Quantum Advantage in Trading
A Game-Theoretic Approach

Faisal Shah Khan[†], Nobert M. Linke[‡], Anton Trong Than[p], Dror Baron[e]
[†]Taqtics LLC & UNC Kenan-Flagler Business School, [‡]Duke Quantum Center, [‡ p]Joint Quantum Institute & Physics Department – UMD, [e]NC State University
Contact: Faisal_Khan@kenan-flagler.unc.edu

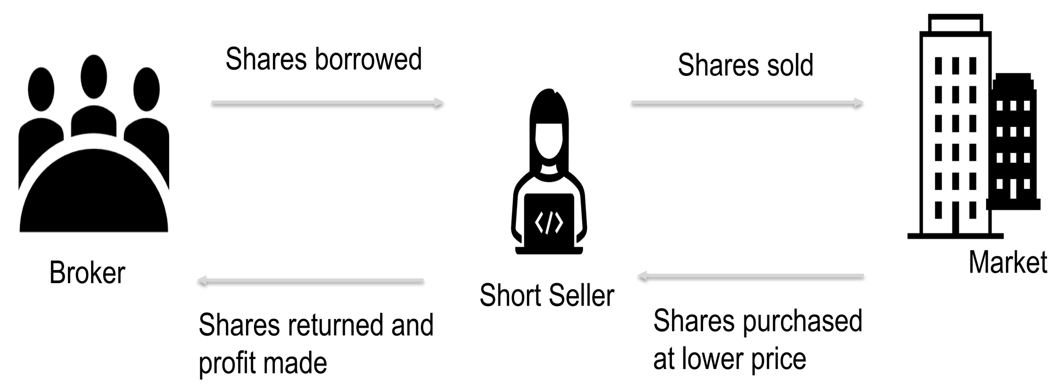
Trading: Going Long vs. Going Short

In trading, there are two fundamental market positions:

- **Going long: buy first, sell later**
  - Betting on a rise in the price of the traded item
- **Going short: sell first, buy later**
  - Betting on a fall in the price of the traded item

When directed toward achieving specific objectives, these actions evolve into strategies designed to meet those goals, and their meaning and execution vary depending on the market in which the trading takes place.

How Going Short Works in Stocks



Problem: Dilemma in Trading

Excessive shorting can be a dominant strategy but can exacerbate the decline in market value [1]. Can new technologies mitigate this problem?

We wish to find a solution to this problem through quantum game theory: games played on a quantum computer.

Game Model: Prisoner's Dilemma

Two traders, **Trade Soros** and **Trader Joe**, engage in trade, both either playing strategies (going) Long or (going) Short:

- Both traders go long: each makes $3.
- One short, the other long: short $5, long $0.
- Both go short: each makes $1 due to possible short-squeeze.

Table 1 shows the four possible strategy pairs and the resulting payoffs. The first number is Soros' payoff and the second is Joe's.

The strategy pair **(Short, Short)** is the unique market (Nash) equilibrium as Short is a best response to itself. The market equilibrium is suboptimal.

		Trader Joe: Long	Trader Joe: Short
Trader Soros	Long	(3,3)	(0,5)
	Short	(5,0)	(1,1)

Table 1

3-Traders

A 3-trader market scenario:

- All traders go long: each makes $3.
- One short, two long: short $5, longs $2.
- One long, two short: long $0, shorts $4.
- All traders go short: each makes $1 due to possible short-squeeze.

Trader Simons goes Long

		Trader Joe: Long	Trader Joe: Short
Trader Soros	Long	(3,3,3)	(2,5,2)
	Short	(5,2,2)	(4,4,0)

Trader Simons goes Short

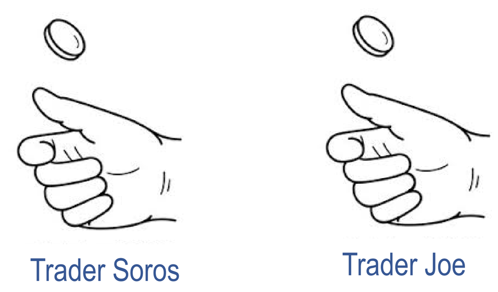
		Trader Joe: Long	Trader Joe: Short
Trader Soros	Long	(2,2,5)	(0,4,4)
	Short	(4,0,4)	(1,1,1)

Table 2

Beyond 3-Traders

Randomization

Players toss individual coins to randomize their choice of strategy. This can improve Nash equilibrium payouts. [2]



Each player looks to randomize so that the opponent is indifferent as to which strategy to reply with.

