THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Understanding Mobile Service Diffusion as an Evolutionary Process: A Study of the Swedish Market

MOHAMMAD TSANI ANNAFARI

Department of Technology Management and Economics
Chalmers University of Technology
Göteborg, Sweden
2012

Understanding Mobile Service Diffusion as an Evolutionary Process: A Study of the Swedish Market

ISBN 978-91-7385-692-8

Doktorsavhandlingar vid Chalmers Tekniska Högskola, Ny series nr 3373
ISSN 0346-718X

Department of Technology Management and Economics
Chalmers University of Technology
SE-41296, Göteborg, Sweden

Printed by Chalmers Reproservice

Göteborg, 2012

Understanding Mobile Service Diffusion as an Evolutionary Process: A Study of the Swedish Market

Mohammad Tsani Annafari

Department of Technology Management and Economics
Chalmers University of Technology

Abstract

This thesis aims to highlight the connections between the diffusion of innovation theory and the evolutionary models for technological changes within the context of mobile communication research. On the basis of empirical findings, the discussion focuses on addressing three research questions: Why should mobile service diffusion be understood as an evolutionary process? How should mobile service diffusion be explained and modelled using evolutionary conceptions? And in what way the evolutionary framework could influence future mobile service diffusion studies?

Based on empirical observations and a literature study, this thesis argues that mobile service diffusion involves dynamic, developmental and historical economic process which is comparable to an evolutionary process. Some essential features of evolutionary processes can also be observed empirically along the mobile service diffusion. For instance, the presence of various generations of mobile service technology along the diffusion timeline as well as different intensities of mobile service use, i.e. single subscriptions and multiple subscriptions, indicates that the variation characterizes the diffusion process of mobile service. The cord-cutter population implicitly indicates the presence of selection mechanism of individuals who choose to retain mobile-only communications rather than other type of communication. Similarly the existence of mobile service non-users also implicitly indicates that retention exists along the diffusion process. All these indications suggest that the evolutionary concepts are relevant in order to comprehend mobile service diffusion.

To explain and model mobile service diffusion using an evolutionary framework, this thesis underlines the importance of data granularity and the use of a relevant diffusion model. The use of data granularity is critical to represent the variation and to serve as a proxy for making trend projection based on the level of interest. The use of a relevant diffusion model is essential to describe the pattern of the data according to selection mechanisms that determine the diffusion process.

The evolutionary variation and selection mechanisms are also considered in two examples of diffusion modelling that address the level of mobile service use and intergenerational technology effects. The results show intuitive trend projections as well as realistic understanding toward the process of mobile service diffusion which are helpful for business strategy and policy planning. However the proposed approach is still unable to address different actors and forces that may internally or externally influence the evolutionary process of mobile service diffusion (i.e. dynamics in pricing, inter-technological substitutions and complementarities, service bundling, etc.). This suggests that future studies in mobile service diffusion should take into account the evolutionary conceptions that could model dynamic interactions of relevant actors and interests in mobile service ecosystem.

Keywords: Innovation diffusion, diffusion modelling, data granularity, mobile service, social evolution, variation, selective retention.

List of appended papers

This thesis is based on the work described in the following papers:

I. Annafari, M.T. and Bohlin E. (2010). Recognizing cord-cutters in the Swedish mobile phone market, in *Proceedings of the International Conference on Management Science and Information Engineering*, Zhengzhou, China, December 16-19. Has been re-written with new title "Dynamic socio-demographics pattern of cord-cutters: A longitudinal study of the Swedish market". Under review for publication in *Technological Forecasting & Social Change*.

II. Annafari, M.T. (2010). An empirical analysis of the factors determining multiple subscriptions in the Swedish mobile phone market, in *Proceeding of the 9th International Conference on Mobile Business (ICMB)*, Athens, Greece June 13-15. Has been re-written with Erik Bohlin as co-author with new title "Empirical exploration of factors that determine multiple mobile phone subscriptions". Accepted for publication in a special issue on best ICMB/GMR 2010 paper in *International Journal of Mobile Communications* (in press).

III. Annafari, M.T., Axelsson, A.S and Bohlin E. (2011). To have or have-nots: A longitudinal study of mobile phone ownerships in Sweden. Under review for publication in *New Media and Society*.

IV. Annafari, M.T. (2011). A multiple ownerships diffusion model of mobile service: A study of the Swedish market, Presented at the 2nd ITS PhD symposium, September 22-23, Budapest, Hungary. Has been revised and under review for a special issue in *Telecommunications Policy*.

V. Annafari, M.T., Lindmark, S. and Bohlin, E. (2011). Intergenerational effect of mobile service diffusion. Presented at the 5th ITS Africa-Asia-Australasia Regional Conference, Perth, Australia, November 13-16. Awarded best student paper prize and under review for a special issue in *International Journal of Management and Network Economics.*

VI. Annafari, M.T., and Bohlin, E. (2011). Why is the diffusion of mobile service not an evolutionary process? in *Lee, I. (ed.), Mobile Services Industries, Technologies, and Applications in the Global Economy*. Hershey, PA, USA: IGI Global (in press).

List of additional papers

The following papers were also written during the PhD study, and some of them have parts that are relevant to the thesis, in particular they were building blocks in the initial stage of the thesis formulation:

I. Annafari, M.T. and Bohlin E. (2009). Counting active SIM cards or subscribers: Implication for policy and research, in *Proceedings of the 8th Conference on Telecommunication and Techno-Economics (CTTE)*, Stockholm, Sweden, June 15-17.

II. Annafari, M.T. and Bohlin E. (2009). Estimating non-subscribers and quasi-subscribers by sampling, in *Proceedings of the2nd IEEE Global Information and Infrastructure Symposium (GIIS)*, Hammamet, Tunisia, June 23-25, ISBN: 978-1-4244-4623-0.

III. Annafari, M.T. Srinuan, P. and Bohlin E. (2010). Who needs more subscriptions? An empirical analysis of the Thai mobile phone market, in *Proceedings of the 18th Biennial International Telecommunication Society (ITS) Conference*, Tokyo, Japan, 27-30 June.

IV. Annafari, M.T. and Bohlin E. (2010). Quasi-subscribers and Demand Saturation: An Analysis in the Swedish Mobile Phone Market", in *Proceedings of the 9th Conference on Telecommunication and Techno-Economics (CTTE)*, Ghent, Belgium, June 7-9, ISBN: 978-1-4244-7988-7.

V. Srinuan, P, Annafari, M.T, Bohlin, E. (2011). An analysis of switching behaviour in the Thai mobile market. *Info*, 13 (4), 64-75. The earlier version of the paper has been presented at in *the 18th Biennial International Telecommunication Society (ITS) Conference*, Tokyo, Japan, June 27-30.

Acknowledgements

A four year journey for a PhD degree at Chalmers is not such a short time for me. However, summing up all ups and downs, I would consider the journey as one of the best and most memorable times in my life. I therefore would like to express my deep gratitude to many wonderful people around me who always kindly share their support during this journey.

First, I am deeply grateful to my supervisor Professor Erik Bohlin who has always given his best to support me to grow as an independent academician and a humble human being. Thank you for always being a great supervisor, a fine friend as well as a caring father for me during my time at Chalmers.

I am also greatly indebted to my co-supervisors, Dr. Ann-Sofie Axelsson and Professor Gary Madden of Curtin University of Technology. Thank you for sharing valuable advices and insightful comments which often elevate the problems of mine and keep me encouraged.

Similarly, I would like to express my gratitude to Professor Staffan Laestadius of Royal Institute of Technology for giving a stimulating class in Stockholm, Professor Dimitris Varoutas of the University of Athens for his valuable comments in my final seminar and Professor Teodosio Pérez Amaral of Complutense University of Madrid for his insightful review of my licentiate thesis.

A special thank is for Professor Hitoshi Mitomo of Waseda University who recommended me to this PhD course. Thank you for always give your best support all this time.

I am also grateful for all thoughts, discussions and good comments from all the colleagues at the division: Professor Ilona Heldal, Dr. Gustav Sjöblom, Orada Teppayayon, Ibrahim Kholilul Rohman, Pratompong Srinuan, Chalita Srinuan, Nattawut Ard-Paru and Chatchai Kongaut. Thank you for always being good friends and colleagues of mine.

