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Platform Competition in Two-Sided Markets: Expectations and the Future of Mobile Payments

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Abstract

This thesis explores the necessary conditions for Mobile payments to gain economy-wide dominance over Card payments. For this purpose, we construct a formal, game-theoretical model of competition between Card and Mobile payment platforms. In a two-sided market, the two distinct user groups of buyers and sellers interact with bounded rationality in a stochastic setting. These users make a platform adoption choice ex-ante and a transaction takes place ex-post if matched users hold compatible platforms. We confirm the possible existence of both efficient and inefficient equilibrium outcomes and show that when a critical mass of users are expected to adopt the Mobile platform, this platform will come to dominate the system. We conclude that the most influential forces for the platform adoption choice of users are (i) expectations, (ii) cost level and structure, and (iii) the possible surplus resulting from a transaction. Further, we introduce a path dependence in the system which embodies the power of convention and favors the initially dominant Card platform. A large enough disruption in user expectations, through an exogenous shock to the information sets of users, may however shift the system to an equilibrium where the Mobile platform dominates.

Keywords: Game Theory, Indirect Network Effects, Two-sided Markets, Platform Competition, Payment Systems

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1. Introduction

“Apple Pay will forever change the way all of us buy things”[1]

(Tim Cook, Apple CEO, September 2014)

Through the launch of mobile payment platforms, a plethora of technology companies are today striving to profoundly change the way that we undertake transactions in our everyday lives. Backed by vast investments and some of the world’s largest corporations, e.g. Apple and Google, there is reason to believe that a new era of retail payments approaches. Ondrus and Lyytinen (2011) predict that in the years to come, a fierce battle for users will take place between payment cards and these new mobile payment platforms. Interestingly, mobile payment technology has been readily available for decades but has yet to be implemented on a global scale, despite of the various benefits described in the literature (see e.g. Hayashi 2012; Mallat and Tuuainen 2005). In 2013 around $50 billion, or less than 1 %, of global payments went through mobile platforms while around $9,000 billion was transacted via payment cards (Shen 2013, 2014). The significance of a possible transition in payments standards is hard to neglect when considering the historical evidence on the economic impact of advancements in payment systems technology. The development of new forms of payment has greatly facilitated trade and led to substantially decreased economy-wide transaction costs (Milne 2006). A report by Moody’s suggests that $983 billion in global GDP growth between 2008 and 2012 was directly linked to improved utilization of electronic payments (Zandi et al. 2013).

An important explanation as to why mobile payment has not yet gained traction may lie in the fact that the value of mobile payment technology to the individual is not self-contained or intrinsic. A merchant’s adoption and consequent acceptance of mobile payment is only beneficial if sufficiently many customers actually use the system, and vice versa. Competition in markets which exhibit these “indirect network effects” has been theoretically examined through the identification of various incentives, or disincentives, for the masses to switch from an existing platform to another. Due to the network structure, it is often the case that one platform achieves status as the standard for a longer period of time, and others die out. The number of end-users on both sides is thereby crucial to any platform’s success and even survival. This thesis adds to

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[1] Words of CEO of Apple, Tim Cook, during the launching event of Iphone 6 in Cupertino, USA. September 9 2014.

the literature on platform competition in two-sided markets by developing a theoretical model specifically applicable to the case of competition between card and mobile payments, which to the best of our knowledge has not yet been done.

Central to the analysis of large-scale transitions in standards is the belief of end-users regarding the general spread of the new technology in the economy. If a critical mass of users is accumulated on the new platform, a so-called "tipping point" may occur that shifts the relative attractiveness of platforms in its favor. If users believe that such a point in platform adoption rates will be reached, this may result in a self-fulfilling prophecy. However, the old platform often has a strong initial advantage through the power of convention (see e.g. Wärneryd 1990a; 1998a). Users in such systems essentially play a large-scale coordination game, where each actor seeks to anticipate the behavior of other actors in the economy in order to maximize their own expected payoffs.

Our thesis applies such theories to construct a game-theoretical model which identifies and analyzes tipping points in the user adoption of card and mobile payments. In particular, it provides insights into the sensitivity of the system to central factors such as the costs of platform adoption and subsequent use, as well as the size of transactions to be made. This enables a prediction of which conditions need to be fulfilled in order to efficiently reach a critical mass of users. Specifically, this work seeks to answer the research question:

Based on theory of platform competition in two-sided markets, what is required for the mobile platform to gain dominance over the card platform in the user market, and may there be equilibria where the platforms coexist?

Previous models on competing platforms in two-sided markets exist in a variety of forms; some quite general and many industry-specific.[2] This thesis derives considerable inspiration from such works and extends the theory to the specific case of competition between card and mobile retail payment platforms and additionally compares the competitive outcome under perfect and imperfect information on the user side. The specificities of mobile payments today are most importantly captured in assumptions of asymmetric complementarity on the buyer side and on the structure and level of platform costs. The asymmetric complementarity arises for consumers through the necessity to also hold a payment card to use the mobile payment platform. This

[2] Some models, e.g. Rochet and Tirole (2003, 2006), Armstrong (2006) and Kim (2012), hold a very high level of general applicability, but yield little industry-specific predictions. Others are narrower in scope, focusing on specific industries such as media and advertising (e.g. Gabszewicz and Anderson 2008) or software (e.g. Economides and Katsamakas 2006). In the payment strand of this literature, there exists models of e.g. competition between cash and payment cards (McAndrews and Wang 2008) and between competing card networks (Chakravorti and Roson 2006).

reflects the fact that in order to pay through the dominant mobile services today the consumer needs to connect the platform to a Visa or MasterCard payment card. This complementarity does not exist on the merchant side, since sellers acquire different payment terminal technology for card- and mobile payments. In regards to costs, mobile payments may require a higher fixed cost of adoption than card, which may however be recouped through the possibility of a lower variable cost of use.[3] We highlight the importance of the introduction of a variable cost through the development of two models: one basic model which only allows for fixed costs and an extended model which additionally introduces variable costs of use.

We find that the power of beliefs are central to the outcome of the game due to imperfect information and the power of convention. Through such market imperfections, it is possible for the system to settle in an equilibrium which is not societally optimal and diverges from the predictions of a simpler game-theoretical analysis which assumes perfect information. Additionally, the likelihood of a platform achieving and maintaining dominance is determined by the platforms' costs of both adoption and of subsequent use, as well the price, and the buyer valuation as well as cost to the seller of the good which is to be transacted. In a dynamic analysis, there may exist a path dependence through the inclusion of the state of the system in the previous period in the information sets of users. This favors the initially dominant card platform and implies that an exogenous shock to the information sets of the population is needed to shift the system to a state where the mobile platform dominates. However, the importance of expectations also infers that as long as the costs of adoption and use of the mobile platform are within reasonable limits[4], it stands a chance to gain dominance even when it is inefficient compared to card. In a real-world application, such a shock to information sets could be due to factors such as media attention, aggressive marketing campaigns or social movements.[5]

The insights of this paper are not necessarily limited to these payment systems, but may serve as a theoretical starting point for an improved understanding of determinants of success for network-dependent innovations.

[3] See e.g. Hayashi (2012) for an overview of investments and costs of mobile payments for consumers, and Hayashi and Bradford (2014) for a review from the perspective of merchants.

[4] I.e. the total payoff from adopting and using mobile payment is zero or higher; meaning the user would not be better off doing nothing as opposed to adopting the mobile platform.

[5] An empirical application of this model would further inform us on the determinants of actors' beliefs and their relationship with their platform adoption choice. However, we must leave this topic up for debate due a lack of accessible survey data on beliefs regarding the future of Mobile payments.

The rest of the paper is organized as follows: *Section 2* explains key concepts and reviews relevant literature. The analytical approach and modelling choices made are presented in *Section 3*. In *Section 4,* a basic and an extended model of competition between card and mobile payment technology are constructed and analyzed in a static equilibrium analysis, followed by a brief non-technical analysis of system dynamics. *Section 5* summarizes and interprets the results. A discussion on the implications and validity of our findings is then presented in *Section 6,* as well as comments on directions of further research. Lastly, *Section 7* concludes.

2. Literature

This section presents fundamental concepts that form the basis of the subsequent analysis, and summarizes the current state of academic research on payment systems and platform competition. We begin by exploring the broader ideas of networks and network effects. We then move on to the concept of two-sided markets and the central characteristics of such. Subsequently, the evidence on platforms and platform competition in such markets is examined followed by the specific applications to payment systems and, more precisely, card and mobile payments.

2.1 Network Effects

A crucial characteristic of payment systems is their network structure. Network markets, as defined in economic research, exhibit what is known in economic literature as "network effects" or "network externalities". Network effects exist when the benefit that in individual user derives from a good changes with the number of other agents who own or use the same type of good (Katz and Shapiro 1985). The network effect constitutes a network externality only when the change in benefit fails to be internalized by the market participants, as noted by Liebowitz and Margolis (1998). These authors further argue that the two terms network effect and network externalities are often used a tad carelessly and interchangeably which may lead to confusion. In this paper's model building and analysis we use the term network effects in order to capture the fact that the externalities may or may not be absorbed by the card and mobile payment platforms.

In much of economic literature it is assumed that network effects are positive, including this paper. Positive networks effects in different forms are discussed extensively in the literature (e.g. Katz and Shapiro 1985, 1994; Raub and Weesie 1990; Bertrand et al. 1998). Negative network effects also exist, arguably to the same extent as positive network effects, but have not been explored to the same extent. However, in earlier works the general non-additive nature of demand curves was highlighted. E.g. Leibenstein (1950) modelled both positive, "bandwagon" network effects and negative "snob" effects. The more recent literature on such cases appears somewhat limited to exploring mitigation of negative effects of specific occurrences such as e.g. congestion problems with certain technologies (Ellison and Fudenberg 2003; Ellison et al. 2004; Yoo 2006). Liebowitz and Margolis (1994) discuss negative networks and exemplifies with highways, where an increase in the network of cars using a highway makes individual car users worse off. One could consider the case where congestion occurs in payment technology due to limitations in the ability of the platform provider to handle many simultaneous requests. However, no negative effects in payments networks appear to have been discussed so far and are not considered in this paper due to the uncertainty regarding what form and extent such effects would have.

There are many markets which exhibit forms of network effects, such as telephone networks, advertising, payment instruments, game consoles, etc. (e.g. Katz and Shapiro 1986; Rochet and Tirole 2003b). Network effects arise in several different forms that yield somewhat different implications. In their seminal paper on network externalities, competition and compatibility, Katz and Shapiro (1985) define three different situations where network externalities arise. First is the case of *direct network effects,* which exist in the traditional example of a telephone network. Here an increase in the number of users connected to the network has a direct effect on the benefit to the individual of being connected to the network. Second are *indirect network effects*, where effects between distinct goods or users produce externalities. An example of this is the relation between software and hardware purchase. The consumer who purchases hardware must anticipate the availability of software for that hardware and this availability will in turn depend on the rate of adoption by other consumers. Another example of indirect network effects more relevant to the topic of this paper, mentioned in later work by Katz and Shapiro (1994), is credit card systems. The card may here be viewed as the hardware and the matching software consists of merchant acceptance of the card. This is additionally a case of a two-sided market which we will elaborate on later in this section. Third are the externalities which arise when the utility derived from the purchase and use of a good is also reliant on the availability of post-purchase service of the good. In our paper, the indirect network effects form the central topic of the analysis.

The network characteristic implies, as argued by Liebowitz and Margolis (1998), that the value of such a good can be divided into two distinct parts. The first part consists of the value of the good to a user absent any other users, called the *autarky value*. The second is what the authors call the *synchronization value*, which is the value which is created when the user is able to interact with others users of the product. Being connected to payment networks would be expected to hold little or no autarky value as these simply are a means of transacting goods or services. These then in turn yield utility for the user (Koeppl et al. 2008). This is also argued by McAndrews and Wang (2008) who model payment technology choice based solely on monetary payoffs and frequency of availability to users.

Other relevant issues discussed in the literature regarding network effects include but are not limited to: the user coordination problem, the benefits of standardization, and the antitrust issue. In the following paragraphs, we discuss the coordination problem, the importance of standardization and then very briefly touch upon the antitrust implications of payment systems.

At the core of using products with network externalities is the recurrent coordination problem, discussed in detail by Farrell and Klemperer (2007). The user may not know which network will be the dominant and therefore runs the risk of making an adoption choice which turns out to be suboptimal ex-post. To solve the issue with recurrent coordination problems, Wärneryd (1990a, 1998a) discusses in detail the importance of conventions and additionally develops an approach to minimize transaction costs through the development of conventions.

Through standardization or perfect compatibility social welfare may at many times be maximized in such situations, at least when it comes to innovation of new technology (Farrell and Saloner 1985). In cases where there exist several competing networks that provide similar but incompatible products, there are two important points to stress as Liebowitz and Margolis (1998) highlight. First, a network will, holding other factors fixed, have an advantage over the others if its market share is larger. This implies the creation of a natural monopoly in the long run. Second, if there is a strong likelihood of a natural monopoly being created, it is crucial that the most societally beneficial product or standard becomes the prominent one.

In addition, Katz and Shapiro (1985, 1994) stress the importance of product compatibility where networks externalities are present, due to the increase in value of such a product when it has a higher degree of compatibility with other products. However, firms may intentionally keep their products incompatible with others in order to lock customers in and maximize profits, yielding societally suboptimal outcomes as no dominant standard is developed. E.g. Farrell and Klemperer (2007) discuss competitive behavior in such a setting where switching costs exist.

One may think that the optimal product would become the dominant one, but as Katz and Shapiro (1985) show in an early model of competition in networks, this is not necessarily true. They conclude that consumers' expectations regarding product compatibility and market share

are crucial in the decision of whether to adopt the good where indirect network externalities are present. Consumer's expectations may result in choosing a product which turns out to be inferior ex-post, if consumers falsely expect the product to be compatible with their current or future products. By applying this reasoning to the setting of payment systems, the consumer expectations regarding how many merchants accept that specific type of payment will be central to their choice of payment technology adoption. The merchant acceptance in turn depends on the consumer adoption of the technology. Since this is an interactive process, the expectation of both user groups (buyers and sellers), may differ between periods and not be consistent with the actual market share outcomes. We will come back to this interaction in later sections.

The power of expectation is evident also in the work of Wärneryd (1990b). He argues that the prevalence of (non-interest bearing) money as a payment instrument rather than an interest-bearing instrument is a consequence of the expectations of the users regarding which instrument will dominate. Dubé et al. (2010) show that user expectations regarding which product will win the "standards war" are crucial for the outcome in markets with indirect network effects.

Another important issue related to expectations is that network markets commonly exhibit a path dependence, as e.g. Liebowitz and Margolis (1998) note. This means that once a technology becomes prominent, that technology will, ceteris paribus, be favored and expected to be dominant in subsequent periods. A society can therefore be somewhat locked in to an inferior solution. One such example of an inferior solution is the QWERTY keyboard standard. This dominant standard that is argued to be inferior from a user perspective but is not expected to change since the switching costs are too high to offset any improvement in efficiency (Shapiro and Varian 1999).

Reaching a dominant position is evidently highly desirable in markets characterized with network effects, making antitrust issues in such markets inherently problematic (see e.g. Evans 2003). The societal optimum can be maximized when one or a few actors have market dominance, rather than having free competition (Katz and Shapiro 1994). However, there are many situations where the extensive market power of one firm can result in raising rivals costs and limit further innovation, which then would not be socially optimal (Economides and White 1994). Therefore, if these markets, which are characterized by a natural monopoly, are not closely monitored or regulated by antitrust laws, they can easily result in non-optimal situations. This is of special importance in the discussion of competing platforms, which we will present later in this literature section.

2.2 Two-Sided Markets

The academic literature on payment systems has progressed considerably over the last decade, aided in particular by the substantial advancements made within the field of two-sided markets and platform competition. Rochet and Tirole (2003a, 2003b, 2006, 2007a) as well as Rysman (2009), Rysman and Wright (2012) and Evans and Schmalensee (2005, 2007, 2008) are some of the authors who have been in the forefront of this progress. With the help of such theoretical tools, models of user behavior have been developed for the analysis of competition between different payment instruments, or payment platforms, such as cash, debit card and credit card.

The theory of two-sided markets is conceptually derived from the theories of network effects of multi-product pricing, and pricing is a field in the literature of two-sided markets that has received a lot of attention (Rochet and Tirole 2003b, 2006; Armstrong 2006; Kaiser and Wright 2006). In their seminal paper, Rochet and Tirole (2003b) on platform competition in two-sided markets define the more modern form of two-sided markets. The term is simultaneously explored in a paper by Evans (2003), and then further developed by mainly Evans and Schmalensee (2005), Armstrong (2006) and Guthrie and Wright (2007). Main findings include that the demand of and costs for consumers are not the only factors affecting profit, since there also exists a participation effect of these customers (Rysman 2009). A large number of participants in one side of a two-sided market can lead to a sharp price change and/or participation rate on the other side. Abnormalities can therefore arise, e.g. a firm can during a long time charge prices under marginal cost or even negative prices to attract a large number of participants on one side of the market. This is an important finding in terms of discussing success factors in the two-sided market for payment platforms. It implies that early adoption and first mover advantages are central strategies for successful competitive participation in a two-sided market (Eisenmann et al. 2006).

In the literature, two-sided markets are sometimes seen as an actual subset of network effects, but this is not an uncontroversial or universal view according to Rysman (2009). Rysman presents a broad definition of two-sided markets which needs to fulfill two conditions: first, two sets of agents interact through an intermediary or platform and second, the decisions of each set of agents affect the outcomes of the other set of agents, typically through an externality. Rochet and Tirole (2006) are more specific in their definition of a two-sided and add the following to the definition: a two-sided market is one in which the volume of transactions between end-users depends on the structure of the platform; where a platform impacts willingness of the two sides to trade once on the platform and thereby their net surpluses from potential interactions; and where the platforms' membership or fixed charges in condition the presence of end users on the platform. In the analysis of this paper the definition of Rochet and Tirole (2006) is used. This definition is fairly standard within the payment strand of the two-sided market literature since it is conducive to the purpose of examining both adoption and use of payment platforms.

Early literature on two-sided markets is quite industry specific, focusing on e.g. computer hardware (Dranove and Gandal 1999), operating systems (Parker and Van Alstyne 2000) and internet intermediation (Caillaud and Jullien 2001). More recent economic research focuses on multi-sided markets aspects of certain industries, where payments are a big subfield according to Evans and Schmalensee (2013). Despite of this, further research is needed on two-sided markets to fill the current gaps in applications in various fields such as e.g. antitrust, according to Filistrucchi et al. (2014). They argue since that there needs to exist clear market definitions for each industry for antitrust laws to be effective, more research in the field forms the necessary founding for effectiveness in the lawmaking to be achieved.

2.3 Platforms and Platform Competition

Platforms provide the institutional framework that facilitates a transaction between distinct user groups such as we find in two-sided markets (Evans 2003). Specifically, a platform in the context of this paper is defined as an entity that provides a technology or place to facilitate a transaction solution to an externality in a way to minimize transaction costs. Platforms are especially useful and/or necessary when externalities between parties cannot be solved directly (Evans and Schmalensee 2008). There are two types of externalities to users connecting to a platform in a two-sided market, namely membership externalities, also referred to as adoption externalities, and usage externalities (Rochet and Tirole 2007a). A membership externality may occur where initial costs are required to acquire membership, and be able to subsequently participate in the activities of, a platform. Usage externalities refers to the externalities that appear each time a platform is used.

The issue of competition between such platforms is central to the research question of this paper, and is explored by e.g. Rochet and Tirole (2003b). These authors denote the term platform competition as competition between platforms with a similar function that compete for the same users. A substantial amount of publications have been made within the field of platform business models and strategy e.g. (Guthrie and Wright 2007; Armstrong 2006; Armstrong and Wright 2007; Caillaud and Jullien 2001, 2003; Hagiu 2006; and Schiff 2003). These papers often discuss the societally optimal design of platforms in terms of their governance, i.e. whether they are for-profit or not-for-profit, as well as the allocation and levels of fee. In summary, this literature mainly explores the structure and supply-side strategies of existing industries and products.

Rochet and Tirole (2003b) discuss important success factors of platforms and mention business model and pricing as fundamental, with six factors deciding how prices will be allocated to the users in the market. These consist of platform governance; end-users' cost of multi-homing (term described below); degree of platform differentiation; the ability of platforms' to use volume-based pricing; the presence of same-side externalities; and platform compatibility. Expanding on price settings in platform competition, Rochet and Tirole (2007a) later present the key insight that the fixed costs affect users' willingness to be present on a certain platform while the variable costs affect users' willingness to trade once they have adopted the platform. They make a distinction between "membership charge" and "usage charge", related to the aforementioned "membership externalities" and "usage externalities". In our model, we make a similar construction but we choose to use the terms "fixed cost" and "variable cost" to reflect that these are not necessarily a charge and to reflect the common terminology within the payment strand of the literature on two sided markets and platform competition.

Few authors look at the case where complementarities exist between several platforms that are in competition. Kim and Musacchio (2009) model the case where there is a monopoly provider of two platforms (old and new) and a cross-platform externality is present due to asymmetric backward compatibility of the new technology. Kim (2012) addresses a case where a platform based on new technology is introduced which exhibits a backward complementarity with an existing platform, and brings up the case with mobile users and the network upgrading from 3G to 4G. Two important characteristics of Kim's model are that there is a new and an old platform, and the fixed cost of adopting the new platform is higher than for the first one, but it has a lower variable cost.

Two terms that are frequently used within the platform, and payment, literature are "home" platform and "multihoming". A home platform is a platform which a user has adopted and thereby has available for use in a given period. A multihoming user has adopted several platforms that fulfil identical or very similar functions. For example, in the application of payment cards a multi-homing user would be a buyer who holds both Visa and MasterCard payment cards and a seller who accepts both cards (Rochet and Tirole 2003b). In addition, the term multi-homing also explains when the user adopts several different technologies that have identical functions, such as the card and mobile payment application.