		Trader Joe: Long (q)	Trader Joe: Short ($1-q$)
Trader Soros	Long (p)	(3,3)	(0,5)
	Short ($1-p$)	(5,0)	(1,1)

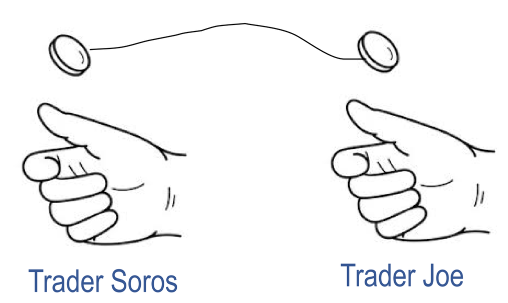
Table 3: Player randomize over their strategies.

These *mixed* strategies are probability distributions, e.g., (p, $1-p$), over strategies. Expected payoff is computed as a weighted average of the payoffs.

Randomizing does not improve Nash equilibrium in trading as shorting strongly dominates going long.

Correlation

Players toss correlated coins to coordinate their choice of strategy. This can improve Nash equilibrium payouts.



The correlated coin system may be considered as a *referee* on whose advice the player *condition* their strategic choice.

		Trader Joe: Long	Trader Joe: Short
Trader Soros	Long	(3,3) p_1	(0,5) p_2
	Short	(5,0) p_3	(1,1) p_4

Table 4: Referee characterized by probability distribution.

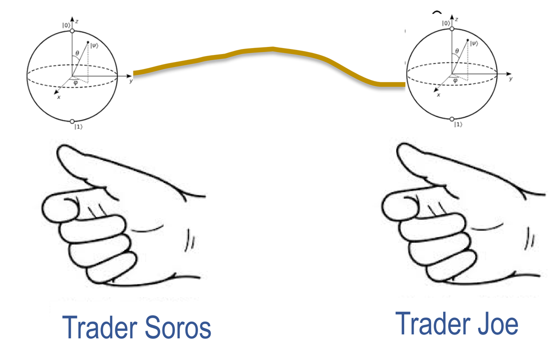
The referee's advice is characterized by a probability distribution (p_1, p_2, p_3, p_4).

If the players **always** agree with the referee's advice, the resulting Nash equilibrium can be better than before.

Correlation is insufficient to improve Nash equilibrium in trading as shorting strongly dominates going long.

Quantum Entanglement

Players toss entangled qubits (correlated quantum coins) to coordinate their choice of *quantum strategy*. This can improve Nash equilibrium payouts[3].



The entangled qubit system may be considered as a "quantum referee" on whose advice the player condition their strategic choice.

		Trader Joe: Long	Trader Joe: Short
Trader Soros	Long	(3,3) μ_1	(0,5) μ_2
	Short	(5,0) μ_3	(1,1) μ_4

Table 5: Quantum referee characterized by quantum superposition.

The referee's advice is characterized by the quantum superposition $(\mu_1, \mu_2, \mu_3, \mu_4)$:

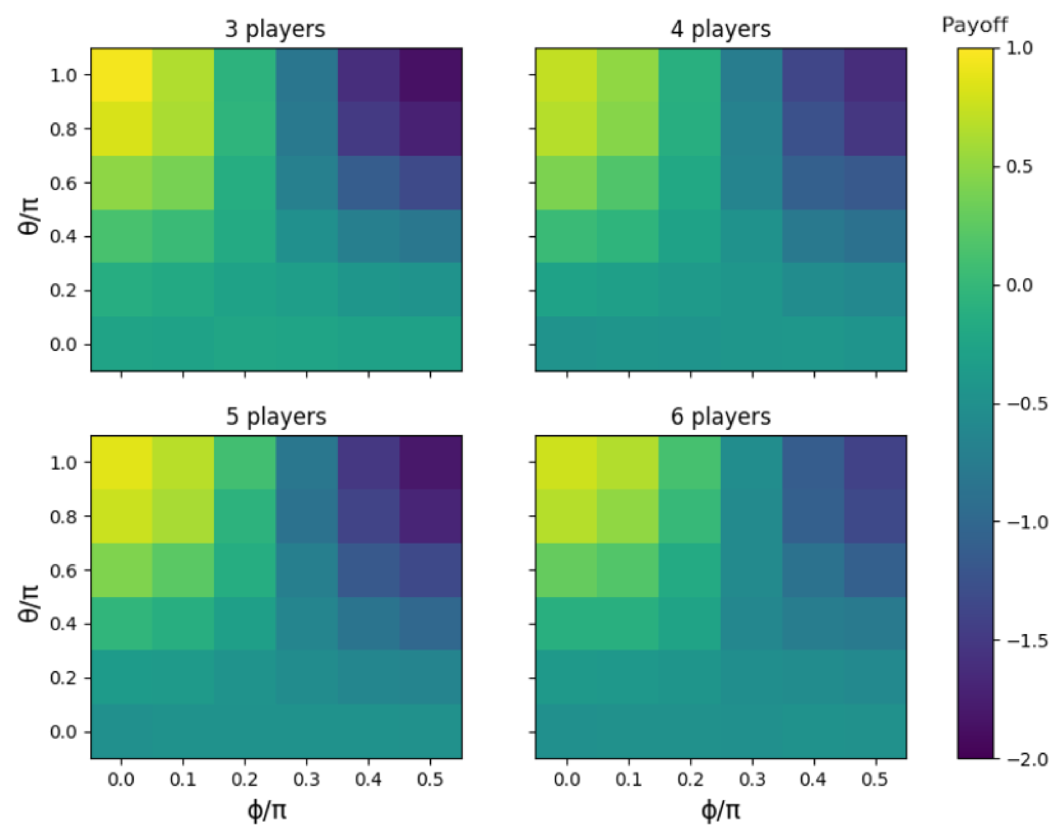
$$\mu_1 := \cos(\phi_1+\phi_2)\cos\left(\frac{\theta_1}{2}\right)\cos\left(\frac{\theta_2}{2}\right),$$
$$\mu_2 := -i\left[\sin(\phi_2)\sin\left(\frac{\theta_1}{2}\right)\cos\left(\frac{\theta_2}{2}\right) - \cos(\phi_1)\cos\left(\frac{\theta_1}{2}\right)\sin\left(\frac{\theta_2}{2}\right)\right],$$
$$\mu_3 := -i\left[\sin(\phi_1)\cos\left(\frac{\theta_1}{2}\right)\sin\left(\frac{\theta_2}{2}\right) - \cos(\phi_2)\sin\left(\frac{\theta_1}{2}\right)\cos\left(\frac{\theta_2}{2}\right)\right],$$
$$\mu_4 := \sin(\phi_1+\phi_2)\cos\left(\frac{\theta_1}{2}\right)\cos\left(\frac{\theta_2}{2}\right) + \sin\left(\frac{\theta_1}{2}\right)\sin\left(\frac{\theta_2}{2}\right).$$

with the parameters of this superposition arising from quantum strategies of player j (j = 1,2):

