Auction in Staffing for Self-scheduling Service

Yanling Chang Lu Sun Matthew F. Keblis Jie Yang

Industrial Distribution
Industrial Systems and Engineering
Texas A&M University

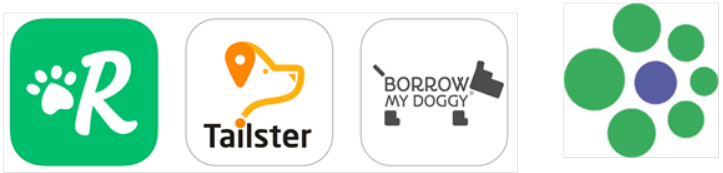
May 23, 2022

Self-Scheduling Business and Gig Economy

ridesharing

freelancing

Grocery delivery

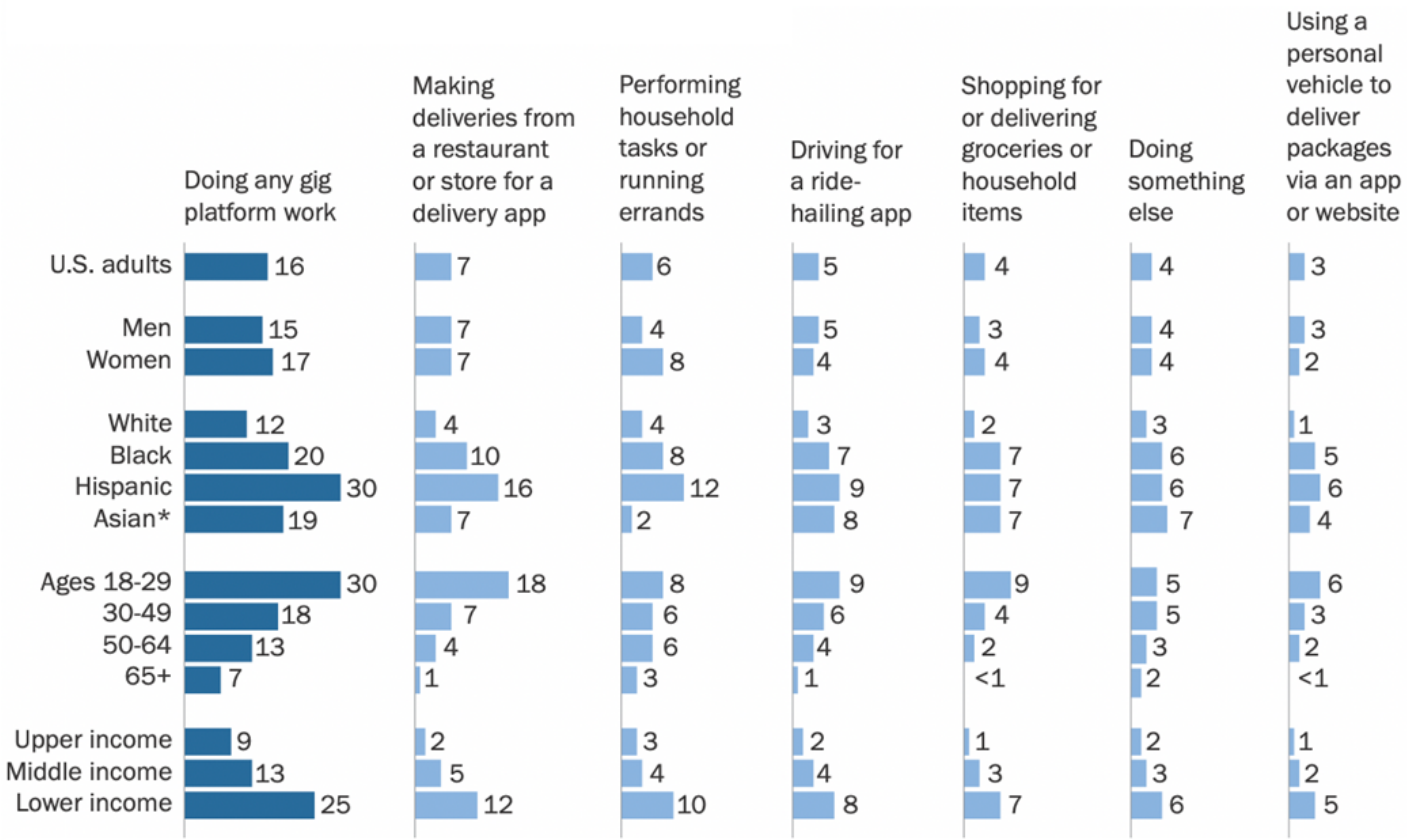


Dog and baby sitting

The State of Gig Work in 2021

16% of Americans have ever earned money via an online gig platform; adults under 30, Hispanic adults and those with lower incomes especially likely to do these jobs

*% of U.S. adults who say they have **ever** earned money by ...*



*Asian adults were interviewed in English only.

Note: Gig platform work refers to earning money by using a mobile app or website to find jobs that directly connect workers with people who want to hire them, or by using a personal vehicle to deliver packages to others. White, Black and Asian adults include those who report being only one race and are not Hispanic. Hispanics are of any race. Family income tiers are based on adjusted 2020 earnings. Those who did not give an answer are not shown.

Source: Survey of U.S. adults conducted Aug. 23-29, 2021.
"The State of Gig Work in 2021"

