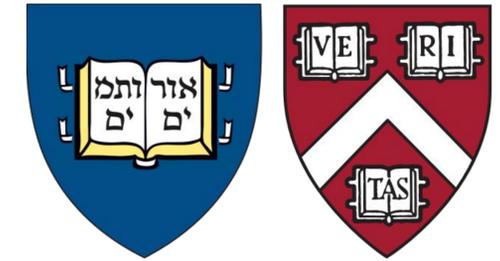


Development of Quantum Machine Learning Agents to Model Simple Economies

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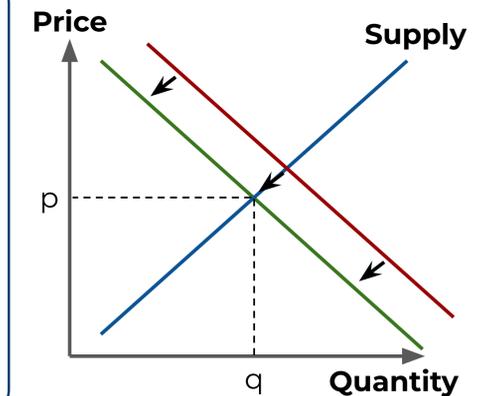


Purpose

- Agent Based Models (ABMs) are computer simulations used to simulate Economic structures and systems; they are especially useful to study experiments impractical to test in the real world.
- Economists, researchers, and analysts use ABMs to study how agents interact with each other or the environment.
- Agents are constituent members that make decisions using internal logic and rules. They are useful to analyze structures and optimizations within an experimental simulation.
- We create buyer agents, seller agents, and release them into a market. Each agent has the instantiated parameters and a logic system.

Methods

- The Market is split into three stages:
 1. **Pre-cycle stage:** Budget and parameters are reset and calculated
 2. **Cycle stage:** Buyers initiate trade with sellers; goods circulate according to trade network
 3. **Post-cycle stage:** Data recorded in memory; price evaluated via logic network
- Four types of agent-based approaches are tested: **computational, bayesian, mixed, and quantum CNNs**. Each individual agent has an internal logic system that determines how they make decisions about purchasing or changing prices.
- We release our agents into a simple economy comprised of only buyers and sellers. One good is being sold, with rational decision-making and perfect communication.

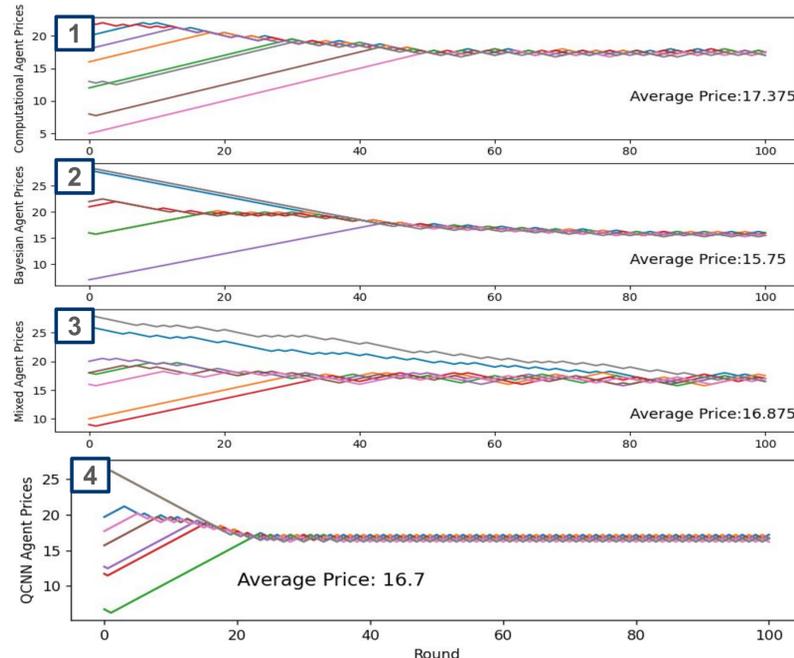


Results

- For a market with a found Equilibrium Price of \$17.8, we observe that all four agents roughly find equilibrium. (**Figures 1-4**), with the computational agents closest to the true equilibrium
- We can further validate our model by showing that it can replicate economic phenomenon, like fluctuating demand and supply curves. Given Ceteris Paribus, If we decrease the budget of the buyers and decrease the number of buyers, the demand curve will shift to the left (**Figures 5-8**).
- The models can find an empirically derived equilibrium. The Quantum CNN structure (**Figures 4, 8**) produced results similar to the Bayesian Agents (**Figures 2, 3**) while converging in fewer rounds. This is preferable; each round in a more complicated system requires a significant amount of computational resources.

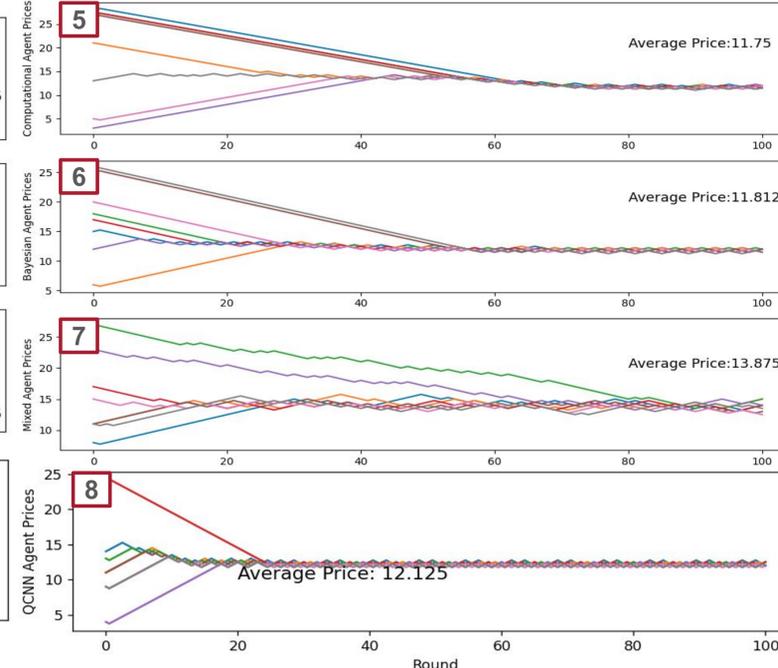
The Buyer agents have the following parameters:

- v_0 : The internal value of the good sold for round 0
- B_0 : The budget for round 0
- C_0 : The consumer surplus heuristic
- μ_0 : The diminishing marginal utility of the good
- μ_0 increases such that amount the buyer is willing to pay is $v_0 - \mu_n$ for the nth item the buyer purchases



The Seller agents have the following parameters:

- P_j : The price for round j
- I_j : The inventory for round j
- X_j : The cost of production
- R_j : The revenue
- π_j : The profit
- λ : The learning rate, modulating price movement



Conclusions

- The Quantum Agents are able to find a Computational Equilibrium to within ~6% error. They are also able to reliably replicate Market trends to a similar degree of certainty. This provides theoretical validity to the convergence properties of the Quantum agents, as they are able to replicate the movements of the other agents to a similar standard.
- The Quantum Agents converge quicker than the Bayesian agents. This is important because the two are only separated by the market structure, so analysts who are modeling complicated structures can rely on the Quantum Agents to converge faster with less resources than the Bayesian Agents.
- Future work will focus on analyzing a more complex system.