Big thanks are for Yvonne Olausson, Sofie Forsberg, Anna Tullsten, Eva Burford and all people in the corridor, not least Igor Insanic. Thank you for always warming the corridor with your friendly and charming smiles as well as helpful support.

I would also express my great appreciations to the Indonesian Ministry of Communication and Information Technology for granting me the scholarships for this study. I would also acknowledge the generous support from the Swedish Post and Telecom Agency (PTS), the National Telecom Commissions of the Kingdom of Thailand (NTC) as well as the Department of Technology Management and Economics of Chalmers University of Technology, Sweden. Thank you for providing me a valuable research support.

Thank you also for all professors and lectures at Chalmers and other universities who have shared their valuable knowledge and great life experiences. I believe all you have given to me will always inspire and motivate me to be a purposeful person for everyone.

Last but not least, I would like to express my great thanks to my wife, my son, my parents and my big family. Your everlasting love, prayers and support always bring me the energy to complete all tasks.

Finally, all praises are only for Allah, the Almighty who made everything possible. Without His will none of this work would be achievable.

Table of contents

List of tables

List of figures

List of abbreviations

1G	First-generation mobile telecommunications, i.e. MTA, MTD, NMT
2G	Second-generation mobile telecommunications, i.e. GSM
3G	Third-generation mobile telecommunications, i.e. UMTS, W-CDMA
4G	Fourth-generation mobile telecommunications, i.e. 3GPP LTE, Mobile WiMAX
GPR	Generalized Poisson Regression
GSM	Global System for Mobile Communications (formerly Groupe Speciale Mobile)
ITU	International Telecommunications Union
LTE	Long term Evolution Technology
MTA	Mobiltelefon system A, also called MTL
MTD	Mobiltelefon system B, or Berglund
NMT-450	Nordic Mobile Telephone System using 450 Mhz frequency
NMT-900	Nordic Mobile Telephone System using 900 Mhz frequency
PTS	Post- och Telestyrelsen (the Swedish post and telecom agency)
UMTS	Universal Mobile Telephone System
SIM	Subscriber Identity Module
W-CDMA	Wideband - Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access

Chapter 1

Introduction

This chapter briefly explains the background and motivations underlying this thesis. It also discusses the research objectives, research questions, research scope and outline of the thesis.

1.1 Background and motivations

This thesis is a study of the interplay between technological change and economic development. In this domain, the analysis of the diffusion of innovations has been recognized by economists and social scientists as a central topic for understanding the contribution of technical progress to economic growth (Cainarca, Colombo and Mariotti, 1988). In addition, as discussed in Stoneman (1983:112), diffusion is also considered by Schumpeter (1939) as an integrated part of the *invention-innovation-diffusion* trilogy which determines technological change process. In this context, the concept of 'diffusion' denotes the process by which new technological forms are integrated into the economy to generate changes in its structure. Diffusion analysis show how the economic significance of a new technology changes over time. This indicates that study on the diffusion of innovation is essential to comprehend the general impact of technical progress on economic development.

According to Metcalfe (1988:560), diffusion–related structural change can be studied from different levels, i.e. from the macro development of an entire industry to the micro level at which a new innovation is diffused to generate corresponding marginal changes in the behaviour of firms and individuals[1]. In the latter case, the diffusion of innovation is often seen as the representation of aggregated demand which often characterizes the technological change (Ben-Zion and Ruttan, 1978). This type of study has been widely applied across different types of innovations including mobile communication.

In the field of mobile communication, studies such as Chen, Watanabe, and Grify-Brown (2007) and Funk (2009) investigate the determinant of the speed of diffusion in the market from a macro level and its impact on industrial dynamic in mobile communication. However, most mobile service diffusion studies focus on explaining the fit of several diffusion models to the penetration rate data of mobile telephony, either in a single market setting or across

[1] Alternatively, Stoneman (1983:67) classified the diffusion into three parts, i.e. intra-firm diffusion, inter-firm diffusion and economy wide diffusion.

countries. In the former case, mobile service as the unit of analysis is typically seen as a form of *firm* or *technological innovation*, while in the latter case mobile service is viewed as a form of *consumer innovation*[2].

In many cases, consumer innovations or users often play an important role as agents of technological change which may influence the diffusion process (Kline and Pinch, 1996). Users are also considered as the most important source of innovation for firms because their demand often determines what the product should actually do (Padmore, et.al., 1998). This can also be observed in the case of mobile service diffusion where some characteristics of mobile service use which may impact on mobile service diffusion such as:

- The presence of multiple-subscriptions for mobile service (Annafari (2010a), Gamboa and Otero (2009), Sutherland (2009))
- The trend of very high mobile service penetration rate which even double the actual population (or potential adopters) in some markets, i.e. UAE, Montenegro[3].
- The presence of mobile-service non-users, even in a country with a very high penetration rate (Annafari and Bohlin, 2009a, 2010a).

These characteristics of mobile service use are related to mobile service adoption and determine the pattern of mobile service diffusion. However, most studies on mobile service diffusion, that view mobile service as a form of consumer innovation, overlook these characteristics. This motivated the author to carry out a series of empirical studies to reveal the underlying factors of the phenomenon, and construct explanations that could frame and explain the observations.

In earlier works, (i.e. Annafari, 2010b), a study was initiated in order to address the phenomenon of quasi-subscribers (i.e. mobile service users with multiple subscription, and its problematic issues related to the accuracy of penetration rate data as well as to the mobile service diffusion. In this thesis, the author aims to extend this work by developing a discourse that can be used to frame the problem at hand as well as enrich the perspective on mobile service diffusion studies.

Based on a literature review and observations, the author found that most studies in mobile service diffusion are dominated by classical diffusion of innovation theories. This results in a static paradigm when viewing and explaining the diffusion process (further discussions on this are found in Chapter 2). Most diffusion models used in the studies, (see e.g. Table 2), are rooted in the fundamental diffusion models[4] which implicitly assume that:

- The diffusion pattern forms a single S-shaped curve
- Each individual can only adopt one mobile phone and the adoption will only occur once.
- Once an individual becomes a mobile phone adopter, her or she cannot be a non-adopter (or disconnected from the service).
- The adoption is disseminated when there is a contact by adopters and potential adopters.

[2] Brown (1981:2) defined *consumer innovations* as innovations adopted by individuals or household, while *firm* or *technological innovations* are defined as new production inputs, machines, processes and techniques adopted by firms or entrepreneurs for their own use.
[3] See ITU statistics database: http://www.itu.int/ITU-D/ICTEYE/Indicators/Indicators.aspx#
[4]Mahajan and Peterson (1985:12) categorized logistic, Gompertz, Bass and probit as fundamental diffusion models which often become the basic inspiration of the other diffusion models.

- The probability that the adoption choice will be transmitted during the contact is constant.
- Only a single source of innovation/technology drives the diffusion

From a theoretical perspective, these assumptions indicate a 'static' paradigm of diffusion modelling, which is considered too parsimonious and mechanistic. This will result in an incomplete explanation of the diffusion process as well as a lower forecasting power (Parker, 1994; Maier, 1996 and 1998). The static paradigm also tends to regard the diffusion process as a single non-linear pattern which in many cases falls short of explaining the actual dynamic in the empirical world. In the case of mobile service diffusion, for instance, arguing that an individual adoption is only for single service, i.e. single mobile service subscription, is not correct since in many markets multiple subscriptions for mobile service is a part of consumer behaviour (Annafari, 2010a).

Assuming that only one single technology exists on the supply side is also irrelevant as mobile technology grows rapidly over time and offers alternative technologies with different characteristics of use. Therefore, Lieven and Gino (2004) argue that the traditional adoption and pattern should not be taken for granted and users' insights should be taken into account. This is because the mobile service diffusion has become increasingly complex and multidimensional, requiring the scholars to broaden the diffusion framework to accommodate recent market trends (Peres, Muller and Mahajan, 2010).

