

Initial orders and subsequent trading

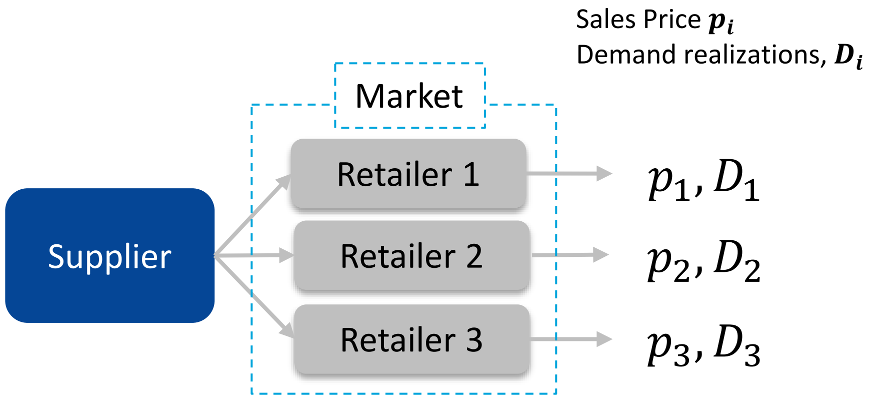
Transshipment literature guides predictions

Retailers act as transshippers

- buy to satisfy customer demand, then sell excess or buy shortage

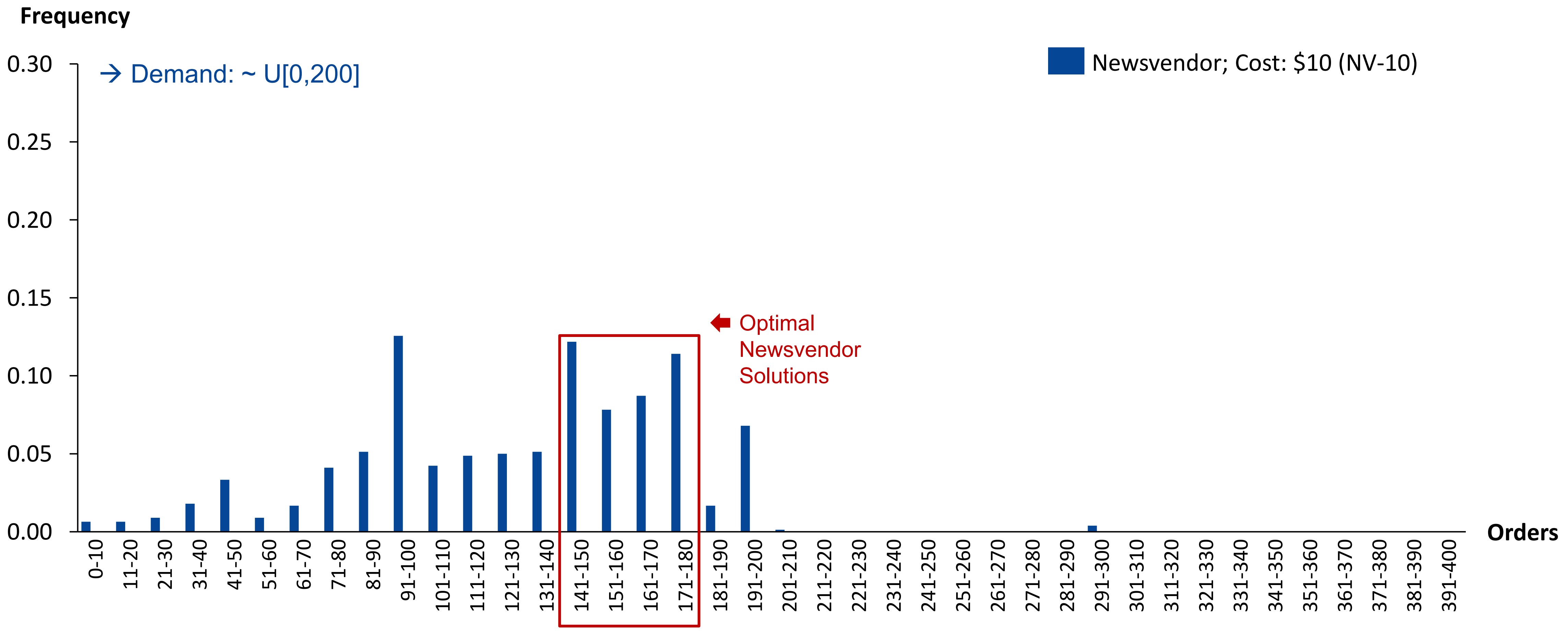
Initial orders will be closer to mean demand in the presence of the market

- Anupindi et al 2001, coopetitive framework
- Inventory pooling benefit among N identical retailers:
  - i.i.d. demand $D_k \sim N(\mu, \sigma^2)$
  - Order per retailer: $Q = \mu + \frac{\sigma}{\sqrt{N}} z^*$
- Katok and Villa 2021, experiment



