國立臺灣大學管理學院資訊管理學系

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# 食物外送平台是否應該強制商家統一內外用價格？

# Should a Food Delivery Platform Regulate Meal Prices Set by Restaurants?

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# 國立臺灣大學碩士學位論文
# 口試委員會審定書

## 食物外送平台是否應該強制商家統一內外用價格？

## Should a Food Delivery Platform Regulate Meal Prices Set by Restaurants?

本論文係李柔萱君（學號 R07725003）在國立臺灣大學資訊管理學系、所完成之碩士學位論文，於民國 109 年 07 月 16 日承下列考試委員審查通過及口試及格，特此證明

口試委員：

孔令傑

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柯冠州

所　　長：魏志平

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謝辭

首先，最感謝的一定是小傑老師。我應該是本屆的問題學生 XD，從找指導教授開始就給老師添了麻煩，但很謝謝老師最後還是給我機會進到這個溫馨的大家庭。老師一直都非常關心我，從入學前的晤談了解自己的職涯興趣，然後在產學合作中分配給我適合的工作。甚至在我碩一下因為不適應研究所生活而壓力過大時，老師還特地騎車載我到 118 吃他的蔥油餅愛店，鼓勵我「努力去做，一切有他在」，讓當時的我能鼓起精神，重新掌握生活的步調。除此之外，在交換學生與雙聯學位計畫上，老師也給了中肯實用的建議，讓我能妥善規劃。而在論文指導上，老師體諒我這個不聰明的學生，總是給予詳細明確的指令，針對不懂的地方也耐心講解。當論文遇到瓶頸時，老師還幫我一起趕進度、想證明、解釋管理意涵，讓我最後能在期限內順利完成口試。謝謝老師在各方面的指導與協助，送舊時的叮嚀我也會牢記在心並努力去做。

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誠的關心與鼓勵，讓我能勇敢嘗試各種新事物。願我們的緣分能如締結時那般幸運，撐過生活中的風雨永續長存。順帶謝謝天使學弟妹們的貼心關懷。

回頭，我想真誠地對家人說聲謝謝。謝謝外婆在我累到跑回桃園的時候把我當小公主照顧，可以盡情耍廢。謝謝阿姨舅舅在我回桃園時總是買各種吃的喝的招待我，讓我體會被團寵的幸福感。謝謝媽咪總是包容我的各種賴皮與抱怨，在我快撐不住的時候也沒有罵我，反而心疼地說「真的不行，不唸也沒關係，我只希望你過的開心」。我一輩子都記得當下的震驚與感動，也是因為這句話才能不服輸地撐到現在。謝謝妹妹們在我壓力大的時候帶我去逛街買衣服，或是帶我追劇，又或是強迫我休息，讓我能在隔天用更好的狀態完成事情。謝謝爸爸在我論文不順利情緒低落時給我一個溫暖的擁抱，並提醒我更積極主動地跟老師溝通，讓我能釐清問題並解決。

最後的最後，我想好好謝謝自己。或許你常常為了大學沒好好玩到而懊惱，但也謝謝你當時的努力，讓我有幸來到臺大接受新的刺激。人生地不熟的環境，迥異的校園風氣，艱澀的專業課程，都讓你感到驚慌失措。但謝謝你願意進行諮商，讓我能更了解內心的情緒，更了解自己與外界的聯繫，更能與過去做不好的自己和解。謝謝你願意完成大學的夢想，歷經重重考驗申請交換，並意志堅定地出發。謝謝你在被挫折打倒後願意站起來，繼續堅持，努力從每次的失敗裡學習，讓我進步也變得堅強，更深刻體會自己的能力並不如想像中不堪。謝謝你完成了高中時的諾言，拿到了碩士學位，證明女兒不比兒子差。希望從這所學校得到的體會，包含開放且不怕挑戰的心境、對自身能力的自信等，都能成為未來的我的養分，幫助自己向前邁進。

李柔萱 謹致<br>于臺大資訊管理研究所<br>民國一百零九年十二月



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# 中文摘要

食物外送產業是一個成長快速且頗具發展潛力的產業。然而近期由於消費者發現登錄在食物外送平台 App 上的餐點價格比實際店面價格高而引起許多爭議。為避免消費者反彈與其他法律爭議，部分食物外送平台決定採取「統一定價」的價格規範策略：強制合作餐廳制定的店面內用價格與線上登錄價格必須一致。但餐廳可能因為失去定價彈性而導致營運無效率，連帶影響平台的獲利。而部分平台採取「差別定價」的價格規範策略：允許合作餐廳自由決定餐點價格。因此，本論文試圖比較實務中兩種不同價格規範策略：「統一定價」與「差別定價」對平台的影響，並找出平台選擇不同價格規範策略的因素。

在本論文中，我們透過建立一個賽局理論模型來回答我們的研究問題。模型所討論的情境如下：市場中存在一個獨占的食物外送平台、一間餐廳與一群消費者。平台先選擇價格規範策略並透過制定運費來最大化自身利益，接著餐廳必須依照價格規範策略的規定制定餐點價格來最大化利潤，最後消費者則可以選擇實際到店面用餐、使用食物外送服務或是不購買餐點。

透過比較兩種不同價格規範策略下的平台獲利，我們發現當消費者的等待成本降低或平台的抽成比例減少時，餐廳需要比較高的彈性來因應需求差異大的消費者，因此「差別定價」能使整個系統有效率地營運，為平台帶來較高的利潤。再者，我們發現當平台給外送員的補貼增加時，平台需要提高每筆訂單的獲利，透過「差別定價」能讓餐廳有提高訂單單價的空間，進而讓平台獲得更高的利潤。

關鍵字：共享經濟、食物外送、價格規範、賽局理論、雙邊平台、統一定價、差別定價



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# Thesis Abstract

Food delivery is a fast-growing industry with high potential. However, recently, the markups on the online menu prices cause fierce controversy. To prevent consumer irritation and avoid possible law issues, some food delivery platforms adopt "uniform pricing" to force restaurants to set a uniform price on different channels. Nevertheless, this makes restaurants suffer from less flexibility and may hurt the platform's profitability. On the contrary, some platforms allow "differentiated pricing" and let restaurants decide different prices on different channels. Hence, the major purpose of our work is to study the profitability of these two price regulation strategies and figure out factors that affect the platform's adoption of price regulation strategy.

We present a game-theoretic model to consider a market with a group of customers, a restaurant, and a monopolistic platform. First, the food delivery platform chooses one price regulation strategy and sets the per transaction freight. The restaurant then follows the rules of price regulation strategy and sets the meal prices. Last, customers decide to dine in the restaurant, to use food delivery services, or to buy nothing.

We obtain two main results. First, when the unit waiting cost per unit waiting time or the commission rate decreases, the restaurant needs higher flexibility to satisfy customer demands. By adopting differentiated pricing, the system can be operated more efficiently, and the platform can earn more profits. Second, when the unit subsidization for drivers increases, the platform needs a higher profit margin. By adopting differentiated pricing, there is room for the restaurant to set a higher online price, and the platform can obtain higher profits.

Keywords: food delivery, game theory, price regulation, sharing economy, two-sided platform, uniform pricing, differentiated pricing



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# Chapter 1

# Introduction

## 1.1 Background and motivation

Thanks to the advances in technology, many companies recognize the value of sharing economy, put multi-sided platforms into practice, and get huge success, like Uber and AirBnb. Food delivery is another emerging industry with multi-sided platforms. According to Statista (2018), the global market size of Platform-to-Customer Food Delivery is expected to grow from 17 billion dollars in 2018 to 32 billion dollars in 2023. Because of that, many food delivery companies which rely on multi-sided platforms aggressively expand their business worldwide, and thus, their business strategies become the key to success.

Before analyzing the difference between their business strategies, we need to understand the business model of these multi-sided food delivery platforms (we will call them "platforms" in the rest of this paper). There are four types of players: platforms, restau-



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rants, customers, and drivers (people who deliver food for customers). First of all, the platform decides the pricing strategy, and some of the restaurants, customers, and drivers join the platform. Then, the customers search for ideal restaurants on the platform and place orders, and the restaurants start to prepare dishes. Next, the drivers decide to take parts of the orders and deliver food to the customers. After completing transactions, the platform collects commission fees from the restaurants, freights from the customers, and give subsidies to the drivers. The interactions between different players can be divided into two aspects which the platform needs to balance the supply and demand: *restaurants-platforms-customers*, and *drivers-platforms-customers*. Though the platform can hire full-time employees to deliver food, it is too difficult for the platform to operate thousands of restaurants by itself. Thus, we think dealing with the restaurants is more important to the platform, and in this study we focus on the former aspect of interactions: restaurants-platforms-customers.

Recently, the markups on the online menu prices cause fierce controversy (Quora, 2017; Tan, 2018; Reddit, 2018a,b, 2019; Knowler, 2019; Liabilityguy, 2019). For the ease of management, most food delivery platforms, like Foodpanda and Uber Eats, simply list the online prices submitted by the restaurants (Chan, 2017; McKane, 2019). However, due to the high commission rates, the restaurants have incentives to inflate online prices to increase profit margins. For the customers, inflated online prices plus freights may be too high. Besides, since most platforms do not list in-store prices on their websites or mobile apps, they are blamed for hiding critical information and cheating on customers. There are even several lawsuits against some leading platforms (Pletz, 2011). As a result, some food delivery platforms, like Foodpanda, add one new rule to their restaurant agreements:



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“Prices listed in the menu uploaded are not marked-up.”[1] which means they enforce *uniform pricing* and regulate meal prices set by restaurants. For example, Deliveroo, Foodpanda, and Ele.me are the food delivery platforms that adopted uniform pricing. Nevertheless, some platforms choose to allow *differentiated pricing* and let the restaurants decide different prices on different channels. For example, DoorDash, Postmates, and Uber Eats are the food delivery platforms that adopted differentiated pricing.

Undoubtedly, it is crucial for the platforms to strike a balance between the restaurants and the customers, so they need to weigh up the pros and cons of uniform pricing. In this study, we look for critical factors that platforms should consider when deciding whether to do uniform pricing. In addition, we investigate the strategic impacts of these two price regulation strategies on food delivery platforms. We hope our study may help explain the rationale behind the food delivery platforms' adoptions of different price regulation strategies in practice.

## 1.2 Research objectives

In this study, we construct a game-theoretic model featuring sharing economy to address our research questions. There are three types of players in the model: a food delivery platform, a restaurant, and a group of potential customers. The platform has the options of (1) uniform pricing: enforcing restaurants to set up a uniform price on different channels, and (2) differentiated pricing: allowing restaurants to post different prices on

[1] For more details about Foodpanda's restaurant contract, please refer to `https://foodpandasg.formstack.com/forms/becomeapartner_tw_en`.



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different channels. By uniform pricing, on the one hand, since there are no markups on online prices, customers may be willing to place more orders, and thus, may be beneficial to the platform's profitability. However, on the other hand, the restaurants suffer from less flexibility. It may lead to system inefficiency and may be harmful to the platform's profitability. Hence, the impacts of uniform pricing on the platform's profitability are not intuitive. Similarly, the impacts of differentiated pricing on the platform's profitability are not straight. The major purpose of our work is to study the profitability of these two price regulation strategies and figure out factors that affect the platform's adoption of price regulation strategy.

