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行動支付服務之雙邊市場最佳定價策略

The Optimal Pricing Strategy of a Mobile Payment Service in a Two-sided Market

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本論文係黃千瑜君（學號 R04725021）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 106 年 6 月 20 日承下列考試委員審查通過及口試及格，特此證明

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中文摘要

隨著行動裝置高度滲透人們的日常，近年來金融科技領域最令人矚目的趨勢之一，莫過於「行動支付」。民眾的生活與消費習慣，因多元化新興支付模式的出現而不斷改變。隨著法規陸續放寬及上路，各產業業者開始積極跨足行動支付市場，瞄準了其所帶動的大餅。百家爭鳴的狀態下，目前國內仍未形成完全統一的市場技術和經營模式，尤其是近端支付之應用。面對這競爭日益激烈的新興市場，行動支付業者紛紛嘗試導入不同行動支付技術，並摸索成功的商業策略。因此，本研究致力於分析行動支付近端支付服務之最佳定價策略，為行動支付生態圈相關業者建構有效的商業模式。

行動支付平台可視為連接著商家與消費者的雙邊平台，故本研究採用賽局理論方法，探討網路外部性影響下，採用不同近端技術之行動支付平台的獲利模型。分析結果顯示，在短期策略上，平台實施交叉補貼策略能夠保證獲利：透過補貼消費者，行動支付平台藉由正向同邊網路效應快速累積消費用戶，進而吸引更多商家加入，再藉由向商家抽取每筆交易手續費，讓平台快速發展、穩定獲利。考慮消費者交易頻率隨商家數變化之趨勢，以及平台開發新商家之服務建置成本，交叉補貼之策略仍是最佳獲利模式。在長期策略上，若行動支付平台合作之金融單位分帳比例不高，則平台更加適合實施交叉補貼策略。本研究也討論，若行動支付平台對消費者也能收取每筆交易手續費或進行每筆交易補貼，面對消費者和商家，平台之補貼對象和定價策略為何？研究發現，最佳獲利模型之補貼策略會隨著採用不同近端技術而改變。補貼對象不再限於消費者，商家也能受補貼，而行動支付平台仍能在策略下持續獲利。

關鍵字：行動支付、多邊平台、賽局理論、定價策略

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Thesis Abstract

Acknowledging the high penetration rate of mobile devices, mobile payment is currently a hot topic and is expected to reach the tipping point of rapid growth. For such a nascent market, a unified business model for successful mobile payment platform is not yet unveiled, especially in proximity payment applications. Players from all industries are trying to adopt different mobile payment technologies and look for corresponding profitable business model. Therefore, we devote this study to investigate the pricing strategy of proximity mobile payment. We hope to make a step forward to understand this promising market for mobile payment executives, financial institutes, and many other players in the ecosystem.

Mobile payment serves as a two-sided platform connecting merchants and customers. Hence, we present a game-theoretic model featuring network externality. Our research suggests, at the beginning of the business, the platform has incentives to adopt the "divide and conquer" strategy. Customers are subsidized to adopt the mobile payment service, and then merchants will be attracted to join the platform due to the positive cross-side network externality. After the ignition, the platform then becomes profitable by charging per transaction fees from the merchants. If the consumption frequency is a function of the number of merchants or there is a system installation cost for each merchant, the same cross subsidization strategy is still optimal. In the long run, the cross-subsidization strategy is suggested to be applied when the bank is not taking a too high processing fee and leaves sufficient market share to the mobile payment platform. Our research also shows that if the mobile payment platform considers customer-side transaction fee as a new revenue source, it can enhance its profitability. With different mobile payment technologies adopted, the optimal cross subsidization strategy may be to subsidize the merchants rather than customers.

Keywords: Mobile Payment, Multi-sided Platforms, Game Theory, Pricing Strategy

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Chapter 1

Introduction

1.1 Background and motivation

The rapid evolution of technology has affected human beings' daily behavior and altered the methods of commerce. From telegraphs, telephones to nowadays mobile phones which most modern people claim cannot live without, communication devices have shortened the time and cost of people to interact with others to a blink of eye. However, mobile phone in today's digital era is not only a communication device but a door to access all variety of services, including information exchange, entertainment, and commerce. According to Forrester (2016), more than 4.8 billion individuals were using a mobile phone at the end of 2016. Data from KPCB (2016) reveal that mobile devices have eclipsed desktop computers as the primary method of Internet access for users globally. The same report shows adults in average spend roughly three hours per day on a mobile device in the United States. As this enormous and potential growth that mobile devices present, it comes with no surprise to see that the battlefield of commerce has extended

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from e-commerce to so-called m-commerce (mobile commerce). Originally introduced in 1997 by Kevin Duffey at the launch of the Global Mobile Commerce Forum, e-commerce means "the delivery of electronic commerce capabilities directly into the consumer's hand, anywhere, via wireless technology."[1]

As this trend evolves, Gartner (2015) predicts that revenue from m-commerce will equal 50 percent of all digital commerce in the United States by 2017. A recent World Payments report by Capgemini (2015) claims that an annual growth of 60.8 percent through 2015 as mobile devices have become common devices for shopping online. Nearly 80 million U.S. consumers, corresponding to half of digital buyers in the U.S., are expected to make purchases using mobile devices. Acknowledging the high penetration rate of mobile devices, mobile payment is currently a hot topic and is expected to reach the tipping point of rapid growth.

Mobile payment, also referred to as mobile wallets, mobile money, or mobile money transfer, is widely defined as a transfer of funds in return for a wide range of services and digital or hard goods, where the mobile phones are involved in both the initiation and confirmation of the payment operated under financial regulation. The location of the payer and supporting infrastructure is not important: she may or may not be "mobile" or "on the move" or at a Point of Sale (POS); the money may be paid by credit cards or by a prepaid wallet (Pandy, 2014). Mobile payment is a new form of value transfer, similar to other payment instruments that consumers can use. However, it relies more on the advanced features of mobile phones and the tokenization of a consumer's financial

[1]For more details, please refer to Global Mobile Commerce Forum 1997 https://cryptome.org/jya/glomob.htm

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credentials.

Based on the location of firms and consumers, mobile payment may be remote or proximity. By adopting remote mobile payment, the parties and entities involved in the authorization and transaction process are not physically close to each other. As remote mobile payment has been established in the e-commerce market for years, its market structure and architecture are relatively mature. In contrast, thanks to the modern wireless communication technology, proximity mobile payment lets consumers use their phones to pay for goods or services at a physical POS or with a mobile POS device at the merchant. According to PwC (2016), in 2014, the transaction volume in the global proximity mobile payment market was valued at 4.6 billion and it is expected to exceed 300 billion by 2020, with a 5-year CAGR of 85.9 percent.

Mobile payment ecosystem is diverse and complex. Many different kinds of firms are involved, ranging from mobile network operators (MNOs) and financial institutions to software and hardware providers. Therefore, inter-firm collaboration is especially crucial for the development and commercialization of this new market. However, the conflicting interests and different roles played by the firms in the system make it hard to reach a universal agreement on a new market architecture. This leads to a variety of models of mobile payments platform, differentiated by technology implementation (NFC, QR Codes), location (remote or proximity), and various stakeholders (financial institutions, mobile network operators, phone providers, regulators) each with their own motivations, expectations and capabilities (Pandy, 2014; Dennehy and Sammon, 2015).

Proximity mobile payment refers to wireless communication transactions in which consumers use their phones to pay for goods or services at a physical POS or with a

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mobile POS device at the merchant.[2] In contrast to proximity wallets, with a remote wallet, the parties and entities involved in the authorization and transaction process are not physically close to each other. Hence the usage scenario is a remote authorization and transaction among the involved parties. As remote mobile wallets have been established in the e-commerce market for years and market architectures are relatively mature in the field of mobile commerce, most business models of proximity mobile payments platform have not yet been widely promoted and adopted by the market. Thus, the scope of this study is restricted to the proximity mobile payment, whose development is currently still constraint by technology of end devices and immature market policies.

The wireless transmission technology of proximity mobile payments can be further categorized into three communication protocols: NFC-based (Near Field Communication), QR code-based, and other contactless technology such as MST-based (Magnetic Secure Transmission).

1. NFC-based:

   The NFC (Near Field Communication) technology is a standard-based wireless communication technology that allows information data to be exchanged between devices located a few centimeters apart. To protect stored data and enable transaction security, payment credential is stored in the mobile phone in a secure element, which is a smart card chip. Secure element can be added to phone with a NFC SIM Card (SIM as a Secure Element, SaaSE), embedded into the mobile phone (embedded Secure Elements, eSE), or held as a virtual representation in the mobile phone operating system (Host Card Emulation, HCE). Examples include Apple

[2] For more details, please refer to Smart Card Alliance http://www.smartcardalliance.org .

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Pay, Android Pay and Samsung Pay.

The eSE and HCE-based solutions are more popular among for mobile phone manufacturers (including Apple and Samsung), mobile payment services providers (e.g., Google and Microsoft) and financial institutes as these models reduce their dependency upon mobile network operators. On the other hand, SIM-based payment systems are launched nonetheless to leverage the brands and reach of mobile network operators and players in SIM ecosystem.

In NFC-SIM model, there exists a special and important role called trusted service manager (TSM). In the provisioning and managing of secure services, TSM acts as a neutral broker that sets up business agreements and technical connections with mobile network operators, phone manufacturers or other entities controlling the secure element on mobile phones. The TSM is an independent business entity and many types of company are entering this competitive market. The role of TSM can be performed by mobile network operators, financial institutes, mobile wallet service providers or third parties, and one part can be delegated by one party to another.

HCE, also phrased as "SE in the cloud" since valuable account-level payment credentials (such as session keys), previously held in the SE, are moved into a secure data center in the "cloud" which is accessible to the mobile app. The absence of a physical security device makes it easy to market, deliver, and scale-up, however, also risky, as customers often see the cloud as less secure. An example is Android Pay.

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Data shown that almost half of smart phone shipments in 2015 support NFC.[3]

2. QR code-based:

   QR code, a matrix barcode which comprises of many "square dots" to represent the data store in it, is widely used for marketing, retailing, texts, and more recently mobile payment. QR code payment has low entry barrier and is convenient for consumers as anybody with a smart phone (camera needed) can use it. Meanwhile, merchants can save cost by not having to invest in expensive equipment and adherence to restrictive rules. It is no wonder that it becomes a form of electronic mobile payment that is gaining popularity fast. However, convenience to access payment information may also lead to fraudulent activities such as false transactions, fake identity, and stolen fund. Besides, as the QR-Code method is accessible only under Internet connection, users have to open a QR code scanner APP so to use mobile wallet.