Initial Orders

Observe pull to the mean



Initial Orders

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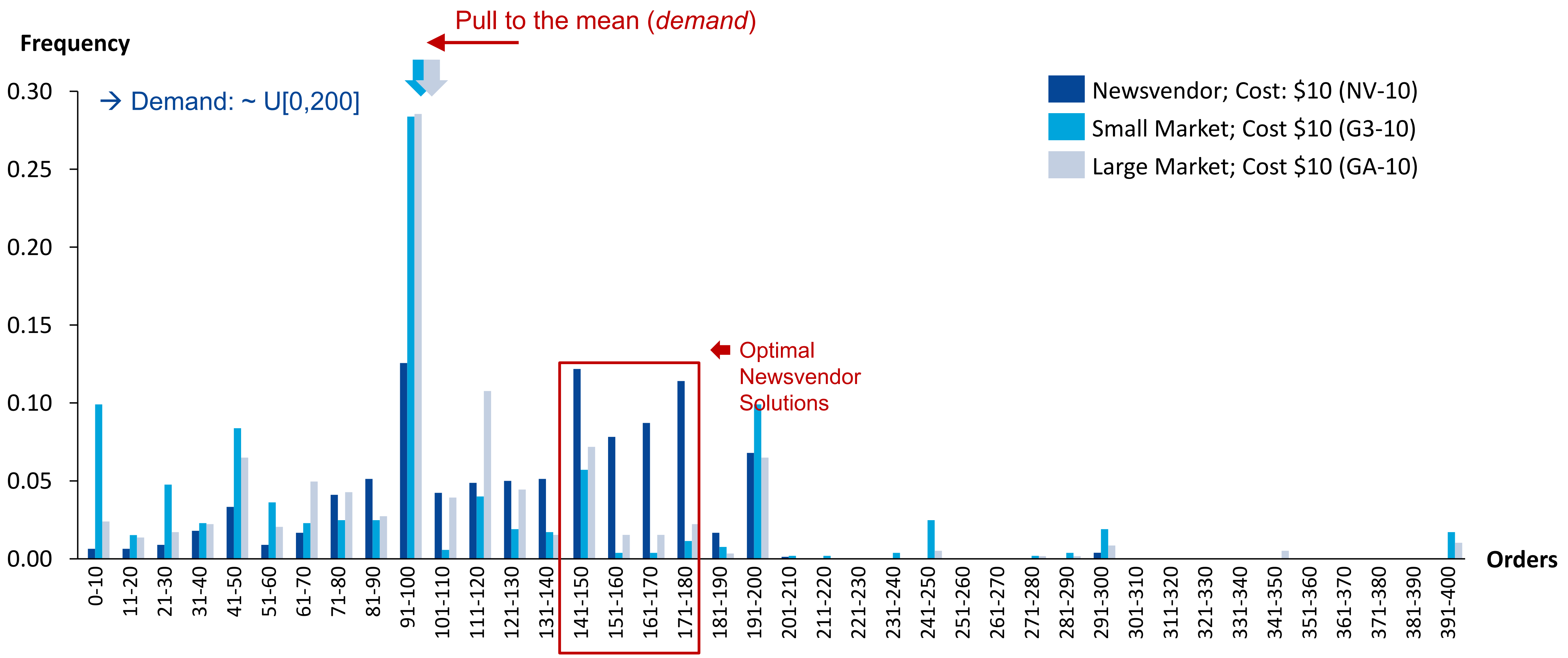
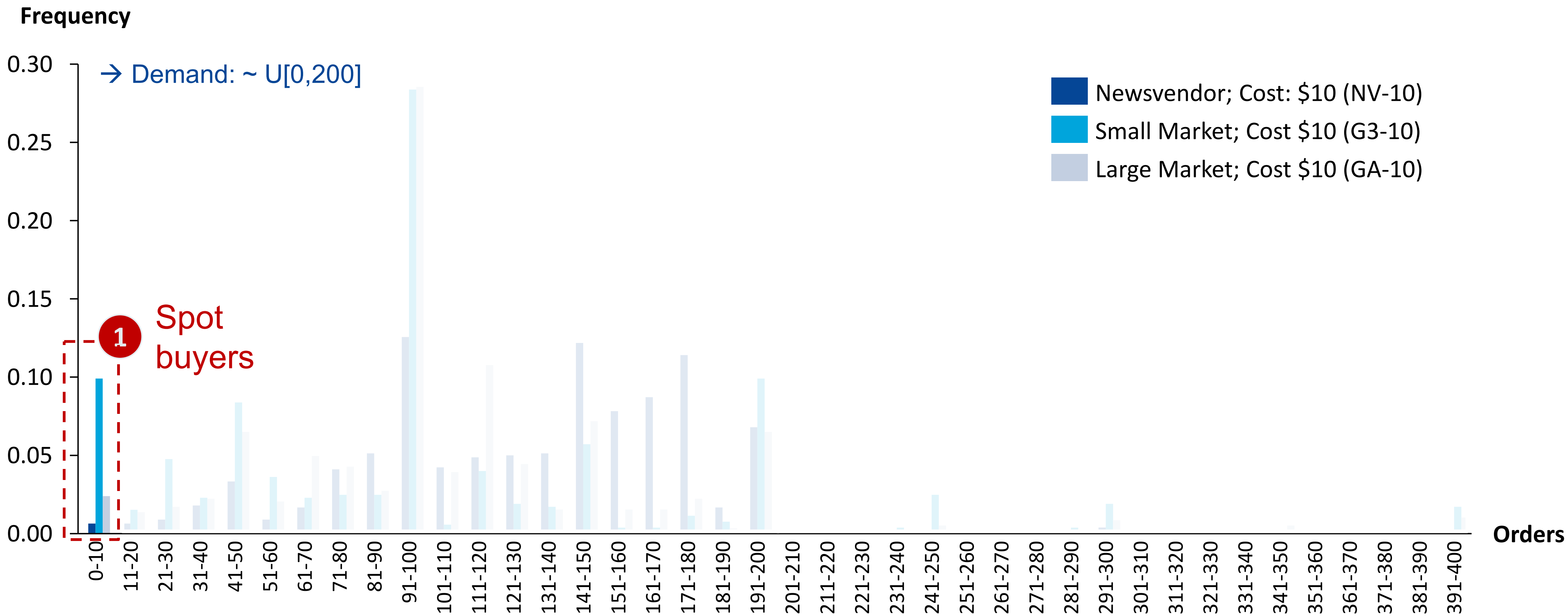