Furthermore, Van Dijk (2005:62-65) also identified some problems in relation to the use of single S-shaped curve- based conceptions, such as:

- The concept fails to precisely identify what constitutes the innovation under consideration. This is because, in practice, innovations can spread both as a single innovation, i.e. the gramophone, fixed phone, radio, etc., and as a bundle of innovations (i.e. the personal computer, mobile services, etc.). Therefore the S-shape curve conception which assumes single curve representation falls short addressing this fact.
- The concept mainly suggests a population-wide diffusion of mass-media which is no longer relevant for advanced technology diffusion. For example, the case of quick uptake of the internet diffusion is probably due to the high quality of existing telecommunication network infrastructure, rather than to the influence of mass-media
- It presents diffusion patterns as a single curve representation which ignores the trend of digital convergence in which some innovations may evolve simultaneously in a bundled product.
- It assumes deterministic stages and rate of diffusion (i.e. early adopters, majority adopters, etc.) which is sometimes not relevant in a wider context (c.f. the leapfrogging phenomenon of mobile phone diffusion in developing countries).
- It assumes diffusion for whole populations and not for partial or target groups. In fact, some segments of the population, such as minors and the disabled, may not be able to adopt the innovations.

All these points prompted the present study to develop an alternative framework that could accommodate the dynamic features of mobile service diffusion.

Based on the literature, especially the work of Veblen (1899), Tarde (1903), White (1947), Nelson and Winter (1982), Grubber (1996) and Ziman (2001) the author found that in many senses the dynamic aspects of diffusion of innovation have some connections with evolutionary notions (further discussion on this theoretical considerations is given in Chapter

2). Some studies such as Cainarca, Colombo and Mariotti (1989), Kwasnicka, Galar and Kwasnicki (1983), Kwasnicki and Kwasnicka (1996), and Metcalfe (2005), have proposed evolutionary perspectives when addressing diffusion processes in the domain of a system of innovation. In these studies, the evolutionary notion is applied in the context of industrial dynamics and considers firms as the unit of analysis. However, the studies do not include discussions on how the evolutionary point of view should be framed and contextualized with the diffusion process.

Some studies on mobile communication, such as Chen, Watanabe, and Grify-Brown (2007) and Funk (2009) also suggest that evolutionary features characterize the diffusion process of mobile phones. However, in these studies the discussion of the evolutionary features and their relation to the dynamics of the diffusion process are still missing. These studies also do not discuss the application of an evolutionary framework to the diffusion of innovation in the context of individual adoptions, which should be the case in mobile service diffusion studies where the service is mainly for personal use.

This motivated the author to consider the evolutionary paradigm as the source of inspiration to explain the mobile service diffusion process at the individual level. This also encouraged the author to fill the gap by developing an evolutionary-based framework that could serve as an alternative framework to explain mobile service diffusion as well as to stimulate further research in this field.

1.2 Research objectives and questions

Distilled from this discussion, the need for an alternative framework to understand the diffusion process, particularly in the mobile communication field is apparent. Also, the use of an evolutionary perspective as a source of inspiration in the field of economics is growing and promising, particularly after the work of Nelson and Winter (1982). Yet, studies within the mobile communication field linking both concepts in the context of mobile service diffusion are rarely found.

Therefore this thesis attempts to contribute by explaining mobile service diffusion, as a form of diffusion of innovation, using the paradigm of evolutionary theory in economics. The main aim is to understand the mobile service diffusion process using a relevant framework in evolutionary economics of technological changes, and to explain some practical implications of having such framework.

To be put into practice, these ideal objectives need to be articulated into research questions as shown in Table 1. As seen in the table, there are three questions addressed in this study. The first question is a “why-question” which seeks explanations to understand why mobile service diffusion should be framed as an evolutionary process. To address that question, this thesis will examine the diffusion of innovation as a social evolutionary process based on a relevant criterion (i.e. whether some essential features of the social evolutionary process characterize the diffusion of mobile service). Empirical and theoretical arguments will be provided to justify the explanation. According to the second question, given the claim that diffusion of mobile service should be framed as an evolutionary, this thesis will show how to incorporate the evolutionary features into mobile service diffusion modelling.

Since the first two questions challenge the fundamental paradigm in understanding the theoretical process of diffusion of innovation (i.e. changing a static and linear process into a ‘more dynamic’ or evolutionary one), a direct implication, particularly one concerning how

the process should be modelled, needs to be discussed. Therefore, the last question in this thesis addresses some implications of the presupposition of the first question to future mobile service diffusion studies.

Table 1.Objectives and research questions

Research objectives	Research questions
▪ Understanding mobile service diffusion as social evolutionary process	1. Why should mobile service diffusion be framed as an evolutionary process? 2. How can the evolutionary features be incorporated into mobile service diffusion modelling?
▪ Understanding the implications of viewing mobile service diffusion as an evolutionary process in mobile service diffusion studies.	3. In what way can the evolutionary framework influence future mobile service diffusion studies?

Even though the implications may be observed more broadly, in their cultural, sociological or anthropological aspects, the author decided to focus only on the diffusion modelling context as this has more practical implication. For instance, diffusion modelling is often used to help decision maker prepare product planning by forecasting the future trend of the diffusion innovation. The diffusion model is also a critical part of empirical studies in diffusion of innovation. Therefore, understanding the implications of the changing paradigm will also be a significant contribution.

1.3 Scope and limitation

Given the restricted resources and time constraints for a PhD study, this thesis delimits the proposed research questions to the context of the Swedish mobile service market. This will be helpful to anchoring the discussion and empirical analysis in a consistent setting. Moreover, taking the Swedish market as the case is also convenient since its market characteristics, in some respects, are comparable to most other mobile service markets in the world. For instance, the Swedish market has a considerably high penetration rate and a significant population of prepaid subscribers as well as a liberalized market, something which are also typical of other markets. This offers a possibility to replicate and extend the relevance of this study in those markets.

Furthermore, this study focuses on the diffusion of consumer innovation rather than on firm or technological innovations. This is because the majority of innovation studies pay most attention to the supply side of the innovation, (i.e. producers, firms or industry) and less attention to demand side, (i.e. consumer or users). In fact, in these days a significant portion of the innovation going on in industrialized economies has been in the form of new consumer goods and services. Therefore, Nelson and Consoli (2010) suggest balancing this situation by studying how individual and household consumers respond to new goods and services. This delimitation was also decided based on the available data from the database of the annual

survey of the Swedish Post and Telecom Agency (PTS), which aims to monitor the dynamics of ICT use among the Swedish population.

In addition, it is important to underscore that this study is interdisciplinary in nature. Even though discussions from management and the economics of innovation are more dominant, this thesis also synthesizes various perspectives from marketing, sociology and anthropology without necessarily restricting itself to a certain discipline. The focus is to frame and comprehend diffusion of innovation theory with the help of perspectives from evolutionary theories in economics and apply this to the mobile communication field.

Nevertheless, since the diffusion of innovation theory is a broad-range theory and evolutionary theories in economics are a growing field of study, fully connecting both theories will require a very extensive analysis and cover wide-ranging discussions. This is obviously beyond what the author can do in this thesis. Rather, the reader should consider this thesis as an introductory theoretical work that could inspire a more advanced work, particularly in the field of mobile service diffusion.

1.4 Terms

In this study, some terms are frequently used. To prevent misconceptions and misinterpretation as well as to give a consistent understanding, these terms are framed as follow:

- *Innovation* is defined as "bringing any new problem solving idea into use" (Kanter, 1983:20). In this study, the practice of using mobile service to satisfy individual needs is considered as a form of consumer innovations.
- *Mobile service* is defined as "a radio communication service between mobile and land stations or between mobile stations," (NTIA, 1995). It includes various categories such as commercial mobile radio services, cellular phones or mobile telephony services, personal communication services, etc., and covers both data and voice communications. In this study, however, most discussion considers mobile phone subscription as a proxy representing mobile service adoption or use. This is based on a general assumption that a possession of mobile phone subscription will allow an individual to access any mobile services, even though an individual may only use a certain service, such as voice communication.
- *Mobile service use* in this study is defined as a dynamic combination of mobile service technology, as a form of artefact, with the set of individual routines that sustain the use and development of the mobile service, as a form of activity. Thus in this context, mobile service use, represents somewhat, of an amalgam of artefact and behavioural routine at the individual level, which can be seen as a form of "artefact-activity coupled" (Fleck, 2000:257).
- A *mobile service user* is an individual who uses mobile service, as determined by the possession of active mobile service subscription(s) or SIM cards regardless the level of usage. In this case, a mobile service user in the context of diffusion of innovation may also be understood as a carrier of a behavioural routine, (i.e. the mobile service use) to satisfy their needs for communication in broad sense. The term of active mobile service subscription implies that the existing service is available for use at the time of observation.