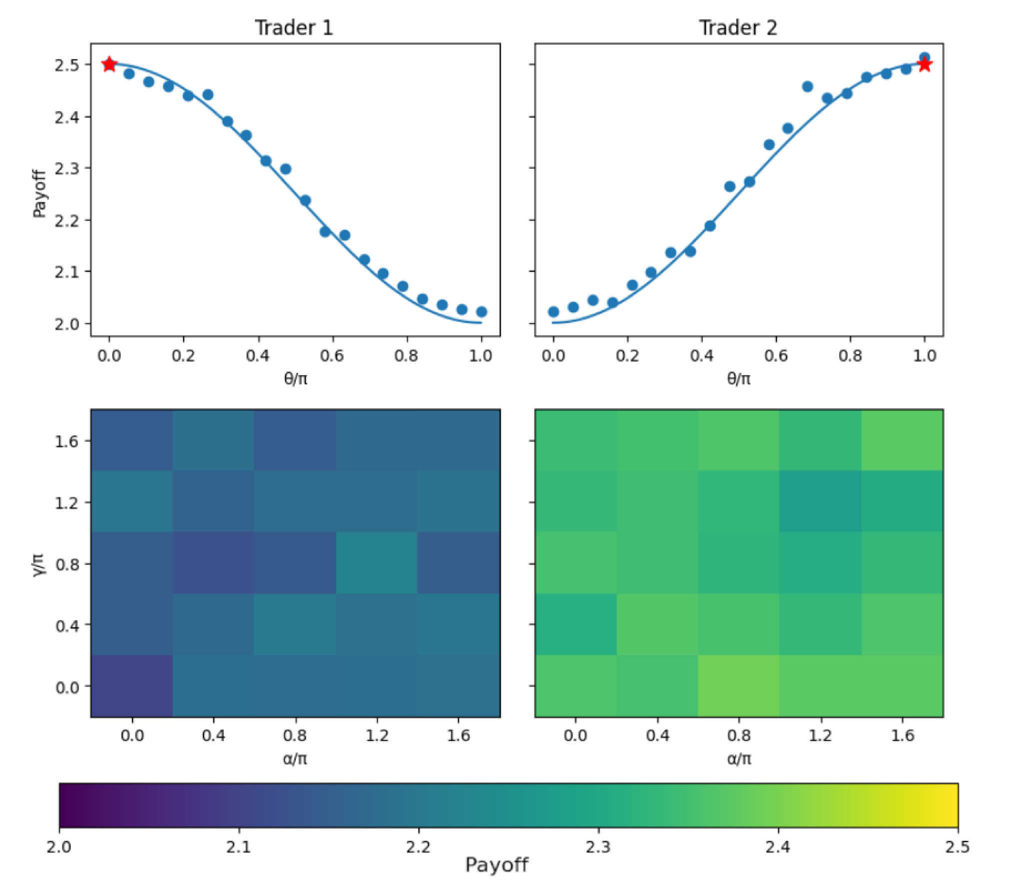
$$U_j = \begin{pmatrix} e^{i\phi_j}\cos\frac{\theta_j}{2} & \sin\frac{\theta_j}{2} \\ -\sin\frac{\theta_j}{2} & e^{-i\phi_j}\cos\frac{\theta_j}{2} \end{pmatrix}$$

When the quantum referee advices the players to play $\phi_j = \frac{\pi}{2}$, $\theta_j = 0$, the players always agree, producing the optimal Nash equilibrium (3,3) upon measurement.

Ion-Trap Implementation [4]



Experimental demonstration of the Nash equilibrium in the quantum Prisoner's Dilemma for n=3,4,5, and 6 players illustrates the payoff for Trader 1 when deviating from equilibrium, which is achieved by selecting (π,0). The graph shows reduced clarity for even numbers of players, attributed to more complex gate decompositions.



Payoffs of players when deviating from the Nash equilibrium strategy for randomized Prisoners' Dilemma. Top: Experimentally measured payoffs for different values of θ are shown. The solid blue line shows the simulated payoff, and the blue dots show the payoff obtained in experiment. The red star is the Nash equilibrium strategy.

References

[1] W. Cruttenden, *Shorting America*, available at https://www.sec.gov/comments/4-627/4627-95.pdf.
[2] K. Binmore, Playing for Real, Oxford University Press.
[3] J. Eisert et al., *Quantum Games and Quantum Strategies*, Phys. Rev. Lett. 83, 3077 (1999).
[4] F. Khan et al., *Quantum Advantage in Trading: A Game-Theoretic Approach, Preprint:* https://doi.org/10.48550/arXiv.2501.17189.