Observations

Order Strategies

Three strategies emerge: (1) spot buyers, (2) spot sellers, and (3) transhippers



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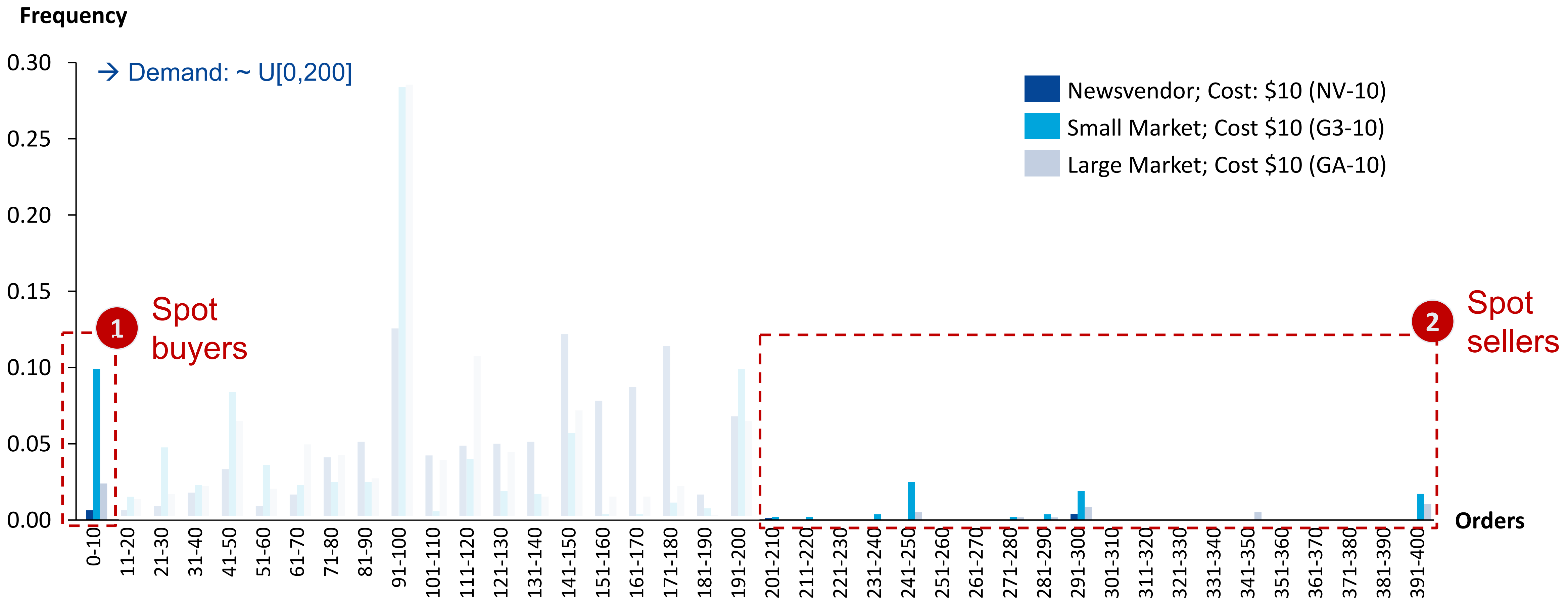

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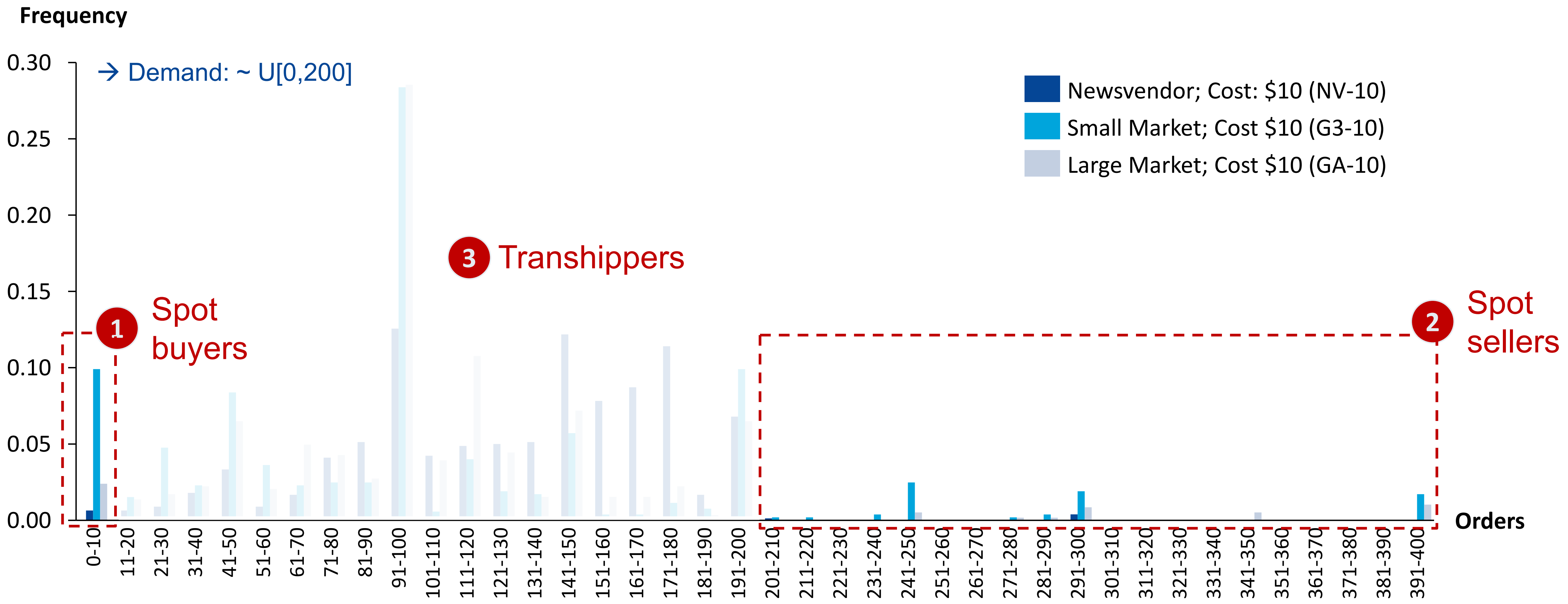