PEW RESEARCH CENTER

Staffing in Self-Scheduling Business

Challenges

- High demand uncertainty
- Little or no control over staff
- Attrition

A Two-sided Problem

Existing Staffing and Wage Models

- Fixed wage model (widely used)
- Auction
- Dynamic pricing

DiDi

TaskRabbit

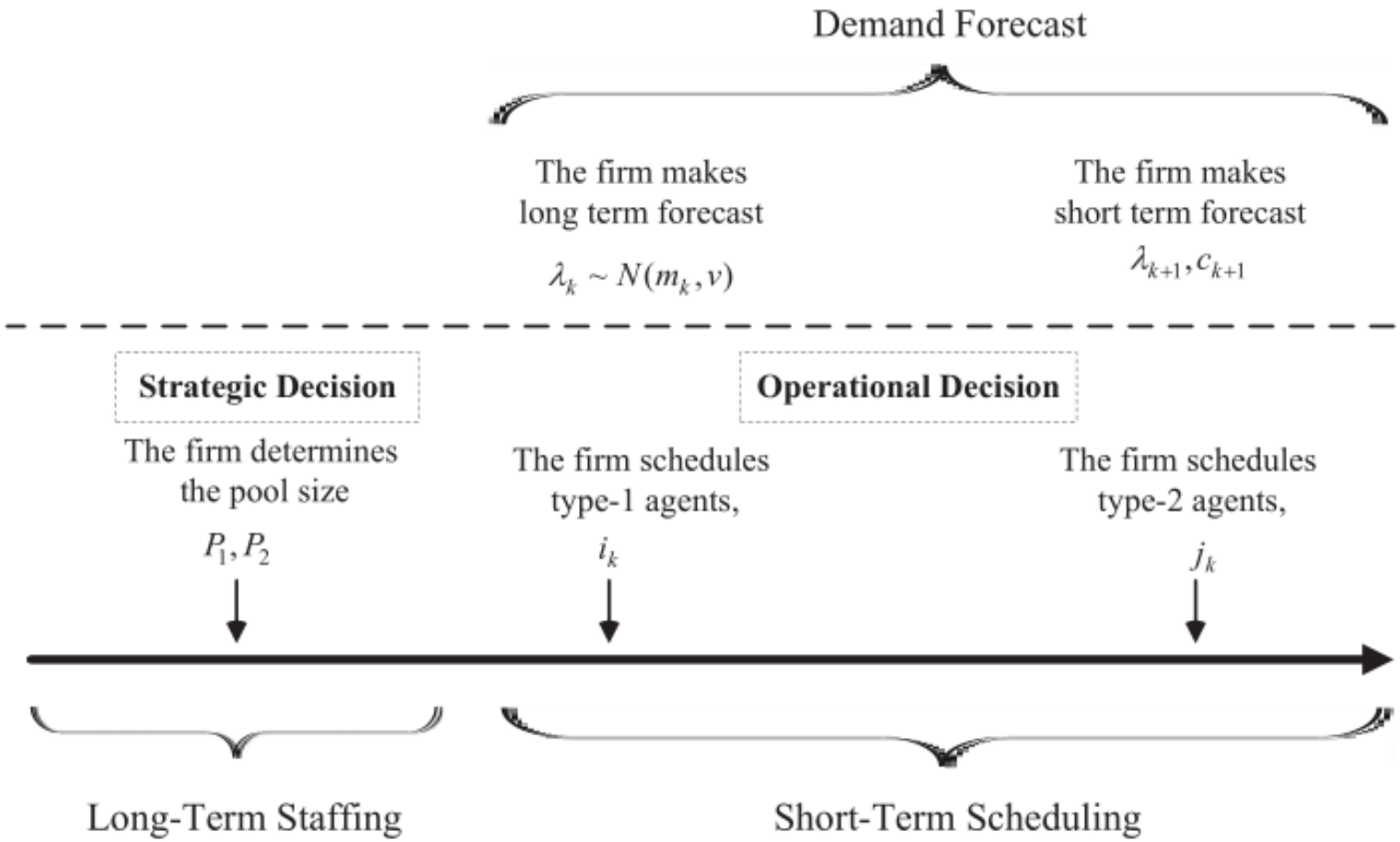
Related Literature

- Staffing and rostering
  - Numerous studies and algorithms for staffing and scheduling, e.g., Buffa et al. (1976), Brucker et al. (2011), Van den Eeckhout et al. (2019), Lin and Ying (2014), Askin and Harker (2003), Bassamboo and Randawa (2010) etc.
  - Not in the context of self-scheduling.
- Auction mechanism
  - Nurse scheduling: De Grano et al. (2009)
  - Driving: Asghari et al. (2016), Zheng et al. (2019), Zhao et al. (2019)
- Self-scheduling service
  - focus on the demand side: Wang et al. (2016), Zha et al. (2016), Cachon et al. (2017), Zha et al. (2017), Taylor (2018), etc.
  - workforce stratification: Ibrahim (2018), Dong and Ibrahim (2017)
- Flexible workers
  - flexible workers and cross-trained agents: Iravani et al. (2005), Tekin et al. (2009), Kesavan et al. (2014)

Two Types of Agents

- **Type 1 - more regular worker**
  - Individuals operating under more constraints and having less flexibility in terms of when available to work
  - The need to make plans in advance of working and are not available to work on short notice
  - e.g. find child or parental care or travel to a location
- **Type 2 - more flexible worker**
  - work with little advance notification

An Integrated Modeling Framework



Objective: maximize profit for a company over K shifts in the long run.