## 1.3 Research plan

The remainder of this study is organized as follows. In the next chapter, we review some related works with respect to multi-channel retailer, multi-sided platform, and food delivery. In Chapter 3, we develop a game-theoretic model that addresses the interaction between the platform, the restaurant, and customers. In chapter 4, we analyze the profitability of two price regulation strategies. Chapter 5 are conclusions and future works. All proofs are in the appendix.



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# Chapter 2

# Literature Review

## 2.1 Multi-channel retailer

For restaurants, joining food delivery platforms means adding a new sales channel which can be seen as an online channel. Since restaurants now operate multiple sales channels, through physical stores and food delivery platforms, they are similar to multi-channel retailers. Thus, by reviewing research related to multi-channel retailers, we hope to find the factors that will affect restaurants' pricing strategies or distribution strategies.

From a broader point of view, Bolton et al. (2010) discover four environmental trends in retailing industry. They analyze the impacts of these trends on retailers' pricing strategies and suggest that retailers prefer to "customized pricing" approach in practice. By using this approach, the retailer can build a reasonable strategy for its products based on its position in the market.

Narrowing down to multi-channel retailers, many existing empirical studies suggest



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that in order to maintain channel consistency and prevent consumer irritation, multi-channel retailers should set uniform prices through different distribution channels. Wolk and Ebling (2010) also do an empirical study of channel-based price differentiation. Nevertheless, their finding contradicts the previous suggestion: many multi-channel retailers do price differentiation based on their different channels. Moreover, the number of this kind of retailers is increasing over time.

Yan (2008) constructs a game theory model to determine the optimal pricing strategy for the multi-channel company under three different market structures. He discovers that the optimal pricing strategy is to set the online price higher than the traditional retail price when the marginal cost of selling products through the online channel is larger than the marginal cost of selling products through the traditional channel, and vice versa.

Similar to Yan (2008), Kireyev et al. (2015) use a game-theoretic model to investigate the reasons why some retailers adopt self-matching (offer the lowest of its online and in-store prices to consumers) across different scenarios. There are two benefits of adapting self-matching. First, this approach can diminish the loss from channel arbitrage. Second, the retailer can charge higher store prices from customers who do not know the exact product they want to buy.

Furthermore, Chen and Ku (2013) construct a game-theoretical model to study the impacts of the dual-channel pricing when facing an Internet store (which is operated by the manufacturer) entry. They find that the physical store price is higher than the online price. Moreover, the manufacturer earns more profits, while the retailer earns less profit. However, the total profits of the market actually increases. Thus, they suggest that the manufacturer should induce the retailer to join the market.



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As stated above, it seems like that multi-channel retailers now are more likely to adopt different prices on different channels. That is, the uniform pricing strategy may be harmful to them, and thus, may also has negative effects on multi-channel restaurants. As a result, whether to do uniform pricing becomes a critical issue for a food delivery platform to keep restaurants on board, and that is one of our research objectives. Besides, whether the coordination with food delivery platform impacts the restaurants pricing strategy is also an interesting question to be answered through our analysis.

## 2.2 Multi-sided platform

Before looking into multi-sided platforms, we first take a glimpse of multi-sided markets. There has been a recent surge of interest in two-sided markets. Rochet and Tirole (2006) give a general definition of two-sided markets: "A market is two-sided if the platform can affect the volume of transactions by charging more to one side of the market and reducing the price paid by the other side by an equal amount."

Back to multi-sided platforms, Evans (2003) uses survey to provide an empirical study in multi-sided platform industries. In this study, multi-sided platforms can be classified into three categories: (1) *market-makers*; (2) *audience-makers*; and (3) *demand-coordinators*. He finds that "divide-and-conquer" is an often used pricing strategy to get both sides on board. Moreover, for entry strategy, many successful multi-sided companies will first test their platforms with little investment and then scaled up.

Narrowing down to one industry of multi-sided platforms, Kung and Zhong (2017) construct a game-theoretic model to examine a grocery delivery platform's two-sided pric-



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ing strategy. They compare the profitability of three pricing strategies: (1) *membership-based pricing* strategy, (2) *transaction-based pricing* strategy, and (3) *cross-subsidization* strategy. Their results show that when the platform prefers to receive revenues quickly or when the per-transaction fee has impacts on customers' order frequency, membership-based pricing strategy is the most profitable.

When there is a competition between multi-sided platforms, the situation becomes more complicating, and pricing strategies may be different. Rochet and Tirole (2003) build a model of platform competition with two-sided markets. First, they find that if there are buyers whose willingness to pay is high, the seller price increases and the buyer price decreases. Second, their results show that if there are buyers who do not like to substitute one product or seller with another, the price structure changes and becomes more beneficiary to sellers.

Armstrong (2006) finds that since platforms control the access to their single-homing customers (similar to monopoly power), they can charge high prices from the multi-homing side. However, because platforms need to compete for the single-homing agents, they usually offer low prices. Thus, the high profits generated from the multi-homing side are used as subsidization for attracting more single-homing agents.

Owing to the aforementioned works, we get a brief overview of multi-sided markets and platforms. Nonetheless, instead of searching for general implications of the whole multi-sided industries, our study concentrates on one specific industry - food delivery. We follow these previous works to construct a game-theoretic model to address our research questions. Whether the uniform pricing strategy is beneficiary to food delivery platforms is our main focus.



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## 2.3 Food delivery

Recently, more and more researchers devoted to investigating food delivery industry (Pigatto et al., 2017; Yusra and Agus, 2018; Correa et al., 2019; Steever et al., 2019). Many different topics has been discussed. For example, Goods et al. (2019) start a industry case study (consists of interview data) to explore job quality of drivers in food delivery industry in Australia. He et al. (2019) focus on the decisions of restaurants (e.g. their locations) and summarize the characters of good restaurants.

There are some other examples. Ye (2015) does an empirical study (consists of online questionnaire and interview) of food delivery situation in China and also analyze the challenges faced by food delivery companies. Additionally, according to Maimaiti et al. (2018), "more than one fifth of total population in China has already became the users of O2O food delivery market." This trend had huge impacts on diet-related behaviors and health care issues. Thus, they focus on analyzing the impacts of fast-growing food delivery industry on health issues, food environment, and social environment in China.

Since customers always play an important role in business world, there are also research about customer perception or customer attitude of food delivery (Alagoz and Hekimoglu, 2012; Siti Sarah, 2018; M. and Park, 2019). Kimes (2011) investigates customers' use of electronic ordering. Her results show that the perception of convenience is one of the keys for customers to adopt online ordering service. To be more specific, customers think online ordering service is convenient because they do not need to leave home. That is, leaving home may be annoying for some customers. As a result, in our model, we use *moving costs* to represent the costs or troublesome that occur when



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customers head to the restaurants.

Kitthanadeachakorn (2016) use interview and other secondary data to explore the factors that may affect customers' decisions on online food delivery service. Through organizing the secondary data, he also finds that convenience (moving costs) is an important factor. Besides, he discovers that the uncertainty of food quality is one of the reasons that why some customers do not use online food delivery service. That is, customers do care about food quality, and we also add this factor into our model.

Abdullah et al. (2011) uses questionnaire to determine the dimensions of customer preference in online food delivery industry. First, their results show that price is an important dimension for the customers who use online food delivery service. In our model, we do consider the impacts of meal prices. Moreover, service quality is another key dimension and the quick service is one of the terms to assess the level of service quality. That is, waiting may be annoying for some customers. Thus, we use *waiting costs* to represent the costs or troublesome that occur when customers wait for meals.

Thanks to these customers oriented research, we identify some important decision making factors of customers and take them into account when designing our model, including food quality, meal prices and customers' moving and waiting costs. However, most of the aforementioned research are qualitative. Besides, there is no similar work related to the platform's price regulation strategies. Therefore, in this study, we construct a game-theoretic model and hope to shed lights on the impacts of platform's different price regulation strategies.



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# Chapter 3

# Model

We consider a market with a group of customers (for each of them, she), a restaurant (he), and a monopolistic platform (it). The platform provides food delivery services to match customers and the restaurant. A customer can choose to go to the restaurant and dine there, or to order on the platform and let a driver deliver food for her, or not to buy any food from the restaurant. In our model, we assume that the food quality $q$ is the same under different dining situations: in-store dining (which equals to dine in the restaurant) and online dining (which equals to order on the platform and dine at somewhere else). In the following, we describe our model under two different strategies: uniform pricing, and differentiated pricing.

## 3.1 Uniform pricing

**Customers.** According to Kimes (2011); Rathore and Chaudhary (2018); Panse et al. (2019), a critical factor for customers to use food delivery services is the convenience



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of not leaving their houses to obtain food. Thus, we know that whether to go out is important to customers and may generate different costs. In the following, we formulate a customer's utility under different dining situations based on whether to leave her house.

As mentioned earlier, a customer can choose (1) to dine in the restaurant (we call it *in-store dining*, denoted by $I$), or (2) to order on the platform and dine at somewhere else (we call it *online dining*, denoted by $O$), or (3) not to buy any food from the restaurant (we call it *buy nothing*, denoted by $N$). Let $q > 0$ be the food quality of in-store dining which equals to the food quality of online dining. Under uniform pricing, there is an uniform meal price $p_U$ set by the restaurant.

For in-store dining, because the customer needs to go to the restaurant by herself, some additional costs occur, like time or efforts spent on transportation. We call them *moving costs*. Intuitively, the distance from the customer's location to the restaurant affects the moving costs. It is natural that customers differ in their distance to the restaurant. For example, some customers who live next to the restaurant can easily get there by walking, while some customers who live in another town need to drive or take public transportation to get to the restaurant. Therefore, we assume that customers are heterogeneous on their distance to the restaurant $\theta$[1], which is uniformly distributed in $[0, 1]$. Then, we use $t_I > 0$ to represent the unit moving cost. The total moving costs of a customer can be written as $\theta t_I$. The net benefit obtained in this choice is $q - p_U - \theta t_I$.

For online dining, though the customer does not go to the restaurant by herself, she

[1] $\theta$ can be interpreted as customers' mental distance to the restaurant and can incorporate customers' different preferences on traveling. For example, because I love to stay at home, my mental distance to the restaurant is greater than the physical distance.



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still needs to spend time waiting for the delivered meal. Thus, the *waiting costs* occur. Similar to the moving costs, the distance from the customer's location to the restaurant also affects the waiting costs. For example, some customers who live far away from the restaurant need to wait for an hour to get the meal, while others only need to wait for ten minutes. We use $t_O > 0$ to represent the unit waiting cost and the total waiting cost can be written as $\theta t_O$. In addition, because the customer orders on the platform, besides the uniform meal price $p_U$, she also needs to pay the *per transaction freight* $f \in \mathbb{R}$ (or sometimes called service fee) charged by the platform. The net benefit obtained in this choice is $q - p_U - \theta t_O - f$.

Since customers usually need to spend more efforts on going to the restaurant by themselves than simply waiting for the meal, we normalize $t_I$ to 1, and let $t_O = t \in (0, 1)$. The net benefit of in-store dining can be rewritten as $q - p_U - \theta$, and the net benefit of online dining can be rewritten as $q - p_U - \theta t - f$.