- *Mobile service diffusion* is a dynamic spreading process of mobile service use in population over time.
- *Meme* is defined in Dawkins (2006:192) as a unit of cultural transmission or a unit of imitation. In this thesis meme is viewed as individual behaviour of using mobile service that spreads from one mind to another various imitable process. This supports the concept that views memes as cultural analogues to genes in that they self-replicate, mutate and respond to selective pressures (Graham, 2002:196). This leads the perception of mobile service use as a meme to serve as the unit of analysis that evolves over time and shapes a given diffusion pattern.
- *Mimicking process* is a process of transferring a meme from one carrier (individual) to others through a social or cultural transmission process. In this process a meme plays a role as both a replicator and interactor. As a replicator a meme passes its most of its structure in sequential replications. As an interactor, a meme makes a cohesive interaction with its environment in such a way as to generate a differentiated replication, which leads to selection – a process in which the differential extinction and proliferation of interactor cause the differential perpetuation of the relevant replicators. This process, in turn, will generate a lineage – an entity that persists indefinitely through time either in the same state or and altered one as a result of replication (Fleck, 2000: 260-21). These processes are identical to variation and selective retention, which are the main features of evolutionary process.
- A *routine* is a "pattern of behaviour that is followed repeatedly, but is subject to change if conditions change" (Winter, 1964:263). This study emphasizes a definition of routines as "recurrent interaction patterns" which is understood, in the diffusion of innovation context, as the collective nature of routines that contrast to the individual nature of habits.
- *Evolutionary process* is defined as the movement of something over time which is dynamic in nature and involves random elements that generates variation in the variables in question, and a selection mechanism that systematically extracts existing variation[5]. In this case, since the term of evolutionary process is applied in the context of social domain, i.e. diffusion of innovation, the term is interchangeable with "social evolutionary process"

1.5 Thesis outline

This thesis comprises six individual papers and a cover paper, each of which corresponds to a research question of the thesis. In this case, the first three papers (Papers I – III) are mostly related to the first research question, while two papers (Papers IV and V) are mostly related to the second research question. The last paper (Paper VI) becomes the main source for discussing the third research question. Detailed discussion on this issue can be found in section 3.2 (see table 4).

The outline of this cover paper can be summarized as follows: Chapter 1 explains the motivation and background of the study. In this chapter the research questions and objectives

[5] This term is derived from Dosi and Nelson (1994) which define "evolutionary" as a class of theories, or models, or arguments, that their purpose is to explain the movement of something over time, or to explain why that something is what it is at a moment in time in terms of how it got there; that is, the analysis is expressly dynamic. In this case the explanation involves both random elements which generate or renew some variation in the variables in question, and mechanisms that systematically winnow on extant variation.

are formulated and the thesis scope and outline are described. In Chapter 2, the theoretical considerations that underline this study are explained. In this chapter a brief overview of related studies will also be given. Chapter 3 discusses the research setting and the process of addressing the research questions. The methods used in the appended papers will also be described and discussed. In Chapter 4, the first research question of this thesis is addressed by presenting the result of empirical observations and theoretical discussions. The second question of this thesis is discussed in Chapter 5 with focus on reviewing the application of alternative diffusion modelling to incorporate the evolutionary features. In chapter 6, the last question of this thesis will be explained by proposing some theoretical considerations to understanding mobile service diffusion as well as its implication to future studies on mobile service diffusion. This thesis concludes in Chapter 7, which will provide a summary of the study and discusses its contribution.

Chapter 2

Theoretical frames of reference

This chapter reviews relevant concepts related to diffusion of innovation theory and evolutionary framework in economics of change and develop assumptions which are grounded on the research questions presented in the introductory chapter. The connections and some relevant common ground between the theories are also discussed.

2.1 Diffusion of innovation theory

The study of diffusion of innovation theory was initiated over a century ago. At the beginning, the diffusion of innovation was studied within the field of sociology, but later this subject also became of interest to scholars in the other fields including economics. In the following subsections a general overview of diffusion of innovation theory will be described. This will include a historical review which is summarized in Figure 1. Given the fact that diffusion of innovation has a long history and involves a broad range of perspectives, the discussion on the development of diffusion innovation theory is helpful to identify the theoretical positioning of this study over the whole range of concepts developed. This is also useful for the reader framing the discussion, as well as giving an intuitive direction for future research as proposed in later part of this thesis.

2.1.1 Historical overview

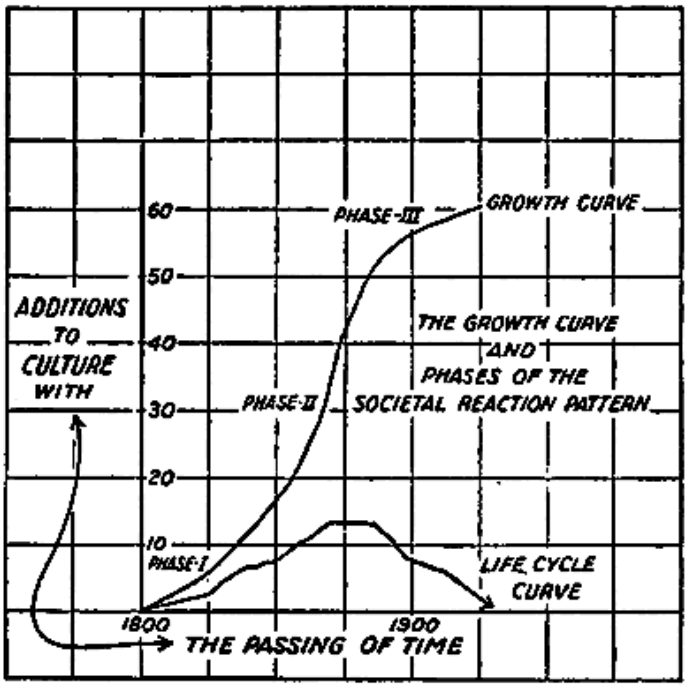
The development of many new inventions at the beginning of the twentieth century, many of which led to social and cultural change, inspired Tarde (1903), a sociologist, to introduce the term “diffusion”. He used that term to explain imitative behaviour at the level of small groups and within communities, and the relation between these micro-level processes to macro-level social change. In his book *The Laws of Imitation* (1903), Tarde introduced the S-shaped curve and opinion leadership as well as the role of socio-economic status to the process of innovation adoption. Further, Tarde also explained that the aim of diffusion study is to explain why some innovations are adopted and spread throughout a society, while others are ignored (1903:140). However, he did not specify and clarify key diffusion concepts. Nevertheless, his insights affected the development of many other scholars in the field. His S-shaped curve, for instance, inspired a sociologist, Chapin (1920), when explaining the longitudinal growth patterns in various social institutions, as shown in Figure 2.

Figure 1.Historical time line of diffusion of innovation studies

	Pre-paradigmatic era			***Paradigmatic era***						
	Before 1900s	***1920s***	***1930s***	***1940s***	***1950s***	***1960s***	***1970s***	***1980s***	***1990s***	***After 2000s***
Sociology	***Tarde*** (1890) The law of imitation	***Chapin*** (1920) Diffusion of Cultural change	***Pamberton*** (1936 &1937) The curve of culture diffusion rate	***Ryan & Gross*** (1947) Diffusion of innovation as a social process	***Sharp*** (1952) Consequences of Innovations	***Greenberg*** (1964) Earliness of knowing about an innovation by members of a social system ***Fliegel and Kivlin*** (1966) Rate of adoption of different innovations in a social system ***Coleman et.al*** (1966) Diffusion networks ***Deustchmann and Borda (1962) and Mohr*** (1969) Innovativeness of members of a social system		***Rogers and Kincaid*** (1981) Rate of adoption in different social system	***Kelly et.al*** (19991, 1997) Opinion leaderships	
Management and Economics			***Schumpeter*** (1934) Trilogy of "invention – innovation – diffusion"		***Von Bertalanffy*** (1957) Von Bertalanffy model ***Griliches*** (1957) Logistic model	***Floyd*** (1969) Floyd model ***Mansfield*** (1961) Logistic model ***Bass*** (1969) Bass model ***Chou*** (1967) Gompertz model	***Sharif & Kabir*** (1976) Sharif-Kabir model ***Midgley*** (1976) Multistage model ***Fisher & Prey*** (1977) Fisher-Prey model ***Mahajan & Peterson*** (1978) Dynamic and multi-innovation diffusion model ***Davies*** (1979) Probit model	***Jeuland*** (1981) Jeuland model ***Harvey*** (1984) Harvey model ***Eastingwood*** (1981, 1983) NSRL model ***Lilien et.al*** (1983) Multi-adoption model ***Norton & Bass*** (1987) Norton-Bass model ***Bayus et.al*** (1989) Durables goods model	***Chatterjee & Eliashberg*** (1990) Heterogeneous adopters' model ***Islam &Meade*** (1997) Islam-Meade model ***Kwasnicki & Kwasnicka*** (1997) Multi-technology substitution - model	***Steffens*** (2003) Multiple-unit ownership diffusion model ***Young*** (2008) Social contagion