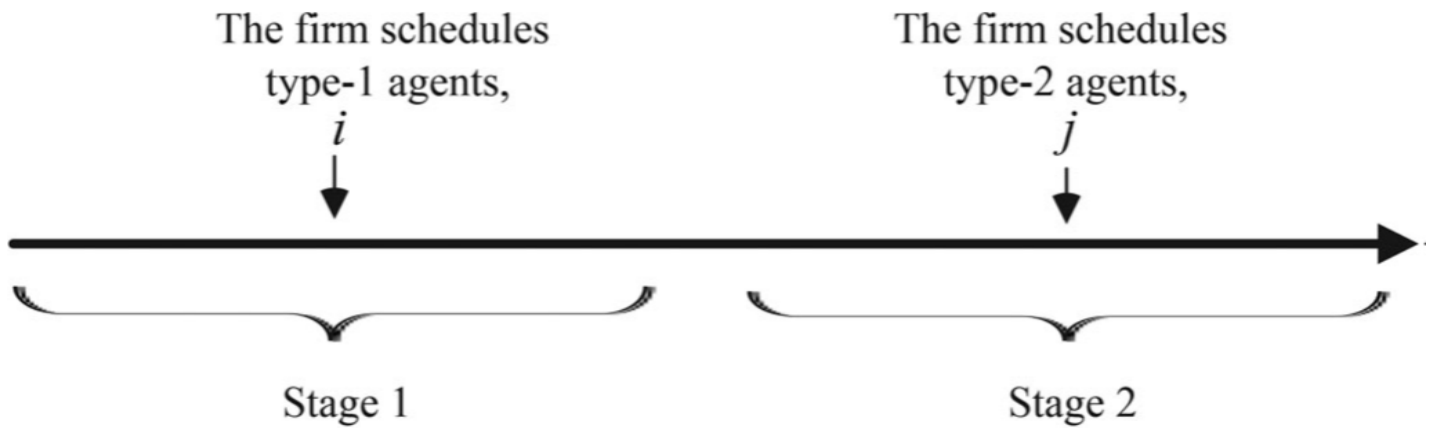
Demand Forecast

- Long-term forecasting $\Rightarrow$ Type-1 service providers
  - estimate average demand for each shift using a long period of *historical* data
  - customers arrive at the platform according to Poisson distribution with mean λ_k
  - λ_k follows $AR(1)$ autoregressive process: $\lambda_{k+1} = \alpha + \rho\lambda_k + \epsilon_k$, where α, ρ are constants, and $\epsilon_k \sim \mathcal{N}(0, \sigma^2)$
- Short-term forecasting $\Rightarrow$ Type-2 service providers
  - determine a more accurate prediction for the upcoming shift based on updated *real-time* data
  - update λ_{k+1} based on the actual number of customers arriving at the service system in shift k.

Short-Term Scheduling

The staffing manager schedules both Type-1 (i) and Type-2 (j) agents via auction for each shift.

- Long before the shift starts (e.g., a week), schedule i out of n_1 bidders in advance to meet its *expected* demand
- Right before the shift, the number of customers that have arrived at the service platform in the last shift is revealed $\Rightarrow$ update demand forecast $\Rightarrow$ schedule j out of n_2 bidders (*real-time adjustment*)