For buy nothing, since the customer does not buy any food from the restaurant, she gets nothing and the net benefit is 0.

As stated above, a type-$\theta$ customer's utility is thus

$$u_C^U = \begin{cases} q - p_U - \theta & \text{if she chooses in-store dining,} \\ q - p_U - \theta t - f & \text{if she chooses online dining,} \\ 0 & \text{if she chooses buy nothing.} \end{cases} \tag{3.1}$$

**Restaurant.** Let $c \geq 0$ be the exogenous unit cost of cooking meals, and $q \geq c$ so that the restaurant can earn profits by selling meals. When a customer places an order on the food delivery platform, the restaurant is charged by the platform at a *commission*



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*rate* $\phi \in [0, 1)$. That is, he earns only $(1 - \phi)p_U$ in each transaction matching by the platform.

Recall that customers can choose in-store dining, online dining or buy nothing. Following our model setting, there exist critical values $\theta^* \in [0, 1]$ and $\theta_O \in [0, 1]$ that divide customers into three groups: A customer chooses in-store dining if and only if her $\theta \leq \theta^*$, chooses online dining if and only if her $\theta^* \leq \theta \leq \theta_O$, or chooses buy nothing. Let $D_I$ be the demand of in-store dining, and $D_O$ be the demand of online dining. In our notations, this means $D_I = \theta^*$ and $D_O = \theta_O - \theta^*$. An illustration of the market segmentation is provided in Figure 3.1.

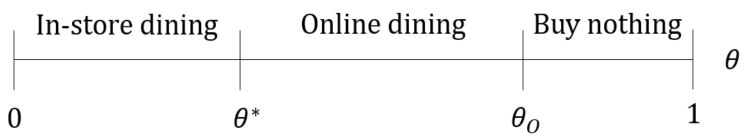


Figure 3.1: Market segmentation

The restaurant's problem is to maximize his profits by setting a uniform price $p_U$ to solve

$$\pi_R^U = \max_{p_U} \quad D_I(p_U - c) + D_O\left[(1 - \phi)p_U - c\right]. \tag{3.2}$$

**Food delivery platform.** Let $\phi \in [0, 1)$ be the exogenous commission rate that is a general consensus in the highly competitive food delivery industry. The platform's problem is to maximize its profits by setting the per transaction freight $f$ to solve

$$\pi_P^U = \max_{f} \quad D_O(\phi p_U + f - s) \tag{3.3}$$

$$\text{s.t.} \quad 0 \leq \theta^* \leq \theta_O \leq 1, \tag{3.4}$$



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where $s \geq 0$ is an exogenous unit subsidization for drivers paid by the platform. Constraint (3.4) ensures that the market segmentation is the same as Figure 3.1. The platform profits from the commission fee collected from the restaurant and the per transaction freight collected from customers in each successful matching transaction.

## 3.2 Differentiated pricing

**Customers.** We simply substitute $p_I$ for $p_U$ in the first function of Equation (3.1), and substitute $p_O$ for $p_U$ in the second function of Equation (3.1). Then, a type-$\theta$ customer's utility is thus

$$u_C^D = \begin{cases} q - p_I - \theta & \text{if she chooses in-store dining,} \\ q - p_O - \theta t - f & \text{if she chooses online dining,} \\ 0 & \text{if she chooses buy nothing.} \end{cases} \tag{3.5}$$

**Restaurant.** The market segmentation is the same as Figure 3.1. We replace $p_U$ in the former part of Equation (3.2) by $p_I$, and replace $p_U$ in the latter part of Equation (3.2) by $p_O$. Then, the restaurant's problem is to maximize his profits by setting $p_I$ and $p_O$ to solve

$$\pi_R^D = \max_{p_I, p_O} \quad D_I(p_I - c) + D_O\left[(1-\phi)p_O - c\right]. \tag{3.6}$$

**Food delivery platform.** By substituting $p_U$ for $p_O$, the platform's problem is to



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maximize its profits by setting the per transaction freight $f$ to solve

$$\pi_P^D = \max_f \quad D_O(\phi p_O + f - s) \tag{3.7}$$

$$\text{s.t.} \quad 0 \le \theta^* \le \theta_O \le 1. \tag{3.8}$$

Constraint (3.8) ensures that the market segmentation is the same as Figure 3.1. The platform looks for the optimal per transaction freight $f$ to maximize its profits $\pi_P^D$.

The sequence of events is depicted in Figure 3.2. First, the food delivery platform decides whether to do price regulation. Second, the platform decides the per transaction freight $f$. Third, the restaurant observes the commission rate and per transaction freight and decides his online price and in-store price. If the platform implements price regulation (equals to do uniform pricing), the online price and in-store price have to be the same. If the platform does not do any regulations (equals to do differentiated pricing), the restaurant can freely decide his meal prices. Finally, potential customers observe the per transaction freight and meal prices and decide their actions. The demands of in-store dining and online dining will then be realized, and the restaurant and platform earn their profits.

A list of notations is provided in Table 3.2.



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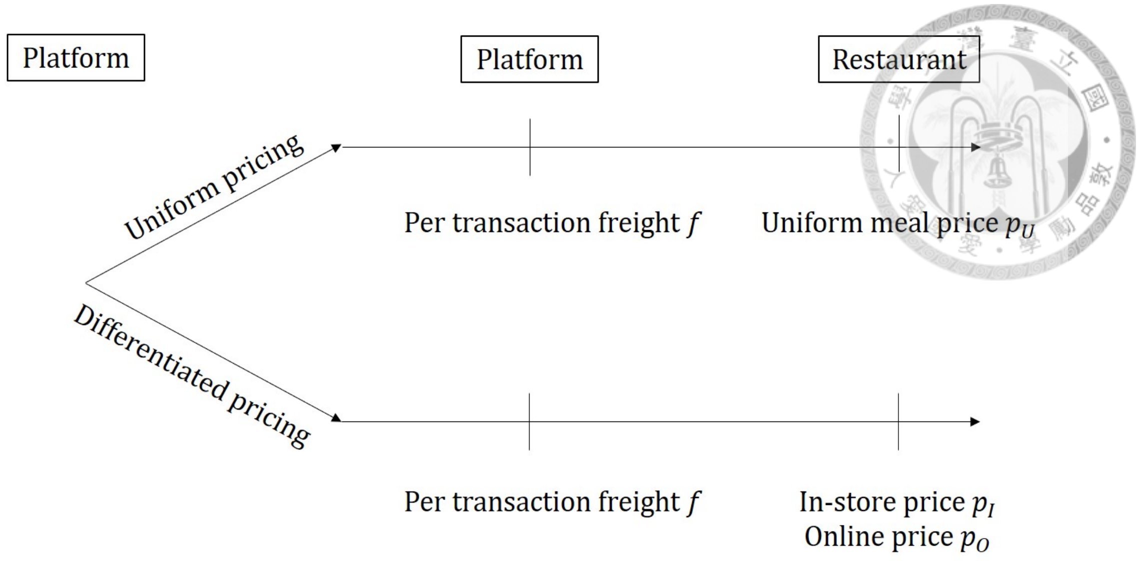


Figure 3.2: Time sequence

| | |
|---|---|
| | **Decision variables** |
| $p_U$ | Restaurant's uniform meal price |
| $p_I$ | Restaurant's in-store price (in-store dining) |
| $p_O$ | Restaurant's online price (online dining) |
| $f$ | Platform's per transaction freight |
| | **Parameters** |
| $q$ | Food quality |
| $t$ | Customers' unit waiting cost |
| $c$ | Restaurant's unit cost of cooking meals |
| $\phi$ | Platform's commission rate |
| $s$ | Platform's unit subsidization for drivers |

Table 3.1: List of decision variables and parameters



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# Chapter 4

# Analysis

We analyze the optimization problems of the food delivery platform and present its optimal solutions and equilibrium profits under the two different pricing strategies. We then provide some managerial implications by comparing them.

In order to make the optimal solutions interior, we assume that all the parameters follow the conditions in Assumption 1.

**Assumption 1.** *Parameters $q$, $t$, $c$, $s$, and $\phi$ should follow $s \leq \frac{2\phi tc}{t-\phi+1}$, $s \leq (1-t)(q-c)$, $t+\phi \leq 1$, and*

$$\begin{cases} (1-t)(2t-\phi t+2)(q-c)-(\phi t-2t+2)s \leq 4t(1-t)(2-\phi), \\ (1-\phi)^2(1-\phi-t)q-(2\phi t-\phi-t+1)c+(1-\phi)(t-\phi+1)s \geq 0, \\ [(-2\phi^3 t-2\phi^2 t^2+4\phi^2 t+\phi^2+6\phi t^2-4\phi t-2\phi-3t^2+2t+1)q \\ -(\phi^2+4\phi t^2-2\phi t-2\phi-3t^2+2t+1)c \\ -(t-\phi+1)(2\phi t-\phi-t+1)s] \leq 2t(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2). \end{cases} \tag{4.1}$$



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## 4.1 Uniform pricing

We first analyze the customers' participation decisions. Given the announced commission rate $\phi$ and the per transaction freight $f$, a type-$\theta$ customer's utility function (3.1) implies

$$q - p_U - \theta^* = q - p_U - \theta^* t - f, \tag{4.2}$$

$$q - p_U - \theta_O t - f = 0. \tag{4.3}$$

These mean that the type-$\theta^*$ customer thinks there is no difference between in-store dining and online dining, and the type-$\theta_O$ customer thinks there is no difference between online dining and buy nothing. By solving Equations (4.2) and (4.3), we obtain $\theta^* = \frac{f}{1-t}$ and $\theta_O = \frac{q-p_U-f}{t}$. Recall that $D_I = \theta^*$ and $D_O = \theta_O - \theta^*$ denote the numbers of the demand of in-store dining and online dining, respectively. Substituting them into Equation (3.2), we have the restaurant's optimization problem as

$$\pi_R^U = \max_{p_U} \quad \frac{f}{1-t}(p_U - c) + \frac{(1-t)q - (1-t)p_U - f}{t(1-t)} \left[(1-\phi)p_U - c\right]. \tag{4.4}$$

By solving Equation (4.4), we obtain $p_U^*$ which is summarized in Lemma 1. Besides, we summarize the impacts of parameters and the per transaction freight changes on $p_U^*$ in Proposition 1.

**Lemma 1.** *Under uniform pricing, the optimal uniform meal price is*

$$p_U^* = \frac{(1-\phi)(1-t)q - (1-\phi-t)f + (1-t)c}{2(1-\phi)(1-t)}. \tag{4.5}$$

**Proposition 1.** *Under uniform pricing, assuming the per transaction freight $f$ has been set by the platform to a fixed amount, the optimal uniform meal price $p_U^*$ is increasing in $q, t, c$, and $\phi$. Furthermore, the optimal uniform meal price $p_U^*$ is decreasing in $f$.*



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Since the parameters $q, t, c$, and $s$ affect the per transaction freight $f$ and $f$ affects $p_U^*$, we discuss the detail impacts of the parameters on $f$ in the latter of this section. In this and the following paragraphs, we assume that $f$ has been set by the platform to a fixed amount. Intuitively, when the food quality $q$ gets higher, since customers are more willing to buy meals from the restaurant, he can increase the meal price. Next, when the unit cost of cooking meals $c$ gets higher, in order to cover the expenses, the restaurant increases the meal price. Similar to the unit cost of cooking meals, when the commission rate $\phi$ gets higher, the restaurant increases the meal price to make profits.