Which trading strategy is successful?

Transshippers earn higher profits on average

	G3 50		GA 50		G3 10		GA 10	
Trading Strategy	Average profit	Diff from Transship	Average profit	Diff from Transship	Average profit	Diff from Transship	Average profit	Diff from Transship
Transshippers	1,144		931		5,005		5,915	
Spot buyers	346	-798 (0.069)	-920	-1,851 (0.037)	1,631	-3,374 (< 0.001)	5,003	-912 (0.129)
Spot sellers	-8,572	-9,716 (< 0.001)	-3,629	-4,560 (< 0.001)	9,616	4,611 (< 0.001)	3,848	-2,067 (0.003)

Effect of markets on SC firms' profits

The supply chain is better with markets, but low-price suppliers are against markets

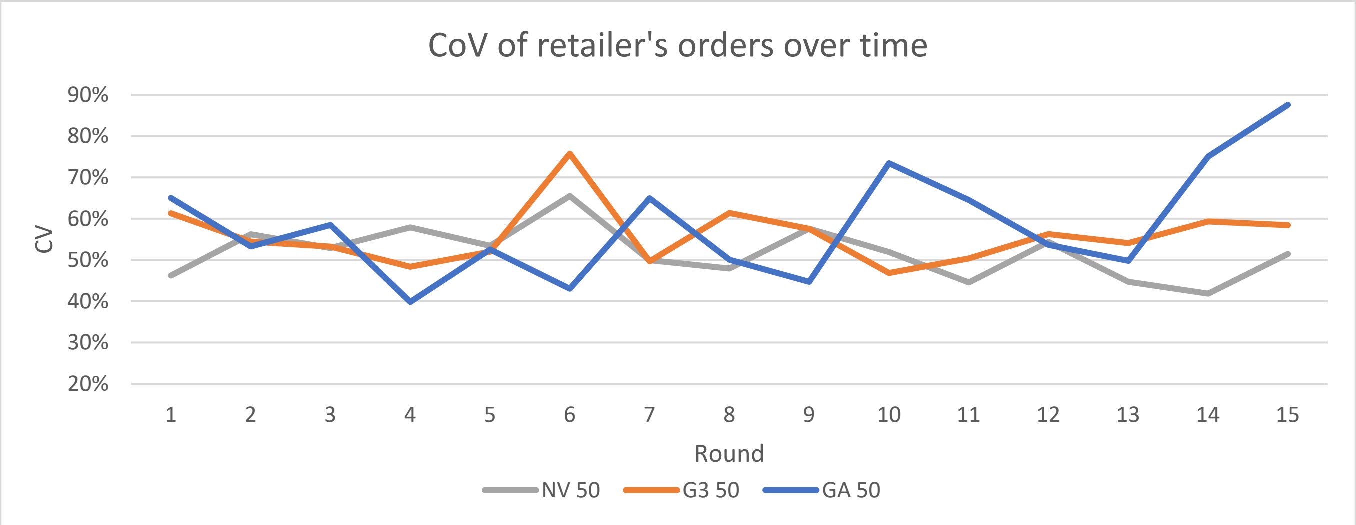
Effect of markets on average profits				
	G3 50 vs NV 50	GA 50 vs NV 50	G3 10 vs NV 10	GA 10 vs NV 10
Retailer	92% (0.003)	40% (0.296)	8% (0.096)	20% (< 0.001)
Supplier	1% (0.731)	29% (< 0.001)	-14% (< 0.001)	-17% (< 0.001)
Supply chain	12% (0.015)	30% (< 0.001)	3% (0.437)	12% (0.001)