2.4 Payments

Payments constitute one case of two-sided markets that has yielded a large number of publications. This literature was initiated by Baxter (1983), who describes the effects of antitrust laws on collectively set interchange fees. Payment is essentially the process of transferring money from a payer to a payee and involves payment instruments, payment processing and payment settlement (Kokkola 2012). Several formal discussions of the payment card industry have been written and focus has been put on interchange fees and their effects (e.g. Carlton and Frankel 1995; Evans and Schmalensee 2005; and Rysman and Wright 2012). In most payment systems today the business model of service providers is based on two-tier pricing. In such a model, the user pays a periodic fee, usually per annum, to gain access and additionally a variable fee based on transaction value (Sveriges Riksbank 2013).[6]

According to Rochet and Tirole (2007a), payment models in the literature generally focus on a single payment system as a complement to cash payments. However, in reality there are several methods of payment available to the consumer besides cash, such as bonds, debit card, credit card, cheques, etc. The authors therefore argue that there is room for further research in comparing different payment systems.

In both single and competing payment system, focus can be on either modelling the entire ecosystem of payments (e.g. Rochet and Tirole 2007b), or putting emphasis on certain aspects in the ecosystem e.g. the benefits of the consumer (Priem 2007). For single payment systems, e.g. Schmalensee (2002) and Rochet and Tirole (2003b, 2006, 2007a) have constructed models where profits are maximized for the card payment network and social welfare maximized with regards to interchange fees. In their models, the benefits to users follow mainly from the level of interchange fees set by card networks. Multiple competing payment systems are less explored due to the vastly added complexity this adds to the modelling (Rochet and Tirole 2007a). Chakravorti and Roson (2006) attempt to create a network where differentiated payment systems are preferred to users and the competition increases consumer and merchant welfare. Guthrie and Wright

[6] Note that the business model may differ across competitors and markets. For example, in Sweden consumers are rarely charged a transaction-based fee while business and governmental clients are (Sveriges Riksbank 2013).

(2007) and Rochet and Tirole (2007b) also create models for competing card schemes, analyzing both industry and social optimum in the short and long-term.

In regards to the characteristic of payment platforms, some authors argue that these platforms should be viewed differently from ordinary goods and services. E.g. McAndrews and Wang (2008) argue that payment platforms should not be viewed as goods themselves which yield some intrinsic payoff to the user, but rather the value of the payment method is directly derived from how often and cheaply it may be used in transactions to acquire the goods desired. This also follows the suggestion by Koeppl et al. (2008) that payment platforms would be expected to hold little to no autarky value.

One important aspect of the payment literature which is central to our topic is that there often is a need for a critical mass of users to be reached before the adoption of a new payment system becomes an individually dominant strategy. When a critical mass of users is accumulated, a tipping point may occur. A tipping point is broadly defined by Lamberson and Page (2012) as a discontinuity between current and future states of a system. In the context of critical mass, when a tipping point is reached the system "tips" towards one of the dominant strategies. Wärneryd (1990b) shows that this characteristic is a key hurdle for a general switch from using ordinary currency to interest-bearing instruments. The establishment of a commonly accepted medium of exchange (CAMOE) provides an institutional solution to the coordination problem inherent in the two-sided markets. As Wärneryd states, the determinant characteristic of such a coordination problem is that we cannot find a strategy which is dominant for individuals seen independently from the actions of others. Regarding coordination conventions, switches to an efficient state do not occur automatically. Connected to this argument is that a shift to mobile payments would not necessarily take place due to some external, such as government, force establishing it as the default payment platform. Indeed, such a scenario currently seems rather unlikely. As Menger (1976) highlights, decentralized actions of self-interested individuals is what explains the establishment of the social institution of a commonly accepted medium of exchange.

2.5 Mobile Payments

Mobile phones with operative systems are called smartphones, and have more advanced functionalities than ordinary mobile phones (Verkasalo et al. 2010). Wang et al. (1999) proposed development of a new secure payment system through the mobile, with help of existing technologies provided to the buyer by VISA and Mastercard. Kreyer et al. (2002) described the importance of a standardization as the most important success factor for mobile payments and

Karnouskos (2004) summarizes the future development alternatives with current available technologies and the multitude of standardization initiatives. Pousttchi (2003) analyzes mobile payments scenarios further through a morphological box, where he stated 10 factors deciding the success of implementing mobile payments. Two central factors which have a bearing on the analysis of this thesis are the transaction costs and convenience of use.

For individuals to wish to adopt mobile payment technologies, some argue that behavioral beliefs and social influences are of central importance (Yang et al. 2012). Yang et al. (2012) conclude that if people believe mobile payments will be adopted by users, they are much more likely to adopt mobile payments themselves. The failure of mobile payments to receive global dominance in the early 2000's is attributable to lack of market standards and the beliefs by consumers that the payments will not be compatible with other products, argue Ondrus and Pigneur (2006). A launch of mobile payments must be on a large scale, or at least prospective users need to expect a large-scale launch. If such a perception is established, case buyers and sellers will feel the demand for the product knowing that it will be useful for future payments (Chen 2008). Beliefs of mobile payment adoption is therefore crucial for actual mobile payment adoption, and is a central focal point of the analysis in the remainder of this paper.

Mobile payments have generated a plethora of papers in the literature which focus mainly on technical proposals for the development of mobile payment systems and standards. In addition, benefits to the consumer have been most extensively discussed, though merchants' benefits are also of great importance (Dahlberg, Mallat et al. 2008). The benefits of mobile payments to the consumer are summarized by Hayashi (2012) and revolve mainly around convenience and safety, while benefits of the merchants are summarized by Mallat and Tuuainen (2005) as consisting mainly of the ability to serve business clients as well as possible cost reductions.

Mallat et al. (2004) divide mobile payments into three different categories: remote, manned Point of Sale (POS) and unmanned POS mobile payment systems. In addition, they define micro payments as payments below $10 and macro payments as payments over $10, which is important when distinguishing the usefulness of the different payments system. Manned POS still stands for a majority of payments (Hayashi, 2012). In this paper, we focus on manned point of sale which is also known as retail, in-store payments.

The technology for mobile payments was initiated over two decades ago, but still has not been implemented on a global scale, despite of the benefits highlighted in previous literature. Today, mobile payments are widely used in a few Asian countries, including Japan, and some African countries, including Kenya through M-PESA (Mas and Radcliffe 2011). However, mobile payments are also characterized by obvious network effect issues as described in the initial part of the literature section: consumers will not demand mobile payments services before they know merchants will accept them, and most merchant cannot justify accepting mobile payments, until a critical mass of consumers utilize the technology (Rysman 2009). As Hayashi (2012) highlights, the success of mobile payments in e.g. Japan can largely be attributed to a push from the government towards this technology through e.g. its introduction for public transport payments. In the theoretical framework of our paper, such external enforcement would largely eliminate any coordination issues for individual users. In the African countries where mobile payments have gained traction, Hayashi (2012) argues that this was possible largely due to the lack of any reliable alternatives such as card or check payments. In such settings the model we develop in this paper would not be directly applicable since it assumes that card payment technology is available to the population.

Recent literature on the mobile payment market discusses why the technology has failed to replace traditional ways of payment thus far. One possible reason is that mobile payment firms have not found a way of collaborating, which would most likely be needed to reach a critical mass (Ozcan and Santos 2014). Kazan and Damsgaard (2013) analyze mobile payment technologies for three different European countries, and conclude that the technologies are technically sound and have the potential to provide both consumers and merchants with solutions that work. The authors thus show that the technology for mobile payments is indeed scalable.

Finally, there is reason to believe that with new mobile payment technology (e.g. NFC) there is a good chance for certain players to be successful in a global launch of mobile payment technology. This is argued by Ondrus and Lyytinen (2011) who predict that in the years to come, a fierce battle for the customers will take place between card and mobile platforms. At present, mobile payment platform providers collaborate with existing card providers, where consumer who wish to make a purchase using mobile technology often need to hold a payment card as well. This implies the asymmetric complementarity property which was discussed in the introduction. Due to the necessity for a consumer to adopt both card and mobile platforms to make a mobile payment transaction, these must pay fixed costs for both platforms. They will then however only need to pay the variable cost for the platform which they subsequently use in an actual transaction. Hayashi (2012) argues that the cost of adoption of mobile payments may vary substantially across technologies, but since most consumers today need a hardware upgrade in order to use the newest technology the fixed cost can generally be argued to be expected to exceed that of card payments. For smaller schemes, e.g. introduced by specific stores such as Starbucks, as well as applications which are not designed for point-of-sale retail payments, such as PayPal, the investment needed can be minimal if it only required the installation of an application. The variable cost is however expected to be equal or lower for mobile payment transactions as compared to card payments. Also for merchants there are several different technologies available to accept mobile payments. As put forward by Hayashi and Bradford (2014), who present the necessary investments to be made in order to accept mobile payments, the fixed costs of investment to merchants are moderate to high. For NFC technology, e.g. mobile payments specifically designed for point-of-sale retail payments as studied in this thesis, substantial investments into terminal hardware as well as software and accounting system adaptation are necessary. Such investments into hard- and software are also required for many of the smaller, and non-point-of-sale schemes. The authors however also highlight that card payments often are the most expensive payment option for merchants in terms of interchange, i.e. variable, fees, which makes alternatives such as mobile payments attractive.

These technological constraints and cost structures are explicitly incorporated in our models, where we assume asymmetric complementarity on the buyer side and explore the impact of different relative platform costs. In the basic model, we consider fixed costs only and put no initial constraints on cost levels. In the extended model, we both introduce the existence of variable costs of platform use as well as constrain the cost levels of the respective platforms. To reflect the cost characteristics of prevalent platform business models that were presented in this section, the mobile platform is then assumed to have a higher fixed cost of adoption but lower variable cost of use than the card platform for both buyers and sellers.

3. Analytical Approach

With a strong foundation in existing theoretical models and empirical evidence, we develop a formal game-theoretical model which analyzes a possible transition between card and mobile payments from the user perspective. The model takes the concepts of critical mass and tipping points as central analytical tools and explores the impact of central parameters. The most important parameters for the prevalence of the respective payment technologies in the economy as identified in previous literature are given by user costs of platform adoption and use, as well as the population's belief regarding the spread of the technology in the economy. Additionally, the asymmetric complementarity is a central feature which helps determine both strategic options available to users and the possible equilibria of the game. In an initial *basic model*, we consider a most basic case where only fixed costs of platform adoption are allowed and no initial conditions on relative cost levels are imposed. This allows for a focus on the centrality of expectations and provides a quite intuitive analysis which conveys the central mechanisms of the model to the reader. In an *extended model*, we more closely model the specificities of the current business models of mobile payment platforms. Here, variable costs of platform use are introduced and conditions imposed on the relative cost levels of platforms, where the mobile platform has a higher fixed cost of adoption per period but a lower variable cost of use compared to the card platform. To the best of our knowledge no formal, game-theoretical model explaining user choice between card and mobile payment platforms currently exists. Subsections 3.1 through 3.4 below present central choices and delimitations made; model design choices; and the static and dynamic tools to be applied in the model analysis.

3.1 Central Choices and Limitations

Our model studies platform adoption and use from the point of view of the two groups of end-users: buyers and sellers. Some academic models, e.g. McAndrews and Wang (2008), build complete payment ecosystems which apart from user behavior also analyze the profit maximizing behavior of platforms and the necessary conditions for achieving a societally optimal outcome. We have chosen not to include the strategic behavior of platforms in the model. This analysis falls outside the scope of the research question which inquires about the conditions necessary for the mass of users to switch between payment technologies. We therefore focus on identifying and analyzing any possible unstable (tipping points) and stable equilibria for platform use in the end-user markets. In subsequent work, however, one could investigate whether the equilibria identified in this paper are feasible also from the perspective of platforms.

The identification and study of tipping points with the help of microeconomic tools form the core of this study. Through close examination of any such points, we may comment on the impact of central parameters on the feasible equilibrium outcomes. It therefore adds to the existing literature of payment platform competition and may serve as theoretical input for the practical implementation of mobile payment platforms by providing insight into the sensitivity and importance of central parameters on the platform adoption behavior of users.

The reader should note that while it is possible to model the case with several competing platforms of the same kind (i.e. multiple card- and mobile platforms), we do not explore the internal market structures of these two platform technologies since the focus of this paper is the relative attractiveness of card and mobile payments as such. We therefore assume that all providers of the same technology are compatible and thus the system may in an intuitive manner be modelled as a competitive process between two platforms.

3.2 Model Design

We explore the platform adoption strategies of a continuum of users who are matched in buyer-seller pairs in a stochastic setting. Prior to the matching procedure, both buyers and sellers make their platform adoption choice. Ex-post, a transaction may or may not take place depending on whether or not the two sides have adopted compatible technologies. We exclude the cases where not participating in the game is a strictly dominant strategy, which in practice means that we impose restrictions on parameter values so that the total utility of adopting and using any of the platforms must exceed zero.

Furthermore, we assume that all actors are rational. Most models of competing payment systems assume perfect rationality, but as Easley and Kleinberg (2010) discuss, users are likely to not have access to perfect information and thus they may react differently to different states of the system. In our model, we therefore examine the case where users' rationality is bounded by an imperfect access to information. Each actor assigns probabilities to the matching scenarios, based on their individual information set. In equilibrium, the expectations of actors does not have a systematic bias so the beliefs of an actor with perfect access to information will be perfectly consistent with the outcome of the game. Additionally, actors with identical information sets make identical platform adoption decisions. The information set of the individual actor may be derived from factors such as e.g. media, advertisements and social interactions. In a dynamic setting, also the outcome of the game in the previous period may be considered as part of the information set. The information sets, and thereby the adoption choices of users, may be subject to exogenous shocks as for example of aggressive marketing campaigns or media attention. The exact properties and distribution of information sets as well as the functional relationship between expectations and outcomes are not further elaborated on since it adds considerable complexity to the model without yielding significantly more nuances to the answer to our research question. Additionally, this provides the model with a generality which makes it suitable for subsequent extension to cases where more specific assumptions on expectations are imposed.

Following e.g. McAndrews and Wang (2008), we assume purely pecuniary payoffs to all users from which it follows that users do not have any intrinsic preferences for the adoption or use of any particular platform. This design is specific to the case of payment instruments and differs from more general models of platform competition that may allow for intrinsic payoffs of adoption and/or use.[7] Buyer utility is simply derived from the user's valuation of the good that is acquired in a possible transaction, less the price paid and costs of platform adoption and use. Seller payoff depends on gross profit in a possible transaction minus costs of platform adoption and use. In the basic version of the model, the platform costs consist only of fixed costs of platform adoption. In the extended version, variable costs proportional to the transaction value are additionally introduced. The case where only variable costs exist is excluded from the analysis, for two reasons. Firstly, such a structure rarely appears in the business models of payment platforms and secondly, such an analysis is trivial since if there is no cost of platform adoption, users will adopt all available platforms and then in the ex-post transaction simply use the platform with the lowest transaction cost. The platform with the highest variable cost will then eventually be forced to exit the market as it is not used in any transactions and thus obtains no revenue.

As previously mentioned, our model importantly exhibits an asymmetric backwards complementarity of adoption and use for the mobile platform, similar to Kim (2012). The complementarity arises in that buyers must adopt both card and mobile technology in order to make a mobile transaction, while for card payments only card technology is needed. The platform adoption choice for buyers thereby stands between card adoption and double-homing. Sellers conversely have the option of adopting any one or a combination of the two platforms, i.e. to either double- or single home any platform. This design reflects the prevalent business models of retail mobile payment platforms today as discussed in the literature section. Such complementarities has very rarely been investigated in the literature on platform competition and thus yields an important research contribution in and of itself.

We allow only for card and mobile payment as available payment options to users. Thereby, we exclude options such as other electronic payments, cash or check as well as the distinction between debit and credit. If one more payment option would be included, the model would exhibit a substantially higher complexity and not contribute in an important way to a better

[7] Following the arguments of McAndrews & Wang (2008) and (Koeppl et al. 2008), we argue that the utility gained from a payment transaction is mostly derived from the good transacted and not from the adoption and use of the payment platforms themselves. For the reader interested in general models that allow for intrinsic user payoffs from platform adoption and use, see e.g. Rochet and Tirole (2003, 2008), Musacchio and Kim (2009) and Kim, (2012).

understanding of the transition between the two forms of payment in focus for this paper. Note that comparing two payment options is sufficient for the purpose of this paper which is to analyze the transition between card and mobile adoption and use, but may not suffice for explaining the payment behavior of an economy in its entirety. With this limitation, the model is fully applicable to economies where these are the only two available payment options but, more realistically, for specific goods or market places where they are the only available options or for users who do not consider other options. Note that it is seemingly unprecedented that an author attempts to capture all available payment methods in a single model. Such an approach might be interesting but is beyond the scope of most studies and indeed ours as well.

Note also that we do not delve deep into the characteristics of buyer utility, but rather construct a model which will capture the possible platform transitions in a way which is as transparent as possible without losing significant explanatory power. We therefore model individuals' utility in an additive form where the utility derived from good α, i.e. $U(\alpha)$, is expressed in monetary terms. This implies that $U(\alpha)$ is a representation of the individual's monetary valuation of the good being transacted. In this way, we may simply subtract the costs associated with acquiring the good to arrive at a final utility which reflects the value that the individual assigns to the transaction of α in its entirety.

No general budget constraint in terms of e.g. income is introduced for the individual buyer. However, a restriction is put on the price and transaction costs that they may not exceed the utility that the user derives from the good to be transacted. Similarly, the seller's cost of the good and transaction may not exceed the price obtained from the good. More succinctly, no transaction will occur if buyer utility or seller profit is less than zero.

3.3 Static Analysis

We use static equilibrium analysis as a solution concept to identify possible outcomes of the game. More specifically, Nash equilibria are searched for and specified. Famously, a Nash equilibrium represents a combination of best response strategies of players, meaning a set of strategies which no player wishes to deviate from (Nash 1951). After identifying any such equilibria, these are classified as stable or unstable. A stable equilibrium will not be disrupted by infinitesimal shock or movement in any direction, and the system will rather gravitate back to the equilibrium. In contrast, an unstable equilibrium would not move back to the equilibrium after the same infinitesimal shock or movement (Easley and Kleinberg 2010).[8] Stable equilibria represent possible outcomes in the "standards war", where one adoption strategy may entirely dominate over another. When these are identified, one may comment on the relative efficiency of the respective outcomes from the user perspective.

In unstable equilibria we may encounter tipping points. Tipping points have been defined in various different ways as discussed by Lamberson and Page (2012). We choose a definition following the work of e.g. Wärneryd (1998a), who uses the synonym term critical mass point to signify the number of users needed to assemble on one strategy in order for a switch in dominant strategy to occur. A tipping point in our model is a point in relative platform adoption rates in the user markets at which users are indifferent between strategic options, and an infinitesimal move in any direction from this point results in a switch in dominant platform adoption strategy. The identification of such tipping points will inform us on when to expect one platform adoption strategy to gain dominance over the other, and what is needed for this to occur. Since we analyze a two-sided market, the tipping point in both markets must simultaneously be taken into account for a full solution of the model. We then conduct a comparative static analysis where the effect of important parameters on the existence and location of possible tipping points are formally identified.

Findings on the existence and location of stable and unstable equilibria as well as the influence of the included parameters are continuously summarized in propositions.

3.4 Dynamic Analysis

Following the static analysis, a brief discussion on model dynamics is conducted. The dynamic analysis informs us on which state is likely to occur given the starting point and assumptions made regarding the behavior of players. As described in Baumol (1968), a dynamic analysis explicitly takes into account the passing of time, while in a static analysis we do not take into account what may have occurred in previous periods or what is to come in the next as a result of the state in the current period.

As discussed in the literature section, there is often a high degree of path dependence in markets with network effects. In the context of this paper, the dominant card payment platform would

[8] For a revision of stable and unstable equilibria in network effects, we refer the reader to Easley and Kleinberg's (2010) book "Networks, Crowds, and Markets: Reasoning about a Highly Connected World". In chapter 17 there is an excellent section on the mathematics of equilibrium analysis, especially considered for network effects, for readers in need to revise basic terms.

be expected to have an initial advantage unless users may perfectly coordinate their strategies to immediately arrive in a new equilibrium. Such simultaneous coordination may be considered quite unlikely due to the huge number of prospective card and mobile users in an economy. Instead, following the predictions of evolutionary dynamics, a movement that takes place from any given starting point eventually arrives in one of the identified stable equilibria. For example, following Wärneryd (1998a), let there exist two distinct equilibria in a user market, at population shares x_1 and x_2. Let a tipping point x^* be present at $x_1 < x^* < x_2$. The set of population shares $x_1 < x < x^*$ will therefore be a *basin of attraction* of the equilibrium at x_1, while the set $x^* < x < x_2$ is a basin of attraction for x_2. As Wärneryd further highlights, if the starting point is set randomly the equilibrium with the largest basin of attraction is the most likely to materialize.

As previously stated, users make their own decisions based on their expectations regarding the state of the system in the coming period. These expectations are in turn formed by their available information set. In a dynamic setting, the outcome in the previous period can form part of a user's information set. This may form a path dependence in the system. Unpredicted movements in the location of the system could occur through exogenous shocks to the information sets of users. If a large enough exogenous shock to the information sets occurs, it may lead to a shift towards an equilibrium which is inconsistent with the initial state of the system, i.e. the initial location in terms of basins of attraction. This would result in so-called self-fulfilling prophecy equilibria (Easley and Kleinberg 2010). If these shocks are of a stochastic nature the equilibrium with the largest basin of attraction is again most likely to be realized in the long-run (Kandori et al. 1993).