Interestingly, when the unit waiting cost $t$ gets higher, the restaurant also increases the meal price. Assuming the per transaction freight has been set by the platform to a fixed amount, when the unit waiting cost gets higher, since customers become more impatient, the utility of online dining decreases. Some customers may turn to in-store dining while some customers decide not to buy meals from the restaurant. Thus, the demand of online dining decreases and the demand of in-store dining increases. Since the demand of online dining is decreasing and the profit margin of online dining is lower, the restaurant is more willing to make profits from the in-store dining customers. Because the in-store dining customers do not need to pay freights, the restaurant can charge a higher meal price to earn more profits.

Nevertheless, when the per transaction freight $f$ gets higher, the restaurant lowers the meal price. It is clear that when the per transaction freight gets higher, the utility of online dining decreases. Thus, some customers may turn to in-store dining and some customers decide not to buy meals from the restaurant. The demand of online dining decreases and the demand of in-store dining increases. However, the number of customers



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lost from online dining is more than the number of customers obtained from in-store dining. Therefore, in order to attract more customers, the restaurant lowers the meal price.

Substituting $p_U^*$ into Equation (3.3), we have the platform's optimization problem as

$$\pi_P^U = \max_f \quad \frac{1}{t(1-t)}\left[(1-t)q - \frac{(1-\phi)(1-t)q + (t+\phi-1)f + (1-t)c}{2(1-\phi)} - f\right]$$
$$\times \left\{\frac{\phi\left[(1-\phi)(1-t)q + (t+\phi-1)f + (1-t)c\right]}{2(1-\phi)(1-t)} + f - s\right\} \tag{4.6}$$

$$\text{s.t.} \quad 0 \leq \theta^* \leq \theta_O \leq 1, \tag{4.7}$$

which is a maximization problem with decision variable $f \in \mathbb{R}$. The optimal per transaction freight is characterized in Lemma 2.

**Lemma 2.** *Under uniform pricing, the optimal per transaction freight is*

$$f^U = \frac{(1-t)\left[(1-\phi)^2(1-\phi-t)q - (2\phi t - \phi - t + 1)c + (1-\phi)(t-\phi+1)s\right]}{(t-\phi+1)(\phi^2 + 3\phi t - 3\phi - 2t + 2)}. \tag{4.8}$$

We may plug in $f^U$ into Equation (4.5), (4.6) and $D_I$, $D_O$. We summarize the impacts of parameters on the platform's equilibrium profits ($\pi_P^U$), its optimal per transaction freight ($f^U$), the restaurant's optimal uniform meal price ($p_U^*$) and the demands ($D_I^U, D_O^U$) in Observation 1.

**Observation 1.** *The impacts of parameters $q, t, c, \phi$, and $s$ on the platform's equilibrium profits $\pi_P^U$, its optimal per transaction freight $f^U$, the restaurant's optimal uniform meal price $p_U^*$, and the demands $D_I^U$ and $D_O^U$ are summarized in Table 4.1*[1].

[1] The proofs for the cells marked with * are provided in the appendix.



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| | $q$ | $t$ | $c$ | $\phi$ | $s$ |
|---|---|---|---|---|---|
| $\pi_P^U$ | increasing | decreasing | decreasing | increasing | decreasing |
| $f^U$ | increasing* | decreasing | decreasing* | decreasing | increasing* |
| $p_U^*$ | increasing | increasing | increasing* | increasing | decreasing* |
| $D_I^U$ | increasing* | decreasing | decreasing* | decreasing | increasing* |
| $D_O^U$ | increasing* | first decreasing then increasing | decreasing* | increasing | decreasing* |

Table 4.1: Impacts of parameter changes under uniform pricing

First, when the unit waiting cost $t$ gets higher, customers become more inpatient and the utility of online dining decreases. Thus, some customers may turn to in-store dining and some customers may decide not to buy any meals from the restaurant. For example, if you are hurry to get to a meeting, instead of waiting for the delivered food, you may simply grab some potato chips at home. The demand of online dining is expected to decrease. For the restaurant, since the demand of online dining is decreasing and the profit margin of online dining is lower, the restaurant is more willing to make profits from the in-store dining customers. Because the in-store dining customers do not need to pay freights, the restaurant can charge a higher meal price to earn more profits. For the platform, because the higher unit waiting cost and meal price are harmful to the demand of online dining, the platform has to lower the per transaction freight to encourage more customers to choose online dining. Since the lower per transaction freight let some customers turn to online dining and the higher meal price makes the utility of in-store dining decrease, the demand of in-store dining decreases. However, because of the lower per transaction freight and the customers come from in-store dining, the demand of online dining increases when the unit waiting cost is high. In general, though the demand of online dining may



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increase, the profit margin keeps shrinking due to the decreasing per transaction freight. Hence, the platform's total profits decrease when the unit waiting cost $t$ gets higher.

Second, when the commission rate $\phi$ gets higher, for the restaurant, doing online dining transactions becomes more costly. Thus, the restaurant is more willing to profit from the in-store dining customers. Because the in-store dining customers do not need to pay freights, the restaurant can charge a higher meal price to earn more profits. The higher meal price makes both the utility of in-store dining and that of online dining decrease. For the platform, in order to attract more online dining customers, it lowers the per transaction freight. Since the lower per transaction freight makes some customers turn to online dining and the higher meal price makes the utility of in-store dining decrease, the demand of in-store dining decreases. However, the lower per transaction freight successfully boosts the demand of online dining. In general, because of the increasing demand of online dining and the expanding profit margin (due to the increasing commission rate), the platform's profits increase when the commission rate $\phi$ gets higher.

Third, when the unit subsidization for drivers $s$ gets higher, the platform's unit cost of making transactions increases. Attracting online dining customers as many as possible is no longer a good idea, because the platform may spend too much on subsidization. Thus, the platform wants to serve fewer customers but increase the profit margin of each order. Then, the platform raises the per transaction freight to expand the profit margin. Because of the higher transaction freight, some customers give up on online dining and the demand of online dining decreases. For the restaurant, since the unit subsidization for drivers does not affect his profits, in order to attract more online dining customers, he lowers the meal price. Next, because additional customers come from online dining



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and the lower meal price also attract more in-store dining customers, the demand of in-store dining increases. Generally, since the demand of online dining decreases and the profit margin is shrinking due to the lower meal price and the higher subsidization, the platform's profits decrease when the unit subsidization for drivers $s$ gets higher.

## 4.2 Differentiated pricing

We analyze the customers' participation decisions. Given the announced commission rate $\phi$ and the per transaction freight $f$, a type-$\theta$ customer's utility function (4.17) implies

$$q - p_I - \theta^* = q - p_O - \theta^* t - f, \tag{4.9}$$

$$q - p_O - \theta_O t - f = 0. \tag{4.10}$$

The type-$\theta^*$ customer thinks there is no difference between in-store dining and online dining, and the type-$\theta_O$ customer thinks there is no difference between online dining and buy nothing. By solving Equations (4.9) and (4.10), we obtain $\theta^* = \frac{-p_I+p_O+f}{1-t}$ and $\theta_O = \frac{q-p_O-f}{t}$. Recall that $D_I = \theta^*$ and $D_O = \theta_O - \theta^*$. Substituting them into Equation (3.6), we have the restaurant's optimization problem as

$$\pi_R^D = \max_{p_I, p_O} \quad \frac{-p_I + p_O + f}{1-t}(p_I - c) + \frac{(1-t)q - p_O + tp_I - f}{t(1-t)}\left[(1-\phi)p_O - c\right]. \tag{4.11}$$

By solving Equation (4.11), we obtain $p_I^*$ and $p_O^*$ which are summarized in Lemma 3. Besides, the impacts of parameters and the per transaction freight changes on $p_I^*$ and $p_O^*$ are summarized in Proposition 2.



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**Lemma 3.** *Under differentiated pricing, the optimal meal prices are*

$$p_I^* = \frac{(2-\phi)[(1-\phi)(1-t)q + (1-t)c] + \phi(1-\phi)f}{4(1-\phi) - (2-\phi)^2 t}, \tag{4.12}$$

$$p_O^* = \frac{2[(1-\phi)(1-t)q + (1-t)c] - [2(1-\phi-t) + \phi t]f}{4(1-\phi) - (2-\phi)^2 t}. \tag{4.13}$$

**Proposition 2.** *Under differentiated pricing, assuming the per transaction freight $f$ has been set by the platform to a fixed amount, both the optimal in-store price $p_I^*$ and the optimal online price $p_O^*$ are increasing in $q$ and $c$. Furthermore, the optimal in-store price $p_I^*$ is increasing in $f$, while the optimal online price $p_O^*$ is decreasing in $f$.*

Since the parameters $q$ and $c$ affect the per transaction freight $f$ and $f$ affects $p_I^*$ and $p_O^*$, we discuss the detail impacts of the parameters on $f$ in the latter of this section. In this paragraph, we assume that $f$ has been set by the platform to a fixed amount. Intuitively, when the food quality $q$ gets higher, since customers are more willing to buy meals from the restaurant, he can increase both of the meal prices. Next, when the unit cost of cooking meals $c$ gets higher, in order to cover the expenses, the restaurant increases both of the meal prices.

Nonetheless, when the per transaction freight $f$ gets higher, the utility of online dining decreases. Some customers may turn to in-store dining or decide not to buy meals from the restaurant. Thus, the demand of online dining decreases and the demand of in-store dining increases. In order to attract more online dining customers, the restaurant decreases his online price. However, since customers are more likely to choose in-store dining, the restaurant will increase his in-store price to make more profits.

Substituting $p_I^*$ and $p_O^*$ into Equation (3.7), we have the platform's optimization



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problem as

$$\pi_P^D = \max_f \quad \frac{1}{t(1-t)} \left\{ (1-t)q - \frac{2[(1-\phi)(1-t)q + (1-t)c] - [2(1-\phi-t)+\phi t]f}{4(1-\phi)-(2-\phi)^2 t} \right.$$
$$\left. + \frac{(2-\phi)t[(1-\phi)(1-t)q + (1-t)c] + \phi(1-\phi)tf}{4(1-\phi)-(2-\phi)^2 t} - f \right\}$$
$$\times \left\{ \frac{2\phi[(1-\phi)(1-t)q + (1-t)c] - \phi[2(1-\phi-t)+\phi t]f}{4(1-\phi)-(2-\phi)^2 t} + f - s \right\} \tag{4.14}$$

$$\text{s.t.} \quad 0 \leq \theta^* \leq \theta_O \leq 1, \tag{4.15}$$

which is a maximization problem with decision variable $f \in \mathbb{R}$. The optimal per transaction freight is characterized in Lemma 4.

**Lemma 4.** *Under differentiated pricing, the optimal per transaction freight is*

$$f^D = \frac{Aq + Bc + Cs}{4(1-\phi)(1-t)(2-\phi)}, \tag{4.16}$$

*where* $A = (1-t)[4(1-\phi)^2 - (2-\phi)^2 t]$, $B = -(1-t)[4-(2-\phi)^2 t]$, *and* $C = 4(1-\phi) - (2-\phi)^2 t$.