Source: Various literatures

Figure 2.The S-shape curve of the longitudinal societal reaction pattern



Source: Chappin (1920: 383)

In the field of Economics, Schumpeter (1934) discussed the importance of innovation and technological change as the driving forces behind the long trade. The discussion is amplified in his work (1947) where he further explains the critical role of diffusion as a part of the "invention-innovation-diffusion trilogy" which determines the process of technological change. Nevertheless, Tarde, Schumpeter and other scholars in this period still view the diffusion of innovation as the spread of innovation, per se, rather than being based upon a generalized diffusion process. Hence, this period is considered as pre-paradigmatic era of diffusion of innovation studies (Valente and Rogers, 1995).

A different paradigm emerges when American sociologists, Ryan and Gross (1943) applied the theoretical view of Tarde to explain the diffusion of hybrid corn. By showing the pattern of hybrid corn adoption in several states, Ryan and Gross explain that the pattern diffusion of innovation typically will follow a certain pattern, which was later described by Rogers in 1962 using the same data set as an S-shaped curve (see Figure 3). This figure, in many senses, is comparable to Figure 2 which was constructed by Chappin (1920), based on the work of Tarde. This indicates that the fundamental conception of the diffusion process is not so much different when applied either in cultural or innovation studies. The difference is only that Ryan and Gross (1943) construct the S-shape curve based on an integrated empirical study with a certain innovation context, (hybrid corn), which is helpful for explaining the S-shape curve projection over time.

In 1950, Ryan and Gross further improved their diffusion conceptions which later inspired Rogers in 1962 to frame the diffusion as "*a process by which an innovation is communicated through certain channels over time among the members of social system*". In this case, Rogers defined innovation as "*an idea, practice or object that is perceived as new by an individual or other unit of adoption*" (Rogers, 2003:12). In this definition, a communication channel refers to a means by which messages get from one individual to

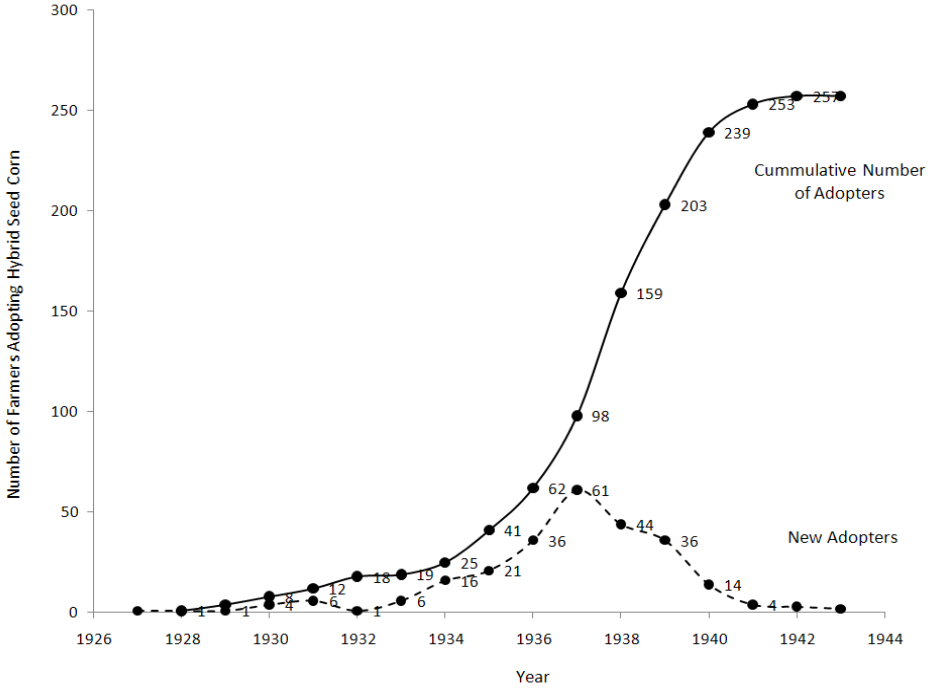
another in which the nature of the information exchange determines the conditions under which a source will or will not transmit the innovation to the receiver and the effect of such a transfer (Rogers 2003:18). A social system denoted as a set of interrelated units that are engaged in join problem solving to accomplish a common goal. In this case a member of a social system may be an individual, informal group, organization and or sub system (Rogers, 2003: 23).

Rogers (2003: 94-100) further groups diffusion research in social science into eight main research focuses:

1. Earliness of knowing about innovations, Mayer et. al. (1990)
2. Rate of adoption of different innovations in a social system, Fliegel and Kivlin (1966)
3. Innovativeness, Deutschmann and Borda (1962)
4. Opinion leadership, Kelly et. al. 1991 and 1997)
5. Diffusion networks, Coleman et. al (1966)
6. Rate of adoption in different social system, Rogers and Kincaid (1981)
7. Communication channel usage, Ryan and Gross (1943)
8. Consequences of innovations, Sharp (1952)

All of these studies are done in theoretical contexts and propose no diffusion modelling.

Figure 3. The S-shape curves of adopters of hybrid seed corn in Ryan and Gross (1943)



Source: Adapted based on Ryan and Gross (1943) with reference to Rogers (2005:273)

In the field of economics, the first empirical work on of diffusion of innovation can be traced to a paper by Griliches (1957) which introduces the use of an econometric model to explain the diffusion process. In his paper, Griliches observed that if the proportion of total maize in a state *i* that is planted with hybrid seed is plotted against time P_i (*t*), then the resulting plot for each state usually has an S-shape. These S-shaped curves of the states suggest that the utilization rate of a new technology typically starts at a low level and at first

increases slowly, and then after a while the increase becomes larger until a point of inflection, after which the rate of utilization decreases although the growth of utilization may still occur.

Further, Griliches explains that the parameters of the curve, including the asymptote, are different across states. The different curve for each state also suggests that the diffusion process is different across social systems. In this case, there are positive correlations between the speed of diffusion, as well as the size of the asymptote, and the profitability of adopting the new technology. This work of Griliches (1957, 1960), in addition to the work Mansfield (1961) and other economist mark the paradigmatic era of diffusion of innovation where the diffusion process is explained uses a certain framework and generalized formulation (i.e. diffusion modelling). The application of this framework mainly focused on developing diffusion model with some empirical application wide areas, including Marketing, Management and Economics.

2.1.2 Diffusion modelling

Since the work of Griliches (1957), econometric-based diffusion modelling has become a tradition in diffusion innovation studies. In this case, the diffusion model is generally used to represent the level of spread of an innovation among a given set of prospective adopters in terms of a mathematical function against the time elapsed since the introduction of the innovation. The purpose of the model is to describe the successive increase in the number of adopters of a certain innovation and predict the continued development of the diffusion of innovation process already in progress (Mahajan and Peterson, 1985:10).