3. MST-based:

   Magnetic Secure Transmission (MST) is the newest technology which generates an alternating current through an inductive loop of changing magnetic fields and emulates magnetic POS terminal, so merchants do not need to upgrade their terminals. This makes MST the more easily accessible technology whilst NFC POS penetration remains low. MST was patented by LoopPay, a mobile wallet solution that allows consumers to pay with their mobile devices and was recently acquired by Samsung. About data security of MST method, a secure element is physically embedded into

[3]Source: EY analysis http://www.ey.com

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	User Experience	Payment Processing Fees	Cost of Installation	Level of Technological Penetration	Example
NFC-eSE	High	Medium	High	Medium	Apply Pay, Samsung Pay
NFC-HCE	Medium	Medium	High	Medium	Android Pay
NFC-SIM	High	High	High	Medium	T-Wallet, friDay
QR-Code	Low	Medium	Low	High	WeChat Wallet, Line pay
MST-eSE	High	Medium	Medium	Low	Samsung Pay

Table 1.1: Mobile payment technology comparison

a phone just as the same NFC-eSE method. Over all, the MST-based model seems to hold the key advantage of mobile payment technology. However, restricted by phone requirement (only on Samsung's latest crop of flagship devices), this method has currently the lowest eligibility.

We summarize different technology aspects mentioned above in Table 1.1. A few characteristics are discussed: user experience, payment processing fees, cost of installation, and the level of technological penetration. User experience takes several aspects into consideration: easy to use, security and usefulness. Payment processing fee is determined by the role of financial institutes under the model. As in NFC-SIM based method, banks are unwilling to let mobile operators keep in charge of the business and thus reflect their power on charging higher payment processing fee per transaction. Cost of installation represents the fixed system implementation cost to set-up the environment of mobile

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payment at the merchants and even the staff-training cost. The level of technological penetration is the phone requirement to access the method.

For a promising payment services markets with a history of numerous tried and failed solutions, how to run a successful proximity mobile payment platform remains unanswered (Dahlberg et al., 2008). Therefore, we devote this study to investigate a business model of proximity mobile payment, whose development is currently still constraint by technology of end devices and immature market policies. It is nature that different mobile payment platforms adopting different payment technologies may diverse their decisions on pricing models. Observing current market players, we find that instead of charging customers, all mobile payment platform profits from charging merchants after customers make a purchase. Customers are sometimes given a small amount of discount codes to join the platform. However, the amount and method of subsidization diverse in different mobile platforms. Line Pay charges merchant per-transaction fee and gives customers reward points after each purchase. Gomaji Pay charges merchant high per-transaction fee but provide customers a fixed amount of discount codes when first join the platform. Apple Pay also charges merchants transaction fee but offer less customer-side subsidizations. Most of Apple pay promotions are provided by their cooperated banks but Apple themselves. These different subsidization decisions intrigue us to invest the optimality for these nascent mobile payment platforms.

Mobile payment serves as a two-sided platform connecting merchants and customers. As a platform, successful ignition relies on it installed base, and user benefit of using the platform increases as the number of users increases. This is known as the so-called *positive cross-side network externality*, which is the extra utility one earns by interacting

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with members at the other side of the platform. The more members at the other side, the more utility one gains. For a mobile payment provider, it faces the challenge of attracting enough merchants to provide goods and services to attract customers, and vice versa. To incentivize merchants and customers to adopt the mobile payment service, pricing (and subsidization) is obviously the key. The platform may profit from the registration fees of customers and merchants, or transaction fee in each payment to make itself financially sustainable. However, the pricing plan will affect the actions of customers and merchants, and thus makes the problem complicated. Consequently, in this study we investigate a mobile payment platform's pricing strategy and the impact of technology options. We hope our study may explain the rationale behind the selection of pricing strategies adopted by mobile payment platforms in industry. Moreover, we may provide a step forward of method to understand this new market that is full of potential.

1.2 Research objectives

To this aim, we build a game-theoretic model featuring network externality and consider mobile payment business settings under different technologies. Game theory is a major method used in economics, business, and social science for modeling behaviors of interacting agents (Shapiro, 1989). One particular application is for studying two-sided platforms (Caillaud and Jullien, 2003; Armstrong, 2006). This research method usually focuses on looking for sets of strategies known as "solution concepts" or "equilibria", under a common assumption that players act rationally. The most famous of these is the Nash equilibrium, in which each player's strategy represents a best response to the

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others' strategies. Researchers analyze behaviors of players to discover economics and business insights.

In this research, three types of players are in the market: a firm constructing the mobile payment platform, a group of potential consumers, and a group of potential merchants. The major purpose of our work is to study the profitability of feasible pricing strategies and figure out factors that affect the platform's equilibrium choice. To focus on the pricing strategies of the platform and the interdependency between merchants and customers, we assume that the decisions of the rest of the players (e.g., banks) are fixed or less flexible to be changed.

1.3 Research plan

In the next chapter, we review some related works with respect to mobile payment ecosystem, network externality and multi-sided platform, and game-theoretic mobile payment platform. In Chapter 3, we develop a game-theoretic model that addresses the interaction among the mobile payment platform, customers, and merchants. Our analysis and findings then follow. The analysis and results of basic model are then presented in Chapter 4. Chapter 5 extends the basic model and delivers further managerial insights. Chapter 6 concludes. All proofs are in the Appendix.

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Chapter 2

Literature review

2.1 Mobile payment ecosystem

During the past few years, the prosper of mobile payments channel has led to an increase in the volume of literature dedicated to the topic.

In a mobile payment ecosystem, there are several decision makers from multiple industries: consumers, merchants, mobile network operators (MNOs), financial institutions, mobile device manufacturers, software and technology providers, and regulators (Boer and Boer, 2009; Dahlberg et al., 2008; Hedman and Henningsson, 2012; Ozcan and Santos, 2015). Hedman and Henningsson (2012) set up a framework to identify the actors and their roles. In their study of how technological payment innovations influence payment ecosystems, they explained that digitalization of payments has caused ecosystem instability by impacting the competitive and collaborative dimensions of ecosystems. In other words, this digitalization creates a new arena for competition.

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In the study on how nascent mobile payment markets emerge, Ozcan and Santos (2015) argue, as the potential partners hold dominant positions in different markets, cooperation between two parties are difficult and may lead to a vicious circle and potential markets are lost due to turf wars. In the history of mobile payment ecosystem, we can find that MNOs and banks are having problem in reaching agreement on NFC-based mobile payment market. Debates on who would "own" the end-customers and who deals with transaction security failed to meet alignment. However, the longer mobile operators and banks delayed commercial projects of NFC mobile payment due to the lack of phones and terminals, the lower the handset-manufacturers and merchants put NFC devices on their priority list. Ultimately, players started to search for alternative market architectures such as QR-Code based model known by WeChat Wallet or NFC plastic cards introduced by Wells Fargo Bank in 2007.

Apart from discussion about the turf war of different players, Ondrus et al. (2015) investigate the impact of openness in mobile payment platform on market potential by examining openness at three levels provider, technology, and user level. The provider level takes strategies as competition, co-opetition, and collaboration and recognizes the strategic involvement may bring platform ignition by greater market potential. The classification of technology level considers the interoperability of a platform across different technologies. The user level strategy is what extent a platform discriminates different segments of the customer base. Positive and negative consequences of openness exist in all level. However, as the platform is launched, players as decision makers need to adopt an appropriate openness strategy to achieve the minimum market potential to support platform ignition and hence the likelihood of success.

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These studies offer contributions to the understanding of the causes that have hindered the developments of mobile payments over the year, and why most mobile payment initiatives have failed before reaching consumers and merchants. However, most of mobile business payment studies use case research and statistical analysis to explain how new type of business model affect the players' actions in an existing industry. However, none of the above mentioned studies conduct rigorous economic modeling to examine the viability of business model as a multi-sided platform. Hence, in this study we construct a game-theoretic model of mobile payment ecosystem to provide a basis for feasible business model.

2.2 Network externality and multi-sided platform

The chicken-or-egg analogy is perfectly used to describe the mobile payment ecosystem challenge facing merchants' and consumers' adoption issues. There are two types of externalities between two sides of agents: on the same side, the bigger the group, the higher the benefits and attractiveness for a given consumer or merchant to join the platform. On the other hand, by cross-side network effect, the more consumers adopt the mobile payment method, the higher the incentives for merchants and agents to join the system. Therefore, the presence of network externality is viewed as an important property of a "two-sided market" (Caillaud and Jullien, 2003; Armstrong, 2006).

According to Hagiu and Wright (2015), multi-side platforms have two key features beyond any other requirements. One is that they enable direct interactions between two or more distinct sides. The other is that each side is affiliated with the platform. In

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mobile payment business model, the key terms of the interaction could be the pricing, consuming, and delivery of the goods or services. "Affiliation" is defined as users on each side consciously make platform-specific investments that are necessary in order for them to be able to directly interact with each other. For example, in a mobile payment ecosystem, the investment could be a fixed access fee (e.g., POS setup fee or registration fee of mobile wallet), expenditure of resources (e.g., developing cost of applications using the iPhone's APIs), or an opportunity cost (e.g., paying by cash, joining a loyalty program). These dimensions significantly affect the adoption of multi-sided models.

Caillaud and Jullien (2003) propose a framework to analyze intermediation service providers' pricing strategy under imperfect competition with consideration of indirect network externalities. They point out that Internet platform are mostly nonexclusive, where users are said to engage "multihoming". By adopting "divide-and-conquer" strategies, where one side of the platform is subsidized (divide) and profits are made on the other side (conquer), users are absorbed to join in the market at the beginning of the business. When the market size reaches the minimum to support platform ignition, platform can then become profitable. Also, as the presence of network externalities, price discrimination based on users' identity and on usage can be sustained in equilibrium. Platforms providers gain market shares by charging registration fees, which paid *ex ante* and only once, and a transaction fee, when a transaction takes place between two matched parties. Price discrimination enables intermediaries to profitably differentiate, as one offering low registration but high transaction fees, the other adopting the mirror-pricing policy.

Similar strategies are analyzed in model of payment card system as well (Baxter, 1983; Rochet and Tirole, 2002; Schmalensee, 2002; Wright, 2004). Baxter (1983) defined a card

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payment as a service offered to two parties (the cardholder and the merchant) jointly by two other parties (the issuer and the acquirer). When consumers use debit cards or credit cards to make purchases in merchants, an interchange fee is paid from the acquirer to the issuer, as the issuer guarantees the transaction. Interchange fee affects the fees charges to cardholders and merchants, and further affects the pricing strategy of merchants and the willingness-to-pay of cardholders.