4. A Model of Competition between Card and Mobile Payment Platforms

In this section, we develop a model of users' choice between Card and Mobile payment platforms. *Section 4.1* presents the basic model where only fixed costs of platform adoption are considered and no initial constraints are imposed on relative cost levels. This design is helpful to identify general, intuitive patterns in the implications of network effects on platform adoption. In *Section 4.2* this model is extended by the addition of variable costs of platform use. This extension allows for consideration of the implications of various platform business models on users' technology adoption. Additionally, costs are constrained so that the Mobile platform has a higher fixed cost of adoption but lower variable cost of use to both user groups. This structure is motivated by the currently prevalent business models of mobile platforms and the extended model is thereby more specific to the case of mobile payments than is the basic model. In each of these two model subsections we present a number of propositions that constitute formal conclusions made in the model analysis. Lastly, *Section 4.3* presents a non-technical discussion of possible model dynamics and their implications. For the convenience of the reader, a summary list of all variables and parameters is presented in *Appendix I* and a summary of restrictions put on parameter values is found in *Appendix II.*

4.1 Basic Model (Fixed Costs Only)

A basic model of competition between Card and Mobile payment platforms is developed, which takes into account a fixed cost per period of adopting the respective platforms. Central design features of the model are put forward in subsection 4.1.1, followed by a presentation of the available adoption strategies and their payoffs in subsection 4.1.2, after which expected payoffs and tipping points in the respective user markets are reviewed in subsections 4.1.3 and 4.1.4. Lastly, subsection 4.1.5 defines any stable equilibria occurring in the model.

4.1.1 Design

There are two sides of the market, consisting of buyers and sellers respectively: $i \in \{B, S\}$, and two types of platforms, Card and Mobile: $j \in \{C, M\}$, that may be used to facilitate a transaction between buyers and sellers. In any given period, a user i faces a total cost for the adoption and use of platform j which is greater than zero, $c_j^i > 0$.

Buyers $b \in B$ and sellers $s \in S$ are matched in pairs in a stochastic manner. In each period, every buyer and seller make an ex-ante platform adoption choice. If technology choices of matched users are compatible, there may be a transaction ex-post. If they are incompatible, there will be no transaction. In a transaction, the buyer pays a price p_α to the seller through a payment platform and obtains a good α in return sellers may not set different prices depending on the platform used for the transaction, and thus $p_{\alpha,c} = p_{\alpha,m} = p_\alpha$. The buyer b assigns good α the value $U(\alpha)$.

Buyer b has two available strategic options in a given period. The first is to adopt Card only and use the card platform in a possible transaction. This buyer, henceforth called Card Buyer, is only able to make transactions with sellers who also have adopted card technology. The second strategy available to buyers is to adopt both Card and Mobile technology. The Card and Mobile Buyer (CM Buyer) has both platforms available and can thus make transactions with any seller they are matched with.

The buyer b will therefore incur a fixed cost per period of c_C^b if adopting Card only, or a cost of $c_C^b + c_M^b$ if adopting both Card and Mobile. If the buyer realizes a transaction, the buyer will then pay price p_α and receive utility $U(\alpha)$ from receiving the good. If the buyer does not realize a transaction, the buyer will still pay the costs for adopting the technology. Cases where the parameter are such that the total expected payoff to users is negative are excluded. The analysis is thus restricted to parameter values where $U(\alpha) - p_\alpha - c_j^i \geq 0$ and $p_\alpha - c_j^i - c_\alpha \geq 0$.

Seller s has three available strategic options in a given period. Strategy one is to adopt Card only and use the card platform in a possible transaction. These Card Sellers can transact with all buyers who have adopted card technology, which includes both Card Buyers and CM Buyers. Strategy two is to adopt both Card and Mobile platforms. The Card and Mobile Sellers (CM Sellers) can transact with any buyer. The third and final strategy is to adopt mobile technology M only. The Mobile Seller can only make transactions through the Mobile platform and thus only if matched with a CM Buyer.

The seller will therefore incur cost c_C^s if adopting Card only, a cost of both c_C^b and c_M^b if adopting both technologies, or c_M^b if adopting Mobile only. If the seller realizes a transaction, the seller will then pay the cost of the good c_α and receive the price paid by the buyer p_α as income. If the seller does not realize a transaction, the seller will still pay the costs for adopting the technology, but not the cost for the good c_α .

In the random matching procedure, users make ex-ante strategy choices based on their expected payoffs. The expected payoffs of the respective strategies from the user's perspective depends on their expected platform population shares of users on the other side of the market. These shares determine the probability of whether or not a transaction may occur and through which platform. Using the fact that the platform population shares represent Buyer-Seller matching probabilities, Neumann-Morgenstern preferences for these random events are assumed. 9 The additive characteristic of expected utilities that this implies reflects the assumed risk-neutrality of users. Let y_1, y_2 and y_3 be the payoffs to user i in three different possible states. The probabilities of the states occurring are x_1, x_2 and x_3. We may then write the expected payoff to user i's as

$$V(x_1, x_2, \dots, x_n, y_1, y_2, \dots, y_n) = \sum_{k=1}^{n} x_k y_k.$$

[9] For revision on further properties of van Neumann-Morgenstern utilities, see chapter 12 in Varian (2010).

The different states in this model are given by the different matching scenarios from the point of view of user i. The likelihood of each state is given by the share of the population subscribing to each platform. In our model, the relevant probabilities in the user's decision are not the actual population shares, but rather the user's expectation of these. The probabilities which an individual actor assigns to different matching scenarios are given by $\emptyset_k^i = E(x_k|\Omega^i)$, where $\emptyset_k^i$ is the assigned probability of matching scenarios user i; x_k are the actual platform population share outcomes; and Ω^i is the information set of user i. Ω^i is continuously distributed across the population and does not hold any systematic bias in equilibrium. From the view of the user, the expected utility is determined by the subjectively assigned probabilities. The individual adoption choice thereby maximizes the expected utility $\sum_{k=1}^{n} E(x_k|\Omega^i)y_k = \sum_{k=1}^{n} \emptyset_k^i y_k$, where $\emptyset_k^i \in [0,1]$ and $\sum_{k=1}^{n} \emptyset_k^i = 1$.

4.1.2 Payoffs in Feasible Matching Outcomes

First, consider the possible outcomes of the matching game. User pairs who have adopted incompatible technology will be unable to make a transaction but the fixed cost of platform adoption has already been incurred. Matched users who have adopted compatible platforms will make a transaction, assuming that the transaction itself yields a payoff of zero or higher to the respective parties. Fixed costs are sunk and are therefore irrelevant for the value of the ex-post transaction. Based on the assumptions regarding user choices, buyers have 2 explicit adoption choices and sellers have 3 explicit adoption choices. There will therefore be 6 matching scenarios. The seller assigns a $\emptyset_C^B$ probability to being matched with a buyer who has adopted Card only, a $\emptyset_{CM}^B$ probability of being matched with a buyer who has adopted both Card and Mobile, and so on.

Table 1 below provides an overview of the expected strategic payoff to individual buyers and sellers. Each user payoff entry in the matrix represents the expected payoff in each matching scenario, i.e. y_k^i. The components of the actual payoffs y_k are given by the transaction surplus (value of the good $U(\alpha)$ minus price p_α to the buyer; and price p_α minus cost of the good c_α to the seller) minus the fixed cost incurred by the strategy. From the point of view of the seller, Buyer plays the strategies with probabilities $\begin{pmatrix} \emptyset_C^B \\ \emptyset_{CM}^B \end{pmatrix}$. From the point of view of the Buyer, the Seller plays the strategies with probabilities $(\emptyset_C^S, \emptyset_{CM}^S, \emptyset_M^S)$.

Table 1. Strategy payoff matrix for individual buyers and sellers in the basic model

		SELLER		
		Card Only (C)	**Card and Mobile (CM)**	**Mobile Only (M)**
BUYER	**Card Only (C)**	$U(\alpha) - p_\alpha - c_C^b,$ $p_\alpha - c_C^s - c_\alpha$	$U(\alpha) - p_\alpha - c_C^b,$ $p_\alpha - c_C^s - c_M^s - c_\alpha$	$-c_C^b, -c_M^s$
	Card and Mobile (CM)	$U(\alpha) - p_\alpha - c_C^b - c_M^b,$ $p_\alpha - c_C^s - c_\alpha$	$U(\alpha) - p_\alpha - c_C^b - c_M^b,$ $p_\alpha - c_C^s - c_M^s - c_\alpha$	$U(\alpha) - p_\alpha - c_C^b - c_M^b,$ $p_\alpha - c_M^s - c_\alpha$

First consider the case where all actors are perfectly rational, this rationality is common knowledge and perfect information is assumed. Evident from the payoffs in *Table 1* above, there exists two possible pure strategy Nash equilibria in this game depending on the parameter values. One equilibrium is located at (C, C). If $c_C^s > c_M^s$, an additional equilibrium lies at (CM, M). These scenarios result in alignment of population share outcomes and expectations at $\binom{1}{0}, (1,0,0)$ and $\binom{0}{1}, (0,0,1)$ for the respective equilibria. In the case when $c_C^s = c_M^s$, players are indifferent between strategies. In the case when both equilibria exist, the buyer prefers (C,C) and the seller prefers (CM, M). Due to this difference in preference, when both equilibria exist the setup amounts to a coordination game. Which equilibrium users coordinate depends on further assumptions regarding the level of fairness, possibility of redistribution and tying-of-the-hand strategies etc. However, the coordination game may also be solved with the explicit incorporation of players' expectations of the outcome.

We therefore now relax the assumption of perfect information and consider the case presented in *Section 4.1.1*. The individual actor is rational but acts on the information available to them. Each actor assigns a probability to the adoption behavior of other users in the economy based on their own information set. There is no systematic bias in the information sets in equilibrium, where expectations are in line with the actual population share outcome. However, exogenous shocks to the information sets may occur that shift the expected probabilities in a way which is random to the system. Therefore, the user must in each game act on their own subjectively assigned probabilities. This is where the tipping point analysis enters the stage, where the relative dominance of strategies depends not only of parameter values but also on the expected population shares.

4.1.3 Tipping Point in Buyer Market

To identify all dominant strategies under imperfect information we now to turn to the expected matching probabilities. By adding the respective payoffs and expected probabilities of the feasible matching scenarios, we arrive at the expected utility of each strategy from the user's point of view. This is performed for each strategy and the results are then applied to identify and analyze any tipping points in user platform adoption. Note that the use of the term "population share" in this section actually signifies *expected* population share.

Card Buyers

Buyers who adopt card only, Card Buyers, are randomly matched with the three categories of sellers with assigned probabilities $\emptyset_C^S$, $\emptyset_M^S$ and $\emptyset_{CM}^S$ respectively. The payoffs of each type of match are as presented in *Table 1* on the previous page. They therefore face an expected utility V_C^b in a given period of

$$V_C^b = E\left(U_C^b\right) = \emptyset_C^S(U_i(\alpha) - p_\alpha - c_C^b) + \emptyset_M^S(-c_c^b) + \emptyset_{CM}^S(U(\alpha) - p_\alpha - c_C^b),$$

Which rearranges to

$$V_C^b = (\emptyset_{C+M}^S + \emptyset_C^S)(U_i(\alpha) - p_\alpha - c_C^b) + \emptyset_M^S(-c_C^b).$$

Since $\emptyset_C^S + \emptyset_M^S + \emptyset_{C+M}^S = 1$, we may substitute $\emptyset_{CM}^S + \emptyset_C^S$ for $1 - \emptyset_M^S$, yielding

$$V_C^b = (1 - \emptyset_M^S)(U_i(\alpha) - p_\alpha - c_C^b) + \emptyset_M^S(-c_C^b),$$

which simplifies to

$$V_C^b = U(\alpha) - p_\alpha - c_C^b - (U(\alpha) - p_\alpha)\emptyset_M^S. \tag{1}$$

Note that the expected utility is a decreasing function of the population share of sellers that have adopted Mobile only, $\emptyset_M^S$, The expected utility for the Card Buyer is thereby $(U(\alpha) - p_\alpha - c_C^b)$ when the population share of Mobile Sellers is zero and $(-c_C^b)$ when only Mobile Sellers exist, i.e. when the population share $\emptyset_M^S = 1$. The slope of the relationship between $\emptyset_M^S$ and the expected payoff is given by $-(U(\alpha) - p_\alpha)$. The relationship is negative since the Card Buyer forgoes a transaction if matched with a Mobile Seller.

CM Buyers

Buyers who adopt both Card and Mobile, CM Buyers, are also randomly matched with sellers and face an expected utility V_{C+M}^b in a given period of

$$V_{C+M}^{b} = E\left(U_{C+M}^{b}\right) = \emptyset_{C}^{S}\left(U(\alpha) - p_{\alpha} - c_{C}^{b} - c_{M}^{b}\right) + \emptyset_{M}^{S}\left(U(\alpha) - p_{\alpha} - c_{C}^{b} - c_{M}^{b}\right) + \emptyset_{CM}^{S}\left(U(\alpha) - p_{\alpha} - c_{C}^{b} - c_{M}^{b}\right).$$

This simplifies to

$$V_{C+M}^{b} = U(\alpha) - p_{\alpha} - c_{C}^{b} - c_{M}^{b}, \qquad (2)$$

which shows that the expected utility is invariant to the platform population shares of sellers. This reflects the fact that the CM Buyer can make a transaction with any seller and therefore faces the same payoff regardless of matching outcome.

Tipping Point

Figure 1 below provides a graphical illustration of the expected utilities of Card Buyers and CM Buyers (Equations (1) and (2)), plotted against the expected share of the population of sellers that has adopted Mobile technology only, $\emptyset_{M}^{S}$.

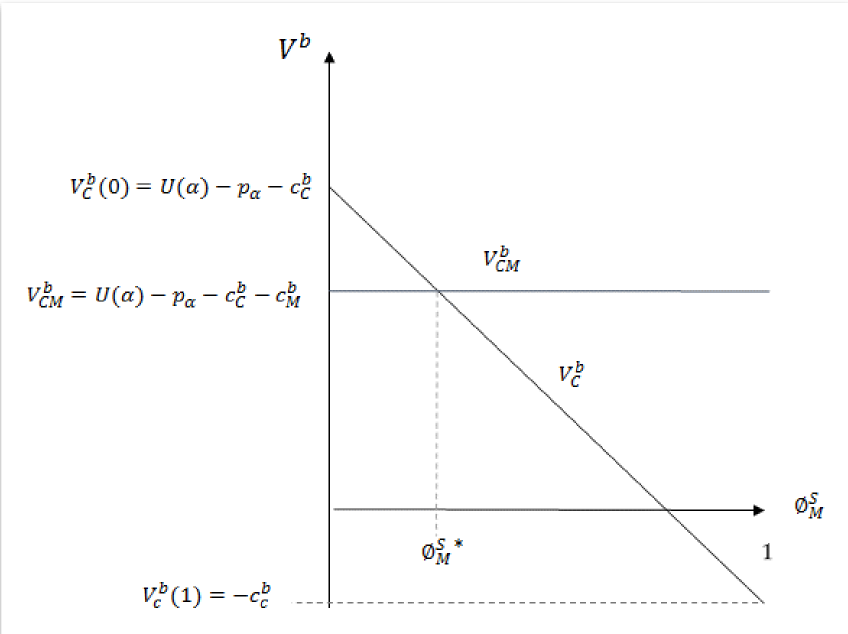

Figure 1. Expected payoffs from the available strategies to buyers in the basic model

As evident from the illustration in *Figure 1* above, there exists an unstable equilibrium, or tipping point, at sellers' Mobile adoption rate $\emptyset_{M}^{S\,*}$, at which buyers are indifferent between adopting Card only or Card and Mobile technology. At all other points $\emptyset_{M}^{S} \neq \emptyset_{M}^{S\,*}$, one platform yields a strictly higher expected utility to the buyer than the other. For lower values of Mobile Sellers' population share, $\emptyset_{M}^{S} < \emptyset_{M}^{S\,*}$, it is a dominant strategy for buyers to adopt card only. For higher values of this population share, $\emptyset_M^S > {\emptyset_M^S}^*$, it is a dominant strategy for buyers to adopt both card and mobile technology.

The tipping point ${\emptyset_C^S}^*$ occurs when users are indifferent between the strategies, i.e. when $V_C^b = V_{C+M}^b$. Combining equations (1) and (2), this occurs when

$$U(\alpha) - p_\alpha - c_C^b - (U(\alpha) - p_\alpha)\emptyset_M^S = U(\alpha) - c_C^b - c_M^b - p_\alpha,$$

or, simplified, at point

$${\emptyset_M^S}^* = \frac{c_M^b}{U(\alpha) - p_\alpha}. \qquad (3)$$

Proposition 1. *There exists an unstable equilibrium* ${\emptyset_M^S}^*$ *in the Buyer market which is a tipping point. This point occurs at*

$${\emptyset_M^S}^* = \frac{c_M^b}{U(\alpha) - p_\alpha},$$

at which buyers are indifferent between adopting Card only and Card and Mobile. For lower values $\emptyset_M^S < {\emptyset_M^S}^*$*, it is a dominant strategy for buyers to adopt Card only, and for higher values* $\emptyset_M^S > {\emptyset_M^S}^*$ *the strategy to adopt Card and Mobile dominates.*

View *Appendix III.I* for further derivation of *Proposition 1*.

Note also that for there to exist a tipping point, each strategy needs to be weakly dominant for some value of $\emptyset_M^S$. Therefore, it needs to hold that $E\left(U_j^b\right) \geq 0$; so for the Card Buyer, $V_C^b = U(\alpha) - p_\alpha - c_c^b - (U(\alpha) - p_\alpha)\emptyset_m^s > 0$ and for the CM Buyer, $V_M^b = U(\alpha) - c_c^b - c_m^b - p_\alpha > 0$.

Having identified the tipping point ${\emptyset_M^S}^*$, now consider the effect of changes in parameter values on the value of ${\emptyset_M^S}^*$. A parameter which has a positive relationship with the value of the tipping point makes adopting the Mobile platform less attractive to the user, which means more sellers must be expected to adopt Mobile before it becomes a dominant strategy for the buyer to do so as well.

The parameters that have an effect on the location of tipping point ${\emptyset_M^S}^*$ are identified in Equation (3). These are constituted by the cost of the mobile platform to the buyer, c_M^b; the value of the good to the buyer, $U(\alpha)$; and the price charged for the good, p_α.

The results for the three parameters are summarized in *Proposition 2* below, and derivations are found in A*ppendix III.I.*

Proposition 2.

(i) The *cost for the buyer to adopt mobile technology*, c_M^b, has a **positive** relationship, ceteris paribus, with the location of the tipping point ${\emptyset_M^S}^*$.

(ii) The *value of the good*, $U(\alpha)$, has a **negative** relationship, ceteris paribus, with the location of the tipping point ${\emptyset_M^S}^*$.

(iii) The *price of the good*, p_α, has a **positive** relationship, ceteris paribus, with the location of the tipping point ${\emptyset_M^S}^*$.

From *Proposition 2(i)* we may first note the intuitive result that a higher fixed cost of adoption makes the Mobile platform less attractive to the buyer, and more sellers must be expected to adopt the Mobile platform before it becomes profitable for the buyer to do so too. The result in *Proposition 2(ii)* shows that if the good to be transacted holds a higher value to the buyer, it is more attractive to adopt both Mobile and Card platform since this ensures that they do not forego the transaction. Lastly, *Proposition 2(iii)* shows that higher priced goods to be transacted make adopting both platforms relatively less attractive. This is true since a higher price means lower surplus from the transaction to the buyer. In fact, *Proposition 2(ii-iii)* could be summarized in that if the transaction may yield a higher surplus, adopting both platform is more attractive since this ensures they do not miss out on the transaction.

4.1.4 Tipping Point in Seller Market

Having identified the tipping point in the buyers' market, the expected profits of sellers are now examined. As in the calculation for the Buyer market, we add the respective payoffs and assigned probabilities of the feasible matching scenarios to arrive at the expected payoff of each strategy to the seller.

Card Sellers

Sellers accepting Card payment only, Card Sellers, are randomly matched with the two types of buyers with assigned probabilities $\emptyset_C^B$ and $\emptyset_{CM}^B$ respectively, with resulting payoffs as presented in *Table 1*. The expected profit $E(\pi_C^s)$ for the Card Seller is given by

$$E(\pi_C^s) = \emptyset_C^B(p_\alpha - c_C^s - c_\alpha) + \emptyset_{CM}^B(p_\alpha - c_C^s - c_\alpha).$$

Since $\emptyset_C^B + \emptyset_{C+M}^B = 1$, this expression rewrites as

$$E(\pi_C^s) = p_\alpha - c_C^s - c_\alpha. \tag{4}$$

This implies a constant payoff, independent of buyers' technology adoption choice, which makes intuitive sense since the Card Seller may transact with any buyer due to the fact that both types of buyers (Card Buyers and CM Buyers) have the Card platform available.

CM Seller

The seller who accepts both modes of payment, CM Seller, will be able to make a transaction with buyers using any platform. The expected profit $E(\pi_{CM}^s)$ of CM Sellers is given by

$$E(\pi_{CM}^s) = \emptyset_C^B(p_\alpha - c_C^s - c_M^s - c_\alpha) + \emptyset_{CM}^B(p_\alpha - c_C^s - c_M^s - c_\alpha),$$

which, due to the necessary property that $\emptyset_C^B + \emptyset_{CM}^B = 1$, simplifies to

$$E(\pi_{C+M}^s) = p_\alpha - c_C^s - c_M^s - c_\alpha. \tag{5}$$

As seen above, the expected profit function for the seller who accepts both payment technologies is constant, i.e. independent of the adoption strategies of buyers. Additionally, it is strictly lower than the expected payoffs of the Card Seller, since $p_\alpha - c_C^s - c_M^s - c_\alpha < p_\alpha - c_C^s - c_\alpha$.