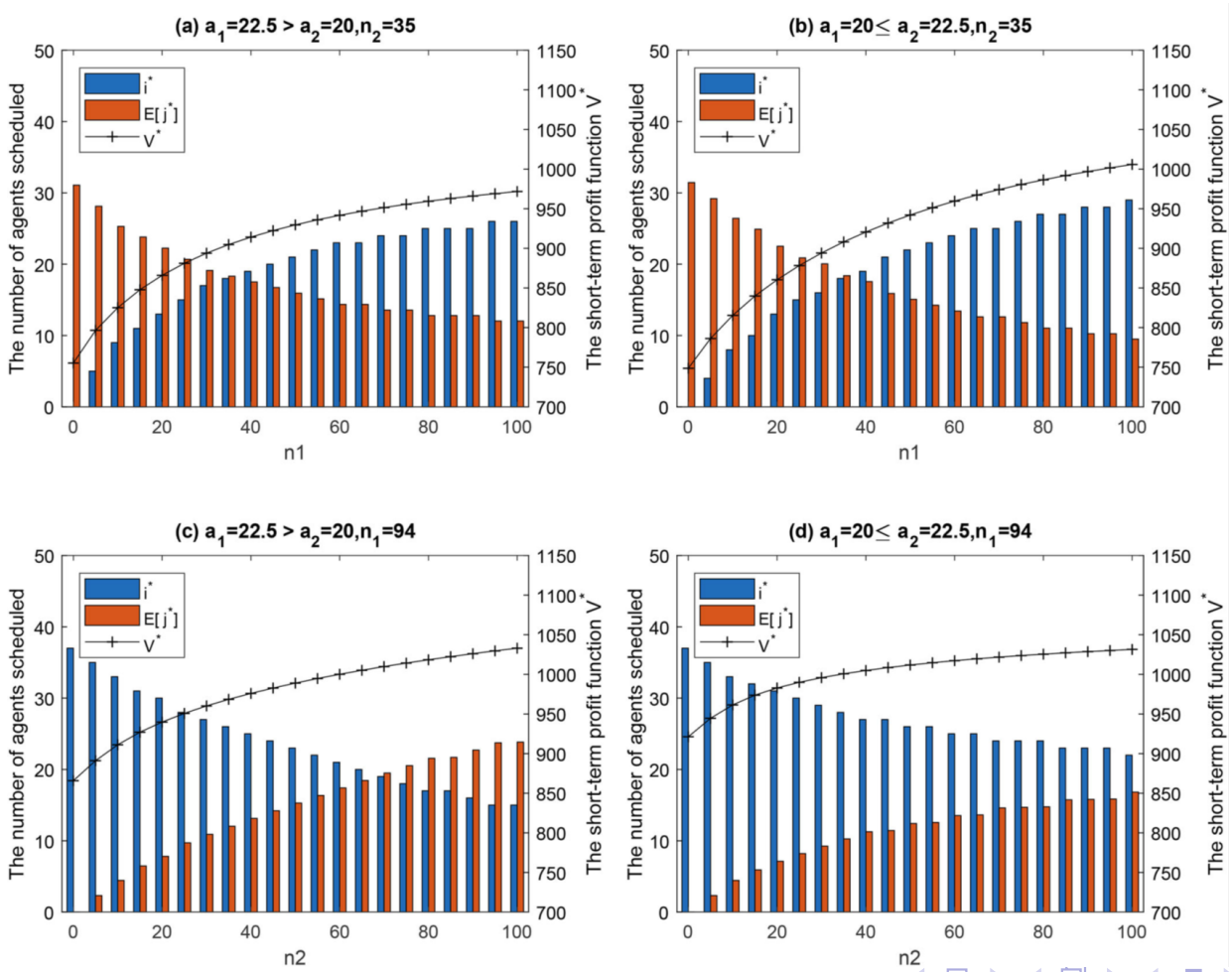
A two-stage decision making process

Long-Term Staffing

- Let P_1 and P_2 be the maximum numbers of agents that could provide service for any shift.
- Not all agents in the first and the second pools are able (or willing) to work (and hence bid) for a given shift.
  - $n_{1,k} = \gamma_{1,k} P_1$, $n_{2,k} = \gamma_{2,k} P_2$
- Attrition cost: call center (30-45%)