Followed Baxter's research, Rochet and Tirole (2002) provide a detailed description of the factors considering merchant resistance, compare cooperative and for-profit business models, and firstly introduce system competition into this topic. They argue that without the existence of interchange fee, large organizations have stronger incentive to break alliance and instead, form their own proprietary systems. Schmalensee (2002), on the other hand, analyze the provision of payment card services as a moral-hazard-in-teams problem, solve for the outcome of this two- stage game for an arbitrary allocation of bargaining power, and show that the profit-maximizing interchange fee enables the system's optimal output plus customer surplus under non-extreme cases. In model of Wright (2004), the result shows that optimal interchange fee is higher as the competition effect between merchants becomes stronger. Also, market failure can be linked to the issue whether retail prices are higher or lower as a result of card acceptance.

These works related to network externality would help us to understands those emerging business models. In order to better clarify the strategies under different types of mobile payment technologies, we leverage network externality and mobile payment to examine decision players' behaviour in our study.

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2.3 Game-theoretic m-payment platform strategy

To the best of our knowledge, only few research articles in mobile payment field provide theoretical models and further discuss platform pricing strategy.

Zhan and Qiao (2015) construct a game-theoretic pricing model of trusted service manager (TSM) in mobile NFC payment industry based on two-sided market platform theory. Followed our brief introduction in the first section, TSM can be played by financial institutions (usually referred as PSP-TSM) or MNOs (MNO-TSM) or cooperated by two different parties. Zhan and Qiao (2015) take such cooperation choices of TSMs into account and analyze the utilities of the TSM platform, its users and merchants under the condition of product differentiation, user single-homing and network externality. Their model suggests that in equilibrium PSP-TSM and MNO-TSM should cooperate to meet a win-win strategy. However, as Ozcan and Santos (2015) argue, banks and MNOs have problems in reaching agreement on mobile payment market. Zhan and Qiao (2015) do not incorporate these cooperation costs in their model.

Chaix and Torre (2010) classify four types of possible economic business models according to the degree of involvement of two main partners, bank(s) and mobile network operator(s): the bank-centric model, telecom-centric model, collaborative model, and independent service provider model. Banks have expertise in financial flow, risk and fraud management. Furthermore, current financial regulations require banks to be unavoidably involved in most mobile payment solution. However, when different technology base of mobile payment method is chosen, banks' degree of impact diverse as well. In NFC-SIM based model, payment credential is written on SIM card and need authorization of its

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SIM-card provider, the MNO, to access. That is, the mobile payment service would control by the mobile operator while banks lost their negotiation privilege in this situation. On the other hand, with embedded SIM or HCE model, financial institutions are allowed to negotiate the relationship with the handset manufacturer directly and to continue to own the responsibility over financial transactions.

Therefore, in this paper, we consider bank as a payment processor instead of a decision maker in the game. As long as the model is profitable, the bank will cooperate with the mobile wallet provider, by charging different degree of payment processing fees judging by the payment technology used. By doing so, we can be generalized Chaix and Torre (2010)'s models into one single model by applying varied parameters in practice. In addition, the mobile wallet provider in our study need not to be a independent service provider. Instead, he can also be a MNO or financial institution. The power of the mobile wallet provider in the industry will reflect on the cost of running the service.

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Chapter 3

Model

We formulate a stylized model integrating the essential features of a mobile payment platform considering settings under different mobile payment technologies. A mobile payment platform is a service offered to two parties, the customers (for each of them, she) and the merchants (for each of them, he), by a mobile payment platform operator.

Customer. To join the platform, a customer pays a registration fee f_C to the mobile payment platform. It is noted that f_C is not necessarily positive since negative registration fee can be viewed as subsidization. After joining the platform, she may pay with her mobile phone in merchants allowing the service. In each transaction, an exogenous cost of using the mobile payment service $c \geq 0$ occurs. The value of c is determined jointly by the easiness-to-use, security, and usefulness of the service

As a two-sided platform, the more merchants adopting the mobile payment method, the higher the incentives for customers to join the system. That is, the payment service quality depends on the number of merchants on the platform in equilibrium, which deter-

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mines the degree of convenience to use the mobile payment service. Let n_{M} be the number of merchants on the platform, and we denote a customer's perceived service quality by $h(n_{\mathrm{M}})$, where $h'(n_{\mathrm{M}}) > 0$ and $h''(n_{\mathrm{M}}) \leq 0$, i.e., increasing the number of merchants is attractive to customers, but the marginal attractiveness decreases. The shape of $h(n_{\mathrm{M}})$ is further visualized in Figures 3.1 and 3.2. If we zoom in the beginning part of Figure 3.1, the curve can be well approximated as a straight line as shown in Figure 3.2. In other words, in the nascent market of mobile payment, the number of merchants approximately affects the customers' willingness-to-use linearly. Therefore, we set $h(n_{\mathrm{M}}) = n_{\mathrm{M}}$ in the short run and consider $h(n_{\mathrm{M}})$ as a general concave function of n_{M} in the long run.

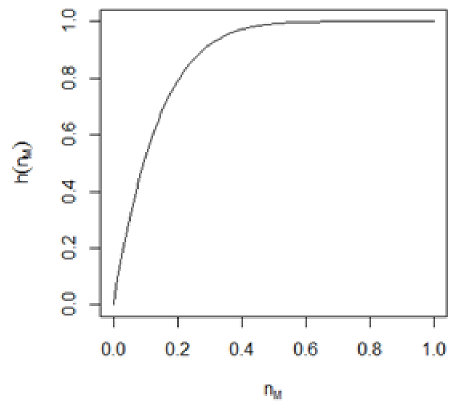

Figure 3.1: $h(n_{\mathrm{M}})$

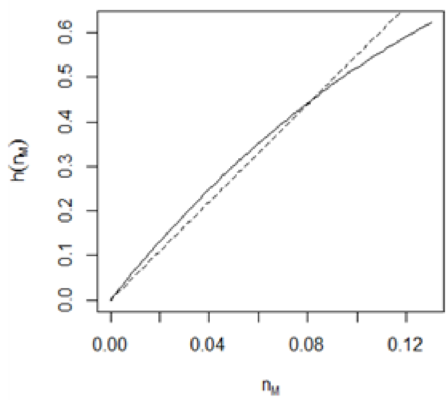

Figure 3.2: $h(n_{\mathrm{M}}) = n_{\mathrm{M}}$

It is natural that customers differ in their willingness to use a mobile payment service. For example, some customers have a low value of time of going to get cash before shopping, while others may consider carrying coins are inconvenient and transaction speed is important. Therefore, we assume that customers are heterogeneous on their willingness-to-use θ, which is uniformly distributed in [0,1]. The net benefit obtained in a transaction is then $\theta - c$. Suppose that a customer in expectation uses the mobile payment service

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$N > 0$ times, a type-θ consumer's utility in a membership period is thus

$$u_C = Nh(n_M)(\theta - c) - f_C. \tag{3.1}$$

i.e., the total amount of benefit obtained through using mobile payment $Nh(n_M)(\theta - c)$ minus the membership fee f_C per membership period.

Merchant. Let $p > 0$ be the exogenous average price of products in a mobile payment transaction. When a customer makes a purchase at the merchant, the merchant is charged by the mobile payment platform operator at a rate r_M. That is, he earns only $p(1-r_M)$ in each transaction. Without loss of generality, we normalize p to 1 throughout this study. We still include p in expressions when that makes the exposition clearer.

We consider merchants to be heterogeneous on their willingness to adopt mobile payment as well. Some merchants may believe that introducing mobile payment can speed up transactions and capture more transaction details for future analysis at the same time. On the contrary, some merchants just dislike mobile payment due to, for example, the resistance to new technology. Therefore, we denote the (physical or mental) cost of performing a mobile payment transaction by η, which distributes uniformly within 0 and 1, to capture the heterogeneity among merchants. A merchant's net earnings per transaction is thus $p(1 - r_M) - \eta$.

Similar to customers, merchants have more incentive to join the platform when more customers sign up on the platform. Let n_C be the number of customers of the mobile payment platform. There will be Nn_C transactions made in one membership period. Given that there are n_M merchants in the market adopting mobile payment, each merchants

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will receive $\frac{Nn_C}{n_M}$ transactions in expectation. Consequently, a type-η merchant's utility is

$$u_M = \frac{Nn_C}{n_M}(p(1 - r_M) - \eta). \tag{3.2}$$

Customers will join the platform if her $u_C \geq 0$, and a merchant will do the same thing if his $u_M \geq 0$. Thus, following our model setting, there exists a critical value θ^* that divides customers into two group: A customer uses the mobile payment service if and only if her $\theta > \theta^*$. Similarly, we can find a critical value η^* that merchant will join the platform if and only if $\eta < \eta^*$. In our notation, this means

$$n_C = 1 - \theta^* \quad \text{and} \quad n_M = \eta^*. \tag{3.3}$$

An illustration of the market segmentation is provided in Figure 3.3.

Figure 3.3: Consumer and merchant segmentation

Mobile wallet platform. The platform's problem is to maximize its profit

$$u_W = n_C f_C + Nn_C p(r_M - b), \tag{3.4}$$

where $b \in [0, 1]$ is an exogenous payment processing fee rate charged by banks. Payment processing fee is determined by the financial institutes. For example, in an NFC-SIM based system, banks are unwilling to let mobile operators keep in charge of the business and thus reflect their power on charging a high payment processing fee per transaction. On the contrary, in an NFC-HCE based system, banks charge a relatively low processing fee due to the absence of mobile operator, shortening the time to market. The platform

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profits from the registration fee of customers and transaction fee in each payment. In other words, it looks for f_{C} and r_{M} to maximize its profit u_{W}.

Throughout this study, we impose the assumption $c < p(1-b)$ to be satisfied for all b, c and p. This assures that the cost will not be greater than the profit from the system's perspective. As we normalize p to 1, this assumption means $b + c < 1$.

The sequence of events is as follows. First, the mobile payment platform decides the per transaction fee rate r_{M} and the registration fee f_{C}. Second, each potential merchant and customer observes the fees and consider his or her own willingness of adopting mobile payment and decides whether to join the platform or not independently. The sizes of the two groups will then be realized, and the platform earns its profit.

A list of notations is provided in Table 3.1.

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	Decision variables
r_{M}	Merchant's transaction fee rate charged
f_{C}	Customer's registration fee
f_{M}	Merchant's registration fee
	Parameters
n_{C}	Number of customers using mobile wallet
n_{S}	Number of merchants using mobile wallet
θ	Customer's type of willingness to use mobile wallet
η	Merchant' s type of willingness to use mobile wallet
N	Number of transactions of a customer
c	Cost of using mobile wallet
p	Average price of product
b	Payment processing fee
$h(n_{\mathrm{M}})$	Customers' perceived service quality

Table 3.1: List of decision variables and parameters

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Chapter 4

Analysis

In this chapter, we analyze the optimization problem of the mobile payment platform. In this section, we study the basic case, where $h(n_{\mathrm{M}}) = n_{\mathrm{M}}$, which represents the short-run situation faced by the platform.