We may plug in $f^D$ into Equations (4.12), (4.13), (4.14) and $D_I$, $D_O$. We summarize the impacts of parameters on the platform's equilibrium profits ($\pi_P^D$), its optimal per transaction freight ($f^D$), the restaurant's optimal meal prices ($p_I^*, p_O^*$) and the demands ($D_I^D, D_O^D$) in Observation 2.

**Observation 2.** *The impacts of parameters $q, c, t, \phi$, and $s$ on the platform's equilibrium profits $\pi_P^D$, its optimal per transaction freight $f^D$, the restaurant's optimal meal prices $p_I^*$ and $p_O^*$, and the demands $D_I^D$ and $D_O^D$ are summarized in Table 4.2*[2]*.*



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| | $q$ | $t$ | $c$ | $\phi$ | $s$ |
|---|---|---|---|---|---|
| $\pi_P^D$ | increasing | decreasing | decreasing | increasing | decreasing |
| $f^D$ | increasing | decreasing | decreasing* | decreasing | increasing* |
| $p_I^*$ | increasing | increasing | increasing* | decreasing | increasing* |
| $p_O^*$ | increasing | increasing | increasing* | increasing | decreasing* |
| $D_I^D$ | increasing | increasing | decreasing* | no impact | increasing* |
| $D_O^D$ | increasing | decreasing | decreasing* | increasing | decreasing* |

Table 4.2: Impacts of parameter changes under differentiated pricing

First, when the unit waiting cost $t$ gets higher, customers become more inpatient and may give up on online dining. The demand of online dining decreases. For the restaurant, since it is hard to attract online dining customers, he decides to serve only the customers who really needs online dining service and increases his online price. Because of the higher unit waiting cost and the increasing online price, the demand of in-store dining increases. Thus, the restaurant can slightly increase his in-store dining price to make more profits. For the platform, since the demand of online dining is decreasing and the online price is increasing, it decides to lower the per transaction freight to induce more customers to choose online dining. In general, because of the decreasing demand of online dining and the shrinking profit margin, the platform's profits decrease when the unit waiting cost $t$ gets higher.

Second, when the commission rate $\phi$ gets higher, for the restaurant, the profit margin of online dining service shrinks. The restaurant decides to serve only the customers who are willing to pay more to get online dining service and wants to attract more in-store

[2]The proofs for the cells marked with * are provided in the appendix.



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dining customers. Thus, the restaurant increases the online price and lowers the in-store dining price. For the platform, since the higher online price makes the utility of online dining decrease, it lowers the per transaction freight to obtain more online dining customers. Because the platform can profit from the commission fees, it is more willing to lower the per transaction freight substantially and can successfully boost the demand of online dining. Moreover, since the lower in-store price can attract more in-store customers, the demand of in-store dining is fixed. In general, due to the increasing demand of online dining, the platform's profits increase when the commission rate $\phi$ gets higher.

Third, when the unit subsidization for drivers $s$ gets higher, the platform's unit cost of making transactions increases. Because serving too many online dining customers may cost too much, the platform wants to serve fewer customers but increase the profit margin of each order. Then, the platform raises the per transaction freight to expand the profit margin. Because of the higher transaction freight, the demand of online dining decreases and the demand of in-store dining increases. For the restaurant whose profits are not affected by the unit subsidization for drivers, he decides to lower the online price to attract more online dining customers. Besides, since the the demand of in-store dining increases, he can slightly increase the in-store price to make more profits. Generally, because of the decreasing demand of online dining and the shrinking profit margin (due to the decreasing online price and increasing subsidization), the platform's profits decrease when the unit subsidization for drivers $s$ gets higher.



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## 4.3 Comparisons

To understand which out of the two price regulation strategies is the best for the platform, we compare the equilibrium profits under these strategies. Our main results are presented in the following three observations and the following two figures provide visualizations for them.

**Observation 3.** *Assuming other parameters are fixed, when the unit waiting cost $t$ decreases, the platform prefers to do differentiated pricing.*

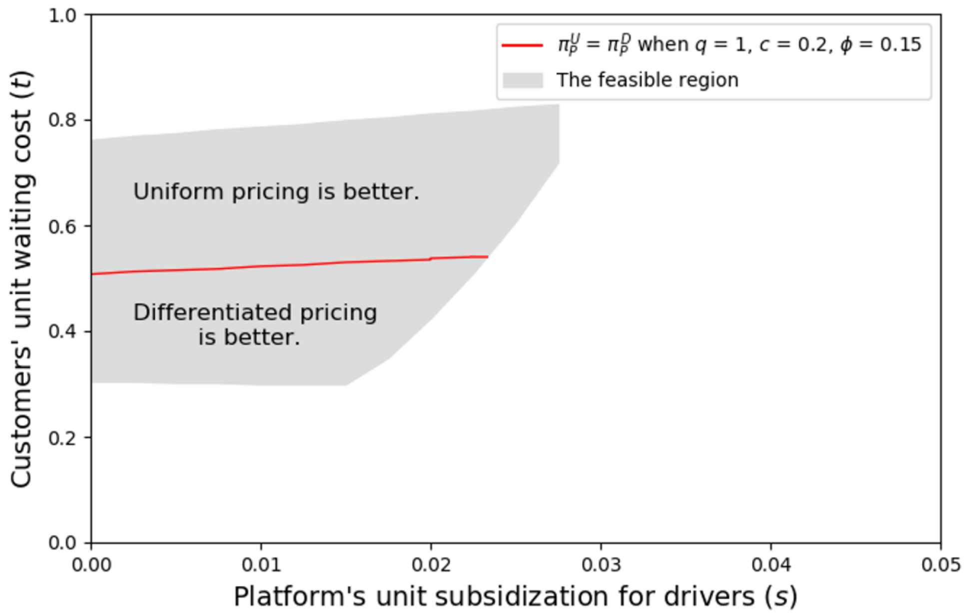


Figure 4.1: Visualization for Observation 3

When the unit waiting cost $t$ decreases, the difference between a customer's utility of in-store dining and online dining increases. That is, customers do consider that in-store dining and online dining are different. We can say that customers who choose online dining are different from customers who choose in-store dining. Since customers' demands



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are diverse, the restaurant needs higher flexibility to satisfy their demands. Through differentiated pricing, the restaurant has more flexibility in deciding meal prices. By offering different meal prices in different channels, the restaurant can adjust the demands of each channel more efficiently and operate better. The platform can also make more profits due to system efficiency.

**Observation 4.** *Assuming other parameters are fixed, when the commission rate $\phi$ decreases, the platform prefers to do differentiated pricing.*

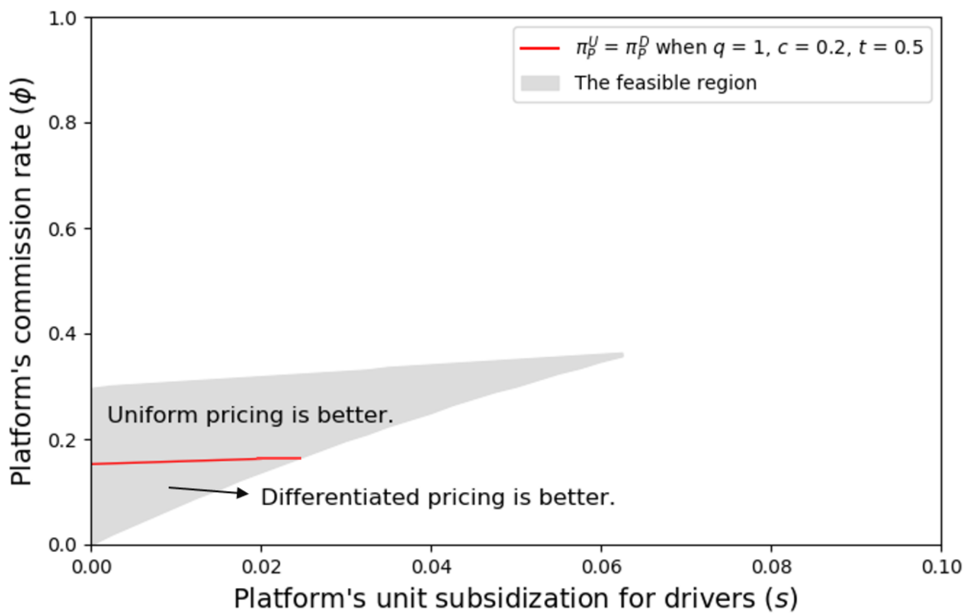


Figure 4.2: Visualization for Observation 4 and 5

When the commission rate $\phi$ decreases, the restaurant's costs of offering online dining decreases. Thus, it seems like there is no need for him to separate and charge different prices on these two dining situations. However, when the commission rate $\phi$ decreases, the platform raises the per transaction freight $f$ to make profits. Higher per transac-



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tion freight $f$ makes customers think that online dining is different from in-store dining. Since customers who choose online dining are different from customers who choose in-store dining, the restaurant needs higher flexibility to satisfy customers' diverse demands. Through differentiated pricing, the restaurant can offer different meal prices in different channels. This helps the restaurant adjust the demands of each channel more efficiently, and thus, he can operate better. The platform also earns more profits due to system efficiency.

**Observation 5.** *Assuming other parameters are fixed, when the unit subsidization for drivers $s$ increases, the platform prefers to do differentiated pricing.*

When the unit subsidization for drivers $s$ increases, the costs of making transactions increases. Serving online dining customers as many as possible is no longer profitable for the platform. The platform wants to serve fewer customers but retain high profits. Thus, it wants to raise its profit margin. Under uniform pricing, since the in-store price has to be the same as online price, it is hard to increase the meal price or the per transaction freight. However, under differentiated pricing, the platform can expand its profit margin by charging a higher online price (decided by the restaurant) or a higher per transaction freight. As a result, the platform's profits are higher under differentiated pricing.

In general, uniform pricing ensures price consistency on different dining channels and prevents loss of customers due to higher online prices. Nevertheless, when the restaurant needs higher flexibility to satisfy customers' demands or when the platform needs a higher profit margin, differentiated pricing is the suitable price regulation strategy for the platform to adopt. The platform can earn more profits due to system efficiency or the higher profit margin.



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## 4.4 Discussions

By collecting related news to food delivery, we discover that many online dining customers are not satisfied with markups on online prices. When they notice the online prices are even higher, they usually feel like they are not treated fairly because they still need to pay additional freights. Thus, the feeling of unfairness generates some negative mental costs on online dining customers. To take these mental costs into account, we may rewrite our customer utility function and get

$$\widetilde{u_C^D} = \begin{cases} q - p_I - \theta & \text{if she chooses in-store dining,} \\ q - p_O - \theta t - f - \eta[p_O - p_I]^+ & \text{if she chooses online dining,} \\ 0 & \text{if she chooses buy nothing.} \end{cases} \tag{4.17}$$

We use $\eta[p_O - p_I]^+$ to represent the negative mental costs. When the online price is lower than the in-store price, the customer does not think she is mistreated when choosing online dining. Thus, $[p_O - p_I]^+$ represents that the negative mental costs only take place when the online price is higher than the in-store price. Intuitively, when the online price is much higher than the in-store price ($p_O - p_I$ is larger), the customer feels worse when choosing online dining and the negative mental costs become larger. $\eta$ represents the severity of feeling of unfairness. For example, if the customers can accept that setting different prices on different channels is natural and reasonable, $\eta$ is small. However, if the customers has a limited budget and cares about the online price, $\eta$ is big.