p-values in parentheses, supplier's profit = supplier's revenue

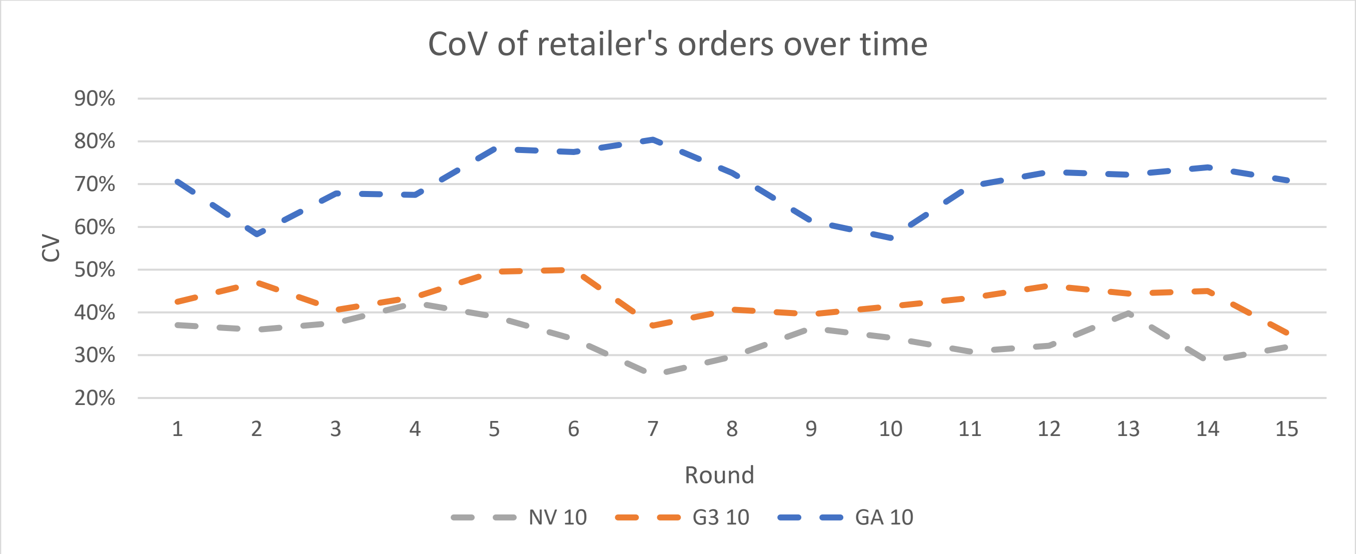
Order uncertainty

Markets do not change CoV for high-price supplier; Large markets increase CoV for low-price supplier

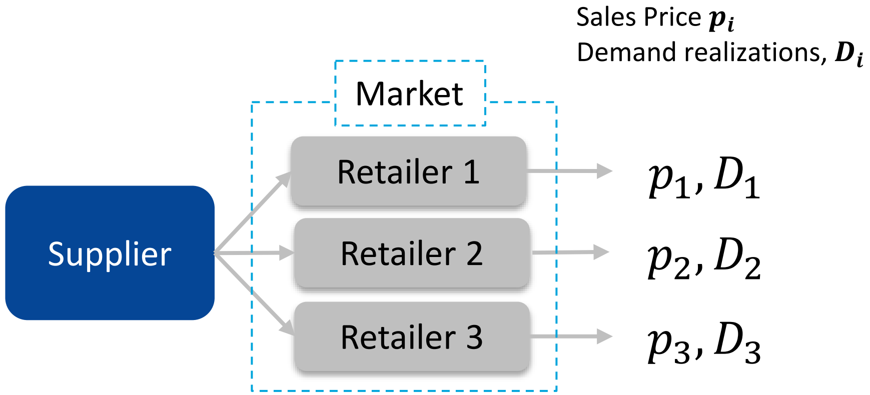
High-wholesale price experiment



Low-wholesale price experiment



Takeaways and break for questions



If a market for trading claims on supplier's capacity were available

1. Would this reduce excess inventory and shortages? — Yes, as expected
2. What would be the market clearing price? — Anchor to wholesale price
3. Would the clearing price signal the value of the goods? — Yes, in small markets only
4. What trading strategies would retailers use?
5. How would initial orders of retailers change?

   Spot buyer and sellers, transshippers
6. How would they affect the supplier?

   Increases revenue if wholesale price is high
   Reduces revenue if wholesale price is low
   Increases CoV of orders if wholesale price is low

Blockchain future applications and research opportunities

Research Themes

- Information
- Tokenization
- Automation

- Tokenizing and trading of supply chain assets
- Managing the Bullwhip Effect
- Consumer choices with granular SC data
- SC automation and commitments
- Supply Chain Risk Management
- Ethical, sustainable, and responsible (ESR) operations
- Crisis management
- Supply Chain Finance
- Economics of information, contracts, and governance
- Industrial organization of Blockchain

Babich V. and Hilary G. (2020) M&SOM, Babich V. and Hilary G. (2022) Springer Nature

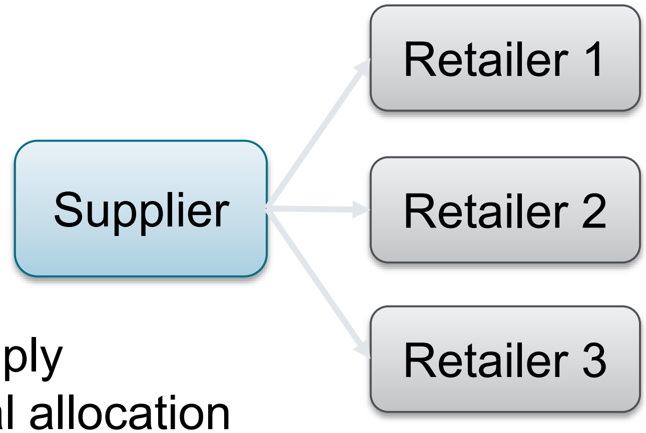
Behavioral simulation of blockchain-enabled order history sharing and the Bullwhip Effect

Managers ask for information to make better decisions:

Supply

History of orders of other retailers

Demand



Limited supply
Proportional allocation

Sources: disaster-game.com
Hellwig D, Wendt K, Babich V, Huchzermeier A (2022)