- Determine P_1 and P_2 to maximize long-term profit.
  - Concave function, gradient ascent method.

Short-Term Scheduling Results

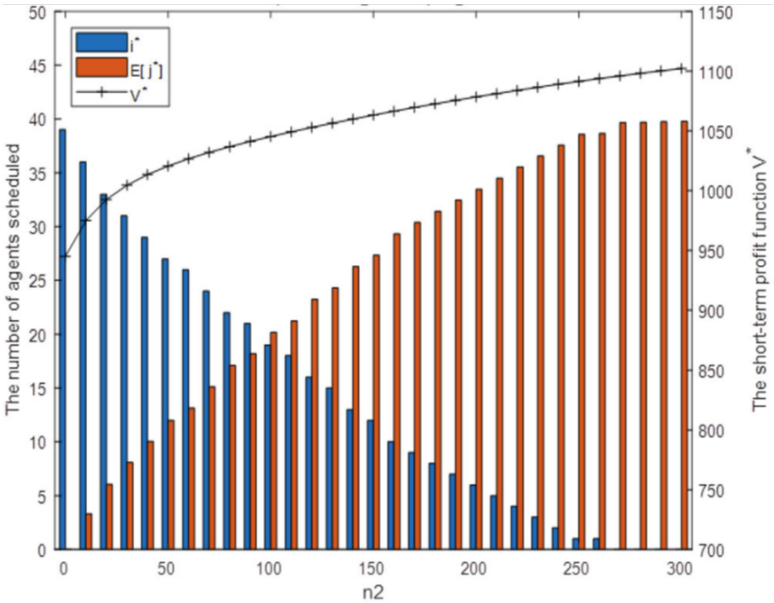
- The optimal short-term profit is strictly increasing in the number of Type-1 bidders n_1 (Type-2 bidders n_2).
- The total number of scheduled agents $i + j$ remains roughly the same as n_1, n_2 changes.