4.1 Basic case

We first derive the profit function of the platform. Given r_{M} and f_{C}, (3.1), (3.2), (3.3), and $q = n_{\mathrm{M}}$ together imply that

$$f_{\mathrm{C}} = N(1 - r_{\mathrm{M}})(\theta - c) \quad \text{and} \quad \frac{Nn_{\mathrm{C}}}{n_{\mathrm{M}}}(1 - r_{\mathrm{M}} - \eta) = 0, \tag{4.1}$$

where the former and latter are for the type-θ^* customer's and type-η^* merchant's utilities to be 0, respectively. By solving the system, we get a unique solution of θ^* and η^*

$$\theta^* = \frac{f_{\mathrm{C}}}{N(1 - r_{\mathrm{M}})} + c \quad \text{and} \quad \eta^* = (1 - r_{\mathrm{M}}). \tag{4.2}$$

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Substituting θ^* and η^* into (3.4), we have the platform's profit function as

$$u_{\mathrm{W}} = \left(1 - \frac{f_{\mathrm{C}}}{N(1-r_{\mathrm{M}})} - c\right)(f_{\mathrm{C}} + N(r_{\mathrm{M}} - b)) \tag{4.3}$$

which is a maximization problem of a platform with decision variables $f_c \in \mathbb{R}$ and $r_{\mathrm{M}} \in [0,1]$. The optimal solution of this problem is characterized in Proposition 1.

Proposition 1. *The optimal registration fee and transaction fee rate are*

$$r^*_{\mathrm{M}} = \frac{1+c+b}{2+c} \quad \textit{and} \quad f^*_{\mathrm{C}} = \frac{Nc}{2+c}(b-1). \tag{4.4}$$

Moreover, for all values of b, c, and N, we have $r^*_{\mathrm{M}} > 0$ and $f^*_{\mathrm{C}} < 0$.

Proposition 1 shows that it is of the platform's best interest to adopt the "divide-and-conquer" strategy, as suggested by Caillaud and Jullien (2003), to subsidize customers and make profits from merchants. Because $f^*_{\mathrm{C}} < 0$, a customer who uses the mobile payment service, instead of paying a registration fee when joining the platform, may receive coupons or discount codes from the platform as a joining gift. With this "promotion", the customer then has more incentive to adopt the mobile payment service at the stores. In the following paragraph, this negative registration fee is termed as "subsidy" for more intuitive understanding, where $|f_{\mathrm{C}}| > 0$is the magnitude of the subsidy. On the contrary, when transactions are made, the platform charges a per transaction fee rate $r^*_{\mathrm{M}} > 0$ from the merchants to generate revenue. While increasing the per transaction fee rate r^*_{M} discourages merchants from joining the platform, the platform would also increase the subsidy to customers $|f_{\mathrm{C}}|$ to enlarge the number of customers and keep the platform being attractive to merchants. In fact, it can be shown that the platform should keep increasing r_{M} and $|f_{\mathrm{C}}|$ until all customers join the platform (cf. Proposition 3 below).

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As we observe in practice, there are several mobile payment platform operators come up with similar pricing strategies to help uptake of latest devices and increase customer acquisition and retention. Samsung's latest offer gives new Samsung Pay users 20 US dollar in gift card credit after they successfully complete their first purchase (Grush, 2016). China UnionPay gives away lucky red packets (hong bao) randomly from 6 to 666 RMB to new users (Yeshb, 2016). These evidences again support the implementation of the subsidization strategy in the mobile payment ecosystem.

We may plug in r_{M}^* and f_{C}^* back to (4.3) and obtain the platform's equilibrium profit

$$u_{\mathrm{W}}^* = \frac{1-b}{2+c}N \tag{4.5}$$

We then inspect how the parameters affect the platform's profit and the amounts of subsidy and transaction fee rate in equilibrium. The result is summarized in the next proposition and Table 4.1.

Proposition 2. *Under the platform's optimal pricing plan:*

1. *The profit of the mobile payment platform u_{W} increases as each of b, c decreases or as each of N increases.*

2. *Subsides per customer $|f_{\mathrm{C}}|$ increases as each of c, N increases or as b decreases.*

3. *Transaction fee rate r_{M} increases as b or c increases.*

In the first part of Proposition 2, it is indicated that the profit of mobile payment platform is better off when the costs of running the business are lower and customers' adoption frequency are higher. This result is intuitive as the platform operator can accordingly earn more transaction fee under a greater market size. However, when the

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	N	p	b	c
u_{W}	$\nearrow$	$\nearrow$	$\searrow$	$\searrow$
$\lvert f_{\mathrm{C}} \rvert$	$\nearrow$	$\nearrow$	$\searrow$	$\nearrow$
r_{M}	–	–	$\nearrow$	$\nearrow$

Table 4.1: Parameter comparison

banks are no longer supportive and charge higher payment processing fee, the profitability of the platform shrinks.

We then take further look into the influences of the factors to the pricing strategy. With a greater size of the market (N is larger), the mobile payment platform is more willing to give away more subsidy to customers. Moreover, when the cost of customer using mobile payment c is higher, or in other words, the user experience for adoption this payment method is lower, the amount of subsidies to customers should be consequently higher in order to motivate new users to join. Yet the platform then has to turn to the merchants and charge higher transaction fee to cover their subsidies expense.

As for higher processing fee b in each transaction, the platform will response by uprising the transaction fee rate charged from merchants. Correspondingly, only merchants with low costs will adopt the mobile payment service, and thus the platform no longer needs to subsidize those customers whose willingness to use mobile payment is low. Hence, subsidies go down as the processing fee goes up.

To further examine the impact of parameters on the user sizes of the platform in equilibrium, we substitute θ^* and η^* back into (3.3) and obtain the results in Proposition 3.

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Proposition 3. *Under the platform's optimal pricing plan:*

1. *All customers use the mobile payment service, i.e.,* $n_{\mathrm{C}} = 1$. .

2. *Some merchants do not use the mobile payment service, i.e.,* $n_{\mathrm{M}} \in [0, 1]$. *Moreover,* r_{M} *increases as* b *or* c *decreases.*

According to our analysis, the platform's optimal strategy is to incentivize all the customers to join the platform by subsidization. As the platform profits from the merchants by charging transaction fees, those merchants with high costs will be excluded from the platform.

4.2 Discussions

The results above help explain some observed examples in practice. The wireless transmission technology of proximity mobile payments can be categorized into three communication protocols: NFC-based (Near Field Communication), QR code-based, and other contactless technology such as MST-based (Magnetic Secure Transmission).

QR code method has low entry barrier compared to the others. Merchants can save cost by not having to invest in expensive equipment and adherence to restrictive rules. However, convenience brings fraudulent activities and thus the cost for customers to use the QR code method is relatively high. The NFC-based or MST-based method, on the other hand, provides a higher degree of security and allows its users to have no Internet access to make in-time transaction. Proposition 2 shows that higher customer cost c leads to a higher subsidy r_{M}, which is well observed. In Taiwan, several new mobile payment

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platform operators are introduced about the same time, but the promotions offered by QR code-based platforms are usually deeper. "GOMAJI Pay" and "All Pay" wallet, for example, give every new user 100 NT dollar that can be used all stores cooperated. Meanwhile, LINE Pay new customers can receive not only LINE Points but also limited edition LINE stickers. But other non-QR code wallet such as "T wallet" or "friDay" only offer discounts on limited stores.

In the NFC-SIM based model, payment credential is written on the SIM card and needs authorization of its SIM-card provider, the MNO, to access. That is, the mobile payment service would be controlled by the mobile operator while banks lose their negotiation privilege in this situation. Consequently, due to the unwillingness of other market player to invest the nascent market, banks tend to set a high payment processing fee to hinder the MNOs and meanwhile invest in alternative architectures within their own industry. As for the embedded SE or HCE model or QR code model, financial institutions are allowed to negotiate the relationship with handset manufacturers or the platform operator directly and equally to continue to own the responsibility over financial transactions. Their payment processing fee is thus lower. Proposition 2 again bespeak the difficulty of NFC-SIM based model to be profitable, argued also by Ozcan and Santos (2015).

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Chapter 5

Extensions

5.1 General consumption frequency

In the model of basic case, we assume the number of merchants affects the service quality and reacts upon customers' willingness-to-use the payment method. In this section, we further discuss the situation if the number of merchants also influence the numbers of transaction. That is, the more places supporting mobile payment service, the higher the frequency customers will make consumption through the mobile payment platform.

Here we denote the consumption frequency of a customer as $g(n_{\mathrm{M}})$, where the general consumption frequency factor $g(n_{\mathrm{M}})$ satisfies $g'(n_{\mathrm{M}}) > 0$ and $g''(n_{\mathrm{M}}) < 0$, i.e., increasing the number of merchants will bring in additional transactions, but the marginal addition decreases. Under the new setting, a type-θ consumer's utility in a membership period is thus

$$u_{\mathrm{C}} = Ng(n_{\mathrm{M}})(1 - r_{\mathrm{M}})(\theta - c) - f_{\mathrm{C}}. \tag{5.1}$$

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With merchant's utility function remains as (3.2), we solve the system and get a unique solution of θ^* and η^*

$$\theta^* = \frac{f_{\mathrm{C}}}{Ng(1-r_{\mathrm{M}})(1-r_{\mathrm{M}})} + c \quad \text{and} \quad \eta^* = 1 - r_{\mathrm{M}}. \tag{5.2}$$

The platform's objective function can then be formulated as

$$u_{\mathrm{W}} = \left(1 - \frac{f_{\mathrm{C}}}{Ng(1-r_{\mathrm{M}})(1-r_{\mathrm{M}})} - c\right)\left(f_{\mathrm{C}} + Ng(1-r_{\mathrm{M}})(r_{\mathrm{M}} - b)\right), \tag{5.3}$$

which is a maximization problem of a platform with decision variables $f_c \in \mathbb{R}$ and $r_{\mathrm{M}} \in [0, 1]$. We follow the same solving procedures and re-examine our optimal pricing strategy in basic case.

Proposition 4. *When a consumer's consumption frequency depends on the number of merchants joining the platform, the platform's optimal strategy is still to increase* r_{M} *until* $n_{\mathrm{C}} = 1$.

Proposition 4 shows that all previous propositions remain valid under a rational general consumption function. For the mobile payment platform, it is still the best strategy to incentivize all the customers by subsidization and profit from the merchants by charging transaction fees.