Supply Chain Design and Events

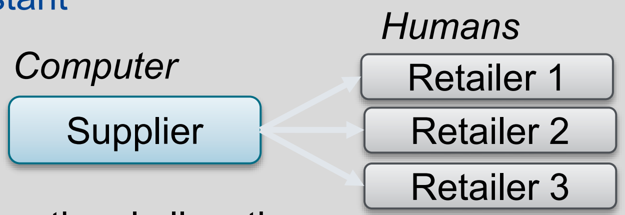
Lab experiments to simulate competition for limited supply

Design

Known supply constant

Order history

Known demand constant



Proportional allocation

$$y_i = \min\left(x_i, \frac{x_i}{x_1 + x_2 + x_3} \cdot K\right)$$

Consistent supply chain parameters

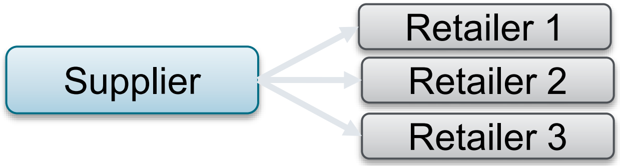
- Demand: constant 50 units
- Supply: constant 120 units (< total demand of 150)
- Units and unsatisfied demand are lost at the end of each round
- Order quantity: integer values 0 – 10,000
- Sales price = constant $20
- Purchase cost = constant $10
- Duration: 30 rounds

Events

$t = 0$	$t = 1$	$t = 2$
Retailers observe competitors' orders of previous round(s) (treatment scenarios)	Retailers submit orders to supplier (quantity)	Supplier allocates supply based on proportional allocation rule if orders > capacity; retailers sell to customers

Experimental Design

We increase the amount of information available to the players

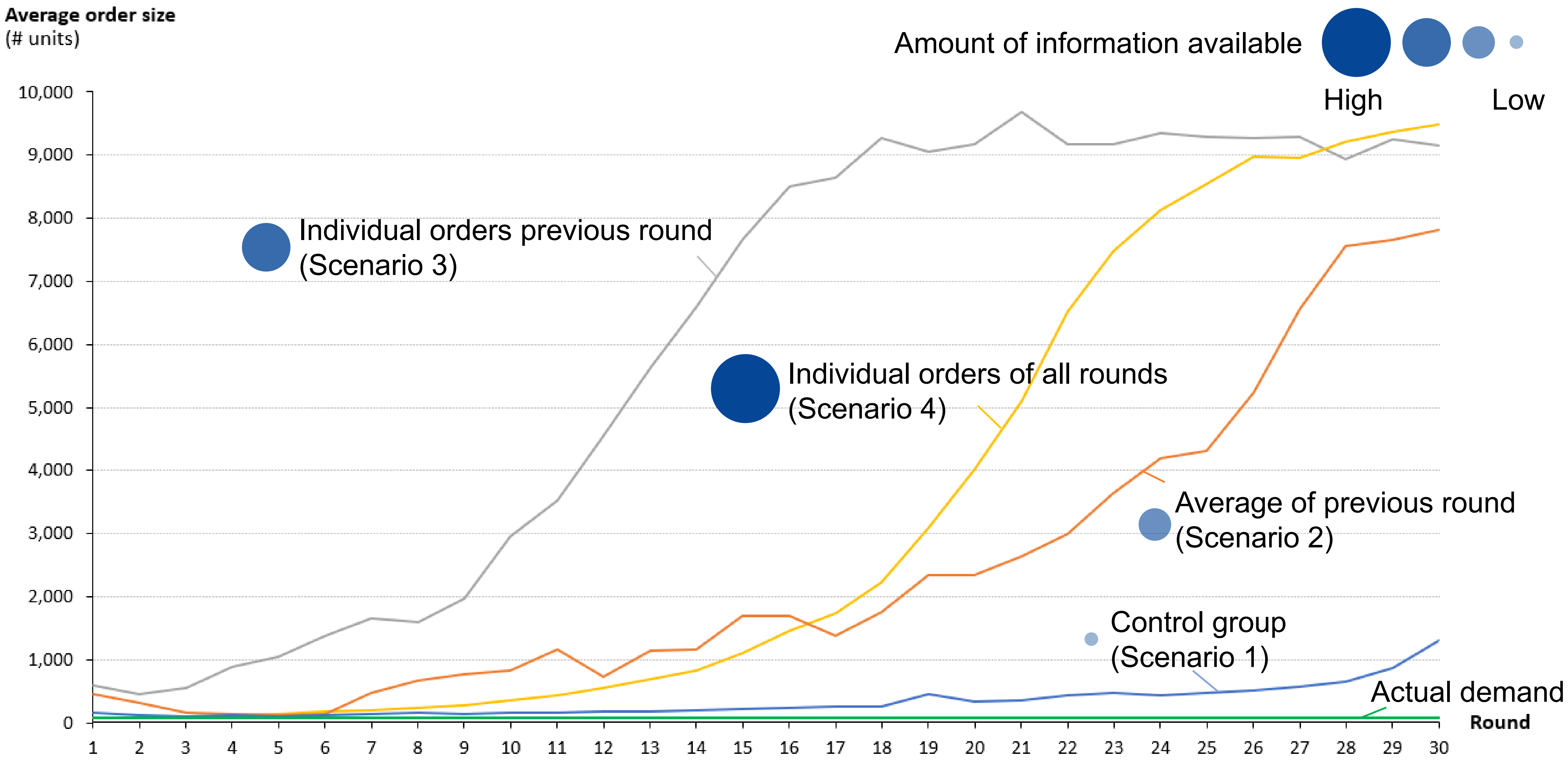


Scenario	# of subjects	Information participant observe	Blockchain application
1 (baseline)	60	No information about competing retailers' orders	• None (emulating traditional supply chains)
2	30	Average order of the other two retailers in the previous round	• Information is anonymized by averaging
3	60	Individual orders of the other two retailers in the previous round only	• Order information is recorded on a distributed ledger, thereby building trust by design • Information is anonymized through encryption
4	60	Individual orders of the other two retailers in all previous rounds	

