Dynamic Pricing Provides Robust Equilibria for Stochastic Ridesharing

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Model Description

- **Stochastic Two-Level Model**: Riders and drivers are discrete agents. Rider and driver decisions governed by microscopic randomness. High-level traffic patterns governed by macroscopic randomness.

- **Stochastic Fluid Model**: Large market limit of two-level model. Riders and drivers are deterministic, continuous agents. Top-level macroscopic randomness of two-level model is retained.

Single Period Dynamics: Microscopic Randomness

![Image showing single period dynamics](image)

- **Left**: Spatiotemporal network similar to previous work on deterministic ridesharing mechanism design.
- **Middle**: Stochastic scenario tree is a new ingredient we introduce to model macroscopic uncertainty.
- **Right**: Cross-product of spatiotemporal network and scenario tree defines a stochastic flow network.

Stochastic Spatiotemporal Network Structure: Macroscopic Randomness

Dynamic Pricing Algorithm for Stochastic Ridesharing Networks

- At beginning of each time period: re-solve fluid problem, incorporating realized driver locations.
- Set prices based on re-computed optimal dual variables.

Results

Strategy profile is an approximate subgame-perfect equilibrium if, from any market state, approximately every driver has approximately no incentive to take a different trip.

Under our dynamic pricing algorithm, in a large-market limit of the two-level model:

- **(Incentive-Compatibility)** Welfare-optimal trips are an approximate subgame-perfect equilibrium.
- **(Welfare-Robustness)** Every approximate subgame-perfect equilibrium is approximately welfare-optimal.

Example: The Need for Driver-Aware Prices

- Scenario-aware prices can achieve incentive-compatibility, but not robustness.
- In stochastic fluid model, equilibrium strategy is not unique: \( \text{Utility(exit)} = \text{Utility(stay)} \).
- In two-level model, small probability of not getting a dispatch: \( \text{Utility(exit)} > \text{Utility(stay)} \).

Takeaways

- Novel model for ridesharing markets combining tractability and realism.
- New robustness property: every approximate equilibrium is approximately welfare-optimal.
- New insights into dynamic pricing in ridesharing markets and re-solving in stochastic optimization.