5.2 Service quality

In this section, we generalize the service quality to $h(n_{\mathrm{M}})$, where $h(n_{\mathrm{M}})$ is a general increasing and concave function. The platform's objective function can then be formulated as

$$u_{\mathrm{W}} = \left(1 - \frac{f_{\mathrm{C}}}{Nh(1-r_{\mathrm{M}})} - c\right)(f_{\mathrm{C}} + N(r_{\mathrm{M}} - b)). \tag{5.4}$$

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Through a derivation similar to that in the short run, we have the optimal amount of registration fee $f_{\mathrm{C}} = \frac{N}{2}((1-c)h(n_{\mathrm{M}}) - (r_{\mathrm{M}} - b))$. The first-order derivative of u_{W} with respect to the transaction fee rate r_{M} under the optimal way of charging the registration fee (or giving out subsidies) is thus

$$\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} = \frac{N}{4(1-h(n_{\mathrm{M}})^2)} H(r_{\mathrm{M}}), \tag{5.5}$$

where

$$H(r_{\mathrm{M}}) = \Big((1-c)h(n_{\mathrm{M}}) + (r_{\mathrm{M}} - b)\Big)\Big(2h(n_{\mathrm{M}}) - h'(n_{\mathrm{M}})((r_{\mathrm{M}} - b) - (1-c)h(n_{\mathrm{M}}))\Big).$$

In this case, $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} > 0$ is not always true. Therefore, we are interested in understanding when the optimal strategy in the short run, i.e., offering subsidies to include all customers and profit from merchant by setting the highest possible r_{M}, can still be applied. In particular, we are curious about how the shape of H affects the optimality of such a strategy.

To conduct an investigation, we set $h(n_{\mathrm{M}}) = n_{\mathrm{M}}^t$, where $0 < t \leq 1$, in the sequel. We first conduct numerical experiments to see whether $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} > 0$ is true for all $r_{\mathrm{M}} \in [0,1]$ under each parameter combination. The results of our experiments are illustrated below in Figure 5.1.

For each of four different values of $t \in \{0.05, 0.1, 0.2, 0.3\}$, we draw a curve that separate the reasonable parameter region (under the line $b+c=1$ due to our assumption $b+c<1$) into two parts. To the left of the curve, we have $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} > 0$; to the right of it, we do not. It can be easily observed that the region of $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} > 0$ enlarges as t increases. In other words, the strategy optimal in the short run is more likely to remain optimal in

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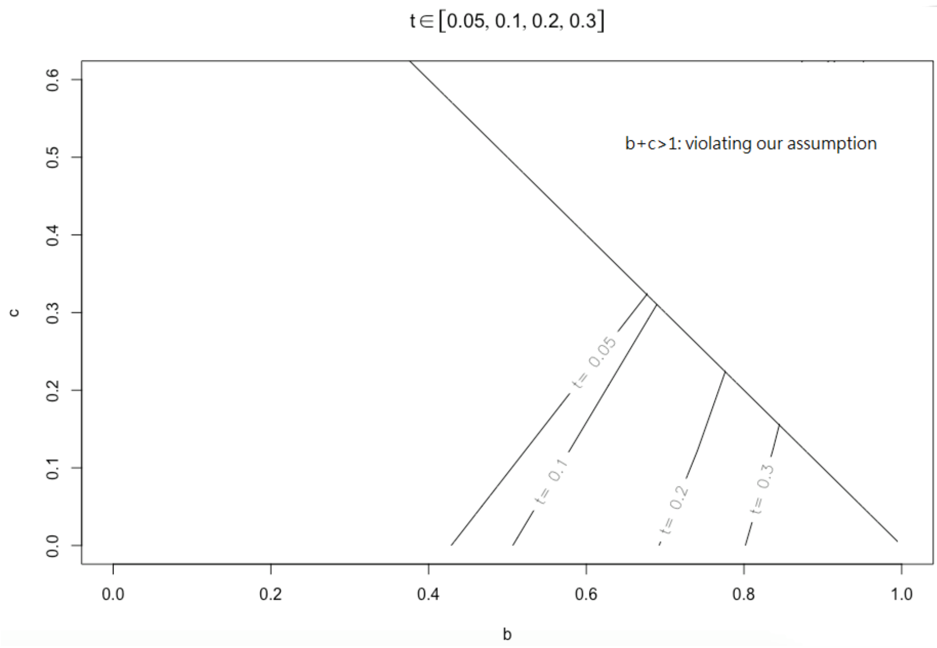

Figure 5.1: Impact of the service quality function

the long run when t is close to 1, i.e., when H is "not too concave." This is trivial, as in that case the situation is close enough to the short run. It can also be observed that the strategy is more likely to be optimal if b is small and c is large. We analytically confirm these observations in the following proposition.

Proposition 5. *For all $t \in (0, 1]$, there exists a cut-off value $\hat{b}(t)$ such that for all $b < \hat{b}(t)$, there exists another cut-off value $\hat{c}(t, b) \in (0, 1)$ such that for all $c > \hat{c}(t, b)$, $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} > 0$ is true for all r_{M} within 0 and 1.*

Proposition 5 indicates that as long as the payment processing fee b is small enough, and the customer's marginal cost c is large enough, we have $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} > 0$ for all $r_{\mathrm{M}} \in [0, 1]$. To understand this, note that if the bank is not charging a too high processing fee, it is easier for the mobile payment platform to profit from the merchants. Moreover, if the

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marginal cost for the customers to use the platform is high, the subsidization strategy for customers will be more needed to incentivize the customers to join the problem. In either case, the original strategy retains its advantages and remains optimal.

5.3 Customer-side transaction fee

In previous sections, we investigate the platform's profitability with a consideration of subsidizing customers with f_{C} and charging merchants per transaction fee r_{M} under short-run and long-run business. In this section, we further consider the possibility of charging customers per transaction fee r_{C}, which can either be positive or negative. Previous sections can be taken as special cases with $r_{\mathrm{C}} = 0$. Pricing strategies contribute to the level of price sensitivity in the market. As customers now sense of being charged during every transaction, it is nature that the number of transactions of a customer N is influenced by the transaction fee. We change N to $N(r_{\mathrm{C}})$ to emphasize the effect, where $N(r_{\mathrm{C}}) \geq 0$ and $N'(r_{\mathrm{C}}) < 0$. When customers are charged more $r_{\mathrm{C}} > 0$, customers will be unhappy and thus $N(r_{\mathrm{C}})$ may be lower. On the contrary, when r_{C} are even more negative, $N(r_{\mathrm{C}})$ is higher as customers are subsidized and encouraged to make more purchases.

5.3.1 Optimal customer-side transaction fee

We reformulate a type-θ consumer's utility in a membership period as

$$u_{\mathrm{C}} = N(r_{\mathrm{C}})(\theta - c - r_{\mathrm{C}}) - f_{\mathrm{C}}. \tag{5.6}$$

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By solving the system, we get a unique solution of θ^*

$$\theta^* = \frac{f_{\mathrm{C}}}{N(r_{\mathrm{C}})(1-r_{\mathrm{M}})} + c + r_{\mathrm{C}} \tag{5.7}$$

With r_{C} as a new source of revenue, platform's maximization problem becomes

$$u_{\mathrm{W}} = n_{\mathrm{C}} f_{\mathrm{C}} + N(r_{\mathrm{C}}) n_{\mathrm{C}} (r_{\mathrm{M}} + r_{\mathrm{C}} - b). \tag{5.8}$$

By substituting θ^* and η^* into (3.3) and (5.8), the platform's maximization problem can be formulated as

$$u_{\mathrm{W}} = \left(1 - \frac{f_{\mathrm{C}}}{N(r_{\mathrm{C}})(1-r_{\mathrm{M}}))} - c - r_{\mathrm{C}}\right)\left(f_{\mathrm{C}} + N(r_{\mathrm{C}})(r_{\mathrm{M}} + r_{\mathrm{C}} - b)\right). \tag{5.9}$$

Therefore, after a mobile payment platform chooses its technical solution, it is a maximization problem of a platform with f_{C}, r_{M}, and r_{C}.

Since $N'(r_{\mathrm{C}}) < 0$, we have $\bar{r}_{\mathrm{C}}$ as the upper bound of r_{C}, which is subject to $N(\bar{r}_{\mathrm{C}}) = 0$. On the other hand, $\underline{r}_{\mathrm{C}}$ is denoted as the lower bound of r_{C}. The exact number of $\underline{r}_{\mathrm{C}}$ is not discussed in our model, but it is certain that this number is bounded in reality. Otherwise, high subsidization in every transaction may cause cash flow burden for the payment platform. In another aspect, customers are risk averse and unwilling to pay a too high membership fee in advance, even though they know they will be well subsidized afterwards. Thus in this paper, we only discuss $|r_{\mathrm{C}}|$ within a rational range.

The optimal pricing and subsidization plan of the platform critically depends on the value of r_{C}. To describe the optimal plan, we divide the set of possible values of r_{C} into two intervals: interval A with $r_C \geq \frac{(1-c-b)^2(2+c)-4+4b}{4-(1-b-c)^2}$ and interval B with $r_{\mathrm{C}} < \frac{(1-c-b)^2(2+c)-4+4b}{4-(1-b-c)^2}$. Note that $\frac{(1-c-b)^2(2+c)-4+4b}{4-(1-b-c)^2} < 0$, and thus in interval B all $r_{\mathrm{C}} < 0$. The optimal plans over the two intervals are summarized in Proposition 6 and 7.

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Proposition 6. *For r_{C} in interval A, the optimal registration fee and platform utility are*

$$\begin{aligned} r^*_{\mathrm{M}}(r_{\mathrm{C}}) &= \frac{1+b+c}{2+c+r_{\mathrm{C}}} > 0 \\ f^*_{\mathrm{C}} &= \frac{-N(r_{\mathrm{C}})}{2+c+r_{\mathrm{C}}}(c+r_{\mathrm{C}})(1-b+r_{\mathrm{C}}) \\ u_{\mathrm{W}} &= \frac{1+r_{\mathrm{C}}-b}{2+c+r_{\mathrm{C}}}N(r_{\mathrm{C}}) \end{aligned} \tag{5.10}$$

Notice that when $r_{\mathrm{C}} = 0$, Proposition 6 will be the same as Proposition 1. In interval A, r^*_{M} is positively charged for all feasible r_{C}. This shows that our optimal strategy to charge merchants in previous sections can still be applied. However, the positivity of r^*_{C} and f^*_{C} is impacted by $N(r_{\mathrm{C}})$, and yet need further discussion. But it is already obvious that $r_{\mathrm{C}} = 0$ may not be optimal, and thus confirms our intuition to add customer-side transaction fee into the model.