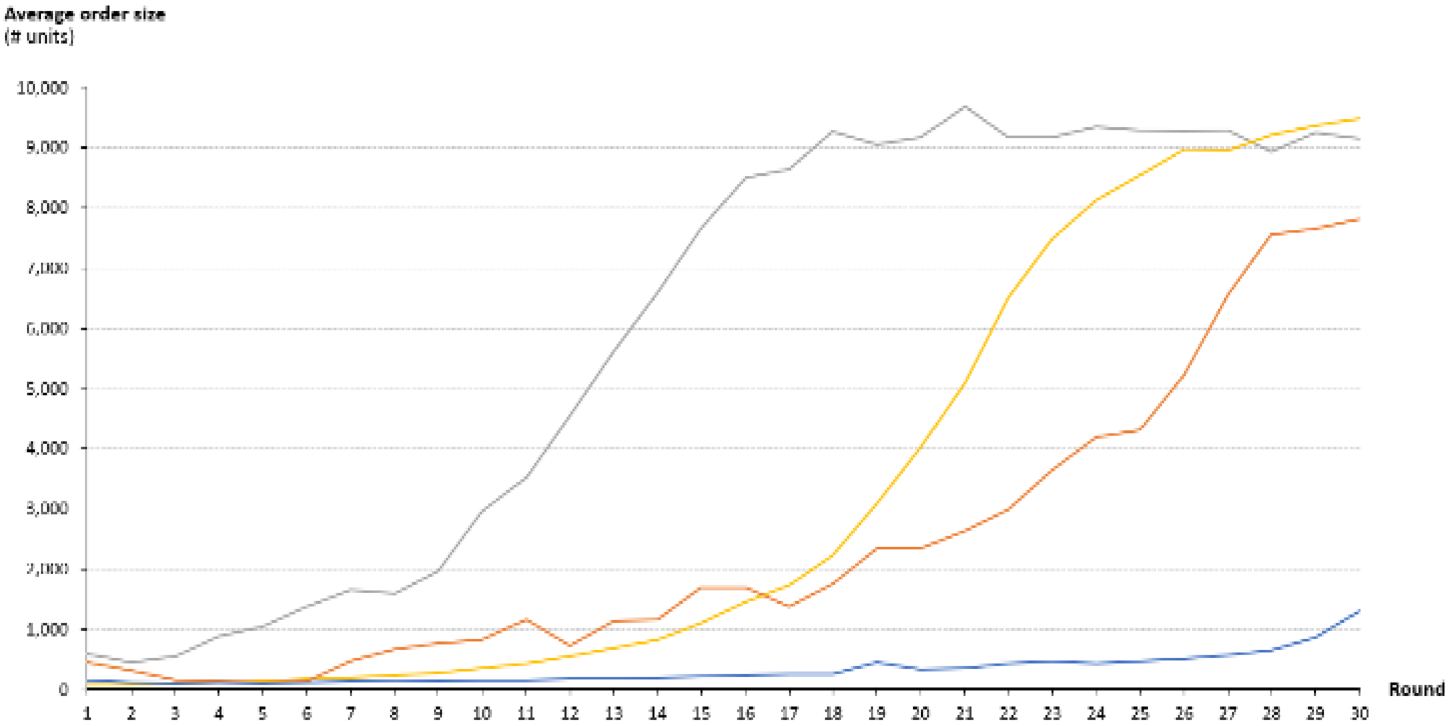
Subjects recruited from a European business school; incentivized by course credit and financial reward based on their performance

Effect of information sharing on order inflation

Information exacerbates order inflation; sharing only the last round's is worse than sharing the entire history



Plenty is not plenty enough: How quickly will panic buying subside?



Two Years Into Pandemic, Shoppers Are Still Hoarding

How the U.S. got into this baby formula mess

Supply Chain Design and Events

Experiment to simulate competition for supply after capacity becomes ample

Design

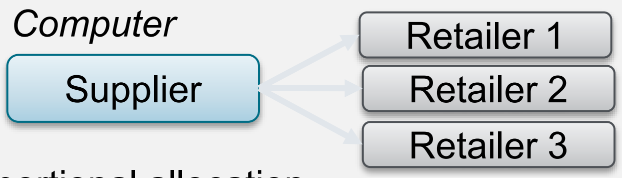
Supply chain parameters

- Duration: 30 rounds
- Demand: constant 50 units (total of 150 units)
- Supply: **rounds 1-15 = 90 units; rounds 16-30 = depending on scenario 150, 190 or 300**
- No backordering or inventory
- Order quantity: integer values 0 – 10,000
- Sales price = constant $20
- Purchase cost = constant $10

Known supply NOT constant

Order history

Known demand constant



Proportional allocation

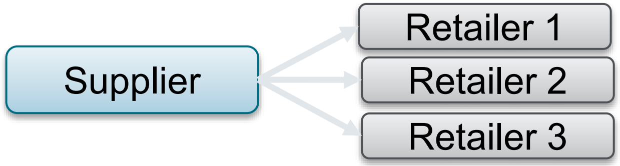
$$y_i = \min\left(x_i, \frac{x_i}{x_1 + x_2 + x_3} \cdot K\right)$$