Mobile Sellers

Sellers who accept mobile only, Mobile Sellers, may do business only through the Mobile platform and thereby only with CM Buyers. The Mobile Seller's expected profit $E(\pi_M^s)$ is given by

$$E(\pi_M^s) = \emptyset_C^B(-c_M^s) + \emptyset_{CM}^B(p_\alpha - c_M^s - c_\alpha).$$

Using $\emptyset_C^B + \emptyset_{CM}^B = 1$, this expression may be rewritten as

$$E(\pi_M^s) = -c_M^s + (p_\alpha - c_\alpha)\emptyset_{CM}^B. \tag{6}$$

Equation (6) above shows that the expected profit for the Mobile Seller amounts to $-c_m^s$ when no CM Buyers exist, and the expected profit increases with a factor of $p_\alpha - c_\alpha$ when all buyers are CM Buyers.

Tipping Point

Figure 2 below provides a graphical representation of the expected utilities of three strategies of Card; Card and Mobile; and Mobile respectively, based on equations (4), (5) and (6).

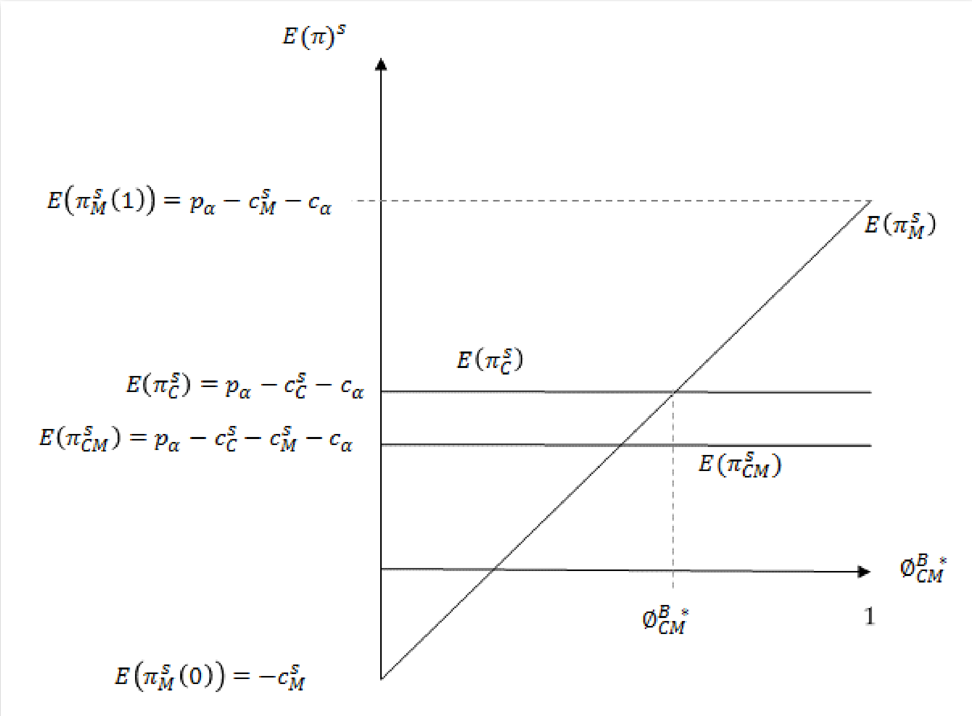

Figure 2. Expected payoffs from the available strategies to sellers in the basic model

Note that Figure 2 above displays the case when $c_M^s < c_C^s$. If $c_M^s \geq c_C^s$, there will exist no values of $\emptyset_{CM}^B$ for which it is a dominant strategy to accept mobile only.

Proposition 3.

(i) *In order for the tipping point to exist, it must hold that* $c_M^s < c_C^s$. *If this does not hold, there are no values of* $\emptyset_{CM}^B \in [0,1]$ *at which adopting Mobile is a dominant strategy.*

(ii) *It holds for all values of* $\emptyset_{CM}^B \in [0,1]$ *that* $E(\pi_C^s) > E(\pi_{CM}^s)$, *since* $c_M^s > 0$. *We can thereby assert that there exists no point at which accepting both card and mobile is a dominant strategy for sellers, and this category is therefore always empty.*

Proposition 3 highlights two important model implications. First, the fixed cost of the Mobile platform needs to be lower than the cost for the Card platform. If this does not hold, sellers never have an incentive to deviate from the strategy of adopting Card only since the Card Sellers may make transactions with all types of buyers. Second, sellers in this model will never choose to adopt both Card and Mobile. Since sellers accepting cards may trade with all buyers, without the additional fixed cost of adopting the mobile platform, accepting only cards is always strictly better than accepting card and mobile.

Adopting Mobile only is a dominant strategy when a sufficiently large proportion of buyers are expected to be CM Buyers: when $\emptyset_{CM}^{B} > {\emptyset_{CM}^{B}}^{*}$. At point ${\emptyset_{CM}^{B}}^{*}$, sellers are indifferent between the strategies of accepting Card only and Mobile only. For lower population shares of CM Buyers, $\emptyset_{CM}^{B} < {\emptyset_{CM}^{B}}^{*}$, accepting Card only is a dominant strategy.

An unstable equilibrium, ${\emptyset_{CM}^{B}}^{*}$, occurs when buyers are indifferent between the strategies, i.e. $E(\pi_C^s) = E(\pi_M^s)$. Using equations (4) and (6), this is expressed as

$$-c_M^s + (p_\alpha - c_\alpha)\emptyset_{CM}^{B} = p_\alpha - c_C^s - c_\alpha.$$

This identifies the unstable equilibrium at

$${\emptyset_{CM}^{B}}^{*} = 1 - \frac{c_C^s - c_M^s}{p_\alpha - c_\alpha}. \tag{7}$$

Proposition 4. *The unstable equilibrium* ${\emptyset_{CM}^{B}}^{*}$ *is a tipping point and occurs at*

$${\emptyset_{CM}^{B}}^{*} = 1 - \frac{c_C^s - c_M^s}{p_\alpha - c_\alpha},$$

at which sellers are indifferent between adopting Card only and Mobile only. For lower values $\emptyset_{CM}^{B} < {\emptyset_{CM}^{B}}^{*}$, *it is a dominant strategy for buyers to adopt Card only, and for higher values* $\emptyset_{CM}^{B} > {\emptyset_{CM}^{B}}^{*}$ *the strategy to adopt Mobile only dominates.*

View *Appendix III.I* for derivations of *Proposition 4*.

Next, consider the effect of changes in parameter values on the location of the tipping point ${\emptyset_{CM}^{B}}^{*}$. The parameters that have an effect on the location of tipping point ${\emptyset_{CM}^{B}}^{*}$ are evident from *Equation (7)*. These are constituted by the cost of the Card platform to the seller, c_C^s; the cost of the Mobile platform to the seller, c_M^s; the price of the good to be transacted, p_α; and the cost of the good to the seller, c_α.

Remember parameters with a positive relationship with the location of the tipping point are factors that make the strategy of adopting Mobile less attractive in relation to the strategy of adopting Card.

Proposition 5.

(i) The *cost for the seller to adopt Card technology*, c_C^S, has a **negative** relationship, ceteris paribus, with the location of the tipping point ${\emptyset_{CM}^B}^*$.

(ii) The *cost for the seller to adopt Mobile technology*, c_M^S, has a **positive** relationship, ceteris paribus, with the location of the tipping point ${\emptyset_{CM}^B}^*$

(iii) The *price of the good*, p_α, has a **positive** relationship, ceteris paribus, with the location of the tipping point ${\emptyset_{CM}^B}^*$.

(iv) The *cost of the good*, c_α, has a **negative** relationship, ceteris paribus, with the location of the tipping point ${\emptyset_{CM}^B}^*$.

Derivations for *Proposition 5* are found in *Appendix III.I.*

From *Proposition 5(i)-(ii)*, note the intuitive result that the Mobile platform will be more attractive if the Card platform has a higher fixed cost and the Mobile platform has a lower fixed cost. *Proposition 5(iii)-(iv)* show that adopting Mobile only is less attractive for goods with a higher price and a lower cost to the seller. The rationale behind this is that by adopting Mobile only, the seller risks meting a seller who does not have the Mobile platform (i.e. a Card Buyer), at which point they would be unable to make a transaction. This opportunity cost is higher for transactions of higher gross value, i.e. price minus cost of the good. The Card Seller faces no such opportunity cost since they may transact with all buyers.

4.1.5 General Equilibria in User Markets

The two weakly dominant strategies available to each user yield two unique general static equilibria for the user markets in this model. These are given by strategy sets (C, C) and (CM, M) respectively. At these points, no single user has any incentive to deviate from their platform adoption choice.

Proposition 6. *One static equilibrium exists where all buyers hold card only and all sellers accept card only, i.e. at* $(\emptyset_{CM}^B = 0, \emptyset_M^S = 0)$ *. A second equilibrium exists where all buyers hold both card and mobile and all sellers accept mobile payment only, i.e. at* $(\emptyset_{CM}^B = 1, \emptyset_M^S = 1)$.

Since total cost to the users is higher for the mobile platform than for the card platform, ending up in equilibrium (M, CM) is inefficient to the buyer, while (C, C) is inefficient to the seller. Which equilibrium is realized will be determined by the beliefs of the population regarding the relative dominance of the platforms, which are given by users' exogenously given information sets.

4.2 Extended Model (Fixed and Variable Costs)

The extended model has identical design properties to the basic model, with the exception of allowing for a more complex platform cost structure with additional constraints imposed on the relative values of both fixed and variable costs. The reader should note that this extension provides a setting which is more complex and also more realistic than the basic model. The network mechanisms inherent to the expected payoffs that were evaluated in the basic model are at work here in a similar way, but present somewhat differently due to the inclusion of variable costs. As will be shown, additional dominant strategies may now be considered that did not exist in the basic case.

4.2.1 Design

In this extension, we introduce the addition of a variable cost of platform use that is proportional to the transaction value. The individual user $i \in \{B, S\}$ now faces two distinct types of costs in the adoption and use of any payment platform $j \in \{C, M\}$. First, the user faces a fixed cost per period $c_j^i > 0$ of having each technology available for use and second, a variable cost of use $f_j^i \in (0,1]$ proportional to any amount transacted.

The new technology, Mobile, has a strictly higher fixed cost of adoption than the old technology, Card. This property does not require any additional assumptions for buyers, who face asymmetrical backwards complementarity between card and mobile adoption. Due to the adoption complementarity, the fixed cost to buyers of adopting mobile technology is $c_C^b + c_M^b$ which by construction is larger than the fixed cost of the card platform alone, $c_C^b + c_M^b > c_C^b$. For sellers, the condition is imposed that $c_C^s < c_M^s$. Additionally, the new mobile technology has a strictly lower variable cost of use $f_M^i < f_C^i$. As in the basic model, the assigned probability that a user population i has adopted platform j is denoted by $\emptyset_i^i$.

Note that in the extended model, the buyer faces two choices: an ex-ante choice of technology adoption and an ex-post choice of transaction technology when the buyer and seller hold compatible platforms. In this framework, the user who has adopted both card and mobile technology always wishes to transact through Mobile if the option is available, due to its lower variable cost. Any fixed costs are at that point viewed as sunk.

For the seller there exists, similar to the basic model, three different fixed costs depending on platform adoption choice. For adoption Card only the fixed cost is c_C^s, for both Card and Mobile the cost is c_C^s+c_M^s and for Mobile only the cost is c_M^s. If a transaction takes place, in this extended model, the seller needs also to pay a fee proportional to the price. If a seller transacts a good using Card, the income for the seller is the price of the good less the fees $(1 - f_C^s)p_\alpha$. If a seller transacts a good using Mobile, the seller's income is the price of the good less the fees $(1 - f_M^s)p_\alpha$. The seller also needs to pay the cost of the good c_α, however, only if a transaction occurs.

4.2.2 Payoffs in Feasible Matching Outcomes

As in the Basic model, first consider the possible outcomes of the matching game. User pairs who have adopted incompatible technology will be unable to make a transaction but the fixed cost of platform adoption has already been incurred. Matched users who have adopted compatible platforms will make a transaction, assuming that the transaction itself yields a payoff of zero or higher to the respective parties. If there is a possibility for the users to transact through the Mobile platform once the matching has been made, they will prefer this over the Card platform.

The matches that may occur between individual buyers and sellers and the corresponding payoffs y_k^i to the users are summarized in *Table 2* below. Also in this extended model, the payoff y_k^i is determined by the fixed cost incurred by the strategy and the transaction surplus. However, in this setting the transaction surplus also depends on the variable cost of platform use. Therefore, the total surplus from an ex-post transaction is given by the valuation of the good $U(\alpha)$ minus price and variable cost paid $(1 + f_j^b)p_\alpha$ to the buyer; and by price minus variable cost $(1 - f_j^b)p_\alpha$ minus the cost of the good c_α to the seller. From the point of view of the seller, buyers play the available strategies with probabilities $\begin{pmatrix} \emptyset_C^B \\ \emptyset_{CM}^B \end{pmatrix}$. From the point of view of the buyer, sellers play strategies with probabilities $(\emptyset_C^S, \emptyset_{CM}^S, \emptyset_M^S)$.

Table 2. Strategy payoff matrix for individual buyers and sellers in the basic model

		SELLER		
		Card Only (C)	**Card and Mobile (CM)**	**Mobile Only (M)**
BUYER	**Card Only (C)**	$U(\alpha) - c_C^b - (1 + f_C^b)p_\alpha$, $(1 - f_C^s)p_\alpha - c_C^s - c_\alpha$	$U(\alpha) - c_C^b - (1 + f_C^b)p_\alpha$, $(1 - f_C^s)p_\alpha - c_C^s - c_M^s - c_\alpha$	$-c_C^b$, $-c_M^s$
	Card and Mobile (CM)	$U(\alpha) - c_C^b - c_M^b - (1 + f_C^b)p_\alpha$, $(1 - f_C^s)p_\alpha - c_C^s - c_\alpha$	$U(\alpha) - c_C^b - c_M^b - (1 + f_M^b)p_\alpha$, $(1 - f_M^s)p_\alpha - c_C^s - c_M^s - c_\alpha$	$U(\alpha) - c_C^b - c_M^b - (1 + f_M^b)p_\alpha$, $(1 - f_M^s)p_\alpha - c_M^s - c_\alpha$

First consider the outcome of this game under the assumption of perfect information. From the payoffs in *Table 2*, we may conclude that also in this extended model there always exists a Nash equilibrium at (C, C) and population shares $\binom{1}{0}$, $(1{,}0{,}0)$. Additionally, if the total cost of platform is lower for Mobile than for Card, $f_M^s p_\alpha + c_M^s > f_C^s p_\alpha + c_C^s$, there exists an equilibrium at strategy set (CM, M) and population shares $\binom{0}{1}$, $(0{,}0{,}1)$. If the variable cost of the Mobile platform to the buyer is low enough to outweigh its fixed cost, the equilibrium at (CM, M) may be efficient for both sides of the market. If it is not, the buyer would prefer (C, C) while the seller prefers (CM, M). In summary, depending on the parameter values this may or may not constitute a coordination game.

As with the basic model, we will now relax the assumption of perfect information and allow for the possibility of coordination through the incorporation of user beliefs. As previously explained, each actor assigns probabilities to the adoption behavior of other users in the economy based on their own information set. Based on these subjective probabilities, they make their own adoption choice.

4.2.3 Tipping Points in Buyer Market

Now, turn to the expected utilities of buyers from the strategic options available. By adding the respective payoffs and assigned probabilities of the feasible matching scenarios, we arrive at the expected utility of each strategy to the user. The expected utility is explicitly stated as a function of the expected platform adoption shares of sellers. Again, note that population shares should be read as the expected outcome.

Card Buyer

The Card Buyer, who adopts Card only, will be able to make a transaction with both Card and CM Sellers, but forgoes this opportunity if matched with a Mobile Seller. The expected payoff V_C^b of the Card Buyer is given by

$$V_C^b = E\left(U_C^b\right) = \emptyset_C^S\left(U(\alpha) - c_C^b - \left(1 + f_C^b\right)p_\alpha\right) + \emptyset_{CM}^S\left(U(\alpha) - c_C^b - (1 + f_C^b)p_\alpha\right) + \emptyset_M^S\left(-c_C^b\right).$$

Substituting $\emptyset_{CM}^S$ with $(1 - \emptyset_C^S - \emptyset_M^S)$, this expression rewrites to

$$V_C^b = \emptyset_C^S\left(U(\alpha) - c_C^b - \left(1 + f_C^b\right)p_\alpha\right) + (1 - \emptyset_C^S - \emptyset_M^S)\left(U(\alpha) - c_C^b - (1 + f_C^b)p_\alpha\right) + \emptyset_M^S\left(-c_C^b\right),$$

which through simplification yields

$$V_C^b = U(\alpha) - c_C^b - (1 + f_C^b)p_\alpha - \left(U(\alpha) - (1 + f_C^b)p_\alpha\right)\emptyset_M^S. \tag{8}$$

Equation (8) above shows that the expected utility of the Card Buyer is negatively correlated with the share of the population of sellers who have adopted Mobile only, $\emptyset_M^S$. The expected utility for the Card Buyer when all sellers adopt Mobile only, i.e. when $\emptyset_M^S = 0$, is $U(\alpha) - c_C^b - (1 + f_C^b)p_\alpha$ and when $\emptyset_M^S = 1$, the expected utility to the Card Buyer is $-c_C^b$. The utility function is graphically presented in *Figure 3* below.

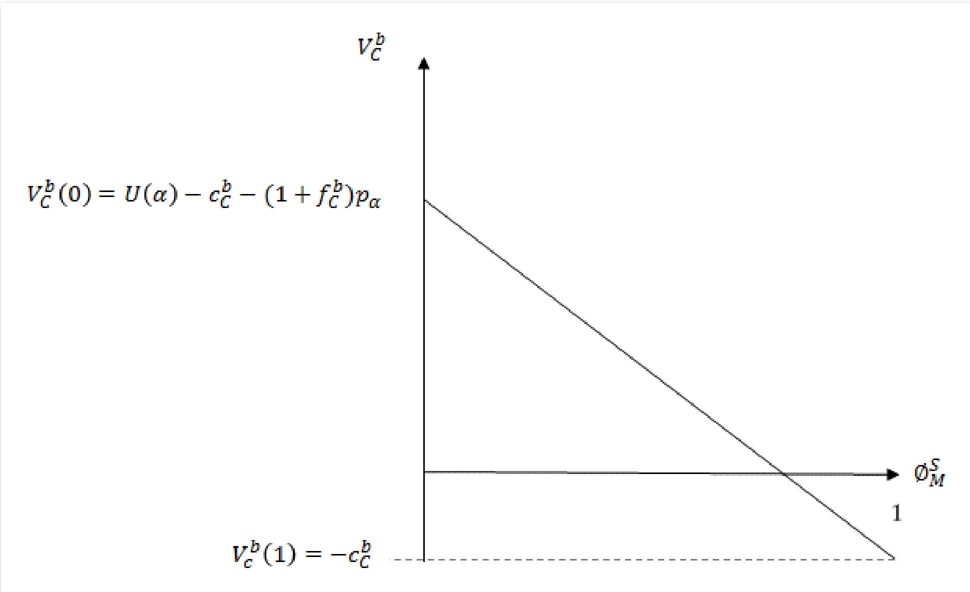

Figure 3. Expected profits of Card Buyers, extended model

The negative relationship between expected utility and the population share of Mobile Sellers is due to the inability of Card Buyers to make transactions with Mobile Sellers. The higher the probability of being matched with a Mobile Seller, the higher the probability of missing out on the transaction in that period. The expression $U(\alpha) - (1 + f_C^b)p_\alpha$ gives the value of good α to the buyer minus the total cost of obtaining that good (note that the fixed costs c_j^b are irrelevant since they are made ex-ante and do not influence the payoff of a transaction made ex-post). The slope of the line in equation (8) thereby represents exactly the possible surplus to be lost if no transaction can occur: $-\left(U(\alpha) - (1 + f_C^b)p_\alpha\right)$.

CM Buyer

Next, consider the buyer who adopts both Card and Mobile technology, i.e. the CM Buyer. The CM Buyer is able to make a transaction with any type of seller and will prefer to pay through the

Mobile rather than Card platform if given the choice due to the lower variable cost. The expected utility for the CM Buyer is given by

$$V_{CM}^b = E\left(U_{CM}^b\right) = \emptyset_C^S\left(U(\alpha) - c_C^b - c_M^b - \left(1 + f_C^b\right)p_\alpha\right) + (\emptyset_{CM}^S)\left(U(\alpha) - c_C^b - c_M^b - (1 + f_M^b)p_\alpha\right) + \emptyset_M^S\left(U(\alpha) - c_C^b - c_M^b - (1 + f_M^b)p_\alpha\right)\emptyset_M^S.$$

Substituting $(1 - \emptyset_C^S - \emptyset_M^S)$ for $\emptyset_{CM}^S$ gives

$$V_{CM}^b = \emptyset_C^S\left(U(\alpha) - c_C^b - c_M^b - \left(1 + f_C^b\right)p_\alpha\right) + (1 - \emptyset_C^S - \emptyset_M^S)\left(U(\alpha) - c_C^b - c_M^b - (1 + f_M^b)p_\alpha\right) + \emptyset_M^S\left(U(\alpha) - c_C^b - c_M^b - (1 + f_M^b)p_\alpha\right).$$

Simplification then yields

$$V_{CM}^b = U(\alpha) - c_C^b - c_M^b - \left(1 + f_M^b\right)p_\alpha - \left(f_C^b - f_M^b\right)p_\alpha \emptyset_C^S. \tag{9}$$

Figure 4 below shows a stylized diagram of the expected utility. If there are no Card sellers in the period, the expected utility for the CM Buyer amounts to $U(\alpha) - c_c^b - c_m^b - (1 + f_m^b)p_\alpha$. If there exists only Card sellers, i.e. $\emptyset_C^S = 0$, the expected payoff to the CM Buyer is $U(\alpha) - c_c^b - c_m^b - (1 + f_c^b)p_\alpha$. The slope of the function is thereby given by $-(f_c^b - f_m^b)p_\alpha$. The slope expresses the possible savings that the CM Buyer misses out on when no Mobile Sellers exist. The savings consist of the lower amount paid in transaction costs if using Mobile rather than Card.