Proposition 7. *For r_{C} in interval B, the optimal registration fee and platform utility are*

$$\begin{aligned} r^*_{\mathrm{M}}(r_{\mathrm{C}}) &= 0 \\ f^*_{\mathrm{C}} &= \frac{N(r_{\mathrm{C}})}{2}(1+b-c-2r_{\mathrm{C}}) \geq 0 \\ u_{\mathrm{W}} &= \frac{N(r_{\mathrm{C}})}{4}(1-b-c)^2. \end{aligned} \tag{5.11}$$

Since $N(r_{\mathrm{C}})$ decreases in r_{C}, local maximum of u_{W} locates in the lower bound of r_{C}. This shows that the best strategy is to set r_{C} as low as we can, which implies that customers are highly subsidize under every transaction. And with f_{C} increases in $|r_{\mathrm{C}}|$, mobile payment platform profits from collecting customer membership fee. The more the platform charges in membership fee, the more it subsidizes back to customers in every transaction.

So far, we have found the local optimal strategy in interval A and B. Overall by

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comparing the two plans, we can find a global optimal strategy. Under different settings of b, c, N, and k, a global optimal value of u_{W} may appear in either interval. That is, when a type of mobile payment technology is chosen to be adopted, the mobile payment platform has its corresponding business pricing plan.

As a function of r_{C}, the shape of u_{W} varies with the shape of $N(r_{\mathrm{C}})$. To better observe the effect of adding r_{C} into the model, we numerically examine the cases where $N(r_{\mathrm{C}})$ is a linear function of r_{C} and $N(r_{\mathrm{C}})$ is a non-linear function of r_{C}: (**Case L**) $N(r_{\mathrm{C}}) = N - kr_{\mathrm{C}}$, and (**Case N**) $N(r_{\mathrm{C}}) = N - k\dfrac{e^{r_{\mathrm{C}}}}{1+e^{r_{\mathrm{C}}}}$.

Case L. We first investigate the result under the setting $N(r_{\mathrm{C}}) = N - kr_{\mathrm{C}}$.

For r_{C} in interval A, $\frac{\partial^2 u_{\mathrm{W}}}{\partial r_{\mathrm{C}}^2} \le 0$. The utility of platform is concave in r_{C}, and thus we can find r_{C}^* subject to $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{C}}}(r_{\mathrm{C}}^*) = 0$. Also the boundaries are $\bar{r}_{\mathrm{C}} = \frac{a}{k}$ and $\underline{r}_{\mathrm{C}} = b-1$.

The interval A local equilibrium results are characterized as follows.

$$\begin{aligned} r_{\mathrm{C}}^* &= -2-c+\sqrt{\frac{1+b+c}{k}\Big(k(2+c)+N\Big)}, \quad r_{\mathrm{M}}^* = \frac{1+b+c}{2+c+r_{\mathrm{C}}^*} \ge 0, \\ f_{\mathrm{C}}^* &= \frac{-N+kr_{\mathrm{C}}^*}{2+c+r_{\mathrm{C}}^*}(c+r_{\mathrm{C}}^*)(1-b+r_{\mathrm{C}}^*), \text{ and } \quad u_{\mathrm{W}}^* = \frac{1+r_{\mathrm{C}}^*-b}{2+c+r_{\mathrm{C}}^*}(a-kr_{\mathrm{C}}^*). \end{aligned} \tag{5.12}$$

For r_{C} in interval B, we have

$$\begin{aligned} r_{\mathrm{C}}^* &= b-1<0, \quad r_{\mathrm{M}}^* = 0, \\ f_{\mathrm{C}}^* &= \frac{N-k(b-1)}{2}(3-b-c) \ge 0, \text{ and } \quad u_{\mathrm{W}}^* = \frac{N-k(b-1)}{4}(1-b-c)^2. \end{aligned} \tag{5.13}$$

Figure 5.2, 5.3, and 5.4 are provided to demonstrate u_{W} within feasible r_{C} range under 3 different sets of b, c, N, and k.

In all three cases, r_{C}^* (the optimal value of r_{C}) does not satisfy in $r_{\mathrm{C}} = 0$. This fact verifies the need to consider the customer-side transaction fee when designing a business model. The platform can gain more profits leveraging more revenue sources. However,

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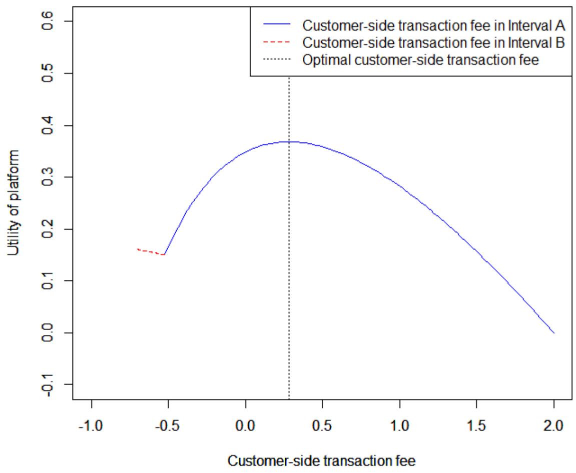

Figure 5.2: Case L-1

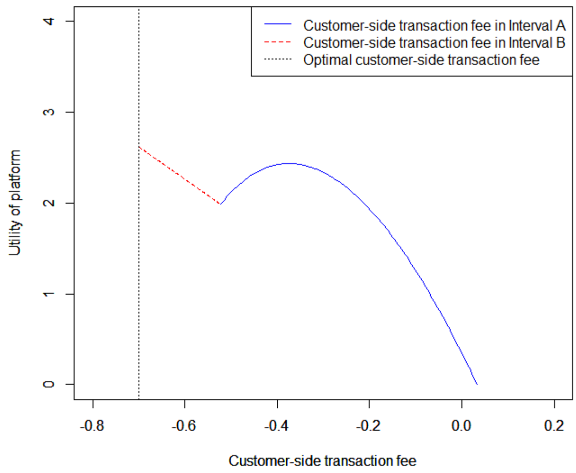

Figure 5.3: Case L-2

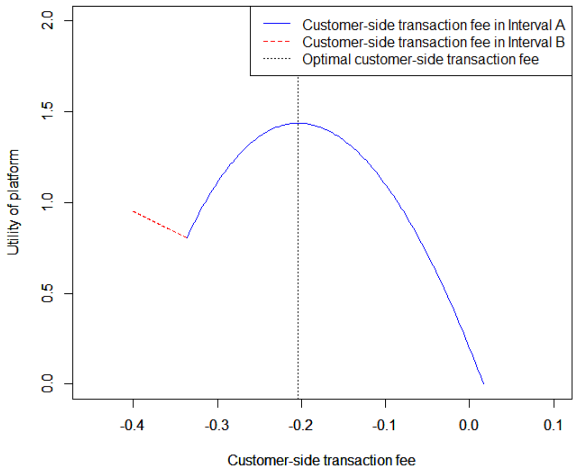

Figure 5.4: Case L-3

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r_{C}^{*} can be positive or negative depending on cases.

In Case L-1, r_{C}^{*} is positive and lies in interval A. The corresponding $r_{\mathrm{M}}^{*} > 0$ and $f_{\mathrm{C}}^{*} < 0$. This represents a model that subsidizes all customers a fixed amount of money to join the platform and then charges a small portion of transaction fee from both customers and merchants. Only merchants with high needs of mobile payment with join the platform. This type of optimal model appears when $\frac{k}{N}$ is relatively small and b is large. That is, when customers are less price-sensitive during each payment, or the platform is optimistic at the potential total transaction amount, it is a good strategy for the platform to give customers some incentives to try out new payment method, and look forward to profit in long-term future. Especially when the banks or other players are charging high payment processing fee, it is inevitable to charge per transaction fee.

When $\frac{k}{N}$ is relatively large, customers are sensitive to price and therefore optimal models are similar to Case L-2 or L-3. In Case L-2, r_{C}^{*} is negative and in interval B. The corresponding $r_{\mathrm{M}}^{*} = 0$ and $f_{\mathrm{C}}^{*} > 0$. This model shows that customers should pay membership to join platform and then enjoy discounts during every transaction. Merchants are not charged and therefore all merchants will join in. In case L-3, r_{C}^{*} is negative but in interval A. Meanwhile, $r_{\mathrm{M}}^{*} > 0$ and $f_{\mathrm{C}}^{*} > 0$. Similar to Case L-2, customers pay in advance to enjoy future discount. But the platform now charges the merchants per transaction fee, and thus only high type of merchants will join the platform.

Compared to Case L-2, Case L-3 fits the scenarios where b is relatively large. Due to high payment processing fee burden from the banks, the mobile payment platform is in needs of per transaction revenue. Therefore, r_{M}^{*} is positive.

Case N.

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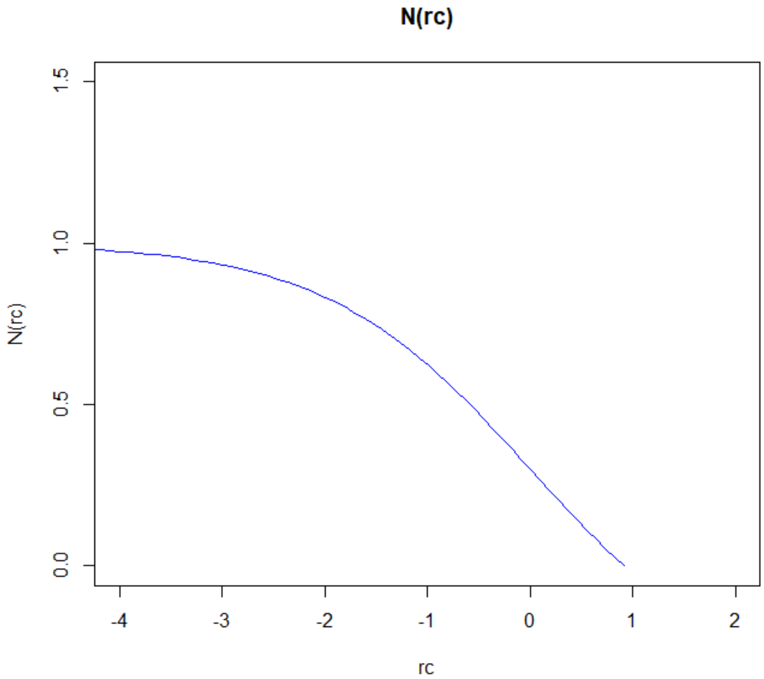

Figure 5.5: $N(r_{\mathrm{C}}) = N - k\dfrac{e^{r_{\mathrm{C}}}}{1+e^{r_{\mathrm{C}}}}$

Here we examine our model when $N(r_{\mathrm{C}})$ is a nonlinear function of r_{C}. Assume $N(r_{\mathrm{C}}) = N - k\dfrac{e^{r_{\mathrm{C}}}}{1+e^{r_{\mathrm{C}}}}$, which is represented as Figure 5.5. The followed boundaries are $\bar{r}_{\mathrm{C}} = \ln(\frac{a}{k-a})$ and $\underline{r}_{\mathrm{C}} = b - 1$.

