Extension of Agent Based Modeling in China's National Volume Based drug Procurement: bidding simulation and policy implications

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Background

- Initiated in 2018, China's National Volume-Based Drug Procurement (NVBP) represents a landmark reform in pharmaceutical pricing, achieving substantial cost reductions through centralized competitive bidding[1-3].
- To date, the number of procured drug varieties has reached 490, with an average price reduction of more than 50%. By 2023, centralized procurement of pharmaceutical products had saved over 500 billion yuan[4].
- NVBP constitutes a complex system scenario involving multi-stakeholder strategic interactions. Previous research on modeling this context has mainly focused on theoretical models and econometric analyses[5-8], which have not sufficiently dissected the outcomes of enterprises' bidding games among multiple agents and are thus inadequate to systematically explain price formation under competitive dynamics.

Objective

To extend agent-based simulation model for competitive bidding in China's NVBP and explore its policy implications for procurement optimization.

Methods

- We developed a multi-agent simulation framework calibrated with real-world data from NVBP rounds 2-9 (excluding Round 6), involving 325 drugs and 2,267 enterprises
- A rule-based Agent-Based Model (ABM) was constructed to simulate bidding of firms under rules
- To address the limitation that rule-based ABMs rely on random single-step actions, we integrated a Markov Decision Process (MDP)
  - ✓ Reinforcement Learning (RL)
  - ✓ Large Language Models (LLMs)
  - ✓ Markup-based pricing algorithm (Rule-based)
- Sensitivity analyses (key policy parameters and market parameters)
  - ✓ Maximum valid bidding price
  - ✓ Agreed procurement volume
  - ✓ …

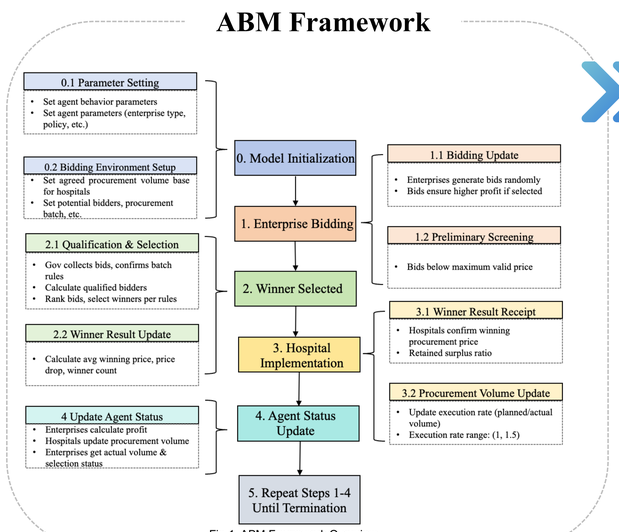

Fig 1. ABM Framework Overview

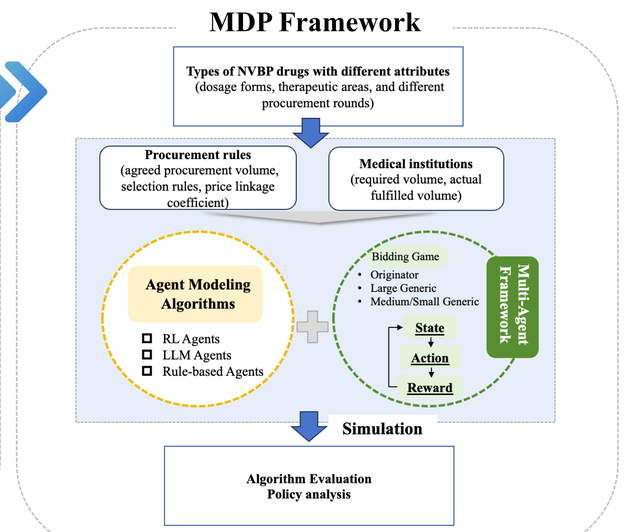

Fig 2. MDP Framework Overview

Conclusion

While the ABM approach effectively reproduced real-world bidding outcomes, the MDP extension further enhanced simulation realism and presented interpretable evidence regarding firm's strategic adaptations. These findings highlighted that accurate demand forecasting and rational rule design of maximum bid price were key policy levers for optimizing NVBP in China.

Results

Evaluation of NVBP ABM simulation

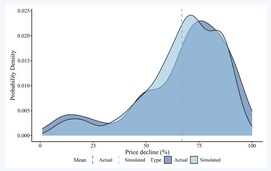

Fig 3.Density Plot of Winning Price Decline Rates

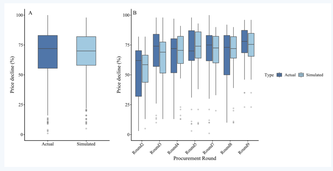

Fig 4. Box Plot of Winning Price Decline Rates

- The ABM demonstrated good fidelity in reproducing real-world outcomes.
  - ✓ overall RMSE 12.86%

Evaluation of NVBP MDP simulation

Table 1. Correlation and Prediction Performance of Different Algorithms

Algorithm	Spearman_ρ	Selection prediction accuracy (%)
IPPO	0.87***	74.97(5.35)
MAPPO	0.88***	75.00(5.98)
LLM	0.87***	65.74(3.08)
Rule-Based	0.85***	64.56(4.2)

Notes, Spearman's ρ indicates the correlation between predicted and actual values. Selection prediction accuracy represents the percentage of correctly predicted selections in simulation. Standard deviations are shown in parentheses. *** p < 0.001.

- Simulated bids strongly correlated with actual bids (Spearman ρ = 0.85-0.88; P<0.001).

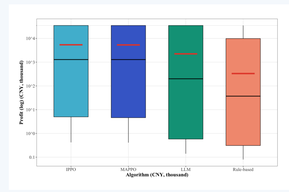

Fig 5. Firm profit of Different Algorithms
Notes, unit: CNY thousand,log-scale profit distribution.

- RL consistently outperforming LLM and Rule-based approaches regarding firm profitability.

Sensitivity analysis results

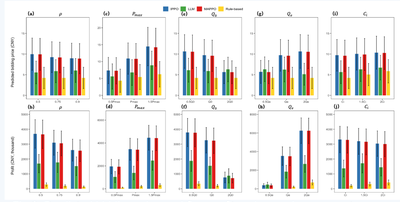

Fig 6. Predicted bidding price and firm profit under varying parameters

Notes, (a,b) agreed procurement ratios (ρ); (c,d) maximum valid bidding prices (P_{max}) (unit: CNY); (e,f) agreed procurement volume (Q_o) (unit: 10^3 dosage units); (g,h) actual procurement volume (Q_e) (unit: 10^3 dosage units); (i,j) unit production costs (C_i) (unit: CNY). Colored bar indicate four algorithms.

- The maximum valid bid price as the most influential policy parameter affecting bidding behavior, whereas the agreed procurement ratio had limited impact.
- Firm profits were highly sensitive to deviations between actual and agreed procurement volumes

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