Events

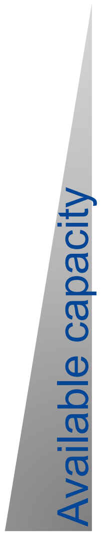
$t = 0$	$t = 1$	$t = 2$
Retailers observe i) outcome of previous round and ii) competitors' orders of previous round	Retailers submit orders to supplier (quantity)	Supplier allocates supply based on proportional allocation rule if orders > capacity; retailers sell to customers

Experimental Design

Capacity becomes ample as of round 16



Total demand = 150 units

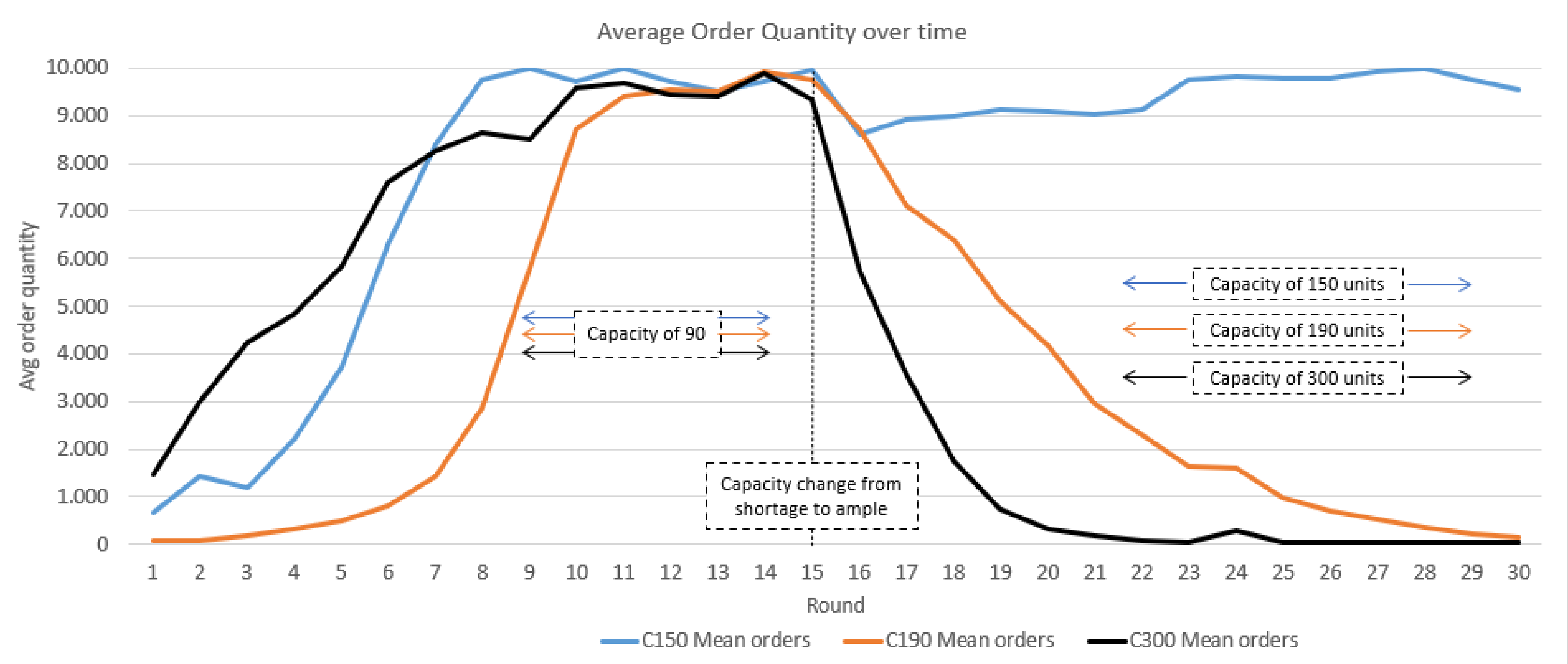


Scenario	Capacity round 1-15	Capacity as of round 16	Comment	# of subjects
1	90 units	**150 units**	• Capacity meets demand (0% excess capacity)	36
2	90 units	**190 units**	• 25% excess capacity	27
3	90 units	**300 units**	• 100% excess capacity	33

Subjects recruited from American and European business schools; incentivized by course credit and financial reward based on their performance

Effect of available capacity on order inflation

Plenty supply is not plenty enough; Even with 200% capacity/demand it takes many rounds until orders are at normal levels



Capacity of 150 (C150)

- It's hard to get out of equilibrium, those who try suffer the consequences and revert to 10k ("safest" equilibrium)

Capacity of 190 (C190)

- Even with 125% capacity/demand, it takes 15 rounds to reach normal order levels

Capacity of 300 (C300)

- Even with 200% capacity/demand, it takes many rounds to reach normal order levels

Overall takeaways

What have we learned?

1. Blockchain technology has useful applications in SCM
   - Beyond current ones in provenance and ethical sourcing
2. Use 5 + 5 framework to decide if BC is right for you
3. Future research themes
   - Information, tokenization, automation
4. Markets work, even in SCM
   - Market clearing prices anchor to wholesale prices
   - Market clearing prices in small markets convey information about value of goods
   - Emergence of mutually reinforcing strategies of spot buying/selling
   - Low-price suppliers suffer lower revenues and higher order variability
5. Sharing history of competitors' orders speeds up order inflation
   - Sharing just the last period is worse then sharing the entire history
6. Plenty of supply is not plenty enough to reduce over-ordering
7. DISASTER platform is a useful research, teaching, training tool