Figure 5.6, 5.7, and 5.8 are provided to demonstrate u_{W} within the feasible r_{C} range under three different sets of b, c, N, and k.

The pricing model in Case N-1 is similar to that of Case L-1. When b is large and $\frac{k}{N}$ small, it is feasible to charge insensitive customer transaction fee. But when customers are price sensitive, like Case N-2 and N-3, platform should subsidize customers in every transaction.

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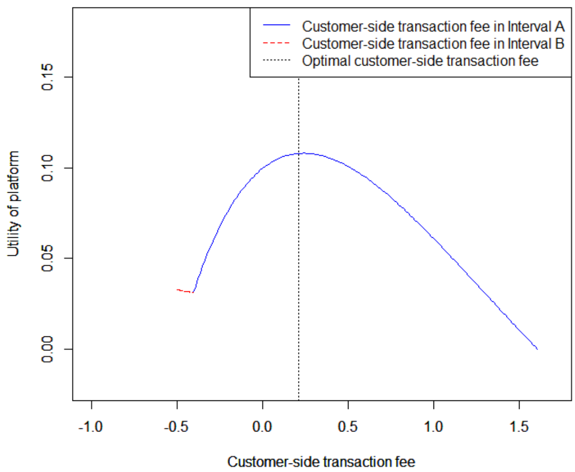

Figure 5.6: Case N-1

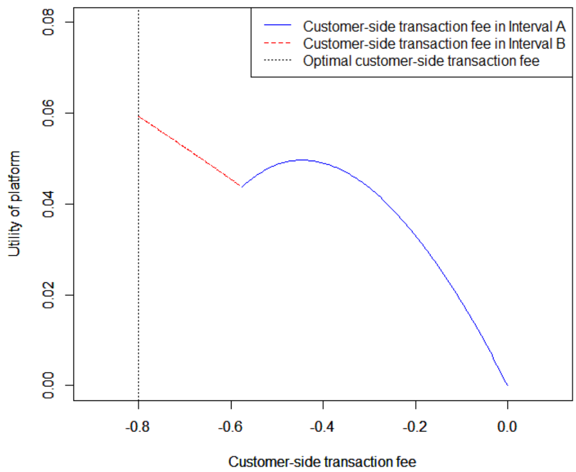

Figure 5.7: Case N-2

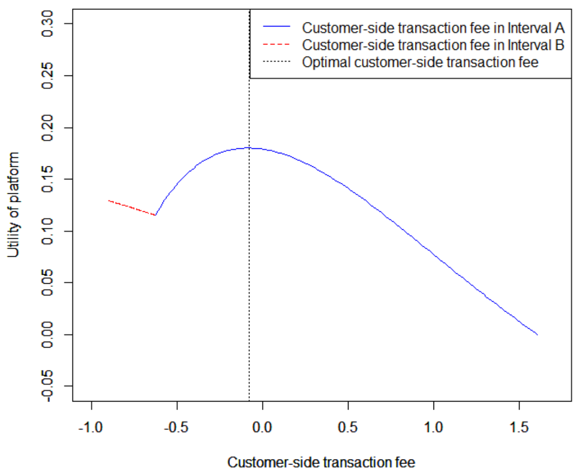

Figure 5.8: Case N-3

5.3.2 Discussions

The platform seems to charge both customers and merchants during every transaction. However, if $f_C > 0$ and $|f_C|$ are proved greater then $N(r_C)r_C$, we can still take this strategy as a kind of customer-side subsidization method. To investigate that, the following

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calculation are taken.

$$|f_{\mathrm{C}}| - N(r_{\mathrm{C}})r_{\mathrm{C}} = \frac{N(r_{\mathrm{C}})}{2 + c + r_{\mathrm{C}}}(c - r_{\mathrm{C}} - bc - br_{\mathrm{C}}) \tag{5.14}$$

In (5.14), if b decreases, $|f_{\mathrm{C}}| - N(r_{\mathrm{C}})r_{\mathrm{C}}$ increases and is more likely to be positive. This implies that the lower the bank charged, the platform are more flexible to adjust its pricing toward merchants instead of pursuing per transaction revenue. Therefore, the platform is more willing to apply subsidization strategy toward customers, as we can see in Case L-2 and N-2.

Through the three cases, we can also observe that r_{C} and f_{C} are in general having the opposite signs. That is, it is optimal for the platform to run the subsidization strategy, but the subsidization will not cover whole customers' membership period. "There is no such thing as a free lunch." Customers either pay registration fee first to enjoy discounts or enjoy fixed amount subsidization first and pay transaction fee.

In the current mobile payment industry, most platforms run business similar to Case L-3/N-3 approach. Customers enjoy a various of transaction discounts, while merchants pay transaction fee to payment platforms and platforms pay processing fee to banks. However, the customer registration fee is averagely close to zero. Only some NFC-based platforms, for example Hami wallet, will charge customer NT$100 to turn on the service.

The reason Case L-1 and N-1 are not in practice is due to high price sensitivity of customers. In Case L-1 and N-1, customers receive only fixed subsidization when they first join the platform. For sensitive customers these are only short-term attraction, but they are used to not paying full price when adopting mobile payment method. When benefits are used up, customers have lower incentives to continue to use the platform and

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may turn to other payment method. Therefore, subsidizing customers in each transaction can be a technique to intrigue the party in long-term business.

Moreover, Case L-2 and N-2 are in fact impractical as we consider customers' behaviours. Under those cases, customers have to pay high registration fee to join the platform so that they can receive discount in the future. It is difficult for a new platform platform to persuade its customers to "invest" a large amount of money to try the service. Case L-3/N-3 is comparably practical since merchants are paying transaction fee to payment platforms, and thus customers' registration fee amount can be less or even zero.

5.4 System installation cost

So far, we have ignored the existence of system installation cost at the merchants. In real world cases, mobile payment platforms usually provide free set-up service to every merchant, which can be offering hardware such as POS device or human resources such as staff training before adopting new payment method. The system installation cost is considered as an investment to run mobile payment platform. It also signals the promising potential of new payment method to the merchants, and encourages them to join in the new system. We may also consider it as merchant-side subsidization.

As we mentioned in the first section, different mobile payment techniques lead to different system installation cost. For example, QR code-based are easy, fast and cost-saving. As long as the merchants own basic mobile devices, they can kick off a new payment business. NFC-based, however, is restricted to physical POS device, which is relatively expensive and difficult to set up.

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To explore the effect of system installation cost, we assume $s > 0$ is a system installation cost paid by the platform to include one merchant. Hence, the mobile payment platform's problem is extended to

$$u_{\mathrm{W}} = n_{\mathrm{C}} f_{\mathrm{C}} + N n_{\mathrm{C}}(r_{\mathrm{M}} - b) + n_{\mathrm{M}}(-s). \tag{5.15}$$

With all other settings remain the same, we adopt the same steps in previous section and obtain the following proposition.

Proposition 8. *Under the platform's optimal pricing plan:*

1. *For all values of $s \in [0, N]$, Proposition 1, 2, and 3 all hold.*

2. *When $s > N$, the mobile payment service will leave the market.*

3. *The profit of the mobile payment platform*

$$u_{\mathrm{W}}^{*} = \frac{1-b}{2+c}(N - s) \tag{5.16}$$

increases as s decreases.

Proposition 8 shows that even merchants are subsidized to join the platform, customer subsidization is still considered an optimal strategy. Therefore, when the merchant-side subsidization is an inevitable method to attract new comers, the mobile payment platform can always find an optimal contract to profit in the long-term business. However, if the system installation cost is high, the expense directly reflects on the mobile payment platform's profit. It then becomes a huge burden for the platform. To the best of the platform, corresponding quality control among merchants is suggested to be taken. When system installation cost is too high($s > N$), the mobile payment service is not profitable and the platform should leave the market.

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This also indicates that the difficulty to start a mobile payment platform with high installation cost (when s is large). High investment to both customer-side and merchant-side is predictable and reasonable. But the bright side is s will eventually be lower, and if the platform continues to be competitive in the market, the number of transaction N in the future will be higher. The platform can thus look forward to a promising business.

In practice, NFC-based model has relatively high system installation cost. Mobile payment platforms adopting NFC-based model are usually those with high capability to support high investment. That is, large firms are better-off. Smaller firms usually prefer QR code-based model, which has low entry barrier compared to the others. Merchants can save cost by not having to invest in expensive equipment and adherence to restrictive rules. In Taiwan, NFC-based players in current mobile payment market are Apple, Samsung, Google, and local telecoms, while QR code-based players are mostly e-commerce companies, which are relatively small companies.

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Chapter 6

Conclusions and future works

6.1 Conclusions

Leveraging the emergent mobile payment technology, we present a game-theoretic model featuring network externality to study a mobile payment platform's pricing strategy. In the basic case, we find the platform will have incentives to apply the "divide and conquer" strategy at the beginning of the business. Customers are subsidized to adopt the mobile payment service, and then merchants will be attracted to join the platform due to the positive cross-side network externality. After the ignition, the platform then becomes profitable by charging per transaction fees from the merchants. With different technologies adopted, the implementation of this pricing strategy alters a little but is still in the same direction. The results are verified by current practices in mobile payment industries.

We also consider some extensions to verify the robustness of our model. The follow-

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ing elements is taken into account: First, when consumption frequency factor is taken into consideration, which means number of merchants affects customers consumption frequency, we still find it optimal to apply the "divide and conquer" strategy. Second, in the long run, where we generalize the influence of number of merchants to platform quality, the same cross subsidization strategy is suggested to be applied when the bank is not taking a too high processing fee, customers do not have a too high marginal cost of using the service, and the marginal consumption frequency does not increase slowly in the number of merchants. Third, if the mobile payment platform considers customer-side transaction fee as a new revenue source, it can enhance its profitability. With different mobile payment technologies adopted, the optimal cross subsidization strategy may be to subsidize the merchants rather than customers. In last extension, we take system installation cost into account. The result shows that even merchants are subsidized to join the platform, customer subsidization is still considered an optimal strategy. We hope these findings can provide a step forward of method to identify this new and promising market.

6.2 Future works

Our study certainly has its limitations. First, it will be interesting to consider customer's heterogeneity in the numbers of transactions made through mobile payment. The subsidization strategy may need be to tailored for different types of customers. Second, since the role played by banks may affect more than payment processing fee, their strategic decisions should also be taken into consideration. We also have not considered how com-

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petition among multiple wallet platforms may change the equilibrium. These extensions of our study call for future investigation.