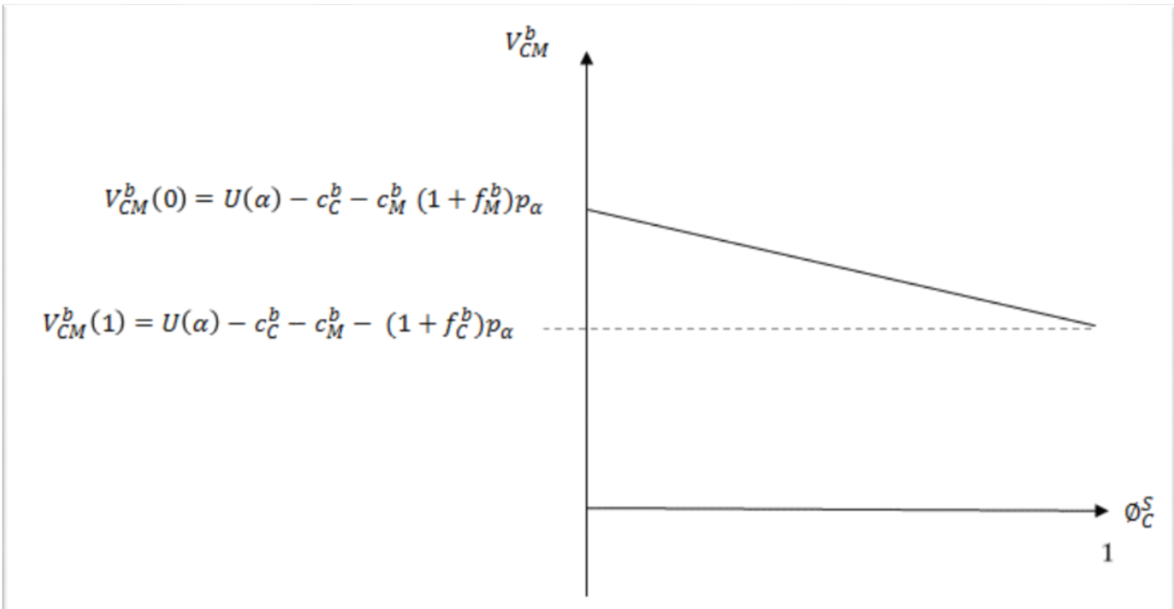

Figure 4. Expected payoffs of CM Buyers, extended model

Tipping Point

When comparing the expected payoffs of Card Buyers and CM Buyers, note that since the expected utilities of the respective buyers are plotted against different explanatory variables ($\emptyset_M^S$ and $\emptyset_C^S$ respectively), the feasible combinations and associated expected utilities occupy a three-dimensional space. Applying the restrictions that $0 \geq \emptyset_j^i \geq 0$ and $\emptyset_C^S + \emptyset_{CM}^S + \emptyset_M^S = 1$, we may compare these in a three-dimensional model. A stylized representation of this is shown in *Figure 5* below, where the utility V_j^b of the respective buyer varies with the population shares of both Card Sellers and Mobile Sellers, i.e. $\emptyset_C^S$ and $\emptyset_M^S$. The line where fields cross in *Figure 5* represents all feasible combinations of the population shares which constitute tipping points for the buyer's platform adoption choice.

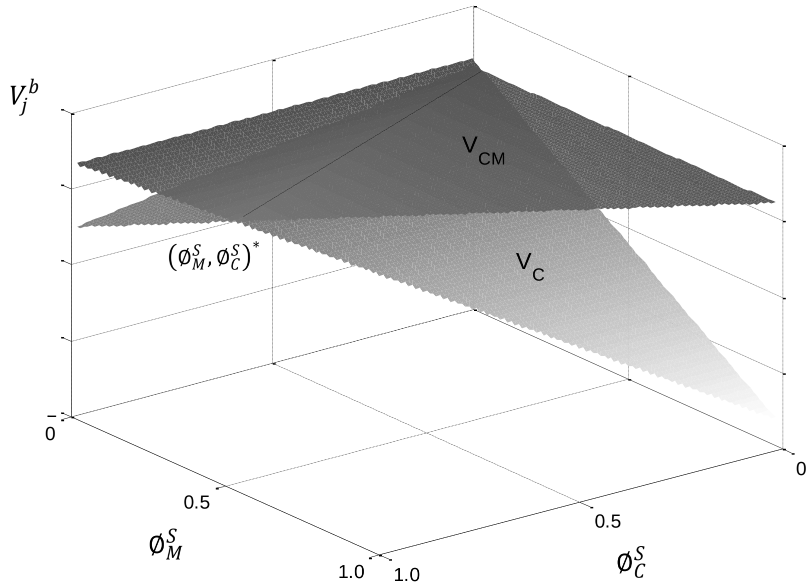

Figure 5. Expected payoffs of Card Buyers and CM Buyers, for all feasible combinations of $\emptyset_C^S$ and $\emptyset_M^S$

Next, formally define the unstable equilibria of buyers' platform adoption choice. Buyers are indifferent between platforms in their ex-ante adoption choice when $V_C^b = V_{C+M}^b$. Using *Equation (8)* and *Equation (9)*, this is expressed as

$$U(\alpha) - c_C^b - \left(1 + f_C^b\right)p_\alpha - \left(U(\alpha) - \left(1 + f_C^b\right)p_\alpha\right)\emptyset_M^S = U(\alpha) - c_C^b - c_M^b - \left(1 + f_M^b\right)p_\alpha - \left(f_C^b - f_M^b\right)p_\alpha \emptyset_C^S.$$

Solving for the critical value of proportion of Mobile Sellers as a function of Card Sellers gives

$$\emptyset_M^{S*} = \frac{c_M^b + (1+f_M^b)p_\alpha + (f_C^b - f_M^b)p_\alpha \emptyset_C^{S*} - (1+f_C^b)p_\alpha}{U(\alpha) - (1+f_C^b)p_\alpha}.$$

Again, we note that this results in a line of indifference rather than one single point as in the basic model. Further simplification gives us an expression for the set of $\emptyset_M^S$and $\emptyset_C^S$ at which tipping points occur:

$$\emptyset_M^{S*} = \frac{c_M^b - p_\alpha(f_C^b - f_M^b)(1 - \emptyset_C^S)}{U(\alpha) - (1 + f_C^b)p_\alpha} \tag{10}$$

Proposition 7. *There exists a set of unstable equilibria which are tipping points at* ${\emptyset_M^S}^*$. *These occur at*

$$\emptyset_M^{S*} = \frac{c_M^b - (f_C^b - f_M^b)p_\alpha(1 - \emptyset_C^S)}{U(\alpha) - (1+f_C^b)p_\alpha},$$

at which buyers are indifferent between adopting Card only and Card and Mobile. For lower values $\emptyset_M^S < \emptyset_M^{S*}$, *it is a dominant strategy for buyers to adopt Card only, and for higher values* $\emptyset_M^S > \emptyset_M^{S*}$ *the strategy to adopt Card and Mobile dominates.*

See derivations for *Proposition 7* in *Appendix III.II.*

The points which may be characterized as tipping points ${\emptyset_M^S}^*$has now been identified and next, the effects of changes in parameter values on the location of ${\emptyset_M^S}^*$are explored. The parameters that have an effect on the location of tipping point ${\emptyset_M^S}^*$are identified in *Equation (10).* These are constituted by the cost of the mobile platform to the buyer, c_M^b; the variable fee for card usage for the buyer f_C^b, the variable fee for mobile usage for the buyer f_M^b, the price charged for the good f_C^b, the population share of card users in the sellers' market $\emptyset_C^{S*}$, the utility for the buyer receives for the good $U(\alpha)$. Again, note that a positive relationship between the location of the tipping point and the parameter implies that an increase in the parameter in question makes it less attractive to adopt both Card and Mobile as opposed to Mobile only.

Proposition 8.

(i) The *fixed cost for the buyer to adopt Mobile technology*, c_M^b, has a **positive** ceteris paribus relationship with the location of the tipping point ${\emptyset_M^S}^*$.

(ii) The *variable cost for the buyer of Card platform use*, f_C^b, has a **negative** ceteris paribus relationship with the location of the tipping point ${\emptyset_M^S}^*$.[10]

(iii) The *variable cost for the buyer of Mobile platform use*, f_M^b, has a **positive** ceteris paribus relationship with the location of the tipping point ${\emptyset_M^S}^*$.

(iv) The *price of the good*, p_α, has a **positive** ceteris paribus relationship with the location of the tipping point ${\emptyset_M^S}^*$ when $c_M^b\left(1+f_C^b\right) > U(\alpha)(1-\emptyset_C^{S*})(f_M^b - f_C^b)$, and a **negative** relationship when $c_M^b\left(1+f_C^b\right) < U(\alpha)(1-\emptyset_C^{S*})(f_M^b - f_C^b)$.

(v) *The share of sellers adopting card only,* $\emptyset_C^{S*}$, has a **positive** ceteris paribus relationship with the location of the tipping point ${\emptyset_M^S}^*$.

(vi) The *value of the good*, $U(\alpha)$, has a **positive** ceteris paribus relationship with the location of the tipping point ${\emptyset_M^S}^*$ when $c_M^b > (1-\emptyset_C^{S*})(f_M^b - f_C^b)p_\alpha$ and a **negative** relationship when $c_M^b < (1-\emptyset_C^{S*})(f_M^b - f_C^b)p_\alpha$.

See *Appendix III.II* for derivations of *Proposition 8*.

First, note some intuitive results presented in *Proposition 8* above. *Proposition 8(i)* and *8(iii)* imply that a higher fixed cost of Mobile adoption as well as a higher variable cost of Mobile platform use make it less attractive to adopt the Mobile platform on top of the Card platform. As shown in *Proposition 8(ii)*, a higher variable cost of the Card platform on the other hand makes the Mobile platform more attractive. Also a higher share of sellers using Card only, $\emptyset_C^{S*}$, makes the Mobile platform less attractive as shown in *Proposition 8(v)*, which due to the inability of the CM Buyer to transact with this seller using the Mobile platform, leaving only the more expensive Card platform.

The implications of *Proposition 8(iv)* and *8(vi)* may require somewhat more extensive explanation. A higher price of the good to be transacted has the negative relationship with the tipping point that we saw in the Basic model only under the condition that $c_M^b\left(1+f_C^b\right) < U(\alpha)(1-$

[10]Assuming $(1-\emptyset_C^{S*})(U(\alpha)-(1+f_M^b)p_\alpha)-c_M^b > 0$, which is needed for any buyers to wish to adopt Mobile. If this does not hold, no tipping point exists in the feasible population share interval $0 \leq \emptyset_M^S \leq 1$ since adopting Mobile then always yields a negative utility.

$\emptyset_C^{S*})(f_M^b - f_C^b)$. The reason for this is that there are two counteracting forces present. The first, which makes adopting the Mobile platform *less* attractive for higher priced goods, is that a higher price implies a higher cost of the transaction and thus a lower surplus to be gained from a transaction. A buyer who does not adopt the Mobile platform risks meeting a Mobile Seller where they are unable to make a transaction, but this opportunity cost is lower for higher priced goods due to the lower surplus. The second force, which makes adopting the Mobile platform *more* attractive for higher priced goods, is the lower, price-proportional transaction cost when using Mobile as opposed to Card. These forces may balance in different ways depending on the parameters. A similar argument but with effects in the opposite direction is applicable to the value $U(\alpha)$ that the buyer assigns to the good to be transacted.

4.2.4 Tipping Point in Seller Market

Now move on to examine the strategic behavior of sellers in the extended model. Again, add the respective payoffs and assigned probabilities of the feasible matching scenarios that were identified in *Table 2* to arrive at the expected utility of each strategy. The expected utility is explicitly stated as a function of the expected platform adoption choices of buyers.

Card Seller

The Card Seller adopts card only and may serve both Card and CM Buyers through the Card platform. The profit of this seller is therefore invariant to the expected platform adoption rates of buyers $\emptyset_j^b$. The expected profit $E(\pi_C^s)$ for this seller is given by

$$E(\pi_C^s) = (1 - f_C^s)p_\alpha - c_C^s - c_\alpha. \qquad (11)$$

Mobile Seller

The Mobile Seller accepts mobile payments exclusively and can only serve CM Buyers. In any other matching, this seller forgoes a possible transaction. The expected profit $E(\pi_M^s)$ for this seller is[11]

$$\begin{aligned} E(\pi_M^s) &= (1 - \emptyset_{CM}^B)(-c_M^s) + \emptyset_{CM}^B\big((1 - f_M^s)p_\alpha - c_M^s - c_\alpha\big) \\ &= -c_M^s + \big((1 - f_M^s)p_\alpha - c_\alpha\big)\emptyset_{CM}^B. \qquad (12) \end{aligned}$$

[11] $E(\pi_M^s) = (1 - \emptyset_{C+M}^B)(-c_M^s) + \emptyset_{C+M}^B\big((1 - f_M^s)p_\alpha - c_M^s - c_\alpha\big) = -c_M^s + c_M^s\emptyset_{C+M}^B + (1 - f_M^s)p_\alpha\emptyset_{C+M}^B - c_M^s\emptyset_{C+M}^B - c_\alpha\emptyset_{C+M}^B = ((1 - f_M^s)p_\alpha - c_\alpha)\emptyset_{C+M}^B - c_M^s$

In a scenario where all buyers have adopted Mobile as well as Card, i.e. when $\emptyset_{CM}^{B} = 1$, the Mobile Seller has an expected profit of $(1 - f_{M}^{s})p_{\alpha} - c_{\alpha}$. When there on the contrary exist no such buyers, the expected profit amounts to $-c_{M}^{s}$.

CM Seller

Moving on to the CM Seller, we note that sellers in this category can serve all buyers. Card Buyers will use card in the transaction and CM Buyers use the mobile platform due to its lower transaction cost. The expected profit $E(\pi_{CM}^{s})$ for the CM Seller is given by[12]

$$E(\pi_{CM}^{s}) = (1 - \emptyset_{CM}^{B})\big((1 - f_{C}^{s})p_{\alpha} - c_{C}^{s} - c_{M}^{s} - c_{\alpha}\big) + \emptyset_{CM}^{B}\big((1 - f_{M}^{s})p_{\alpha} - c_{C}^{s} - c_{M}^{s} - c_{\alpha}\big) = (1 - f_{C}^{s})p_{\alpha} - c_{C}^{s} - c_{M}^{s} - c_{\alpha} + (f_{C}^{s} - f_{M}^{s})\emptyset_{CM}^{B}p_{\alpha}. \quad (13)$$

When only Card Buyers exist, i.e. when $\emptyset_{CM}^{B} = 0$, the expected profit for this seller is $(1 - f_{C}^{s})p_{\alpha} - c_{C}^{s} - c_{M}^{s} - c_{\alpha}$, which changes to $(1 - f_{M}^{s})p_{\alpha} - c_{C}^{s} - c_{M}^{s} - c_{\alpha}$ when only CM Buyers exist. The difference in payoffs in these scenarios reflects the savings that the seller can make when using Mobile instead of Card in a transaction due to the lower transaction cost.

Tipping Point

As opposed to in the basic model there may now, depending on the parameter values, exist values of $\emptyset_{j}^{i}$ for which it is a dominant strategy for sellers to adopt both card and mobile technologies. We will examine this scenario in particular detail. The conditions under which the different strategies are dominant are explored in the next section. *Figure 6* below shows the expected payoffs of the different sellers with two conditions imposed on the parameter values, ensuring that the strategy CM may dominate in some interval:

a) $(f_{C}^{s} - f_{M}^{s})p_{\alpha} > (c_{M}^{s} - c_{C}^{s})$, ensuring that $E(\pi_{M}^{s}) < E(\pi_{C}^{s}) | \emptyset_{CM}^{B} = 0)$

b) $(f_{C}^{s} - f_{M}^{s})p_{\alpha} > c_{M}^{s}$, which ensures that that $E(\pi_{M}^{s}) < E(\pi_{C}^{s})) | \emptyset_{CM}^{B} = 0)$

Note that if condition $b)$ is fulfilled, so is $a)$ since it is less strict.

[12] $E(\pi_{C+M}^{s}) = (1 - \emptyset_{C+M}^{B})\big((1 - f_{C}^{s})p_{\alpha} - c_{C}^{s} - c_{M}^{s} - c_{\alpha}\big) + \emptyset_{C+M}^{B}\big((1 - f_{M}^{s})p_{\alpha} - c_{C}^{s} - c_{M}^{s} - c_{\alpha}\big) = -c_{C}^{s} - c_{M}^{s} - c_{\alpha} + \emptyset_{C+M}^{B}(c_{C}^{s} + c_{M}^{s} + c_{\alpha}) + (1 - \emptyset_{C+M}^{B})\big((1 - f_{C}^{s})p_{\alpha}\big) + \emptyset_{C+M}^{B}\big((1 - f_{M}^{s})p_{\alpha}\big) - \emptyset_{C+M}^{B}(c_{C}^{s} + c_{M}^{s} + c_{\alpha}) = \big((1 - f_{C}^{s})p_{\alpha}\big) - \emptyset_{C+M}^{B}\big((1 - f_{C}^{s})p_{\alpha}\big) + \emptyset_{C+M}^{B}\big((1 - f_{M}^{s})p_{\alpha}\big)\big) - c_{C}^{s} - c_{M}^{s} - c_{\alpha} = \big((1 - f_{C}^{s})p_{\alpha}\big) - \emptyset_{C+M}^{B}(p_{\alpha} - f_{C}^{s}p_{\alpha}) + \emptyset_{C+M}^{B}(p_{\alpha} - f_{M}^{s}p_{\alpha}) - c_{C}^{s} - c_{M}^{s} - c_{\alpha} = (1 - f_{C}^{s})p_{\alpha} - c_{C}^{s} - c_{M}^{s} - c_{\alpha} + (f_{C}^{s} - f_{M}^{s})p_{\alpha}\emptyset_{C+M}^{B}$

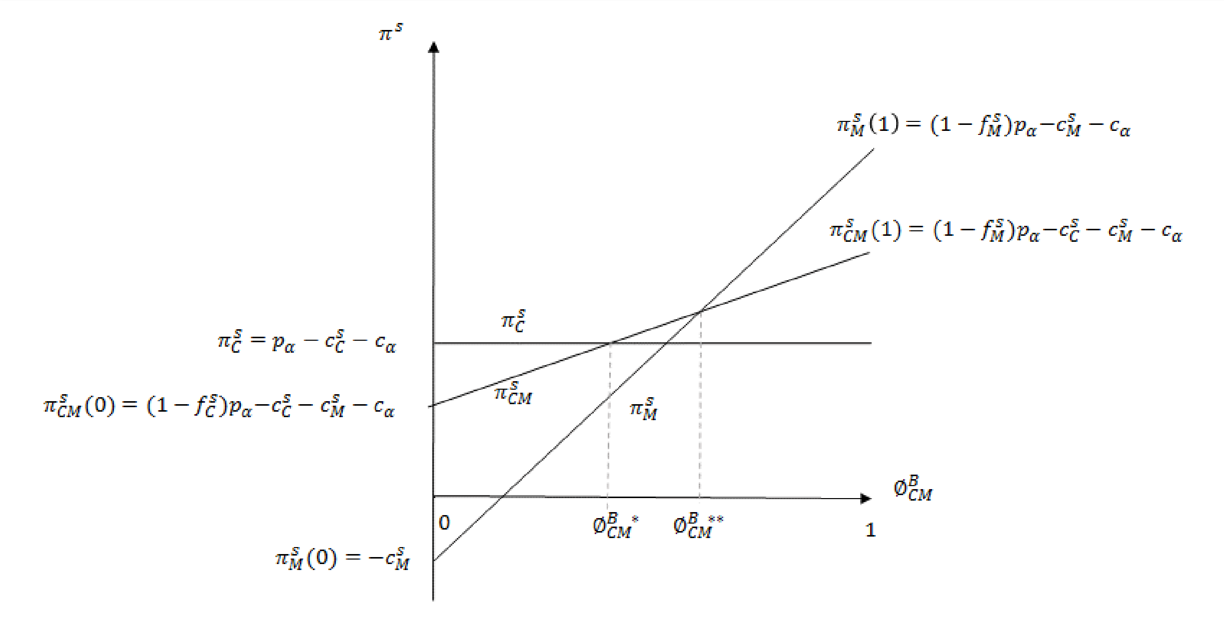

Figure 6. Expected payoffs of sellers under conditions a) and b)), extended model

If these restrictions are dropped, there may exist between zero and two unstable equilibria, in three different scenarios. In scenario one, none of conditions $a)$ and $b)$ are fulfilled, there exists no unstable equilibria and adopting card only is a strictly dominant strategy. In a second scenario, only condition $a)$ is violated and there may exist one unstable equilibrium which is also a tipping point, between Card and Mobile technology. In a third scenario, both conditions $a)$ and $b)$ are fulfilled and there may exist two unstable equilibria: one between Card only and Card and Mobile, and one between Card and Mobile and Mobile only.