Obviously, the negative mental costs are harmful to the platform because the utility of online dining may decrease. Since different meal prices may generate additional costs, the platform is more willing to adopt uniform pricing. Nevertheless, we believe that if



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the severity of feeling of unfairness $\eta$ is small enough, differentiated pricing can still be better when the restaurant needs higher flexibility or the platform needs a higher profit margin.



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# Chapter 5

# Conclusions and Future Works

In this study, we present a game-theoretic model featuring sharing economy to investigate two price regulation strategies in food delivery, i.e., uniform pricing, and differentiated pricing. In our model, we analytically calculate the optimal per transaction freight of these two strategies and compare the platform's equilibrium profits. Our main result shows that normally, the uniform pricing strategy brings higher profits to the platform. However, when the restaurant needs higher flexibility (when the unit waiting cost or the commission rate decreases) or when the platform needs a higher profit margin (when the unit subsidization for drivers increases), the platform should turn to the differentiated pricing strategy. It can help the platform earn more profits due to system efficiency or the higher profit margin. The platform should choose the suitable price regulation strategy based on its own operating conditions which matches our observations in the real world.

Our study certainly has its limitations. First, it would be interesting to consider that the food quality is different under in-store dining and online dining. Since it may affect consumers' participation decisions, the platform's equilibrium profits may change.



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Second, because the role played by the drivers may affect more than the unit subsidization, their strategic decisions should also be taken into consideration. Finally, we have not considered how multiple restaurants or multiple platforms may change the equilibrium. These extensions of our study call for future investigation.



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# Appendix A

# Proofs

**Proof of Lemma 1.** Organize Equation (4.4) and we can get

$$\pi_R^U = \max_{p_U} \quad \frac{-(1-\phi)(1-t){p_U}^2 + \left[(1-\phi)(1-t)q + (t+\phi-1)f + (1-t)c\right] p_U + (1-t)(f-q)c}{t(1-t)}. \tag{A.1}$$

We differentiate Equation (A.1) twice with respect to $p_U$ and can get

$$\frac{\partial^2 \pi_R^U}{\partial p_U^2} = \frac{-2(1-\phi)(1-t)}{t(1-t)}. \tag{A.2}$$

Since $\phi \in [0,1)$ and $t \in (0,1)$, Equation (A.2) can be easily shown to be negative. Thus, we can use first order condition to solve for $p_U^*$. Then, we differentiate Equation (A.1) with respect to $p_U$ and get

$$\frac{\partial \pi_R^U}{\partial p_U} = \frac{-2(1-\phi)(1-t)p_U + \left[(1-\phi)(1-t)q + (t+\phi-1)f + (1-t)c\right]}{t(1-t)} = 0. \tag{A.3}$$

As a result, we obtain $p_U^* = \frac{(1-\phi)(1-t)q-(1-\phi-t)f+(1-t)c}{2(1-\phi)(1-t)}$.

A customer chooses online dining only if her utility of online dining is nonnegative. That is, $q - p_U - \theta t - f \geq 0$. Since both $\theta$ and $t$ are positive, we can get that $q > f$. For



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the denominator of $p_U^*$, since $\phi \in [0,1)$ and $t \in (0,1)$, it is positive. For the numerator of $p_U^*$, the coefficient of $q$ is greater than the coefficient of $f$ $((1-\phi)(1-t) = (1-\phi-t+\phi t) > (1-\phi-t))$. Besides, $(1-t)c$ is positive. As a result, $p_U^*$ can be easily shown to be positive.

**Proof of Proposition 1.** Differentiate $p_U^* = \frac{(1-\phi)(1-t)q-(1-\phi-t)f+(1-t)c}{2(1-\phi)(1-t)}$ with respect to $q$ and get $\frac{\partial p_U^*}{\partial q} = \frac{1}{2}$. We know that $p_U^*$ is increasing when $q$ is larger. Differentiate $p_U^*$ with respect to $f$ and get $\frac{\partial p_U^*}{\partial f} = \frac{t+\phi-1}{2(1-\phi)(1-t)}$. Since $t+\phi \leq 1$, the former equation can be easily shown to be nonpositive. We know that $p_U^*$ is decreasing or remains the same when $f$ is larger. Differentiate $p_U^*$ with respect to $c$ and get $\frac{\partial p_U^*}{\partial c} = \frac{1}{2(1-\phi)}$ which can be easily shown to be positive. We know that $p_U^*$ is increasing when $c$ is larger. Differentiate $p_U^*$ with respect to $\phi$ and get $\frac{\partial p_U^*}{\partial \phi} = \frac{tf+(1-t)c}{2(1-t)(1-\phi)^2}$. Since $(1-\phi)^2(1-\phi-t)q - (2\phi t - \phi - t + 1)c + (1-\phi)(t-\phi+1)s \geq 0$, $f$ is nonnegative. $\frac{\partial p_U^*}{\partial \phi}$ can be easily shown to be nonnegative. We know that $p_U^*$ is increasing or remains the same when $\phi$ is larger. Differentiate $p_U^*$ with respect to $t$ and get $\frac{\partial p_U^*}{\partial t} = \frac{\phi f}{2(1-\phi)(1-t)^2}$. Since $f$ is nonnegative under assumptions, $\frac{\partial p_U^*}{\partial t}$ can be easily shown to be nonnegative. We know that $p_U^*$ is increasing or remains the same when $t$ is larger.

**Proof of Lemma 2.** Organize Equation (4.6) and we can get

$$\begin{aligned}\pi_P^U = \max_f \quad & \frac{1}{4(1-\phi)^2(1-t)^2 t}\left\{-(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)f^2+(1-t)\right.\\ & [(1-\phi)(2\phi^2+2\phi t-4\phi-2t+2)q-(4\phi t-2\phi-2t+2)c+2(1-\phi)(t-\phi+1)s]f\\ & \left.+[\phi(1-\phi)^2(1-t)^2q^2-2(1-\phi)^2(1-t)^2qs+2(1-\phi)(1-t)^2cs-\phi(1-t)^2c^2]\right\}.\end{aligned} \tag{A.4}$$



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We differentiate Equation (A.4) twice with respect to $f$ and can get

$$\frac{\partial^2 \pi_P^U}{\partial f^2} = \frac{-2(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}{4(1-\phi)^2(1-t)^2 t}. \tag{A.5}$$

Since $\phi \in [0,1)$ and $t \in (0,1)$, the denominator is positive and $(t-\phi+1)$ is nonnegative. Since $\phi \in [0,1)$ and $t \in (0,1)$, we get $-2(t-\phi+1)$ is negative. We differentiated $\phi^2+3\phi t-3\phi-2t+2$ with respect to $t$ and get $(3\phi-2)t+(1-\phi)(2-\phi)$. First, when $\phi > \frac{2}{3}$, the coefficient of $t$ becomes positive, and the minimum happens when $t=0$. We substitute $t=0$ into the previous function and get $(1-\phi)(2-\phi)$ which is always positive. Since $t \in (0,1)$, the qualified minimum is greater then the minimum that happens when $t=0$ and is a positive number. Second, when $\phi < \frac{2}{3}$, the coefficient of $t$ becomes negative, and the minimum happens when $t=1$. We substitute $t=1$ into the previous function and get $\phi^2$ which is always positive. Since $t \in (0,1)$, the qualified minimum is greater then the minimum that happens when $t=1$ and is a positive number. Last, when $\phi = \frac{2}{3}$, the coefficient of $t$ becomes zero and the function turns to $(1-\phi)(2-\phi)$ which is always positive. Thus, we know that $\phi^2+3\phi t-3\phi-2t+2$ is always positive under our assumption. Thus, Equation (A.5) can be easily shown to be nonpositive and we can use first order condition to solve for $f^U$. According to first order condition, we can get

$$\begin{aligned}\frac{\partial \pi_P^U}{\partial f} =& \frac{1}{4(1-\phi)^2(1-t)^2 t}\big\{-2(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)f \\ &+(1-t)[(1-\phi)(2\phi^2+2\phi t-4\phi-2t+2)q-(4\phi t-2\phi-2t+2)c+2(1-\phi)(t-\phi+1)s]\big\} \\ &=0.\end{aligned} \tag{A.6}$$

As a result, we obtain $f^U = \frac{(1-t)\left[(1-\phi)^2(1-\phi-t)q-(2\phi t-\phi-t+1)c+(1-\phi)(t-\phi+1)s\right]}{(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}$.

**Proof of Observation 1.** Differentiate $f^U = \frac{(1-t)\left[(1-\phi)^2(1-\phi-t)q-(2\phi t-\phi-t+1)c+(1-\phi)(t-\phi+1)s\right]}{(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}$ with respect to $q$ and get $\frac{\partial f^U}{\partial q} = \frac{(1-\phi)^2(1-t)(1-\phi-t)}{(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}$. For the denominator, since



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$\phi^2+3\phi t-3\phi-2t+2$ is shown to be positive in the proof of Lemma 2 and $\phi \in [0,1)$, the denominator is positive. For the numerator, since $\phi \in [0,1)$, $t \in (0,1)$, and $t+\phi \le 1$, it is nonnegative. Because the denominator is positive and the numerator is nonnegative, $\frac{\partial f^U}{\partial q}$ can be easily shown to be nonnegative. We know that $f^U$ is increasing or remains the same when $q$ is larger. Differentiate $f^U$ with respect to $c$ and get $\frac{\partial f^U}{\partial c} = -\frac{(1-t)(2\phi t-\phi-t+1)}{(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}$. The denominator is positive. For the numerator since $t \in (0,1)$, $\phi \in [0,1)$, and $t+\phi \le 1$, it is positive. Because the fraction is positive and there is a negative sign, $\frac{\partial f^U}{\partial c}$ can be easily shown to be negative. We know that $f^U$ is decreasing when $c$ is larger. Differentiate $f^U$ with respect to $s$ and get $\frac{\partial f^U}{\partial s} = \frac{(1-\phi)(1-t)(t-\phi+1)}{(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}$. The denominator is positive. For the numerator since $t \in (0,1)$ and $\phi \in [0,1)$, it is positive. Because both of the numerator and denominator are positive, $\frac{\partial f^U}{\partial s}$ can be easily shown to be positive. We know that $f^U$ is increasing when $s$ is larger.