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Appendix A

Proofs of lemmas and propositions

Proof of Proposition 1. The derivative of (4.3) with respect to f_{C} can be deduced as

$$\frac{\partial u_{\mathrm{W}}}{\partial f_{\mathrm{C}}} = -\frac{2f_{\mathrm{C}}}{N(1-r_{\mathrm{M}})} - \frac{r_{\mathrm{M}}-b}{1-r_{\mathrm{M}}} + 1 - c, \tag{A.1}$$

which implies that an optimal solution must satisfy $\frac{\partial u_{\mathrm{W}}}{\partial f_{\mathrm{C}}} = 0$, i.e., $f_{\mathrm{C}} = \frac{N}{2}(1 - 2r_{\mathrm{M}} - c + r_{\mathrm{M}}c + b)$. We substitute (A.1) into (4.3) and then differentiate it with respect to r_{M} to obtain $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} = \frac{N}{4(1-r_{\mathrm{M}})^2}(1 - c + r_{\mathrm{M}}c - b)(1 + c - r_{\mathrm{M}}c - b)$. As $b + c < 1$, $\frac{\partial u_{\mathrm{M}}}{\partial r_{\mathrm{M}}} > 0$ is always true, which implies that r_{M} should to be set as large as it can reach. We know $n_{\mathrm{C}} = 1 - \theta^* = 1 - c - \frac{f_{\mathrm{C}}}{N(1-r_{\mathrm{M}})}$, which can be expressed as $n_C = 1 - c - \frac{1-2r_{\mathrm{M}}-c+r_{\mathrm{M}}c+b}{2(1-r_{\mathrm{M}})}$ after we replace f_{C} by $\frac{N}{2}(1-2r_{\mathrm{M}}-c+r_{\mathrm{M}}c+b)$. As n_{C} is bounded above by 1, we obtain $r^*_{\mathrm{M}} = \frac{1+c+b}{2+b}$ as the maximum possible value. It can be easily verified that $0 \leq r_{\mathrm{M}} \leq 1$. Therefore, our optimal pricing strategy will be $r^*_{\mathrm{M}} = \frac{1+c+b}{2+b}$ and $f^*_{\mathrm{C}} = \frac{Nc}{2+c}(b-1)$. □

Proof of Proposition 2. To prove this proposition, all we need is to look at the sign of the first derivatives of r_{M}, $|f_{\mathrm{C}}|$ and u_{W} with respect to each parameters. While almost all the signs of the first derivatives can be found trivially through direct observations,

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here we investigate only r_{M} with respect to b and $|f_{\mathrm{C}}|$ with respect to c. First, we have $\frac{\partial r_{\mathrm{M}}}{\partial b} = \frac{1-c}{(2+b)^2} > 0$; second, we have $\frac{\partial |f_{\mathrm{C}}|}{\partial c} = \frac{2(1-b)}{(2+b)^2} > 0$. This completes the proof. □

Proof of Proposition 3. We plug in f_{C}^* and r_{M}^* into (4.2), and obtain $n_{\mathrm{C}} = (1-\theta^*) = \frac{1}{2}(1 - c + \frac{(1+c+b)-(2+c)b}{1-b}) = 1$ and $n_{\mathrm{M}} = \eta^* = \frac{1-b}{2+c} \in (0,1)$. □

Proof of Proposition 4. The derivative of (5.3) with respect to f_{C} can be deduced as $\frac{\partial u_{\mathrm{W}}}{\partial f_{\mathrm{C}}} = -\frac{2f_{\mathrm{C}}}{Ng(1-r_{\mathrm{M}})(1-r_{\mathrm{M}})} - \frac{r_{\mathrm{M}}-b}{1-r_{\mathrm{M}}} + 1 - c$, which implies that an optimal solution must satisfy $\frac{\partial u_{\mathrm{W}}}{\partial f_{\mathrm{C}}} = 0$, i.e., $f_{\mathrm{C}} = \frac{Ng(1-r_{\mathrm{M}})}{2}(1 - 2r_{\mathrm{M}} - c + r_{\mathrm{M}}c + b)$. We substitute (A.1) into (4.3) and then differentiate it with respect to r_{M} to obtain

$$\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} = \frac{N}{16(1-r_{\mathrm{M}})^2}\Big(4(1-r_{\mathrm{M}})L(r_M) + Ng(1-r_{\mathrm{M}})K(r_{\mathrm{M}})^2\Big),$$

where $K(r_{\mathrm{M}}) = 1 - c + r_{\mathrm{M}}c - b$ and $L(r_M) = g'(1-r_{\mathrm{M}})(K(r_{\mathrm{M}}) - 2r_{\mathrm{M}}c)^2 + 2cg(1-r_{\mathrm{M}})K(r_{\mathrm{M}})$. As $b + c < 1$, $\frac{\partial u_{\mathrm{M}}}{\partial r_{\mathrm{M}}} > 0$ is always true, which implies that r_{M} should to be set as large as it can reach. □

Proof of Proposition 5. To examine $H(r_{\mathrm{M}})$ in (5.5) is positive when c is sufficiently large and b is sufficiently small, we put $c = 1$ and $b = 0$ into (5.5) to obtain $H(r_{\mathrm{M}}) = r_{\mathrm{M}}\Big(2h(n_{\mathrm{M}}) + r_{\mathrm{M}}h'(n_{\mathrm{M}})\Big) > 0$, which is positive for all $r_{\mathrm{M}} \in [0,1]$. We may then prove that $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} > 0$. □

Proof of Proposition 6. Similar to how we derive proposition (5.5), we have

$$f_{\mathrm{C}}^* = \frac{N(r_{\mathrm{C}})}{2}\Big(-r_{\mathrm{M}} - r_{\mathrm{C}} + b + (1-r_{\mathrm{M}})(1-c-r_{\mathrm{C}})\Big) \text{ and}$$
$$u_{\mathrm{W}} = \frac{N(r_{\mathrm{C}})}{4(1-r_{\mathrm{M}})}\Big((1-c-r_{\mathrm{C}})(1-r_{\mathrm{M}}) + r_{\mathrm{M}} + r_{\mathrm{C}} - b\Big)^2.$$

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Moreover, we have

$$\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{C}}} = \frac{1}{(2+c+r_{\mathrm{C}})^2}, \Big((1+b+c)N(r_{\mathrm{C}}) + N'(r_{\mathrm{C}})(1+r_{\mathrm{C}}-b)(2+c+r_{\mathrm{C}})\Big)$$
$$\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} = \frac{N(r_{\mathrm{C}})}{4(1-r_{\mathrm{M}})^2}\Big((r_{\mathrm{C}}+c)r_{\mathrm{M}} - c - b + 1\Big)\Big((r_{\mathrm{C}}+c)r_{\mathrm{M}} - 2r_{\mathrm{C}} - c + b - 1\Big), \text{ and}$$
$$\frac{\partial^2 u_{\mathrm{W}}}{\partial r_{\mathrm{M}}^2} = \frac{N(r_{\mathrm{C}})}{2(1-r_{\mathrm{M}})^3}(1-b+r_{\mathrm{C}})^2 \geq 0.$$

With $\frac{\partial^2 u_{\mathrm{W}}}{\partial r_{\mathrm{M}}^2} \geq 0$, u_{W} as the function of r_{M} is proved to be convex. That is, for a certain r_{C}, the maximum value of u_{W} will appear in endpoints, either $r_{\mathrm{M}} = 0$ or $r_{\mathrm{M}} = \frac{1+b+c}{2+c+r_{\mathrm{C}}}$. By plugging these two values of r_{M} into u_{W}, we obtain

$$u_{\mathrm{W}}(0) = N(r_{\mathrm{C}})\frac{(1-c-b)^2}{4} \quad \text{and} \quad u_{\mathrm{W}}\left(\frac{1+b+c}{2+c+r_{\mathrm{C}}}\right) = N(r_{\mathrm{C}})\frac{1+r_{\mathrm{C}}-b}{2+c+r_{\mathrm{C}}}$$

We then have $u_{\mathrm{W}}(\frac{1+b+c}{2+c+r_{\mathrm{C}}}) - u_{\mathrm{W}}(0) > 0$ if and only if $r_{\mathrm{C}} \geq \frac{(1-c-b)^2(2+c)-4+4b}{4-(1-b-c)^2}$. The associated value of f_{C} can be found by plugging the optimal r_{M} into f_{C}. □

Proof of Proposition 7 The proof is basically the same as that of Proposition 6 and is thus omitted. □

Proof of Proposition 8. The derivative of 4.3 with respect to f_{C} is

$$\frac{\partial u_{\mathrm{W}}}{\partial f_{\mathrm{C}}} = -\frac{2f_{\mathrm{C}}}{N(1-r_{\mathrm{M}})} - \frac{r_{\mathrm{M}}-b}{1-r_{\mathrm{M}}} + 1 - c, \tag{A.2}$$

which implies that an optimal solution must satisfy $\frac{\partial u_{\mathrm{W}}}{\partial f_{\mathrm{C}}} = 0$, i.e., $f_{\mathrm{C}} = \frac{N}{2}(1 - 2r_{\mathrm{M}} - c + r_{\mathrm{M}}c + b)$. Then we substitute (A.3) into (5.15) and then differentiate it with respect to r_{M} to obtain $\frac{\partial u_{\mathrm{W}}}{\partial r_{\mathrm{M}}} = s + \frac{N}{4(1-r_{\mathrm{M}})^2}(1-c+r_{\mathrm{M}}c-b)(1+c-r_{\mathrm{M}}c-b)$. As $b+c<1$, $\frac{\partial u_{\mathrm{M}}}{\partial r_{\mathrm{M}}} > 0$ is always true, which implies that r_{M} should to be set as large as it can reach. As we replace f_{C} by $\frac{N}{2}(1-2r_{\mathrm{M}}-c+r_{\mathrm{M}}c+b)$ and plug it into n_{C}, we obtain $n_{\mathrm{C}} = 1 - c - \frac{1-2r_{\mathrm{M}}-c+r_{\mathrm{M}}c+b}{2(1-r_{\mathrm{M}})}$. Since n_{C} is bounded above by 1, $r_{\mathrm{M}}^* = \frac{1+c+b}{2+b}$ is found as the maximum possible value. It can be easily verified that $0 \leq r_{\mathrm{M}} \leq 1$. Therefore, our optimal pricing strategy will be

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$r_{\mathrm{M}}^* = \frac{1+c+b}{2+b}$ and $f_{\mathrm{C}}^* = \frac{Nc}{2+c}(b-1)$, which is the same as Proposition 1 suggested. This also shows that the first derivatives of r_{M}, $|f_{\mathrm{C}}|$ and u_{W} with respect to each parameters are the same, and thus proposition 2 remains valid. Moreover, we observe the first derivatives of u_{W} with respect to s, and find $\frac{\partial u_{\mathrm{W}}}{\partial s} = 1 > 0$. Proposition 3 is then proven as r_{M}^*, $|f_{\mathrm{C}}^*|$ remain the same even when system installation cost is considered in the model. □

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