Who Benefits from Drone-Enhanced Food Delivery? Economic and Welfare Impacts of Drone Adoption

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1 INTRODUCTION

The growing popularity of food delivery platforms has led to an increasing preference for delivery over dining in. Platforms, which reply on crowdsourced couriers for point-to-point, on-demand services, face mounting pressure to reduce delivery times and meet customer expectations. However, the reliance on ground-based transportation networks has led to increasing concerns over congestion, traffic accidents, and inconsistent delivery reliability. Since these challenges stem from physical constraints in urban road networks, incremental improvements in routing and dispatching cannot fully resolve them.

The emergence of drone-based delivery, by leveraging the abundant low-altitude airspace, offers a promising alternative to bypass the challenges associated with ground-based delivery. Since its introduction in 2021, Meituan, the giant in the Chinese food delivery market, has completed over 210,000 drone deliveries, saving users nearly 30,000 hours of waiting time, demonstrating their potential to enhance delivery efficiency (Meituan News Center (2024)). Alongside real-world adoption, research has advanced drone delivery operations through route optimization, task assignment, and human-drone collaboration. (Lemardel *et al.*, 2021, Chen *et al.*, 2021, Sun *et al.*, 2024). While these studies have improved drone delivery logistics, fewer have explored the economic implications of drone deployment, including its impact on pricing, labor demand, and social welfare.

To bridge this gap, this paper develops an economic framework to analyze optimal investment and pricing strategies for drone-enhanced food delivery market. Similar studies in ride-hailing markets have examined the competition between autonomous and human-driven vehicles Lian & van Ryzin (2024). Built upon a linear city framework, our analytical model captures strategic interactions among platforms, crowdsourced drivers, and customers in different market structures, including perfect competition, monopoly, and duopoly. Both supply and demand are endogenous: supply is represented by delivery efficiencies per human deliverer or drone, while demand is heterogeneous and price-sensitive. Bertrand competition is adopted to model the interactions when two platforms exist in the market, analyzing how competitive pressures influence pricing and investment decisions under varying market powers.

We hope this pioneering work serves as a foundation for future economic analysis of drone-enhanced delivery, offering insights into its long-term viability, competitive dynamics, and policy implications.

2 The Model

We consider a linear city with a restaurant located at the origin, where customers are uniformly distributed at $[0, x]$ from the origin with a density of $f(x)$. Each customer's valuation of the order service is v, uniformly distributed on the interval $[0, V]$, with a probability density function of $g(v) = \frac{1}{V}$.

Market Configuration. We first consider three types of single-platform delivery models:

1. A human-only platform, which serves as our baseline.
2. A mixed platform where both drones and human drivers participate, but they operate independently
3. A drone-only platform.

Drone delivery services are provided by third-party outsourcing suppliers, who offer a menu of drone quantities n_d and price p_s combinations to the platform. Outsourcing companies operate under two market conditions: perfect competition and monopoly. In a perfectly competitive market, we assume that the number of potential drone suppliers is infinite. If a drone generates positive expected profits, potential suppliers will enter the market until the expected profits fall to zero. In this case, the price p_s of a drone is set such that the expected profit is equal to the cost of purchasing a drone (i.e., the fixed cost C_f and variable cost C_v). Under monopoly conditions, drone suppliers aim to maximize their profits.

Human Driver Decision. To simplify the model, we assume that human drivers are always available in a perfectly elastic labor market, where their wages are determined by market forces and equal to the competitive wage rate w. The supply of human drivers is perfectly elastic, as they are indifferent to working for the platform.

Customer Decision. We assume consumers are price-sensitive and primarily focus on the service prices offered by the platform. Let U_i denote the utility of customer ordering, where the subscript $i \in \{r, d, h\}$ is mnemonic for three delivery options: (a) dine-in; (b) drone delivery; (c) human driver delivery. In the case of dine-in, no delivery service is involved. We assume customers are highly sensitive to the waiting time for delivery services, with a positive time sensitivity coefficient β, and incur an additional waiting cost based on the waiting time T. The waiting time consists of both delivery and pickup time. Drone delivery is assumed to be faster than human drivers with the ratio $\tau > 1$ to the human driver speed s, but customers must spend additional time picking up the food delivered by drones ($t_c > t_p$) at designated pickup locations, since the drones couldn't achieve door-to-door delivery as human drivers.