Proposition 9. *There may exist between zero and two unstable equilibria in this model. Depending on the parameter values, such points may occur between Card and Card & Mobile ($\emptyset_{CM}^{B\,(C,CM)}$); Card & Mobile and Card ($\emptyset_{CM}^{B\,(CM,M)}$); and Card and Mobile ($\emptyset_{CM}^{B\,(C,M)}$).*

(i) If $(f_C^s - f_M^s)p_\alpha > (c_M^s - c_C^s)$, there exists no tipping point and adopting Card only is a strictly dominant strategy for sellers.

(ii) If $c_M^s < (f_C^s - f_M^s)p_\alpha < (c_M^s - c_C^s)$, there may exist one tipping point, between strategies of adopting Card only and Mobile only, $\emptyset_{CM}^{B\,(C,M)}$. This tipping point occurs when $E(\pi_C^s) = E(\pi_M^s)$, which holds at point

$$\emptyset_{CM}^{B\,(C,M)} = \frac{(1 - f_C^s)p_\alpha - c_C^s - c_\alpha + c_M^s}{((1 - f_M^s)p_\alpha - c_\alpha)}$$

(iii) If $(f_C^s - f_M^s)p_\alpha > c_M^s$ there may exist two unstable equilibria: one between Card and Card & Mobile, $\emptyset_{CM}^{B\,(C,CM)}$, and one between Card & Mobile and Mobile, $\emptyset_{CM}^{B\,(CM,M)}$. $\emptyset_{CM}^{B\,(C,CM)}$ occurs at the point of indifference $E(\pi_C^s) = E(\pi_{CM}^s)$:

$$\emptyset_{CM}^{B\,(C,CM)} = \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha}.$$

The other occurs when $E(\pi_{C+M}^s) = E(\pi_M^s)$, i.e. at point

$$\emptyset_{CM}^{B\,(CM,M)} = 1 - \frac{c_C^s}{((1-f_C^s)p_\alpha - c_\alpha)}.$$

For derivation of *Proposition 9*, please view *Appendix III.II*

We move on to further analyzing scenario three (presented in *Proposition 9(iii)*, since we wish to define conditions under which all strategies may occur in the course of the game. In this scenario, the strategy to adopt Card only dominates for values $\emptyset_{CM}^B < \frac{c_C^s + c_\alpha}{(f_M^s - f_C^s)p_\alpha}$; in the interval $\frac{c_C^s + c_\alpha}{(f_M^s - f_C^s)p_\alpha} < \emptyset_{CM}^B < \frac{(1-f_C^s)p_\alpha + c_M^s}{((1-f_C^s)p_\alpha - c_\alpha)}$ the dominant strategy is for sellers to adopt both Card and Mobile and in the $\emptyset_{CM}^B > \frac{(1-f_C^s)p_\alpha + c_M^s}{((1-f_C^s)p_\alpha - c_\alpha)}$ the dominant strategy is to adopt Mobile only.

The determinant parameters for the first unstable equilibrium $\emptyset_{CM}^{B\,(C,CM)}$ are given by the fixed cost of adopting Card, c_C^s; the cost of good α to the seller, c_α; the variable cost of using the Mobile platform, f_M^s; the variable cost of using the Card platform, f_C^s; and the price charged for the good, p_α.

Proposition 10. *A first unstable equilibria in the seller market when* $(f_C^s - f_M^s)p_\alpha > c_M^s$ *is the point of indifference between adopting Card only and adopting both Card and Mobile. It occurs at point*

$$\emptyset_{CM}^{B\,(C,CM)} = \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha}$$

(i) The *fixed cost of adopting Mobile for the seller,* c_M^s*,* has a **positive** relationship, ceteris paribus, with the location of the first unstable equilibrium $\emptyset_{CM}^{B\,(C,CM)}$.

(ii) The *variable cost of using the Card platform,* f_C^s*,* has a **negative** relationship, ceteris paribus, with the location of the first unstable equilibrium $\emptyset_{CM}^{B\,(C,CM)}$.

(iii) The *variable cost of using the Mobile platform (f_M^S)* has a **positive** relationship, ceteris paribus, with the location of the first unstable equilibrium $\emptyset_{CM}^{B\,(C,CM)}$.

(iv) The *price of the good,* p_α, has a **negative** relationship, ceteris paribus, with the location of the first unstable equilibrium $\emptyset_{CM}^{B\,(C,CM)}$.

Derivations for Proposition 10 are found in *Appendix III.II*.

Remember that the tipping point examined in *Proposition 10* above represents the point of indifference of sellers between adopting Card only and adopting both Card and Mobile. A negative relationship between the parameter and the location of the tipping point implies that an increase in that variable makes being a CM Seller more attractive in relation to being a Card Seller. Higher fixed and variable costs of adopting the Mobile platform makes being a CM Seller less attractive, while a higher variable cost of the Card platform makes it more attractive, as presented in *Proposition 10(i)-(iii)* above. A higher price of the good to be transacted has a negative relationship with the location of the tipping point. This means that it is more attractive to adopt both platforms when there is a larger transaction at stake, which holds true since the seller who adopts both platforms does not risk to forgo a transaction.

The second unstable equilibrium in the seller market in the extended model depends on the variable cost of using the card platform in a transaction, f_C^S; the price charged for the good to be transacted, p_α; the fixed cost per period of the Mobile platform, c_M^S; and the cost to the seller of the good transacted, c_α.

Proposition 11. *A second unstable equilibria in the seller market when $(f_C^S - f_M^S)p_\alpha > c_M^S$ is the point of indifference between adopting both Card and Mobile and adopting Mobile only. It occurs at point*

$$\emptyset_{C+M}^{B\,(CM,M)} = 1 - \frac{c_C^S}{((1-f_C^S)p_\alpha - c_\alpha)}.$$

(i) The *fixed cost of Card adoption for the seller, c_C^S,* has a **negative** relationship, ceteris paribus, with the location of the second unstable equilibrium $\emptyset_{CM}^{B\,(CM,M)}$.

(ii) The *variable cost of Card adoption for the seller, f_C^S,* has a **negative** relationship, ceteris paribus, with the location of the second unstable equilibrium $\emptyset_{CM}^{B\,(CM,M)}$.

(iii) The *price of the good transacted,* p_α, has a **positive** relationship, ceteris paribus, with the location of the second unstable equilibrium $\emptyset_{CM}^{B\,(CM,M)}$.

(iv) The *cost of the good transacted,* c_α, has a **negative** relationship, ceteris paribus, with the location of the second unstable equilibrium $\emptyset_{CM}^{B\,(CM,M)}$.

See derivations for *Proposition 11* in *Appendix III.II.*

The unstable equilibrium analyzed in *Proposition 11* above constitutes the point of indifference and tipping point for sellers between strategies of adopting both Card and Mobile platforms and adopting the Mobile platform only. A positive relationship between the parameter and this point thereby means that an increase in the parameter makes it less attractive to adopt the Mobile platform only as opposed to both Mobile and Card platforms. As implied by *Proposition 11(i)-(ii)*, a higher fixed cost as well as a higher variable cost of the Card platform makes it more attractive to adopt only the Mobile platform. Conversely, a higher variable cost of the Mobile platform makes it less attractive to only adopt the Mobile platform. From *Proposition 11(iii)-(iv)*, we may note that the gross transaction surplus (i.e. $p_\alpha - c_\alpha$,) is positively correlated with the tipping point. This means that it is less attractive to be a Mobile seller compared to a CM Seller when the gross transactions surplus is large, which is intuitively appealing since the seller will be more reluctant to forgo a transaction (by not having all platforms available) if the opportunity cost is large.

4.2.5 General Equilibria in User Markets

The two weakly dominant strategies available to buyers and three weakly dominant strategies available to sellers yield two unique general static equilibria for the user markets. These are given by strategy sets (C, C) and (CM, M) respectively. At these points, expectations are consistent with the outcome and no single user has any incentive to deviate from their platform adoption choice.

Proposition 12. *Like in the basic model, there are two general stable equilibria in the user markets. One equilibrium exists where all buyers hold card only and all sellers accept card only, i.e. at* $(\emptyset_{CM}^{B} = 0, \emptyset_{M}^{S} = 0)$ *. A second equilibrium exists where all buyers hold both card and mobile and all sellers accept mobile payment only, i.e. at* $(\emptyset_{CM}^{B} = 1, \emptyset_{M}^{S} = 1)$.

The other parameters will decide which equilibrium is most efficient. However, either equilibrium constitutes a feasible outcome in a game where beliefs are exogenously given.

4.3 Model Dynamics

We now analyze the implications of the model in a dynamic context, where the game is played in several subsequent periods. This more closely resembles the setting of payment systems in the real world where users make continuous adoption choices over the course of their lifetime.

We know from the static analysis that the strategy which dominates is determined by users' expectations as well as the model parameter values. Holding parameters fixed, the expectations of the user of the adoption rates on the other side of the market decides which strategy is dominant. If e.g. the buyer expects the population share of Mobile Sellers to be in the interval above the tipping point, it is a dominant strategy for buyers to adopt both Card and Mobile. If it is expected to be in the interval below this point, adopting Card only dominates.

Now first consider the case when the user's belief on the location of the system is entirely exogenous and randomly given. There is then always a higher probability that users favor the platform which dominates in the equilibrium with the larger basin of attraction. Remember that the basin of attraction of a certain equilibrium is constituted by all the points at which the dynamics of the system 'pull' in the direction of that point. The platform with the largest basin of attraction is the most likely to dominate simply because it has the largest interval in which it constitutes the dominant strategy. For large basins of attraction and the small variance in users' expectations, one platform adoption strategy is likely to achieve total dominance. For smaller basins of attraction and a large variance in the expectations of actors, a strategy is unlikely to completely dominate the population's strategic choice.

We then move from the case of randomly set beliefs and introduce a path dependence in the system where population shares from the previous period, $\emptyset^i_{j,t-1}$ are incorporated in the information set of each user. Subjectively assigned probabilities are then given by $\emptyset^i_{kt} = E\left(x_{k,t} \middle| \Omega^i_t, \emptyset^i_{k,t-1}\right)$. In such a system the strategies that dominate in the first period, (C, C) in the real-world context of this model, will have an initial advantage over the alternative equilibrium strategies of (CM, M). When the system is located at a stable equilibrium there may however still occur a shift due to the possibility of exogenous shocks to the information sets of actors. If a) this shock affects a large enough share of the population and b) the tipping point lies close enough to the initial equilibrium, a shift towards another equilibrium may take place. This would constitute the realization of a self-fulfilling prophecy.

Lastly, note that intrinsic user preferences over the two platforms are not considered in this model. If they were, a change in the distribution of preferences among the population, for example favoring the Mobile platform higher due to new design features of the program used, could also lead to a shift from one equilibrium to another.

5. Model Implications

If we consider the platform adoption game in world with perfect rationality where users have perfect access to information, users will coordinate on the solution of the game which is efficient to both sides of the market if parameter values are such that this solution exists. For parameter values where such solutions do not exist the system takes on the form of a coordination game, the outcome of which we cannot perfectly predict without further assumptions on user preferences or allowing for additional strategic behavior.

However, when we relax the assumption of perfect access to information and thus have a setting with bounded rationality of users, the competitive outcome is dependent on users' expectations regarding the relative dominance of platforms in the period. These expectations are imperfectly correlated with the actual population outcome. In this more realistic scenario, the tipping points of the system play a crucial role in deciding the outcome of the game. If beliefs among the population regarding which platform will dominate are coordinated, the system may land in equilibrium. For such a coordination to occur, users need to believe that a high enough share of the population hold the same belief of which platform adoption strategy will dominate in the period. Possible points of coordination occur in the unstable equilibria (tipping points) where users are indifferent between the strategies, and in two possible stable equilibria. In one equilibrium, all actors adopt Card only. In another equilibrium, all buyers adopt both Card and Mobile and all sellers adopt Mobile only. When beliefs are exogenously and randomly given the platform with the largest basin of attraction, i.e. which has the largest interval at which it constitutes the dominant strategy, is the most likely to dominate. The variance of beliefs across the population as well as the relative size of the basins of attraction will determine whether any strategy may dominate completely, i.e. the system falls completely in one equilibrium. For this to occur, all users must share the belief of which interval population shares will fall in. A larger variance in beliefs might conversely lead to the inability of any platform to reach total dominance.

In a dynamic setting, the population shares of the previous period may form part of a user's information set. This embodies the power of convention and leads to a path dependence in the system. Therefore, an external shock to the information sets of the population is needed to shift out of equilibrium and move the system to a state where a new platform dominates. For such a shift to occur the tipping point needs to be located close enough to the original equilibrium. Based on the character of the identified tipping points, this implies that the total transaction value and the total cost of the new (Mobile) platform need to be attractive enough in relation to the old (Card) platform. Additionally, the shock needs to affect a high enough share of users and be of a sufficient magnitude to move the expectation above the tipping point. Expectations on, and an outcome in, an unstable equilibrium are extremely unlikely since this consists of a single point in a continuous interval. The minimum required for a shift in dominance to occur is therefore that a collective bias of beliefs occurs which places the attractiveness of a strategy infinitely close to the tipping point on the opposing side. The initially dominant platform, Card in the real-world setting, holds an initial advantage since it continues to dominate in the absence of a shock to the system.

The determinants of the tipping point are apart from the expected population shares given by two general factors: the characteristics of the transaction to be made in the period, and the costs of enabling and performing a transaction. The transaction to be made is characterized by the possible surplus it generates for the user. For the buyer, this surplus is determined by the buyer's valuation of the good minus the price charged. To the seller, it depends on the price charged minus the cost of the good transacted. For higher valued transactions, the tipping point is biased towards the adoption option that i) results in the highest probability of a transaction (i.e. the choice which is compatible with the choice of a majority of users on the other side of the market) and ii) the platform with the lowest variable cost of use, i.e. the Mobile platform (extended model only). These two forces may push in different directions so the direction of the total effect of a higher valued transaction will differ depending on parameter values. As for the costs of enabling and performing a transaction, these are constituted by the fixed and variable costs of a platform to the user. The costs of competing platforms have the intuitive relationships with the relative attractiveness of the platforms. In the *basic model*, fixed costs of platform adoption are completely crucial. Since buyers must adopt both Card and Mobile to make a transaction with a Mobile seller, their total costs are higher in this strategy than for Card only. Only if the seller's fixed cost of Mobile adoption is lower than for Card does Mobile have the possibility to dominate. In the *extended model,* the Mobile platform may gain dominance even when the fixed cost of adoption is higher than that of the Card platform for both user groups. In this case the variable cost of Mobile payment needs to be set sufficiently low in relation to the variable cost of Card payment, in order for the user to expect to recoup the additional fixed cost incurred.

6. Discussion

Our models showed how the Mobile platform may gain dominance over Card even when it is assumed to provide no additional non-pecuniary functionality and to require dual platform adoption for buyers. Additionally, even when the initial cost of adoption per period is higher for the Mobile platform, it may reach a dominant position if this platform is able to offer sufficiently low variable costs of use. The results also shine a light on how the value of transactions made between the parties correlates with the propensity to adopt the Mobile platform. These results are consistent with the predictions of the theory of platform competition in two-sided market and the implications of the fee structure mirrors similar results from the payment literature focusing on payment cards. Most important might however be the highlighted role of imperfect information and possible shifts in expectations among the population.

The external validity of the models developed in this paper however also warrants some attention. First and perhaps most evident is that this model is a simplified game-theoretical representation of a complex real-world phenomenon. Importantly, the model takes into account a limited number of factors which the individual then takes into account to decide upon their strategy. Differing preferences across individuals and time are not taken into consideration and actors are assumed to be risk-neutral in their valuation of outcomes, which may not hold in reality. Therefore the analysis should be seen as a stylized explanation of how a transition to a new technology with a higher fixed cost may take place even when it does not yield any additional non-pecuniary benefits.

On the other hand, the generality of the model is rather high due to the lack of assumptions made on the characteristic of expectations. In subsequent applications, the model would be easily modified to accommodate specific characteristics of individuals' information sets as well as functional relationship between expectations and the actual outcome of the game. Furthermore, the model could with little required adjustments and negligible changes of implications be extended to the case where platform costs are non-monetary and incorporate for example convenience of use and safety. This modification would not be possible if for costs had been modelled exclusively as fees to the payment platforms, which appears frequently in the payment literature.

Additionally, in line with much of the tipping point literature, the game constructed here works through a random pairwise matching of buyers and sellers which may or may not result in a transaction ex-post based on their ex-ante platform adoption choices. Of course, in real life the matching between buyer and seller is not fully random as the users, primarily the buyer, seek out a pairing which is specific to their needs. However, the random matching procedure is still quite powerful as it reflects a general usefulness of a platform to its holder in an economy, which is a crucial aspect of payment systems of any kind.

Another limitation is that the model examines the case where card and mobile are the only available payment options. This of course excludes an analysis of the substitutability and strategic role of e.g. cash or credit payments, and the model therefore only strictly applies to a subset of markets where card and mobile are the options at hand. This limitation is made for the sake of simplicity and however should not substantially draw from the central implications of the analysis.

An additional issue to consider is that the model assumes an asymmetric complementarity of card and mobile on the buyer side, but not on the seller side. This construction is an attempt to reflect the current technological structure of the payment options. However, this structure is likely to change over time or even across competitors. If there is no longer a complementarity present, the model developed here could simply be extended by adding the additional strategy available to the buyer, namely to adopt and use the mobile platform in isolation. This may result in the existence of additional equilibria. The explicit analysis of an asymmetric complementarity is however one of the central contributions of our model since this has been quite insufficiently explored in previous literature. The model may therefore be interesting to apply to similar settings where no model previously has fit the realities of the competitive situation.

It would also be of great interest to apply this model on empirical data, not only for academic purposes but also to promote the interests of businesses and policy makers. If data could be obtained on user expectations, platform adoption rates and values transacted as well as the fixed and variable costs of Mobile and Card payments, the results of the model could be confirmed or refuted in an econometric analysis. Furthermore, an empirical analysis could serve to further develop the model as it would enlighten us on matters such as the functional form of the network effects, which in this paper are supposed to be constant to scale[13], and whether users hold intrinsic preferences for the respective platforms. It could also serve as an opportunity to explore whether any negative network effects may exist for Card or Mobile payment platforms, in the form of e.g. congestion.

[13] These would not be constant to scale if we for example take into account risk-averseness of users.

A theoretical extension that would be of interest is to add the possibility for intrinsic, and heterogeneous, preferences across platforms. To determine whether such preferences exist for payment platforms, and to what extent, an empirical analysis such as in experimental or survey form might also be of interest. More pressing, however, would be to analyze the strategic behavior of platforms in this model setting. Such an analysis would inform us on whether the required cost levels and structures for platform adoption presented in this model are feasible for profit maximizing platforms or under Ramsey pricing.[14] Furthermore, taking optimization behavior of the platforms into account would yield more information on which equilibrium is the most likely outcome of the coordination game. It would also shed light on which equilibrium, i.e. the dominance of which platform, is more societally beneficial as it would provide information on the likely levels and structures of platform costs. The strategic fee-setting behavior of the platforms to attract users and maximize volumes transacted could then be studies, such as discussed in some of the platform competition literature mentioned in the theory section of this paper.

Performing a formal dynamic version of the model may also be an appropriate next step. The non-technical dynamic analysis made in this paper presents some intuitive results of the most common dynamic mechanisms discussed in the literature, but proving it mathematically may be useful for a more formal model development.

7. Conclusion

With the rapid technological advancements made in the 21st century, some argue that it is only a matter of time before mobile technology becomes the dominant mode of transaction, outmaneuvering payment cards that currently dominate electronic retail payments. Transitions in payment standards arguably have great potential economic and societal impact since they may significantly lower transaction costs and increase the level of interconnectivity in the economy. Understanding if and how such a transition might occur is therefore of great interest to academics, businesses and policymakers alike. To explore the necessary conditions for such a transition to take place, we constructed and analyzed a formal game-theoretical model of the competition for users between card and mobile platforms to answer the following research question:

[14] Ramsey pricing consists of pricing which maximizes social welfare, subject to some minimum constraint on profits (Ramsey 1927). An exploration of fees charged under such a scheme is often explored in addition to a scenario where platforms profit maximize.

Based on theory of platform competition in two-sided markets, what is required for the mobile platform to gain dominance over the card platform in the user market, and may there be equilibria where the platforms coexist?

To answer this research question, we divided the analysis into a *basic model* and an *extended model* that explored user behavior under different assumptions imposed on platform cost structure. The basic model analyzed the strategic outcome in a scenario where platform costs consist of fixed costs of adoption only, while the extended model additionally included variable costs of platform use. We concluded that in both scenarios models tipping points may exist, signifying a transition from one dominant platform adoption strategy to another. The two platforms may coexist in the market on the buyer side, which is due to the asymmetric complementarity preventing mobile payments to entirely crowd out the card platform. On the seller side, the platforms will not coexist in equilibrium. The tipping points of the models were identified and analyzed to arrive at conclusions regarding the relationship between central parameters and the ease at which the mobile platform may gain dominance. The most important implications of the model may be summarized in the following three points:

First, expectations are crucial. The beliefs of users regarding which platform will dominate in the period determine the outcome of this coordination game as long as platform pricing lies within a reasonable spectrum. Expectations were determined by exogenously given information sets to reflect the differences among the population in e.g. market understanding and social context that are expected to exist in a real world setting.

Second, both level and structure of costs matter. When only fixed costs exists, the cost to sellers of adopting the Mobile platform must be less than that of the Card platform. In the case where variable costs are introduced, Mobile may gain dominance even when the fixed cost of adoption is higher than that of the Card platform to both user groups if it has a relatively low transaction cost.