In this case, generally, there are three categories of diffusion modelling in use (Ibid: 70):

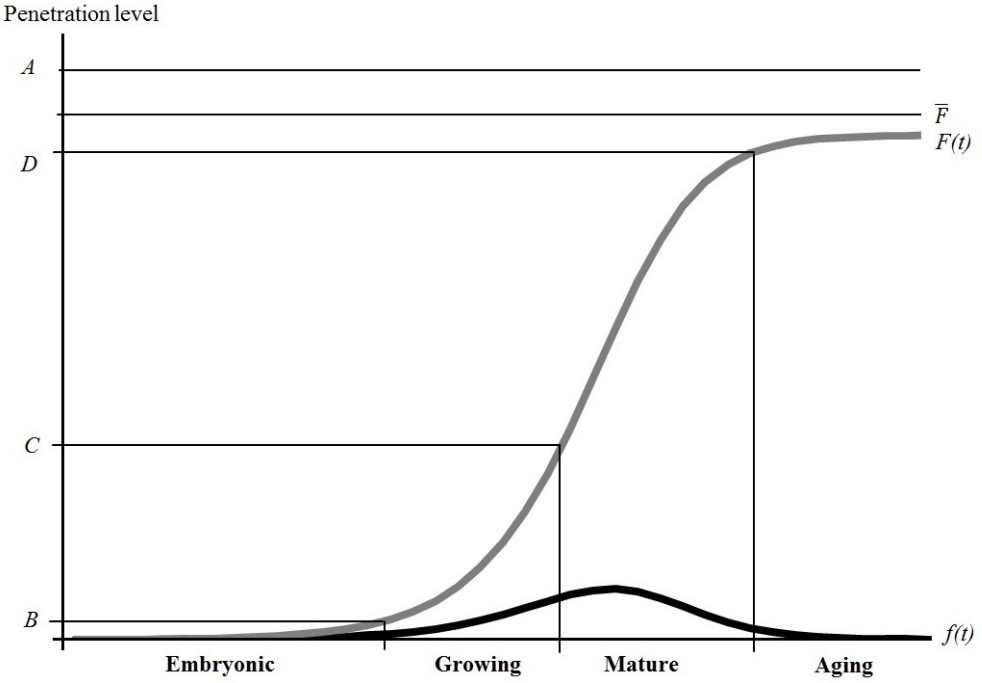
- To describe behavioural events, (the spread of a certain innovations)
- Normative use, (as the basis to explain of how product should be marketed)
- Forecasting, (to forecast the success or failure of new products)

This thesis, as well as most diffusion studies in the mobile communication field, falls into the first use.

According to Jaakola et.al (1998), the diffusion process is typically modelled by two functions describing the *cumulative* and *noncumulative* spread of the product which have a regular form, as illustrated in Figure 4. In this case, notations in the figure can be specified as follows:

- $f(t)$ is a noncumulative adoption function
- $F(t)$ is a cumulative adoption function
- $\bar{F}$ is the potential adopter population(in most cases assumed a priori, as a fixed number of potential adopters during the adoption period;
- (A) is the state where the *whole population* of which the potential adopter population is a subset
- (B) is the *lower threshold level* of penetration or the critical mass; If the innovation diffusion reaches this point, then it typically will proceed to its completion;
- (C) is the inflection point $t = t^*$, at this point $f(t)$ has its maximum value, and increasing diffusion growth changes to decreasing growth
- (D) is the upper threshold level, or saturation level.

Figure 4. Fundamental diffusion model formulation



Source: Adapted from Jaakola et.al (1998)

If a comparison is made between Figure 2, Figure 3 and Figure 4, it is clear that the diffusion curves are very similar. This indicates that the basic conceptions of diffusion of innovations remain the same since this study initiated about a century ago. However, the latter curve, which shows a detailed mathematical specification, indicates a significant formulation which allows a more comprehensive modelling process as well as wider applications.

Through its parsimonious form, the diffusion modelling technique can be applied in different types of innovations. New diffusion models, either improved or newly constructed, appear in the literature over time. Therefore, it is not surprising that at present there have been many diffusion models available in economics literature. Some studies have reviewed and classified these models, such as those by Mahajan and Peterson (1985), Geroski (2000) and Islam and Maede (2006). However, Mahajan and Peterson offer a systematic classification which takes into account both historical context and model formulation. In general, Mahajan and Peterson (1985: 12) classify diffusion models into three groups:

a. Fundamental diffusion models

Fundamental diffusion models are a group of diffusion models that have the simplest formulation in their context of assumptions and are often used as the basis for other diffusion models. According to Mahajan and Peterson (1985: 35), there at least are seven basic assumptions of fundamental diffusion models:

- The adoption process is binary, i.e. to adopt or not adopt.
- There is a fixed ceiling on the number of potential adopters
- There is only one adoption by an adopting unit
- There is a complete mixing of prior and potential adopter with model parameters constant over the diffusion process.

- The innovation is independent of other innovations
- The geographical boundaries of the social system do not change over the diffusion process
- All relevant information about the diffusion process is "captured" by the model.

Based on these assumptions, the fundamental diffusion models categorize the adopter potential into two groups - adopters ($F(t)$) and non-adopters ($\bar{F} - F(t)$) respectively. The diffusion incremental growth is based on the internal and external influence that directed to non-adopters to make a positive adoption decision. *External influence* comes from advertising, mass media communication, and the like. *Internal influence* denotes interaction within the potential adopter population, (experiences of the product). This interaction may have positive or negative effects, and its source may be either the class of adopters or the non-adopters. Mahajan and Peterson (1985:16) formulated the fundamental diffusion model as:

$$f(t)=g(t)\,(\bar{F}-F(t)) \qquad (1)$$

where $g(t)$ is the pressure function that represents the influence of the group of non-adopters to make a positive adoption decision where:

$$g(t)= a+bF(t) \qquad (2)$$

In this case when b=0 then *g(t)* represent external influence, when a=0, then *g(t)* represent internal influence and when a and b ≠0, then *g(t)* represent mixed influence (internal and external).

b. Flexible diffusion models

Despite its parsimonious formulation, fundamental diffusion models suffer from two inflexible mathematical properties that determine the shape of diffusion curves - point of inflection and symmetry (Mahajan and Peterson, 1985:37). Most diffusion models, for instance, allow the point of inflection to occur only when the maximum rate of diffusion is achieved. In fact the point of inflection should be able to occur at any time during the diffusion time line. In addition, the diffusion patterns should allow both non-symmetric and symmetric shapes, which is not the case in fundamental diffusion models.

Some scholars address this problem and relax the assumption by developing generalizations based on an existing diffusion model which is considered by Mahajan and Peterson (1985: 26-29) as flexible diffusion models. Floyd (1968) for instance, modifies the logistic model so it has the non-symmetric inflection at a certain point (i.e. around the 0.33 of the overall diffusion process). This work is revisited by Sharif and Kabir (1976) and results in a model that can accommodate symmetric as well as asymmetric pattern, even though the point of inflection (F) must take place in certain range, i.e. $0.33<F<0.5$. Other models such as, Von Bertalanffy (1958), Non Symmetric Responding Logistic (NSRL) model (Easingwood, 1981) and Harvey model (Harvey, 1984) also similarly address the issue. In short, flexible diffusion models allow the generalized S-shaped diffusion curve to be both symmetrical and non-symmetrical with the point of inflection responding to the diffusion pattern instead of being predetermined.

c. Extension and refinement models

The last category of diffusion models, the extended and refinement models, aim to relax one or several of the assumptions of fundamental diffusion model. As a result, there is a wide range of model modifications, but mostly are based on fundamental diffusion models as their

starting point. Among these models, is the dynamic diffusion model (Mahajan and Peterson, 1978) which attempts to ease the requirement that the ceiling on the number of potential adopters is static or fixed at the time an innovation is introduced and remains constant over the diffusion process. There is also the multi-innovation diffusion model (Steffens, 2003) which aims to model the occurrence of several innovations in the social system during the diffusion process. In this case that model categorizes interrelationships between the innovations as independent, complementary, contingent and substitutes, and extends the mixed-influence model to represent the interdependency among these.

Other models include the multistage diffusion models, such as Midgley (1976) which seeks to ease the basic binary ceiling assumptions in the diffusion process, Lilien (1981), which attempts to relax the assumptions that there is only one adoption by an adopting unit and allows multiple adoptions by a unit adopter. Lilien models the phenomenon of repeated purchase or replacement purchase through a multi-adoption diffusion model. This modelling concept is further extended by Bayus et.al (1998) and Steffens (2003).

A more complex modelling, which addresses the adopters' heterogeneity, is proposed by Kalish and Lilien (1983) as well as Chatterjee and Eliashberg (1990) through diffusion models with influencing agents. There is also the evolutionary diffusion model by Kwasnicka, Galar and Kwasnicki (1983) and Kwasnicki and Kwasnicka (1997), which attempts to model technological substitution with a model based on biological analogy, rooted in the Fisher and Pry model.