Platform Decision The platform determines the charges p for the different delivery services, where p_d represents the price for drone delivery and p_h for human driver delivery. The total demand is endogenous and depends on the delivery prices. We assume that both drones and human drivers can only deliver one order per trip, with identical order quality and non-overlapping delivery areas. Customers will choose the option that provides the highest utility, provided that the utility is non-negative. In a perfectly competitive platform, all profits are transferred to customers, and the platform operates at a zero-profit equilibrium (i.e., $\Pi = 0$). The monopolistic platform is profit-driven. We assume that profits at each point are divisible, and therefore, the profit maximization problem of drone delivery per unit distance is given by:

$$\max_{p_d(x)} \ \pi(x, v) = \int_0^V (p_d - p_s) x f(x) g(v) \, dv \tag{1}$$

$$\text{s.t.} U_d \geq 0$$

Events Sequence With consideration of the decisions to be made by the customer, platform and deliverers, Figure 1 depicts the sequence of events. A potential customer (x, v) first considers placing an order, and the platform will use this information to determine its decisions about the delivery price and the quantities of deliverers, and assigns the order to the appropriate deliverer based on the customer's preferences. The customer's indifference point x^* plays a crucial role in this process, as it defines the critical distance that influences the customer's choice between the different delivery options.

The model is analyzed via backward induction. Starting with the customer's decision-making process, we identify the delivery method chosen by the customer, then the supplier's decisions and the platform's pricing strategy.

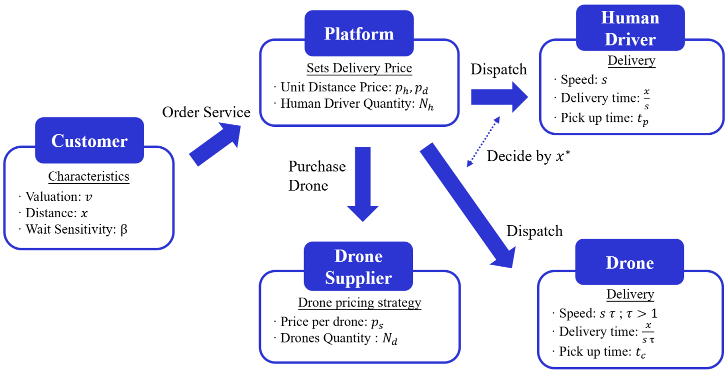


Figure 1 – *Delivery Sequence*

Bertrand Competition We now extend the model to a Bertrand competition scenario between two platforms in a linear city, where the distance between platform A and platform B is L, with platform A located at the origin $x = 0$ and platform B at $x = L$. We focus on how customers choose between platforms and derive the new equilibrium prices p^* under a mixed-platform scenario. Both human labor and drone suppliers are assumed to be in perfectly competitive markets. Customers choose the platform that maximizes their utility, and platforms are profit-driven. When the utilities between the two platforms are equal, customers prefer a shorter delivery time. We start by considering the scenario of homogeneous platforms and then extend the analysis to an asymmetric scenario, where platform A's drones are more efficient than those on platform B.