Third, the possible surplus to be gained from a transaction must be considered. In short, we identified dual forces in the relationship between the value of the transaction to be made and the favored adoption strategy. On the one hand, adopting fewer platforms creates a risk of forfeiting the surplus a transaction generates. The opportunity risk of transitioning to any single platform for the user is higher for higher surplus transactions. On the other hand, the expected reduction in transaction fees in the extended model achieved by transitioning to Mobile payment is larger for larger transaction values.

In a dynamic analysis, we conclude that when the system exhibits a path dependence the power of convention will favor the initially dominant Card platform. Either dramatically favorable pricing by the Mobile platform or a shock to the information sets of users will be needed to shift the system out of this initial equilibrium.

The conclusions presented above shed light on important features of the mobile payment platform that might dominate in the decades to come. The results of the new analytical approach to the rise of mobile payments presented in this paper may hopefully aid firms and policymakers in making optimal decisions regarding pricing, regulation and investment. The requirements on cost parameters and their relationship with the characterization of transactions could help Mobile platforms provider make suitable strategic choices. However, most important is the realization that mobile payments will only come to dominate if the general public believes that it will. In this light, the aggressive lobbying and marketing campaigns conducted by central investors into Mobile payment technology may be equally, if not more, central as the actual business models of the platforms to achieving a systemic shift to mobile payments.

8. References

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9. Appendix

Appendix I. List of Variables

Variables	Explanations
α	Good to be transacted
p_α	Price charged for good α
$U(\alpha)$	The value buyers assign to good α
c_α	Cost of good α to the seller
i	Type of user; Buyer or Seller
j	Type of platform; Card or Mobile
b	Buyer
s	Seller
C	Card Platform
M	Mobile Platform
CM	Card and Mobile Platforms
c_j^i	Fixed Cost of adoption of platform j to user i
f_j^i	Variable Cost of use of platform j to user i, proportional to transaction value
$E(\pi_j)$	Expected Profit of the seller adopting platform j
V_j	Expected Utility of the buyer adopting platform j
$\emptyset_j^i$	Expected share of user population i who have adopted platform j
x_k	Actual proportion of users on one side of the market playing strategy k
y_k^i	Actual payoff to user i when the matched user plays strategy k
Ω_i	Information set of user i

Appendix II. Summary of Restrictions Imposed on Parameter Values

Following from Model Construction

$0 \leq \emptyset_j^i \leq 1,$ $\emptyset_C^S + \emptyset_{CM}^S + \emptyset_M^S = 1,$ $\emptyset_C^B + \emptyset_{CM}^B = 1$

$c_j^i > 0$ $p > 0$ $c_\alpha > 0$ $U(\alpha) > 0$

Basic Model

Total utility of buyers may not be negative. Therefore $U(\alpha) - p_\alpha - c_j^i \geq 0$. Transaction surplus is thereby strictly positive; $U(\alpha) - p_\alpha > 0$.

Total profit of sellers may not be negative. Therefore $p_\alpha - c_j^i - c_\alpha \geq 0$. Transaction surplus is thereby strictly positive; $p_\alpha - c_\alpha > 0$.

Extended Model

The fixed cost of adopting platform j exceeds zero, and is higher for the Mobile platform than for the Card platform to the seller: $c_j^i > 0$, $c_M^s > c_C^s > 0$.

The variable, transaction-proportional, cost of using platform j is higher for the Card platform than for the Mobile plaform: $f_C^b > f_M^b > 0$.

Total utility of buyers may not be negative. Therefore $U(\alpha) - (1 + f_j^b)p_\alpha - c_C^i \geq 0$, and the transaction surplus $U(\alpha) - (1 + f_j^b)p_\alpha$ is thereby strictly positive.

Total profit of sellers may not be negative. Therefore $(1 - f_C^s)p_\alpha - c_j^i - c_\alpha \geq 0$, and the transaction surplus $(1 - f_C^s)p_\alpha - c_\alpha$ is thereby strictly positive.

Appendix III. Derivations

III.I Basic Model

Proposition 1. In the interval $\emptyset_M^S < {\emptyset_M^S}^*$ the dominant strategy for buyers is to adopt card only, if there exists a $\emptyset_M^S$ such that

$$\emptyset_M^S : \emptyset_M^S < \frac{c_M^b}{U(\alpha)-p_\alpha} \qquad \text{for all} \quad \emptyset_M^S \in [0, {\emptyset_M^S}^*).$$

At point $\emptyset_M^S = {\emptyset_M^S}^*$ buyers are indifferent between the strategic options of platform adoption, if there exists a $\emptyset_M^S$ such that

$$\emptyset_M^S : \emptyset_M^S = \frac{c_M^b}{U(\alpha)-p_\alpha} \qquad \text{for all} \quad \emptyset_M^S \in [{\emptyset_M^S}^*].$$

In the interval $\emptyset_M^S > {\emptyset_M^S}^*$ the dominant strategy for buyers is to adopt both Card and Mobile, if there exists a $\emptyset_M^S$ such that

$$\emptyset_M^S : \emptyset_M^S > \frac{c_M^b}{U(\alpha)-p_\alpha} \qquad \text{for all} \quad \emptyset_M^S \in ({\emptyset_M^S}^*, 1].$$

The unstable equilibrium at point ${\emptyset_M^S}^*$ is a tipping point, since an infinitesimal positive change in $\emptyset_M^S$ from the point ${\emptyset_M^S}^*$ leads to a different dominant strategy from an infinitesimal negative change.

Proposition 2. *Change in cost of Mobile platform for the buyer (c_M^b):* We start by exploring the relationship between the Mobile platform cost and the tipping point in the buyer market.

Taking the first derivative of ${\emptyset_M^S}^* = \frac{c_M^b}{U(\alpha)-p_\alpha}$ with respect to c_M^b gives

$$\frac{\partial \emptyset_M^{S*}}{\partial c_M^b} = \frac{1}{U(\alpha)-p_\alpha}.$$

This shows that a change in c_M^b by one unit leads to a change in ${\emptyset_M^S}^*$ in the same direction by $\frac{1}{(U(\alpha)-p_\alpha)}$ percentage points, since $U(\alpha) - p_\alpha > 0$.

Change in the value of the good ($U(\alpha)$): Next, we take the first derivative of $\emptyset_M^{S*}$ with respect to $U(\alpha)$ to arrive at the ceteris paribus relationship between the utility that the buyer derives from good α and the tipping point. This relationship is given by[15]

$$\frac{\partial \emptyset_M^{S*}}{\partial U(\alpha)} = -\frac{c_M^b}{(U(\alpha)-p_\alpha)^2}.$$

Change in the price of the good (p_α): Finally, we take the first derivative of $\emptyset_M^{S*}$ with respect to p_α, which gives us the ceteris paribus impact of a change in the price of good α[16]:

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[15] ${\emptyset_M^S}^* = \frac{c_M^b}{(U(\alpha)-p_\alpha)} = c_M^b * (U(\alpha)-p_\alpha)^{-1} \rightarrow \frac{\partial \emptyset_M^{S*}}{\partial U(\alpha)} = -1 * c_M^b * (U(\alpha)-p_\alpha)^{-2} * 1 = \frac{-c_M^b}{(U(\alpha)-p_\alpha)^2}$

[16] ${\emptyset_M^S}^* = \frac{c_M^b}{(U(\alpha)-p_\alpha)} = c_M^b * (U(\alpha)-p_\alpha)^{-1} \rightarrow \frac{\partial \emptyset_M^{S*}}{\partial p_\alpha} = 1 * c_M^b * (U(\alpha)-p_\alpha)^{-2} * 1 = \frac{c_M^b}{(U(\alpha)-p_\alpha)^2}.$

$$\frac{\partial \emptyset_M^{S*}}{\partial p(\alpha)} = \frac{c_M^b}{(U(\alpha)-p_\alpha)^2}.$$

Proposition 4. In the interval $\emptyset_{CM}^B < \emptyset_{CM}^{B\,*}$ the dominant strategy for sellers is to adopt Card Only, if there exists a $\emptyset_M^S$ such that

$$\emptyset_{CM}^B : \emptyset_{CM}^B < \emptyset_{CM}^{B\,*} = 1 - \frac{c_C^S - c_M^S}{p_\alpha - c_\alpha} \quad \text{for all} \quad \emptyset_{CM}^B \in [0, \emptyset_{CM}^{B\,*}).$$

At the point $\emptyset_{CM}^B = \emptyset_{CM}^{B\,*}$, sellers are indifferent between the two strategies to adopt Card only to adopt Mobile Only, if there exists a $\emptyset_{CM}^B$, such that

$$\emptyset_{CM}^B : \emptyset_{CM}^B = \emptyset_{CM}^{B\,*} = 1 - \frac{c_C^S - c_M^S}{p_\alpha - c_\alpha} \quad \text{for all} \quad \emptyset_{CM}^B \in [\emptyset_{CM}^{B\,*}].$$

In the interval $\emptyset_{CM}^B > \emptyset_{CM}^{B\,*}$ the dominant strategy for sellers is to adopt Mobile Only, if there exists a $\emptyset_M^S$ such that

$$\emptyset_{CM}^B : \emptyset_{CM}^B > \emptyset_{CM}^{B\,*} = 1 - \frac{c_C^S - c_M^S}{p_\alpha - c_\alpha} \quad \text{for all} \quad \emptyset_{CM}^B \in (\emptyset_m^{s\,*} : 1].$$

The unstable equilibrium at point $\emptyset_{CM}^{B\,*}$ is a tipping point since an infinitesimal positive change in $\emptyset_{CM}^B$ from the point $\emptyset_{CM}^{B\,*}$ leads to a different dominant strategy from a positive infinitesimal negative change.

Proposition 5.

The tipping point examined occurs at

$$\emptyset_{CM}^{B\,*} = 1 - \frac{c_C^S - c_M^S}{p_\alpha - c_\alpha}.$$

Change in cost of Card platform for the seller (c_C^S). We start by exploring the relationship between the cost of the Card platform and the tipping point in the seller market. By taking the first derivative of $\emptyset_{CM}^{B\,*}$ with regards to c_C^S, we identify the ceteris paribus relationship

$$\frac{\partial \emptyset_{CM}^{B\,*}}{\partial c_C^S} = -\frac{1}{p_\alpha - c_\alpha}.$$

So that a higher cost c_C^S by one unit results in the value of the tipping point being $\frac{1}{p_\alpha - c_\alpha}$ percentage points lower.

Change in cost of Mobile platform for the seller (c_M^S). Next, we take the first derivative of $\emptyset_{CM}^{B\,*}$ with respect to c_M^S to arrive at the ceteris paribus relationship between the cost of the Mobile platform and the tipping point. This relationship is given by

$$\frac{\partial \emptyset_{CM}^{B\,*}}{\partial c_M^S} = \frac{1}{p_\alpha - c_\alpha}.$$

This means that a one unit higher cost of the Mobile platform results, ceteris paribus, in the value of the tipping point being $\frac{1}{p_\alpha - c_\alpha}$ percentage points higher.

Change in the price of the good (p_α). We now take the first derivative of ${\emptyset_{CM}^{B}}^{*}$ with respect to p_α, which gives us the ceteris paribus impact of a change in the price of good α[17]:

$$\frac{\partial {\emptyset_{CM}^{B}}^{*}}{\partial p_\alpha} = \frac{c_C^s - c_M^s}{\left(p_\alpha - c_\alpha\right)^2}.$$

In *Proposition 3*, it was established that for a tipping point to exist, it needs to hold that $c_C^s > c_M^s$. Therefore, $c_C^s - c_M^s$ is a positive expression. Next, note that the denominator is always positive since $p_\alpha - c_\alpha > 0$. The relationship between the price of the good, p_α, and the tipping point ${\emptyset_{CM}^{B}}^{*}$ is therefore positive.

Change in cost of the good to the seller (c_α). Finally, we take the first derivative of ${\emptyset_{CM}^{B}}^{*}$ with respect to c_α, which gives us the ceteris paribus impact of a change in the cost of good α to the seller[18]:

$$\frac{\partial {\emptyset_{CM}^{B}}^{*}}{\partial c_\alpha} = \frac{-(c_C^s - c_M^s)}{(p_\alpha - c_\alpha)^2}.$$

It has been defined that $(p_\alpha - c_\alpha) > 0$, which makes the denominator of this expression positive. It has been defined in *Proposition 3* that $c_M^s < c_C^s$, and thus the numerator is negative. The relationship between the tipping point and the cost of good c_α is therefore negative.

III.II Extended Model

Proposition 7. In the interval $\emptyset_M^S < {\emptyset_M^s}^*$ the dominant strategy for buyers is to adopt Card Only, if there exists a $\emptyset_M^S$ such that

$$\emptyset_M^S : \emptyset_M^S < \frac{c_M^b - (f_C^b - f_M^b)p_\alpha(1 - \emptyset_C^S)}{U(\alpha) - (1 + f_C^b)p_\alpha} \qquad \text{for all} \quad \emptyset_M^S \in [0, {\emptyset_M^S}^*).$$

At point $\emptyset_M^S = {\emptyset_M^S}^*$ buyers are indifferent between the strategic options of platform adoption, if there exists a $\emptyset_M^S$ such that

$$\emptyset_M^S : \emptyset_M^S = \frac{c_M^b - (f_C^b - f_M^b)p_\alpha(1 - \emptyset_C^S)}{U(\alpha) - (1 + f_C^b)p_\alpha} \qquad \text{for all} \quad \emptyset_M^S \in [{\emptyset_M^S}^*].$$

In the interval $\emptyset_M^S > {\emptyset_M^s}^*$ the dominant strategy for buyers is to adopt both Card and Mobile, if there exists a $\emptyset_M^S$ such that

$$\emptyset_M^S : \emptyset_M^S > \frac{c_M^b - (f_C^b - f_M^b)p_\alpha(1 - \emptyset_C^S)}{U(\alpha) - (1 + f_C^b)p_\alpha} \qquad \text{for all} \quad \emptyset_M^S \in ({\emptyset_M^S}^*, 1].$$

The unstable equilibrium at point ${\emptyset_M^S}^*$ is a tipping point, since an infinitesimal positive change in $\emptyset_M^S$ from the point ${\emptyset_M^S}^*$ leads to a different dominant strategy from an infinitesimal negative change.

[17] ${\emptyset_{CM}^{B}}^{*} = 1 - \frac{(c_C^S - c_M^S)}{(p_\alpha - c_\alpha)} = 1 - (c_C^S - c_M^S)\,(p_\alpha - c_\alpha)^{-1} \to \frac{\partial {\emptyset_{CM}^{B}}^{*}}{\partial p_\alpha} = \frac{\partial}{\partial p_\alpha}(1) - (c_C^S - c_M^S)\frac{\partial}{\partial p_\alpha}(p_\alpha - c_\alpha)^{-1} = \frac{c_C^S - c_M^S}{(p_\alpha - c_\alpha)^2}.$

[18] ${\emptyset_{CM}^{B}}^{*} = 1 - \frac{(c_C^S - c_M^S)}{(p_\alpha - c_\alpha)} = 1 - (c_C^S - c_M^S)\,(p_\alpha - c_\alpha)^{-1} \to \frac{\partial {\emptyset_{CM}^{B}}^{*}}{\partial c_\alpha} = \frac{\partial}{\partial c_\alpha}(1) - (c_C^S - c_M^S)\frac{\partial}{\partial c_\alpha}(p_\alpha - c_\alpha)^{-1} = \frac{-(c_C^S - c_M^S)}{(p_\alpha - c_\alpha)^2}.$

Proposition 8.

Remember that the tipping point exists at

$$\emptyset_M^{S*} = \frac{c_M^b - p_\alpha (f_C^b - f_M^b)(1-\emptyset_C^S)}{U(\alpha) - \left(1+f_C^b\right)p_\alpha}.$$

Change in fixed cost of Mobile platform for the buyer (c_M^b): We start by exploring the relationship between the Mobile platform cost and the tipping point in the buyer market.

Taking the first derivative of $\emptyset_M^{S\,*} = \frac{c_M^b - (f_C^b - f_M^b)p_\alpha(1-\emptyset_C^S)}{U(\alpha) - \left(1+f_C^b\right)p_\alpha}$ with respect to c_M^b gives

$$\frac{\partial \emptyset_M^{S*}}{\partial c_M^b} = \frac{1}{U(\alpha) - \left(1+f_C^b\right)p_\alpha}.$$

This shows that a change in c_M^b by one unit leads to a change in $\emptyset_M^{S\,*}$ by $\frac{1}{U(\alpha) - \left(1+f_C^b\right)p_\alpha}$ percentage points. Since it must hold in order for any consumer to wish to adopt Card and conduct a transaction that $U(\alpha) - (1+f_C^b)p_\alpha - c_C^b > 0$ and c_C^b is larger than zero, $U(\alpha) - (1+f_C^b)p_\alpha > 0$. Thereby the denominator and the whole expression are positive.

Change in variable cost of Card usage for the buyer (f_C^b): Next, we take the first derivative of $\emptyset_M^{S*}$ with respect to f_C^b to arrive at the ceteris paribus relationship between variable fee for Card usage for the buyer and the tipping point. This relationship is given by[19]

$$\frac{\partial \emptyset_M^{S*}}{\partial f_C^b} = \frac{-p_\alpha((1-\emptyset_C^S)\left(U(\alpha) - (1+f_M^b)p_\alpha\right) - c_M^b)}{\left(U(\alpha) - (1+f_C^b)p_\alpha\right)^2}$$

The denominator positive since $U(\alpha) - (1+f_C^b)p_\alpha > 0$. The terms $(1-\emptyset_C^{S*})$and $\left(U(\alpha) - (1+f_M^b)p_\alpha\right)$ in the numerator are both positive, resulting in a positive product. Thereby, when parameter values are such that $(1-\emptyset_C^{S*})\left(U(\alpha) - (1+f_M^b)p_\alpha\right) - c_M^b > 0$, the relationship is negative. if $(1-\emptyset_C^{S*})\left(U(\alpha) - (1+f_M^b)p_\alpha\right) - c_M^b < 0$, there is a positive ceteris paribus relationship between the variable fee of Card usage $f_C^b$and the location of the tipping point. However, it must hold that $(1-\emptyset_C^{S*})\left(U(\alpha) - (1+f_M^b)p_\alpha\right) - c_M^b > 0$, which is evident when going through the terms one by one. This expression states the likelihood of being matched with a seller who has Mobile technology available $(1-\emptyset_C^{S*})$, times the total surplus that a Buyer can get from an ex-post transaction through the Mobile platform $\left(U(\alpha) - (1+f_M^b)p_\alpha\right)$, minus the ex-ante fixed investment made into adopting the Mobile platform (c_M^b). If this expression is negative, no buyer will wish to adopt Mobile payments since the expected payoff of that choice is negative. When the denominator $U(\alpha) - \left(1+f_C^b\right)p_\alpha = 0$, it is undefined.

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19 $\emptyset_M^{S\,*} = \frac{c_M^b - (f_C^b - f_M^b)p_\alpha(1-\emptyset_C^S)}{U(\alpha) - \left(1+f_C^b\right)p_\alpha} = (c_M^b - (f_C^b - f_M^b)p_\alpha(1-\emptyset_C^S))\ \left(U(\alpha) - \left(1+f_C^b\right)p_\alpha\right)^{-1} \quad \rightarrow \quad \frac{\partial \emptyset_M^{S*}}{\partial f_C^b} = \left(U(\alpha) - \left(1+f_C^b\right)p_\alpha\right)\left(\frac{\partial}{\partial f_C^b}(c_M^b - p_\alpha\left(1-\emptyset_C^S\right)\left(f_C^b - f_M^b\right) + \frac{\partial}{\partial f_C^b}(1) + \frac{\partial}{\partial f_C^b}(f_C^b)p_\alpha(c_M^b - p_\alpha(1-\emptyset_C^S)(f_C^b - f_M^b)\left(U(\alpha) - (1+f_C^b)p_\alpha\right)^{-2} = \frac{-p_\alpha(\left(1-\emptyset_C^S\right)\left(U(\alpha)-(1+f_M^b)p_\alpha\right)-c_M^b)}{\left(U(\alpha)-(1+f_C^b)p_\alpha\right)^2}$

Change in variable cost of Mobile usage for the buyer (f_M^b): Next, we take the first derivative of $\emptyset_M^{S*}$ with respect to f_M^b, which gives us the ceteris paribus impact of a change in the variable fee of the Mobile platform f_M^b:

$$\frac{\partial \emptyset_M^{S*}}{\partial f_M^b} = \frac{(1-\emptyset_C^S)p_\alpha}{(U(\alpha)-(1+f_C^b)p_\alpha)}.$$

This numerator is always positive for the defined parameter values. Additionally, since the denominator $U(\alpha) - (1 + f_C^b)p_\alpha > 0$ the ceteris paribus relationship between the variable cost of using the Mobile platform and the location of the tipping point $\emptyset_M^{S*}$ is positive.

Change in price of good α (p_α): Taking the first derivative of $\emptyset_M^{S*}$ with respect to p_α gives us the ceteris paribus impact of a change in the price of the good transacted[20]:

$$\frac{\partial \emptyset_M^{S*}}{\partial p_\alpha} = \frac{c_M^b\left(1 + f_C^b\right) + U(\alpha)(1 - \emptyset_C^S)(f_M^b - f_C^b)}{\left(U(\alpha) - \left(1 + f_C^b\right)p_\alpha\right)^2}$$

The first term in the numerator, $c_M^b\left(1 + f_C^b\right)$, is always positive. In the second term, $U(\alpha) > 0$, $(1 - \emptyset_C^{S*}) > 0$ and $\left(f_M^b - f_C^b\right) < 0$. The denominator $U(\alpha) - (1 + f_C^b)p_\alpha$ is always positive. Therefore, for parameter values $c_M^b\left(1 + f_C^b\right) > U(\alpha)(1 - \emptyset_C^{S*})(f_M^b - f_C^b)$, the derivative is positive and for values $c_M^b\left(1 + f_C^b\right) < U(\alpha)(1 - \emptyset_C^{S*})(f_M^b - f_C^b)$, the derivative is negative.