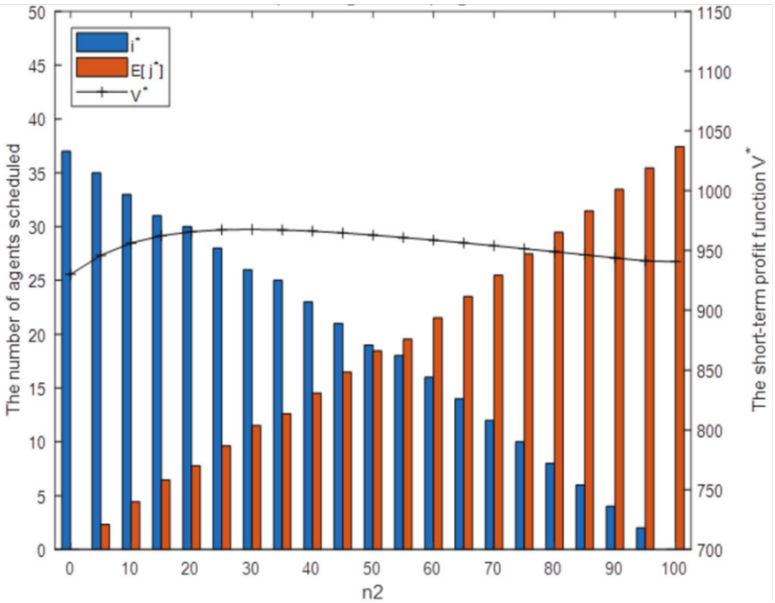
Valuation of Work for Short-Term

Intuitively, maintaining a hybrid pool comprised of both Type-1 and Type-2 agents is expected to be more profitable than recruiting only one type of agents.

Low Valuation



High Valuation



Not necessarily!! Depends on how type-2 agents value their work.

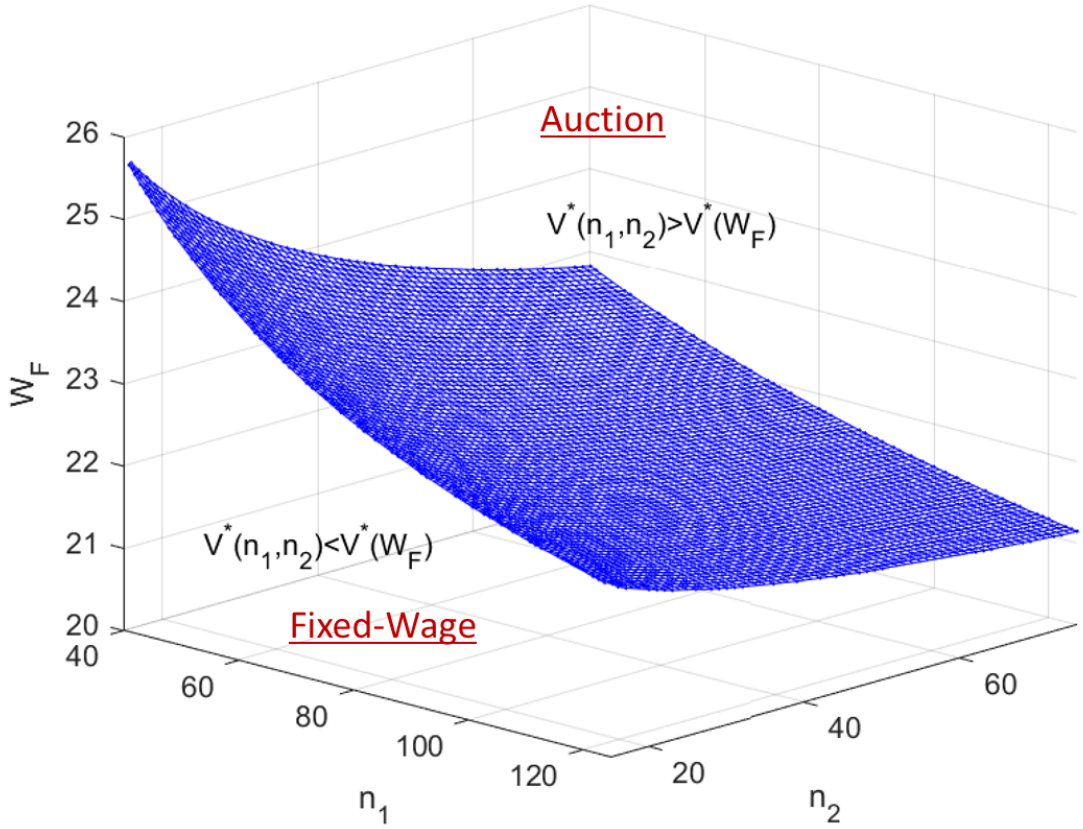
Long-Term Staffing

Table 1: The impact of attrition rate on the pool sizes and the optimal profit.