Since there are many diffusion models available in the literature, selecting or constructing the relevant model is critical. Meade and Islam (2002:591-593) propose the following principles of diffusion model selection:

1. No single diffusion model is best for all processes
2. Unconditional forecasts from data-based estimates of a fixed saturation level is a difficult benchmark to beat
3. Simpler diffusion models tend to forecast better than more complex ones
4. Short-term forecasts are a good indicator of the appropriateness of diffusion model

In addition to these principles, a researcher should also take into account the purpose of diffusion modelling as discussed in Mahajan and Peterson (1985:10). This means describing the successive increase in the number of adopters of a certain innovation and predicting the continued development of the diffusion of innovation process already in progress, as well as the underlying assumptions that motivates the study. It is important to frame the results of the diffusion modelling with proportional interpretation.

2.1.3 Diffusion modelling of mobile communication studies

As discussed in Annafari (2010b), generally there are two categories of diffusion studies in the mobile communication field, cross country settings and single country settings. The former typically is intended to identify factors that influence the diffusion process as well as for comparison between countries. These studies usually also aim to explain the causal relation of mobile service diffusion and economic growth.

As shown in Table 2, typically this kind of study uses an econometric model which is constructed based on a certain diffusion model, (e.g. the logistic model or Gompertz model), with some economic variables such Gross Domestic Product (GDP), population density, level of competition and so on. This type of study does not give a diffusion pattern description, but

rather how the level of mobile phone diffusion, which is often represented by penetration rate, contributes to the economic growth, and vice versa.

In contrast, the latter category focuses on identifying the diffusion pattern in single country setting. This type of study typically aims to describe behavioural events, such as the spreading pattern of mobile telephony in the market, for normative use (as the basis to explain of how product should be marketed), and for forecasting (to forecast the success or failure of new products) (Mahajan and Peterson, 1985:70).

Table 2. Recent cross-countries studies of mobile phone diffusion

Study	Dependent variables	Independent variables	Countries	Period	Findings
Madden et.al (2004)	Mobile phone penetration rate	GDP per cap., pop, mobile user cost	56	1995 - 2000	High wealth, low users cost and large user base promote diffusion.
Koski and Kretschmer (2005)	Mobile phone penetration rate,user cost and entry	GDP per cap., GDP growth pop, pop. In urban areas, mobile user cost, fixed lines per capita, ICT investment, regulatory and competition variables	25	1991 - 2000	Standardization accelerates 2G entry and diffusion; an early monopolist will price more aggressively to build up an installed base. Liberalizing markets for incumbent technologies (i.e., fixed line telephony) has accelerated the commercialization of 2G.
Rouvinen (2006)	Mobile phone penetration rate	Pop. Total, Pop. City, illiteracy, agrarian status, trade, freedom, fixed user cost, fixed penetration,, mobile user cost, diigital and analog penetration., etc.	200	1992 - 2000	The speed of diffusion per se isnot significantly different between developed and developing countries. Late entrants experience rapid diffusion.
Grajek and Kretschmer (2008)	Mobile phone penetration rate	GDP, minutes if use, average revenue, prop. fixed subscribers, prepaid consumers shares, prop. own subscribers and subscribers to competing operators	41	1998-2004	Consumer heterogeneity is considerable and network effects are moderate in comparison. Fixed-mobile usage complementarity in the early stages of diffusion. Substitution of fixed-line with cellular minutes driven by changes in the fixed-line subscriber base.
Bohlin, A. et.al (2010)	Mobile phone penetration rate	GDP per cap., fixed penetr. and digitalization rate, mobile user cost	177	1990 - 2007	Per capita income, urbanisation and Internet/broadband penetration, as well as regulation, positively affect diffusion across all generations of mobile technologies.

In general, most recent studies with single country settings as depicted in Table 3 apply fundamental diffusion models with, a limited adjustment, if any. Most of these studies compare several fundamental models to determine the best fit with the data which in many cases depends on the market characteristics and the data structure. In fact, as discussed earlier, the diffusion model is too parsimonious to model the actual process of mobile service diffusion. For instance, the models do not take into account the uncertainty in the adoption process. Instead, they assume that everyone will adopt the innovation. Moreover, the models also overlook the multiple-adoption situation, which is common in mobile service diffusion. Most of these studies also use secondary data, such as the mobile phone penetration rate, which has been identified as problematic (Annafari and Bohlin, 2009a and 2009b). This is

because the penetration rate, for some reasons, such as multiple subscriptions, tends to exaggerate the actual number of mobile adopters and creates *quasi-subscribers*[6].

This suggests that alternative diffusion models that could overcome these problems are needed. In addition finding an alternative paradigm that could incorporate dynamic features of mobile service diffusion process is also critical. Therefore, the aim of this thesis, seeking alternative diffusion paradigms to understand mobile service diffusion, is timely and relevant.

Table 3.Mobile phone diffusion studies with single country setting

Study	Proxy	Model	Country	Period	Results
Michalakelis, Vorutas, and Sphicopoulos (2008)	Mobile penentration rate	Bass model, the Fisher–Pry model, Gompertz model and some representatives of the logistic variants	Greece	1994-2005	S-shaped curves – based diffusion models are suitable enough for accurate fitting and foreca sting the diffusion of mobile telephony in Gree ce.
Singh, S.K. (2008)	Mobile penentration rate	Logiticand Gompertz models	India	1995-2005	All models forecast a saturation level greater than 100%. The different values of estimations for the market potential or the saturation level spanning 111–126%.
Gamboa and Otero(2009)	Mobile pe netration rate	Gompertz and logistic models	Columbia	1992 - 2000	The pattern of diffusion can be best characterised as following a logistic model. The rate of growth of mobile phone subscribers will continue to grow .The estimated saturation level is consistent despite the multiple subscriptions.
Hwang, Cho and Long (2009)	Mobile Penetration rate	Bass, Gompertz, and logistic models	Vietnam	1995-2006	Logistic model is the best fit for the Vietnam case. the potential market is about 76% of the population. the most influential determinant factors for mobile phone diffusion is market competition.
Wu and Chu (2010)	Mobile penentration rate	Gompertz, logistic, Bass, and time-series autoregressive moving average (ARMA) models	Taiwan	1988-2007	The Gompertz model outperforms the other models before diffusion take-off, and the Logistic model is superior after inflection and over the aggregate range of the diffusion. Network externalities are the dynamics of the logistic model and account for its excellence. The appropriate diffusion model for mobile telephony is stage-dependent.

2.2 Some connections of evolutionary conceptions and diffusion of innovation

The use of an evolutionary perspective on diffusion of innovation is not something new. For instance, Tarde (1903:382) indicated: *"…What did Darwin's thesis about natural selection amount to? To have proclaimed the fact of competition among living things? No, but in having for the first time combined this idea with the ideas of variability and heredity. The former idea, as it was proclaimed by Aristotle, remained sterile until it was associated with the two latter ideas. From that as a starting point, we may say that the generic term, of which invention is but a species, is the fruitful interference of repetitions."*

[6] Quasi-subscribers is a mobile service user with multiple mobile service subscriptions, which by then double or multi counted as a mobile service adopter. For further discussion see Annafari (2010a)

This excerpt indicates that Tarde considered evolutionary biology a source of inspiration when viewing the social world. In this case he uses a different approach, not from the perspective of the individual or the group, but from the point of view of the products, acts, and ideas that were used to classify those individuals or groups. By focusing on how these features 'evolved', Tarde argues that it is possible to reveal certain regularities or laws that appeared to pattern the social world that he called "imitation".

In practice, however, most innovation literature studies diffusion of innovation and the evolutionary concepts as separated notions. The early empirical work in diffusion of innovation studies by Griliches (1957) and Mansfield (1961) views the diffusion of innovation as a function of the accumulated adoption of innovation, (e.g. hybrid corn or machinery), over time, which typically forms an S-shaped curve. In this case, the accumulated adoption or use of hybrid corn can be seen as a cultural entity that replicates a certain idea or a complex of ideas. However, unlike an evolutionary entity in an evolutionary system that evolves dynamically, the adoption of hybrid corn in the Griliches study is understood as a homogeneous process that only assumes two possibilities: to adopt or not to adopt.