Differentiate $p_U^* = \frac{(1-\phi)(1-t)q-(1-\phi-t)f+(1-t)c}{2(1-\phi)(1-t)}$ with respect to $c$ and get $\frac{\partial p_U^*}{\partial c} = \frac{(2-\phi)^2-(1+t)^2+4\phi t}{2(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}$. The denominator is positive. For the numerator, if $(2-\phi)^2-(1+t)^2 < 0$, since $t \in (0,1)$ and $\phi \in [0,1)$, it means that $(2-\phi) < (1+t)$. That is, $t+\phi > 1$ which violates our assumption. Thus, $(2-\phi)^2-(1+t)^2 \ge 0$. As a result, the numerator is nonngative. Because the denominator is positive and the numerator is nonngative, $\frac{\partial p_U^*}{\partial c}$ can be easily shown to be nonngative. We know that $p_U^*$ is increasing or remains the same when $c$ is larger. Differentiate $p_U^*$ with respect to $s$ and get $\frac{\partial p_U^*}{\partial s} = -\frac{1-\phi-t}{2(\phi^2+3\phi t-3\phi-2t+2)}$. The denominator is positive. For the numerator, since $t+\phi \le 1$, it is nonnegative. Because the fraction is nonnegative and there is a negative sign, $\frac{\partial f^U}{\partial s}$ can be easily shown to be nonpositive. We know that $p_U^*$ is decreasing or remains the same when $s$ is larger.

Differentiate $D_I^U = \frac{f}{1-t}$ with respect to $q$ and get $\frac{\partial D_I^U}{\partial q} = \frac{(1-\phi)^2(1-\phi-t)}{(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}$. Since



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$t \in (0,1)$, $\phi \in [0,1)$, and $t+\phi \leq 1$, $\frac{\partial D_I^U}{\partial q}$ can be easily shown to be nonnegative. We know that $D_I^U$ is increasing or remains the same when $q$ is larger. Differentiate $D_I^U$ with respect to $c$ and get $\frac{\partial D_I^U}{\partial c} = -\frac{2\phi t-\phi-t+1}{(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}$. Since $t \in (0,1)$, $\phi \in [0,1)$, and $t+\phi \leq 1$, $\frac{\partial D_I^U}{\partial c}$ can be easily shown to be negative. We know that $D_I^U$ is decreasing when $c$ is larger. Differentiate $D_I^U$ with respect to $s$ and get $\frac{\partial D_I^U}{\partial s} = \frac{(1-\phi)(t-\phi+1)}{(t-\phi+1)(\phi^2+3\phi t-3\phi-2t+2)}$. Since $t \in (0,1)$, $\phi \in [0,1)$, and $t+\phi \leq 1$, $\frac{\partial D_I^U}{\partial c}$ can be easily shown to be positive. We know that $D_I^U$ is increasing when $s$ is larger.

Differentiate $D_O^U = \frac{(1-t)q-f-(1-t)p_U}{t(1-t)}$ with respect to $q$ and get $\frac{\partial D_O^U}{\partial q} = \frac{2\phi t-\phi-t+1}{2t(\phi^2+3\phi t-3\phi-2t+2)}$. Since $t \in (0,1)$, $\phi \in [0,1)$, and $t+\phi \leq 1$, $\frac{\partial D_O^U}{\partial q}$ can be easily shown to be positive. We know that $D_O^U$ is increasing when $q$ is larger. Differentiate $D_O^U$ with respect to $c$ and get $\frac{\partial D_O^U}{\partial c} = -\frac{1-\phi-t}{2t(\phi^2+3\phi t-3\phi-2t+2)}$. Since $t+\phi \leq 1$, $\frac{\partial D_O^U}{\partial c}$ can be easily shown to be nonpositive. We know that $D_O^U$ is decreasing or remains the same when $c$ is larger. Differentiate $D_O^U$ with respect to $s$ and get $\frac{\partial D_O^U}{\partial s} = -\frac{t-\phi+1}{2t(\phi^2+3\phi t-3\phi-2t+2)}$. Since $t \in (0,1)$, $\phi \in [0,1)$, and $t+\phi \leq 1$, $\frac{\partial D_O^U}{\partial s}$ can be easily shown to be negative. We know that $D_O^U$ is decreasing when $s$ is larger.

**Proof of Lemma 3.** Organize Equation (4.11) and we can get

$$\begin{aligned}\pi_R^U = \max_{p_I,p_O} \quad & \frac{1}{t(1-t)}\left\{-tp_I^2-(1-\phi)p_O^2+(2-\phi)tp_Ip_O+tfp_I\right.\\ & \left.+[(1-\phi)(1-t)q+(1-t)c-(1-\phi)f]p_O+(1-t)(f-q)c\right\}. \qquad (A.7)\end{aligned}$$

We need to examine whether Equation (A.7) is negative semi-definite, so we calculate



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the Hessian matrix of it which is

$$H(\pi_R^D) = \begin{bmatrix} \frac{\partial^2 \pi_R^D}{\partial p_I^2} & \frac{\partial^2 \pi_R^D}{\partial p_I p_O} \\ \frac{\partial^2 \pi_R^D}{\partial p_O p_I} & \frac{\partial^2 \pi_R^D}{\partial p_O^2} \end{bmatrix} = \begin{bmatrix} \frac{-2t}{t(1-t)} & \frac{(2-\phi)t}{t(1-t)} \\ \frac{(2-\phi)t}{t(1-t)} & \frac{-2(1-\phi)}{t(1-t)} \end{bmatrix}. \tag{A.8}$$

First, since $t \in (0,1)$, we know that $\frac{\partial^2 \pi_R^D}{\partial p_I^2} = \frac{-2t}{t(1-t)} < 0$. Next, we check whether the determinant of Matrix (A.8) is positive. The determinant of Matrix (A.8) is $\frac{-\phi^2 t + 4\phi t - 4t - 4\phi + 4}{t(1-t)^2}$. Since $t \in (0,1)$, the denominator is positive, we only need to consider the sign of the numerator. The numerator can be rewritten as $\phi t(4-\phi) + 4(1-\phi-t)$. According to Assumption 1, we know that $t + \phi \leq 1$ which means that the customer's distance to the restaurant cannot be too far and her unit waiting cost cannot be too high. Because of the previous assumption, the numerator can be easily shown to be positive. Therefore, we can say that Matrix (A.8) is negative semi-definite and can use first order condition to find the optimal prices. Then, we differentiate Equation (A.7) with respect to $p_I$ and $p_O$ and get

$$\frac{\partial \pi_R^D}{\partial p_I} = \frac{-2p_I + (2-\phi)p_O + f}{1-t} = 0, \tag{A.9}$$

$$\frac{\partial \pi_R^D}{\partial p_O} = \frac{-2(1-\phi)p_O + (2-\phi)tp_I + [(1-\phi)(1-t)q + (1-t)c - (1-\phi)f]}{t(1-t)} = 0. \tag{A.10}$$

Reorganize Equations (A.9) and (A.10), we can get

$$p_I = \frac{(2-\phi)p_O + f}{2}, \tag{A.11}$$

$$p_O = \frac{(2-\phi)tp_I + (1-\phi)(1-t)q + (1-t)c - (1-\phi)f}{2(1-\phi)}. \tag{A.12}$$

As a result, by solving the above system, we obtain $p_I^* = \frac{(2-\phi)[(1-\phi)(1-t)q+(1-t)c]+\phi(1-\phi)f}{4(1-\phi)-(2-\phi)^2 t}$ and $p_O^* = \frac{2[(1-\phi)(1-t)q+(1-t)c]-[2(1-\phi-t)+\phi t]f}{4(1-\phi)-(2-\phi)^2 t}$.



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A customer chooses online dining only if her utility of online dining is nonnegative. That is, $q - p_O - \theta t - f \geq 0$. Since both $\theta$ and $t$ are positive, we can get that $q > f$. For the denominator of $p_I^*$, it is shown to be positive in the proof of Proposition 2. For the numerator of $p_I^*$, the coefficient of $q$ is greater than the coefficient of $f$ ($2(1-\phi)(1-t) - \phi(1-\phi) = (1-\phi)[2(1-t)-\phi] \geq (1-\phi)[2(1-t-\phi)] \geq 0$). Besides, $(2-\phi)(1-t)c$ is positive. As a result, $p_I^*$ can be easily shown to be positive. For the numerator of $p_O^*$, the coefficient of $q$ is greater than the coefficient of $f$ ($2(1-\phi)(1-t) = 2(1-\phi-t)+2\phi t > 2(1-\phi-t)+\phi t$). Besides, $2(1-t)c$ is positive. As a result, $p_O^*$ can be easily shown to be positive.

**Proof of Proposition 2.** Differentiate $p_I^* = \frac{(2-\phi)[(1-\phi)(1-t)q+(1-t)c]+\phi(1-\phi)f}{4(1-\phi)-(2-\phi)^2 t}$ with respect to $q$ and get $\frac{\partial p_I^*}{\partial q} = \frac{(2-\phi)(1-\phi)(1-t)}{4(1-\phi)-(2-\phi)^2 t}$. For the numerator, since $\phi \in [0, 1)$ and $t \in (0, 1)$, the numerator is positive. For the denominator, since $t + \phi \leq 1$, we know that $t \leq 1 - \phi$. We set $t = 1 - \phi$ and substitute it into the denominator. Then, we can get $4(1-\phi) - (2-\phi)^2(1-\phi) \leq 4(1-\phi) - (2-\phi)^2 t$ (the denominator). Reorganize $4(1-\phi)-(2-\phi)^2(1-\phi)$ and get $(1-\phi)[4-(2-\phi)^2]$. Since $\phi \in [0, 1)$, we only need to identify the sign of the latter part of the previous function $4-(2-\phi)^2$. Reorganize $4-(2-\phi)^2$ and get $2^2-(2-\phi)^2$. Since $\phi \in [0, 1)$, we know that $2 \geq 2-\phi > 0$, and thus, $4-(2-\phi)^2$ is nonnegative. That is, $4(1-\phi)-(2-\phi)^2(1-\phi)$ is also nonnegative. Since the denominator $4(1-\phi)-(2-\phi)^2 t$ is greater than or equal to an nonnegative number and the denominator cannot be zero, it is positive. Because both the numerator and the denominator are positive, $\frac{\partial p_I^*}{\partial q}$ can easily be shown to be positive. We know that $p_I^*$ is increasing when $q$ is larger. Differentiate $p_I^*$ with respect to $c$ and get $\frac{\partial p_I^*}{\partial c} = \frac{(2-\phi)(1-t)}{4(1-\phi)-(2-\phi)^2 t}$. For the numerator, since $\phi \in [0, 1)$ and $t \in (0, 1)$, the numerator is positive. Since the denominator is the same as $\frac{\partial p_I^*}{\partial q}$, it is shown to be positive. Because both the numerator and the denominator are positive,



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$\frac{\partial p_I^*}{\partial c}$ can easily be shown to be positive. We know that $p_I^*$ is increasing when $c$ is larger. Differentiate $p_I^*$ with respect to $f$ and get $\frac{\partial p_I^*}{\partial f} = \frac{\phi(1-\phi)}{4(1-\phi)-(2-\phi)^2 t}$. For the numerator, since $\phi \in [0, 1)$, the numerator is nonnegative. Because the denominator is positive and the numerator is nonnegative, $\frac{\partial p_I^*}{\partial f}$ can easily be shown to be nonnegative. We know that $p_I^*$ is increasing or remains the same when $f$ is larger.