β_0	attrition rate	attrition cost	pool-1 size	pool-2 size	Optimal profit
0.01	0.204	\$434,112	194	72	\$8,362,592
0.02	0.212	\$447,744	192	72	\$8,341,427
0.03	0.22	\$461,120	190	70	\$8,320,430
0.04	0.228	\$474,240	188	72	\$8,299,513
0.05	0.236	\$487,104	188	70	\$8,278,765
0.06	0.244	\$499,712	186	70	\$8,258,186
0.07	0.254	\$520,192	184	68	\$8,237,706
0.08	0.26	\$524,160	184	68	\$8,217,444
0.09	0.27	\$544,329	184	68	\$8,197,284
0.10	0.278	\$556,000	182	68	\$8,177,282
0.11	0.286	\$567,424	180	68	\$8,157,361
0.12	0.296	\$587,264	180	68	\$8,137,521
0.13	0.302	\$589,504	178	66	\$8,117,936
0.14	0.31	\$600,160	176	66	\$8,098,432
0.15	0.32	\$619,520	176	66	\$8,079,072

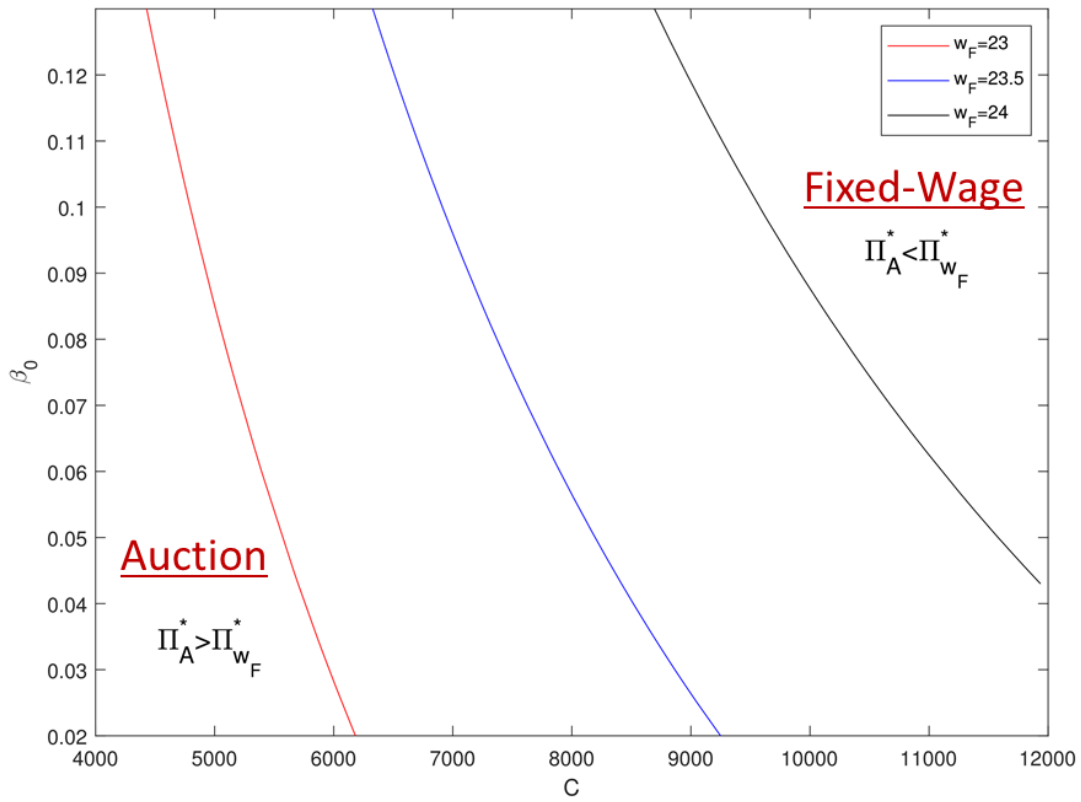
High attrition rates may limit the use of auction in self-scheduling services.