Change in the share of sellers adopting Card Only ($\emptyset_C^{S*}$): Next, we take the first derivative of $\emptyset_M^{S*}$ with respect to $\emptyset_C^{S*}$, which gives us the ceteris paribus impact of a change in the population share of sellers adopting Card Only on the tipping point in the buyer market:

$$\frac{\partial \emptyset_M^{S*}}{\partial \emptyset_C^{S*}} = \frac{p_\alpha(f_C^b - f_M^b)}{U(\alpha) - \left(1 + f_C^b\right)p_\alpha}$$

Since $f_C^b - f_M^b > 0$, and $U(\alpha) - \left(1 + f_C^b\right)p_\alpha > 0$ for any tipping point to exist, this derivative is positive.

Change in the value of good α to the user ($U(\alpha)$): Finally, we take the first derivative of $\emptyset_M^{S*}$ with respect to $U(\alpha)$, yielding the ceteris paribus relationship between the value of the good to be transacted and the location of the tipping point[21]:

[20] $\emptyset_M^{S\,*} = \frac{c_M^b-(f_C^b-f_M^b)p_\alpha(1-\emptyset_C^S)}{U(\alpha)-(1+f_C^b)p_\alpha} = (c_M^b - (f_C^b - f_M^b)p_\alpha(1 - \emptyset_C^S))\ \ (U(\alpha) - \left(1 + f_C^b\right)p_\alpha)^{-1} \rightarrow \frac{\partial \emptyset_M^{S*}}{\partial p_\alpha} = (U(\alpha) - \left(1 + f_C^b\right)p_\alpha)\frac{\partial}{\partial p_\alpha}(c_M^b - p_\alpha\left(1 - \emptyset_C^S\right)\left(f_C^b - f_M^b\right) - (c_M^b - p_\alpha\left(1 - \emptyset_C^S\right)\left(f_C^b - f_M^b\right))\frac{\partial}{\partial p_\alpha}(U(\alpha) - \left(1 + f_C^b\right)\frac{\partial}{\partial p_\alpha}p_\alpha\left(U(\alpha) - \left(1 + f_C^b\right)p_\alpha\right)^{-2} \ = \frac{c_M^b(1+f_C^b)+U(\alpha)(1-\emptyset_C^S)(f_M^b-f_C^b)}{\left(U(\alpha)-(1+f_C^b)p_\alpha\right)^2}$

[21] $\emptyset_M^{S\,*} = \frac{c_M^b-(f_C^b-f_M^b)p_\alpha(1-\emptyset_C^S)}{U(\alpha)-(1+f_C^b)p_\alpha} = (c_M^b - (f_C^b - f_M^b)p_\alpha(1 - \emptyset_C^S))\ \ (U(\alpha) - \left(1 + f_C^b\right)p_\alpha)^{-1} \rightarrow \frac{\partial \emptyset_M^{S*}}{\partial U(\alpha)} = \ (c_M^b - \left(1 - \emptyset_C^{S*}\right)\left(f_M^b - f_C^b\right)p_\alpha)(\frac{\partial}{\partial U(\alpha)}(-(U(\alpha) + \left(1 + f_C^b\right)p_\alpha)\left(U(\alpha) - \left(1 + f_C^b\right)p_\alpha\right)^{-2} \ = \frac{c_M^b+(1-\emptyset_C^{S*})(f_M^b-f_C^b)p_\alpha}{\left(U(\alpha)-(1+f_C^b)p_\alpha\right)^2}$

$$\frac{\partial \emptyset_M^{S*}}{\partial U(\alpha)} = \frac{c_M^b + (1 - \emptyset_C^{S*})(f_M^b - f_C^b)p_\alpha}{\left(U(\alpha) - \left(1 + f_C^b\right)p_\alpha\right)^2}$$

The denominator in this equation is always positive. In the numerator, $(1 - \emptyset_C^{S*}) \geq 0$ and $\left(f_M^b - f_C^b\right) < 0$. Therefore, if parameter values are such that $c_M^b > (1 - \emptyset_C^{S*})(f_M^b - f_C^b)p_\alpha$, the derivative is positive and if $c_M^b < (1 - \emptyset_C^{S*})(f_M^b - f_C^b)p_\alpha$, the derivative is negative.

Proposition 9.

Remember that the respective expected profits of Card, CM and Mobile sellers in the extended model are given by equations (11), (12) and (13):

$$E(\pi_C^s) = (1 - f_C^s)p_\alpha - c_C^s - c_\alpha \tag{11}$$

$$E(\pi_{CM}^s) = (1 - f_C^s)p_\alpha + (f_C^s - f_M^s)p_\alpha \emptyset_{CM}^B \tag{12}$$

$$E(\pi_M^s) = -c_M^s + \left((1 - f_M^s)p_\alpha - c_\alpha\right)\emptyset_{CM}^B \tag{13}$$

There may exist an unstable equilibrium ${\emptyset_{\mathrm{CM}}^{\mathrm{B}}}^*$at the point of indifference for buyers between adopting Card Only and adopting both Card and Mobile. This point occurs when $E(\pi_C^s) = E(\pi_{CM}^s)$, i.e. when it holds that

$$(1 - f_C^s)p_\alpha - c_C^s - c_\alpha = (1 - f_C^s)p_\alpha - c_C^s - c_M^s - c_\alpha + (f_C^s - f_M^s)\emptyset_{CM}^B p_\alpha.$$

This equilibrium therefore exists at point

$$\emptyset_{CM}^{B\ (C,CM)} = \frac{(1 - f_C^s)p_\alpha - c_C^s - c_\alpha - ((1 - f_C^s)p_\alpha - c_C^s - c_M^s - c_\alpha)}{(f_C^s - f_M^s)p_\alpha},$$

which simplifies to

$$\emptyset_{CM}^{B\ (C,CM)} = \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha}.$$

Only for lower values $\emptyset_{\mathrm{CM}}^{\mathrm{B}} < \emptyset_{\mathrm{CM}}^{\mathrm{B\ C,CM}}$ is it a dominant strategy for buyers to adopt Card Only.

A point of indifference between adopting Card and Mobile and adopting Mobile Only, occurs when

$$E(\pi_{CM}^s) = E(\pi_M^s),$$

I.e. when

$$(1 - f_C^s)p_\alpha - c_C^s - c_M^s - c_\alpha + (f_C^s - f_M^s)\emptyset_{CM}^B p_\alpha = -c_M^s + \left((1 - f_M^s)p_\alpha - c_\alpha\right)\emptyset_{CM}^B$$

Which, simplified, defines the unstable equilibrium[22]

$$\emptyset_{CM}^{B\ (CM,M)} = 1 - \frac{c_C^s}{((1 - f_C^s)p_\alpha - c_\alpha)}.$$

And lastly, we can define a point for transition straight from Card to Mobile acceptance, which may occur if condition $i)$ is violated but $ii)$ holds. Such a point would occur when

$$E(\pi_C^s) = E(\pi_M^s).$$

[22] $(1 - f_C^s)p_\alpha - c_C^s - c_M^s - c_\alpha + c_M^s = \left((1 - f_M^s)p_\alpha - c_\alpha\right)\emptyset_{C+M}^B - (f_C^s - f_M^s)\emptyset_{C+M}^B p_\alpha \rightarrow (1 - f_C^s)p_\alpha - c_C^s - c_\alpha = \left((1 - f_M^s)p_\alpha - c_\alpha - (f_C^s - f_M^s)p_\alpha\right)\emptyset_{C+M}^B \rightarrow \frac{(1 - f_C^s)p_\alpha - c_C^s - c_\alpha}{\left((1 - f_M^s)p_\alpha - c_\alpha - (f_C^s - f_M^s)p_\alpha\right)} = \emptyset_{C+M}^B \rightarrow \emptyset_{C+M}^B = \frac{(1 - f_C^s)p_\alpha - c_C^s - c_\alpha}{((1 - f_C^s)p_\alpha - c_\alpha)} = \frac{(1 - f_C^s)p_\alpha - c_\alpha}{((1 - f_C^s)p_\alpha - c_\alpha)} - \frac{c_C^s}{((1 - f_C^s)p_\alpha - c_\alpha)} = 1 - \frac{c_C^s}{((1 - f_C^s)p_\alpha - c_\alpha)}$

Combining equations (11) and (13), this may be expressed as

$$(1 - f_C^s)p_\alpha - c_C^s - c_\alpha = -c_M^s + \big((1 - f_M^s)p_\alpha - c_\alpha\big)\emptyset_{CM}^B,$$

which yields the unstable equilibrium point[23]

$$\emptyset_{CM}^{B\,(C,M)} = \frac{(1 - f_C^s)p_\alpha - c_C^s - c_\alpha + c_M^s}{(1 - f_M^s)p_\alpha - c_\alpha}$$

In the interval $\emptyset_{CM}^B < \emptyset_{CM}^{B\ C,CM}$ the dominant strategy for sellers is to adopt Card Only, if there exists $\emptyset_{CM}^B$ such that

$$\emptyset_{CM}^B : \emptyset_{C+M}^B < \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha} \qquad \text{for all} \quad \emptyset_{CM}^B \in [0, \emptyset_{CM}^{B\ C,CM}).$$

At point $\emptyset_{CM}^B = \emptyset_{CM}^{B\ C,CM}$ sellers are indifferent between the strategic options of adopting Card Only and adopting both Card and Mobile, if there exists a $\emptyset_{C+M}^B$ such that

$$\emptyset_{CM}^B : \emptyset_{CM}^B = \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha} \qquad \text{for all} \quad \emptyset_{CM}^B \in [\emptyset_{CM}^{B\ C,CM}].$$

In the interval $\emptyset_{CM}^{B\ C,CM} > \emptyset_{CM}^B < \emptyset_{CM}^{B\ CM,M}$ the strategy of adopting both Card and Mobile is the dominant strategy, if there exists $\emptyset_{C+M}^B$ such that

$$\emptyset_{C+M}^B : \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha} < \emptyset_{CM}^B < 1 - \frac{c_C^s}{(1 - f_C^s)p_\alpha - c_\alpha} \qquad \text{for all} \quad \emptyset_{CM}^B \in (\emptyset_{CM}^{B\ C,CM}, \emptyset_{CM}^{B\ CM,M}).$$

At point $\emptyset_{CM}^B = \emptyset_{CM}^{B\ CM,M}$ sellers are indifferent between the strategic options of adopting both Card and Mobile and adopting Mobile Only, if there exists a $\emptyset_{C+M}^B$ such that

$$\emptyset_{CM}^B : \emptyset_{CM}^B = 1 - \frac{c_C^s}{(1 - f_C^s)p_\alpha - c_\alpha} \qquad \text{for all} \quad \emptyset_{CM}^B \in [\emptyset_{CM}^{B\ CM,M}].$$

In the interval $\emptyset_{CM}^{B\ CM,M} > \emptyset_{CM}^B$ the strategy of adopting both Card and Mobile is the dominant strategy, if there exists $\emptyset_{CM}^B$ such that

$$\emptyset_{CM}^B : \emptyset_{CM}^B > 1 - \frac{c_C^s}{(1 - f_C^s)p_\alpha - c_\alpha} \qquad \text{for all} \quad \emptyset_{CM}^B \in (\emptyset_{CM}^{B\ C,CM}, 1].$$

Proposition 10.

Now examine the first unstable equilibrium, where sellers are indifferent between adopting Card Only and adopting both Card and Mobile. Remember that this point occurs at

$$\emptyset_{CM}^{B\,(C,CM)} = \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha}$$

Change in fixed cost of adopting Mobile for the seller (c_M^s). We start by exploring the relationship between the fixed cost per period of the Card platform and the first unstable equilibrium in the seller market. By taking the first derivative of $\emptyset_{CM}^{B\,(C,CM)}$ with regards to c_M^s, we identify the ceteris paribus relationship[24]

[23] $(1 - f_C^s)p_\alpha - c_C^s - c_\alpha = -c_M^s + \big((1 - f_M^s)p_\alpha - c_\alpha\big)\emptyset_{C+M}^B \to \frac{(1-f_C^s)p_\alpha - c_C^s - c_\alpha + c_M^s}{\left((1-f_M^s)p_\alpha - c_\alpha\right)} = \emptyset_{C+M}^B \to \emptyset_{C+M}^{B\,(C,M)} = \frac{(1-f_C^s)p_\alpha + c_M^s - c_C^s - c_\alpha}{\left((1-f_M^s)p_\alpha - c_\alpha\right)}$

[24] $\emptyset_{C+M}^{B\,(C,CM)} = \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha} \to \frac{\partial \emptyset_{C+M}^{B\,(C,CM)}}{\partial c_M^s} = \frac{1}{(f_C^s - f_M^s)p_\alpha}$

$$\frac{\partial \emptyset_{CM}^{B\,(C,CM)}}{\partial c_M^s} = \frac{1}{(f_C^s - f_M^s)p_\alpha}.$$

Since $(f_C^s - f_M^s) > 0$, this relationship is positive.

Change in the variable cost of using the Card platform (f_C^s). We now take the first derivative of $\emptyset_{CM}^{B\,(C,CM)}$ with respect to f_C^s, which gives us the ceteris paribus impact of a change in the variable cost of the Card platform [25]

$$\frac{\partial \emptyset_{CM}^{B\,(C,CM)}}{\partial f_C^s} = \frac{-c_M^s}{p_\alpha (f_C^s - f_M^s)^2}.$$

This relationship is negative since the nominator is negative and the denominator is positive.

Change in the variable cost of using the Mobile platform (f_M^s). Next, take the first derivative of $\emptyset_{CM}^{B\,(C,CM)}$ with respect to f_M^s, giving the ceteris paribus impact of a change in the variable cost of the Card platform to the seller[26]:

$$\frac{\partial \emptyset_{CM}^{B\,(C,CM)}}{\partial f_M^s} = \frac{c_M^s}{p_\alpha (f_C^s - f_M^s)^2}.$$

Since both numerator and denominator in this function are positive, this relationship is positive.

Change in the price charged for the good (p_α): Lastly, we determine the impact of a ceteris paribus change in the price charged for the good to be transacted on the location of the first unstable equilibrium $\emptyset_{CM}^{B\,(C,CM)}$[27]:

$$\frac{\partial \emptyset_{CM}^{B\,(C,CM)}}{\partial p_\alpha} = \frac{-c_M^s}{(f_C^s - f_M^s){p_\alpha}^2}.$$

The numerator in this equation is negative, and the denominator is positive since $f_C^s > f_M^s$, and thus this derivative is negative.

Proposition 11.

Now turn to the second unstable equilibrium, where sellers are indifferent between adopting both Card and Mobile and adopting Mobile Only. Remember that this point occurs at

$$\emptyset_{CM}^{B\,(CM,M)} = 1 - \frac{c_C^s}{(1 - f_C^s)p_\alpha - c_\alpha}.$$

First, note that since $0 \le \emptyset_{CM}^B \le 1$, the second term $\frac{c_C^s}{(1 - f_C^s)p_\alpha - c_\alpha}$ in the equation above may not be negative. This implies that it always must hold that $((1 - f_C^s)p_\alpha - c_\alpha) > 0$.

[25] $\emptyset_{C+M}^{B\,(C,CM)} = \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha} = c_M^s * \left((f_C^s - f_M^s)p_\alpha\right)^{-1} \rightarrow \frac{\partial \emptyset_{C+M}^{B\,(C,CM)}}{\partial f_C^s} = p_\alpha c_M^s * \left((f_C^s - f_M^s)p_\alpha\right)^{-2} * -1 = \frac{-p_\alpha c_M^s}{\left((f_C^s - f_M^s)p_\alpha\right)^2} = \frac{-c_M^s}{p_\alpha (f_C^s - f_M^s)^2}$

[26] $\emptyset_{C+M}^{B\,(C,CM)} = \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha} = c_M^s * \left((f_C^s - f_M^s)p_\alpha\right)^{-1} \rightarrow \frac{\partial \emptyset_{C+M}^{B\,(C,CM)}}{\partial f_M^s} = -1 * c_M^s * \left((f_C^s - f_M^s)p_\alpha\right)^{-2} * -p_\alpha = \frac{c_M^s p_\alpha}{\left((f_C^s - f_M^s)p_\alpha\right)^2} = \frac{c_M^s}{p_\alpha (f_C^s - f_M^s)^2}$

[27] $\emptyset_{C+M}^{B\,(C,CM)} = \frac{c_M^s}{(f_C^s - f_M^s)p_\alpha} = c_M^s * \left((f_C^s - f_M^s)p_\alpha\right)^{-1} \rightarrow \frac{\partial \emptyset_{C+M}^{B\,(C,CM)}}{\partial p_\alpha} = -1 * c_M^s * \left((f_C^s - f_M^s)p_\alpha\right)^{-2} * (f_C^s - f_M^s) = \frac{-c_M^s (f_C^s - f_M^s)}{\left((f_C^s - f_M^s)p_\alpha\right)^2} = \frac{-c_M^s}{(f_C^s - f_M^s){p_\alpha}^2}$

Change in fixed cost of Card adoption for the seller (c_C^s). Start by exploring the relationship between the fixed cost per period of the Card platform for sellers and the second unstable equilibrium in the seller market. Take the first derivative of $\emptyset_{CM}^{B\,(C,CM)}$ with regards to c_C^s to arrive at the ceteris paribus relationship

$$\frac{\partial \emptyset_{CM}^{B\,(CM,M)}}{\partial c_C^s} = \frac{-1}{(1-f_C^s)p_\alpha - c_\alpha}.$$

The numerator is negative and since the denominator $((1 - f_C^s)p_\alpha - c_\alpha) > 0$, this relationship is negative.

Change in the variable cost of Card use (f_C^s): Next, take the first derivative of $\emptyset_{CM}^{B\,(C,CM)}$ with respect to f_C^s to arrive at the ceteris paribus relationship between the variable cost of Card platform use and the location of the second equilibrium. This relationship is given by[28]

$$\frac{\partial \emptyset_{CM}^{B\,(CM,M)}}{\partial f_C^s} = \frac{-c_C^s p_\alpha}{\left((1-f_C^s)p_\alpha - c_\alpha\right)^2},$$

and is negative, since the numerator is has a negative value and the denominator is a squared term and thereby positive.

Change in the price of the good to be transacted (p_α): Next, take the first derivative of $\emptyset_{CM}^{B\,(CM,M)}$ with respect to p_α, which gives the ceteris paribus impact of a change in the price charged for the good that may be transacted[29]:

$$\frac{\partial \emptyset_{CM}^{B\,(CM,M)}}{\partial p_\alpha} = \frac{c_C^s * (1-f_C^s)}{\left((1-f_C^s)p_\alpha - c_\alpha\right)^2}.$$

This expression is positive since $(1 - f_C^s) < 0$, making the numerator positive. The denominator is a squared therefore always positive.

Change in the cost of the good to be transacted (c_α): Lastly, take the first derivative of $\emptyset_{CM}^{B\,(CM,M)}$ with respect to c_α, which gives[30]:

$$\frac{\partial \emptyset_{CM}^{B\,(CM,M)}}{\partial c_\alpha} = \frac{-c_C^s}{((1 - f_C^s)p_\alpha - c_\alpha)^2}$$

Since the nominator is negative and the denominator positive due to it being a squared term, the relationship is negative.

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[28] $\emptyset_{C+M}^{B\,(CM,M)} = 1 - \frac{c_C^s}{((1-f_C^s)p_\alpha - c_\alpha)} = 1 - c_C^s * ((1 - f_C^s)p_\alpha - c_\alpha)^{-1} \rightarrow \frac{\partial \emptyset_{C+M}^{B\,(CM,M)}}{\partial f_C^s} = -c_C^s * ((1 - f_C^s)p_\alpha - c_\alpha)^{-2} * -1 * -p_\alpha = \frac{-c_C^s * -1 * -p_\alpha}{\left((1-f_C^s)p_\alpha - c_\alpha\right)^2} = \frac{-c_C^s p_\alpha}{\left((1-f_C^s)p_\alpha - c_\alpha\right)^2}$

[29] $\emptyset_{C+M}^{B\,(CM,M)} = 1 - \frac{c_C^s}{((1-f_C^s)p_\alpha - c_\alpha)} = 1 - c_C^s * ((1 - f_C^s)p_\alpha - c_\alpha)^{-1} \rightarrow \frac{\partial \emptyset_{C+M}^{B\,(CM,M)}}{\partial p_\alpha} = -1 * -c_C^s * ((1 - f_C^s)p_\alpha - c_\alpha)^{-2} * (1 - f_C^s) = \frac{-1 * -c_C^s * (1-f_C^s)}{\left((1-f_C^s)p_\alpha - c_\alpha\right)^2} = \frac{c_C^s * (1-f_C^s)}{\left((1-f_C^s)p_\alpha - c_\alpha\right)^2} = \frac{c_C^s * (1-f_C^s)}{\left((1-f_C^s)p_\alpha - c_\alpha\right)^2}$

[30] $\emptyset_{C+M}^{B\,(CM,M)} = 1 - \frac{c_C^s}{((1-f_C^s)p_\alpha - c_\alpha)} = 1 - c_C^s * ((1 - f_C^s)p_\alpha - c_\alpha)^{-1} \rightarrow \frac{\partial \emptyset_{C+M}^{B\,(CM,M)}}{\partial c_\alpha} = -1 * -c_C^s * ((1 - f_C^s)p_\alpha - c_\alpha)^{-2} * -1 = \frac{-c_C^s}{\left((1-f_C^s)p_\alpha - c_\alpha\right)^2}$