3 Results

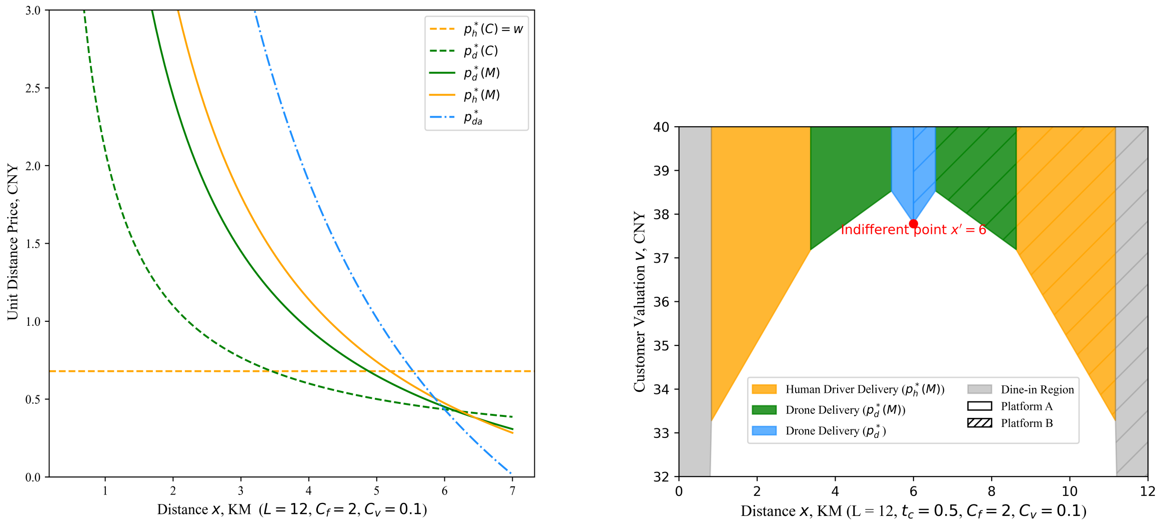
We compared the results of different market configurations and performed numerical simulations. Our findings show that drone integration significantly expands delivery coverage and enhances customer surplus across all market structures, making customers the primary beneficiaries. However, the magnitude of adverse effects on human driver earnings varies with drone market penetration. Bertrand competition further reduces delivery prices, improving affordability but intensifying competitive pressures on platforms. The magnitude of adverse effects on human driver surplus (HS) exhibits direct proportionality to drone market penetration rates. Although platform profitability varies under different market configurations, mixed delivery systems consistently prove socially optimal.

The pricing mechanism analysis reveals distance-dependent price elasticity. Monopolistic platforms maintain peak pricing levels, while perfectly competitive markets drive prices down to the minimum. Notably, increased Bertrand competition drives further price reductions p^*_{da} in long-distance (Fig. 2a). This competitive dynamic effectively addresses food desert phenomenon by providing drone-assisted order fulfillment services to previously underserved customers (Fig. 2b).

Platform	Delivery Region (KM)	Profit	CS (CNY)	HS	SW
HOP	0.83-5.19	488	159	79	726
DOP	0.92-6.15	160	116	–	276
MP	0.83-6.15	490	162	77	729
MP(B)	0.83-6	490	189	77	755
MP(B')	0.83-7.15	479	250	51	780

Note: HOP, DOP, and MP denote the Human Only Platform, Drone Only Platform, and Mixed Platform, respectively. B and B' represent the homogeneous mixed platform under Bertrand competition and the advanced drone mixed platform, respectively. Parameter settings: $C_f = 2$, $C_v = 0.1$, $s = 25$ km/h, $\tau = 2$, $t_p = 0.4$, $t_c = 0.5$, and advanced $t_c' = 0.45$.

Table 1 – *Monopolistic Market Comparison*



(a) *Optimal unit distance price on x*

(b) *Bertrand Competition Delivery Region*

Note: C and M denote the perfectly competitive market and the monopolistic market, respectively.

Figure 2 – *Numerical Simulation on optimal price (a) and customer distribution (b)*

Next, we will validate the analytical model through simulations using real-world food delivery data, incorporating traffic conditions and restaurant distribution. The results will be presented as an accurate delivery coverage map, along with the performance measures used in the analytical model.

References

Chen, Heng, Hu, Zhangchen, & Solak, Senay. 2021. Improved delivery policies for future drone-based delivery systems. *European Journal of Operational Research*, **294**(3), 1181–1201.

Lemardel, Clément, Estrada, Miquel, Pagès, Laia, & Bachofner, Mónica. 2021. Potentialities of drones and ground autonomous delivery devices for last-mile logistics. *Transportation Research Part E: Logistics and Transportation Review*, **149**, 102325.

Lian, Zhen, & van Ryzin, Garrett. 2024. Capturing the Benefits of Autonomous Vehicles in Ride Hailing: The Role of Market Configuration. *Management Science*.

Meituan News Center. 2024. *China's first drone delivery route for port scenarios opens in Shenzhen*. https://www.meituan.com/news/NN241023053008001. Accessed: 2024-10-23.

Sun, Xuting, Fang, Minghao, Guo, Shu, & Hu, Yue. 2024. UAV-rider coordinated dispatching for the on-demand delivery service provider. *Transportation Research Part E: Logistics and Transportation Review*, **186**, 103571.