Model Selection: Auction vs. Fixed-Wage



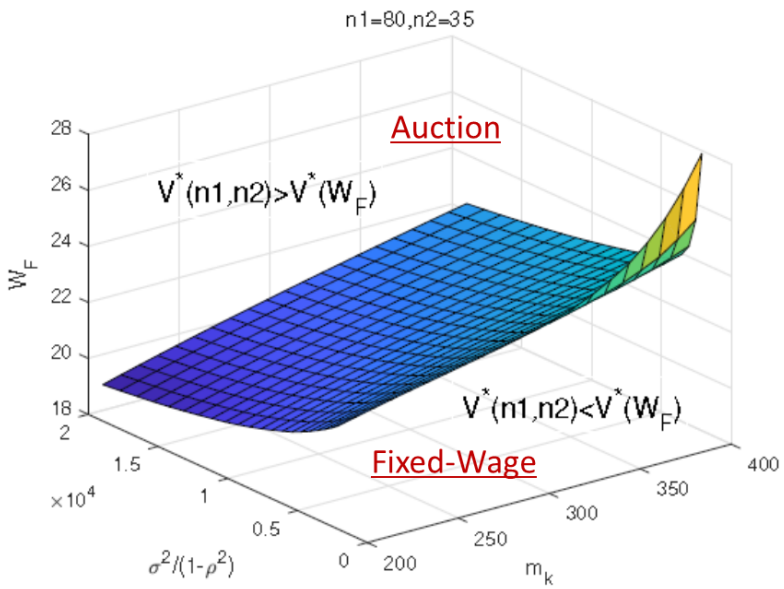
Fixed-wage models work better for low-wage jobs (e.g., delivery services, Instacart and Walmart).

Model Selection: Auction vs. Fixed-Wage

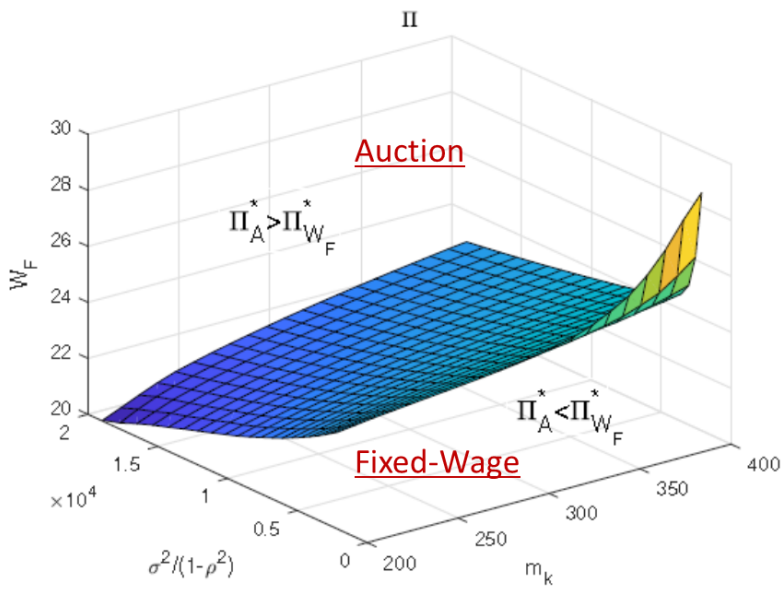


Auction models work better for industries with low attrition.

Model Selection: Auction vs. Fixed-Wage



(a) short-term



(b) long-term

Auction models work better for markets with high volatility.

Conclusions

- We develop an integrated methodological framework to jointly determine the optimal pool sizes for the long-term planning and the desirable numbers of agents for each shift in the short-term scheduling
- Analysis of the auction model
  - The effectiveness of the auction model hinges upon a large number of potential bidders being available.
  - The stratified workforce and auction enable firms to schedule agents on-demand.
  - The auction model can properly adjust staff scheduling based on agents' valuation of work.
- Selection between *Auction* and *Fixed-wage*. *Auction* is more preferable for
  - Low attrition cost industries
  - High volatile markets
  - High-wage jobs (usually require advanced skill sets)