Differentiate $p_O^* = \frac{2[(1-\phi)(1-t)q+(1-t)c]-[2(1-\phi-t)+\phi t]f}{4(1-\phi)-(2-\phi)^2 t}$ with respect to $q$ and get $\frac{\partial p_O^*}{\partial q} = \frac{2(1-\phi)(1-t)}{4(1-\phi)-(2-\phi)^2 t}$. For the numerator, since $\phi \in [0, 1)$ and $t \in (0, 1)$, the numerator is positive. Since the denominator is the same as $\frac{\partial p_I^*}{\partial q}$, it is shown to be positive. Because both the numerator and the denominator are positive, $\frac{\partial p_O^*}{\partial q}$ can easily be shown to be positive. We know that $p_O^*$ is increasing when $q$ is larger. Differentiate $p_O^*$ with respect to $c$ and get $\frac{\partial p_O^*}{\partial c} = \frac{2(1-t)}{4(1-\phi)-(2-\phi)^2 t}$. For the numerator, since $t \in (0, 1)$, the numerator is positive. Because both the numerator and the denominator are positive, $\frac{\partial p_O^*}{\partial c}$ can easily be shown to be positive. We know that $p_O^*$ is increasing when $c$ is larger. Differentiate $p_O^*$ with respect to $f$ and get $\frac{\partial p_O^*}{\partial f} = \frac{-[2(1-\phi-t)+\phi t]}{4(1-\phi)-(2-\phi)^2 t}$. For the numerator, since $\phi \in [0, 1)$, $t \in (0, 1)$ and $t + \phi \leq 1$, the numerator is nonpositive. Because the denominator is positive and the numerator is nonpositive, $\frac{\partial p_O^*}{\partial f}$ can easily be shown to be nonpositive. We know that $p_O^*$ is decreasing or remains the same when $f$ is larger.



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**Proof of Lemma 4.** Organize Equation (4.14) and we can get

$$
\begin{aligned}
\pi_P^D = \max_f \quad & \frac{1}{t(1-t)[4(1-\phi)-(2-\phi)^2 t]^2}\big\{-4(2-\phi)(1-\phi)^2(1-t)^2 f^2 \\
& + 2(1-\phi)(1-t)[4(1-\phi)^2(1-t)q-(1-t)(2-\phi)^2 tq-4(1-t)c \\
& + (1-t)(2-\phi)^2 tc+4(1-\phi)s-(2-\phi)^2 ts]f \\
& + \big\{(1-t)[4(1-\phi)-(2-\phi)^2 t]q+[(2-\phi)t-2][(1-\phi)(1-t)q+(1-t)c]\big\} \\
& \times \big\{2\phi[(1-\phi)(1-t)q+(1-t)c]-[4(1-\phi)-(2-\phi)^2 t]s\big\}\big\} \qquad \text{(A.13)}
\end{aligned}
$$

We differentiate Equation (A.13) twice with respect to $f$ and can get

$$
\frac{\partial^2 \pi_P^D}{\partial f^2} = \frac{-8(1-\phi)^2(1-t)^2(2-\phi)}{t(1-t)[4(1-\phi)-(2-\phi)^2 t]^2}. \qquad \text{(A.14)}
$$

Since $\phi \in [0,1)$ and $t \in (0,1)$, through some simple derivations, Equation (A.14) can be easily shown to be negative and we can use first order condition to solve for $f^D$. According to first order condition, we can get

$$
\begin{aligned}
\frac{\partial \pi_P^D}{\partial f} =& \frac{1}{t(1-t)[4(1-\phi)-(2-\phi)^2 t]^2}\big\{-8(1-\phi)^2(1-t)^2(2-\phi)f \\
& + 2(1-\phi)(1-t)[4(1-\phi)^2(1-t)q-(1-t)(2-\phi)^2 tq-4(1-t)c \\
& +(1-t)(2-\phi)^2 tc+4(1-\phi)s-(2-\phi)^2 ts]\big\} = 0. \qquad \text{(A.15)}
\end{aligned}
$$

As a result, we obtain $f^D = \frac{(1-t)[4(1-\phi)^2-(2-\phi)^2 t]q-(1-t)[4-(2-\phi)^2 t]c+[4(1-\phi)-(2-\phi)^2 t]s}{4(1-\phi)(1-t)(2-\phi)}$.

**Proof of Observation 2.** Differentiate $f^D = \frac{(1-t)[4(1-\phi)^2-(2-\phi)^2 t]q-(1-t)[4-(2-\phi)^2 t]c+[4(1-\phi)-(2-\phi)^2 t]s}{4(1-\phi)(1-t)(2-\phi)}$ with respect to $c$ and get $\frac{\partial f^D}{\partial c} = -\frac{4-(2-\phi)^2 t}{4(1-\phi)(2-\phi)}$. For the denominator, since $\phi \in [0,1)$, the denominator is positive. For the numerator, we can reorganize it and get $2^2-(2-\phi)^2 t$. Since $\phi \in [0,1)$, we obtain that $2^2 \geq (2-\phi)^2$. Besides, since $t \in (0,1)$, we obtain that $(2-\phi)^2 > (2-\phi)^2 t$. Thus, we get that $2^2 > (2-\phi)^2 t$ and the numerator is positive.



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Because both of the denominator and numerator are positive and there is a negative sign, $\frac{\partial f^D}{\partial c}$ can easily be shown to be negative. We know that $f^D$ is decreasing when $c$ is larger. Differentiate $f^D$ with respect to $s$ and get $\frac{\partial f^D}{\partial s} = \frac{4(1-\phi)-(2-\phi)^2 t}{4(1-\phi)(1-t)(2-\phi)}$. For the denominator, since $\phi \in [0,1)$ and $t \in (0,1)$, the denominator is positive. For the numerator, since it is the same as the denominator of $\frac{\partial p_I^*}{\partial q}$, it is shown to be positive in the proof of Proposition 2. Because both of the denominator and numerator are positive, $\frac{\partial f^D}{\partial s}$ can easily be shown to be positive. We know that $f^D$ is increasing when $s$ is larger.

Differentiate $p_I^* = \frac{(2-\phi)[(1-\phi)(1-t)q+(1-t)c]+\phi(1-\phi)f}{4(1-\phi)-(2-\phi)^2 t}$ with respect to $c$ and get $\frac{\partial p_I^*}{\partial c} = \frac{4(2-\phi)^2(1-t)-4\phi+(2-\phi)^2\phi t}{4(2-\phi)[4(1-\phi)-(2-\phi)^2 t]}$. For the denominator, since $\phi \in [0,1)$ and $4(1-\phi)-(2-\phi)^2 t$ is shown to be positive, it is positive. For the former part of the numerator, since $t+\phi \leq 1$, we obtain that $4(1-t)-4\phi = 4(1-t-\phi) \geq 0$. Besides, since $\phi \in [0,1)$, we obtain that $(2-\phi)^2 > 1$. Thus, we get that $4(2-\phi)^2(1-t)-4\phi > 4(1-t)-4\phi \geq 0$. For the latter part of the numerator, since $\phi \in [0,1)$ and $t \in (0,1)$, $(2-\phi)^2\phi t$ is positive. Thus, the numerator is shown to be positive. Because both of the denominator and numerator are positive, $\frac{\partial p_I^*}{\partial c}$ can easily be shown to be positive. We know that $p_I^*$ is increasing when $c$ is larger. Differentiate $p_I^*$ with respect to $s$ and get $\frac{\partial p_I^*}{\partial s} = \frac{\phi}{4(1-t)(2-\phi)}$. For the denominator, since $\phi \in [0,1)$ and $t \in (0,1)$, it is positive. For the numerator, since $\phi \in [0,1)$, it is nonnegative. Because the denominator is positive and the numerator is nonnegative, $\frac{\partial p_I^*}{\partial s}$ can easily be shown to be nonnegative. We know that $p_I^*$ is increasing or remains the same when $s$ is larger.

Differentiate $p_O^* = \frac{2[(1-\phi)(1-t)q+(1-t)c]-[2(1-\phi-t)+\phi t]f}{4(1-\phi)-(2-\phi)^2 t}$ with respect to $c$ and get $\frac{\partial p_O^*}{\partial c} = \frac{2(1-t)-[2(1-\phi-t)+\phi t]\frac{\partial f^D}{\partial c}}{4(1-\phi)-(2-\phi)^2 t}$. For the denominator, it is shown to be positive. For the former part of the numerator, since $t \in (0,1)$, it is positive. For the latter part of the numerator,



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since $t \in (0,1)$, $\phi \in [0,1)$, $t+\phi \leq 1$, and $\frac{\partial f^D}{\partial c}$ is shown to be negative, this part is positive. Thus, the numerator is positive. Because both of the denominator and numerator are positive, $\frac{\partial p_O^*}{\partial c}$ can easily be shown to be positive. We know that $p_O^*$ is increasing when $c$ is larger. Differentiate $p_O^*$ with respect to $s$ and get $\frac{\partial p_O^*}{\partial s} = \frac{-[2(1-\phi-t)+\phi t]\frac{\partial f^D}{\partial s}}{4(1-\phi)-(2-\phi)^2 t}$. For the denominator, it is shown to be positive. For the numerator, since $t \in (0,1)$, $\phi \in [0,1)$, $t+\phi \leq 1$, and $\frac{\partial f^D}{\partial s}$ is shown to be positive, it is negative. Because the denominator is positive and the numerator is negative, $\frac{\partial p_O^*}{\partial s}$ can easily be shown to be negative. We know that $p_O^*$ is decreasing when $s$ is larger.

Differentiate $D_I^D = \frac{-p_I+p_O+f}{1-t}$ with respect to $c$ and get $\frac{\partial D_I^D}{\partial c} = -\frac{4(1-\phi-t)+\phi t(4-\phi)}{4[4(1-\phi)^2-(2-\phi)^2 t]}$. For the denominator, it is shown to be positive. For the numerator, since $t \in (0,1)$, $\phi \in [0,1)$, $t+\phi \leq 1$, it is positive. Because both of the the denominator and numerator are positive and there is a negative sign, $\frac{\partial D_I^D}{\partial c}$ can be easily shown to be negative. We know that $D_I^D$ is decreasing when $c$ is larger. Differentiate $D_I^D$ with respect to $s$ and get $\frac{\partial D_I^D}{\partial s} = \frac{1}{4(1-t)}$. Since $t \in (0,1)$, $\frac{\partial D_I^D}{\partial s}$ can be easily shown to be positive. We know that $D_I^D$ is increasing when $s$ is larger.

Differentiate $D_O^D = \frac{(1-t)q-f-p_O+tp_I}{t(1-t)}$ with respect to $c$ and get $\frac{\partial D_O^D}{\partial c} = -\frac{4(1-\phi-t)+(4-\phi)\phi t}{2t(2-\phi)[4(1-\phi)^2-(2-\phi)^2 t]}$. For the denominator, since $t \in (0,1)$ and $\phi \in [0,1)$, it is positive. For the numerator, since $t \in (0,1)$, $\phi \in [0,1)$, $t+\phi \leq 1$, it is positive. Because both of the the denominator and numerator are positive and there is a negative sign, $\frac{\partial D_O^D}{\partial c}$ can be easily shown to be negative. We know that $D_O^D$ is decreasing when $c$ is larger. Differentiate $D_O^D$ with respect to $s$ and get $\frac{\partial D_O^D}{\partial s} = -\frac{1}{2t(1-t)(2-\phi)}$. Since $t \in (0,1)$ and $\phi \in [0,1)$, $\frac{\partial D_O^D}{\partial s}$ can be easily shown to be negative. We know that $D_O^D$ is decreasing when $s$ is larger.



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