Accordingly, Rogers (2005:6) defines diffusion of innovation as "*the process by which an innovation is communicated through certain channels over time among the members of a social system.*" Like Griliches, Rogers assumes that the cumulative number of adopters of an innovation over time typically forms an S-shaped curve, initially with a few adopters per unit of time, followed by a take-off in the rate of adoption as the opinion leaders decide to use the innovation, and eventually by a slowing of the rate of adopters as the number of potential adopters remaining decreases. This theory, together with Griliches-type generalization as well as other fundamental diffusion models that are rooted in the epidemic approach, (e.g., the driving force is the dispersion of knowledge through discourse between an adopter and potential adopter of technology), influences most studies in mobile service diffusion as depicted in Table 2. However, these models seem too crude as they only consider time variation on the basis of innovativeness (the degree to which an individual is earlier relative to others in adopting the innovation), resulting in five adopter categories: innovators (the first to adopt), early adopters, early majority, late majority, and laggards. In fact, there are more variations on the way individuals adopt an innovation, including the quantity of the adoption, i.e., multiple-adoption, as well as the type of innovation to adopt, (e.g. GSM and UMTS/CDMA). Therefore a more realistic explanation is therefore required for the mobile phone diffusion process.

Based on various empirical examinations, Grubler (1996) concludes that even though diffusion is basically a process of imitation and homogenization, it develops clusters of adopters and stages of adoption that indicate variety. In the long run, this will typically be disrupted by crises that emerge in transitional periods. Therefore, Gruber mentioned that "*as such, diffusion process may be among the inherent features of the evolutionary process that governs social behaviour"*.

In the context of diffusion modelling, Metcalfe (2005) theoretically shows that the logistic laws of evolution in the diffusion model in Mansfield (1961), which provides the economic explanation of the diversity in utilization growth rates, are related to the explanation of dynamic diversity as the fundamental evolutionary feature. In this case, Metcalfe proposes "*Logistic laws of evolution*" to address the population dynamics of innovations which is driven by a process of competitive selection. Using empirical perspective, Kwasnicka, Galar

and Kwasnicki (1983), as well as Kwasnicki and Kwasnicka (1997), consider evolutionary conceptions as the source of inspiration to explain the inter-technology competition that determines the dynamic pattern of innovation diffusion in sectoral innovation, such as energy industry.

All these literatures underscore the proposition that evolution is an intrinsic part of the diffusion process and, as a result there should be no problem viewing the diffusion of innovation from an evolutionary perspective. However, some questions such as why the diffusion of innovation should be framed as evolutionary process? And how to incorporate evolutionary features in diffusion modelling, remain unaddressed. In fact, in addressing such questions in the field of diffusion of innovation would be wise to apply the evolutionary conceptions in a more practical context. This gives rise to the challenges that will be addressed in this thesis.

2.3 Implications for the research questions

Earlier discussions have shown that framing diffusion of innovation studies using evolutionary conceptions is a promising research agenda. Theoretically, bridging both conceptions is also a possibility. However few attempts that propose such connections can be found in the literature. Most of the discussions are also given in the general context of systems of innovations, and very little attention is paid to the context of consumer innovation. In fact, the application of evolutionary perspective can be a useful as it offers alternative perspectives, such as the dynamic paradigm, which is loosely provided by existing diffusion conceptions. This perspective is even more relevant in the context of the mobile communication field where rapid technological advancement and dynamic consumer behaviour characterize the market. Such a research ambition is set up as an agenda in this thesis with application to the mobile communications field. For this purpose, three research questions are proposed as shown in Table 1.

Nevertheless, it is important to take into account that this research is carried out within management of innovation studies. Therefore, it will not offer a sophisticated mathematical formulation for diffusion modelling to address the problem. Rather it will try to characterize and understand the main features and applications of evolutionary theory within the social domain, i.e. diffusion of innovation studies. For this purpose, this thesis considers a framework proposed by Dosi and Nelson (1994) to present the evolutionary view of an economic process, including diffusion of innovation.

Based on this framework, the term ‘evolutionary’ in this context of study should be seen as a theory, argument, or model that has the following characteristics:

- The purpose is to explain, using a dynamic view, the movement of something over time or to explain that thing at a given moment in time in terms of how it got there.
- The explanation involves both random elements that generate or renew some variation in the variables in question and a mechanism that systematically examines existing variation.

This implies that viewing diffusion of innovation using an evolutionary perspective requires investigations to show a dynamic process of diffusion that consists of a heterogeneous pattern of a unit of selection that progress over time as a result of variation and a selection mechanism. In this study, this task will be addressed through some empirical observations as well as literature studies as will be discussed in the next chapter.

Chapter 3

Methodology

This chapter explains and justifies the chosen methodologies, specifies the data use in this thesis and the design and performance of this research. It will start by explaining the research setting and follow with discussions on issues related to research process, as well as data collection and analysis.

3.1 Research setting

This study considers an evolutionary paradigm to understand the mobile service diffusion process. This implicitly suggests that a market with dynamic diffusion pattern of mobile service would be a suitable research setting. Consequently, this study considers the Swedish mobile service market as the context for empirical observations, since it shows dynamic diffusion characteristics as has been discussed in previous studies, i.e. Lindmark (1995). In addition, this single country setting is necessary to ensure a consistent context for discussions and empirical observations. With a single market setting the diffusion pattern observations can also be carried out with a continuous and steady stand point.

According to Tscherning and Damsgaard (2008) the dynamic pattern of diffusion of innovation is likely to be influenced by both the supply side, (the dynamic supply of mobile technology) and the demand side, (the dynamic of users or consumers behaviour). Any diffusion curve is actually the outcome of two processes: one related to the growth of the market for the technology and another process related to the capacity to supply the technology to the market (Metcalfe, 1988:562).

This study, therefore, considers the use of mobile service to be a unit of analysis, as it can represent the equilibrium of both the supply and demand for mobile communication service. Furthermore, the use of mobile service as the unit of analysis is also common in most mobile service diffusion studies. Traditionally, mobile diffusion studies use the penetration rate – the number of subscriptions per 100 populations - as the proxy to represent the diffusion pattern. In this case, the use of mobile service is assumed dynamically to evolve over time following a certain pattern, typically an S-shaped curve, which predetermined by a certain diffusion model.

Nevertheless, the use of mobile use as a unit of analysis poses some challenges that have to be further explained. First, the mobile use as an entity actually consists of a physical

element, (technology artefact), and a cultural element, (behavioural routine in using the mobile service as a means of communication).

The technology artefact itself can be further differentiated, (the mobile handset and mobile service technology). Each of these elements actually can be considered as an innovation which may have its own diffusion pattern. The mobile handset for instance, diffused and evolved over time from larger to smaller. At the same time, mobile technology which transformed from the first generation technology to Long Term Evolution (LTE) technology.

The cultural element relates to behaviours when using mobile service as a means of communication, also has varying levels of practice. As can be observed in daily life, some people use the mobile service solely for voice and text communication, while others also use this medium for data communication. Some people only have single subscriptions and others need two or more. These behavioural practices also diffuse and evolve over time. As a result, this thesis needed to provide relevant theoretical assumptions that could frame the use of mobile service as a proper single entity of unit of analysis. In this case the reader should also be aware from the beginning that the focus of this thesis is not on firm adoptions, as is the case in most evolutionary based diffusion of innovation studies, but rather on individual adoptions. This is because mobile service is considered as innovation bound up with the tendency for personal use rather than for business or other uses, even though this may change in the future.

Secondly, the assumption that mobile use as a unit of analysis diffuses over time through an evolutionary nature requires an explanation of how the diffusion process actually takes place. If the diffusion process is assumed as an accumulation of individual adoptions, then the mechanism of individual adoption as well as its contagion to other potential adopters has to be explained. The next challenge is how to formulate the theoretically based assumptions that have been built into a relevant diffusion model. In this case, the critical point is to identify what dynamic regularities of the diffusion process can be modelled to explain the implication of an applying evolutionary framework.

In this case, however, due to time constraint and data resources, this thesis will only focus the discussion on identifying and describing the mobile service diffusion pattern and proposing a relevant framework. The causal-relation between the diffusion patterns other marketing mix variables will not be part of the discussion since the modelling purpose of this thesis is merely to explain the behavioural events, in this case, the spreading pattern of mobile service as a form of innovation.

3.2 Research design and process

Based on the specified research setting, this research essentially has positivistic[7] features as it seeks the empirical evidence to explicitly point out the connections between the mobile diffusion process and evolutionary process. Most of the appended papers have empirical features which also accord with this epistemological standpoint. This section will show the research design, (i.e. the logical sequence that links the empirical observations to research

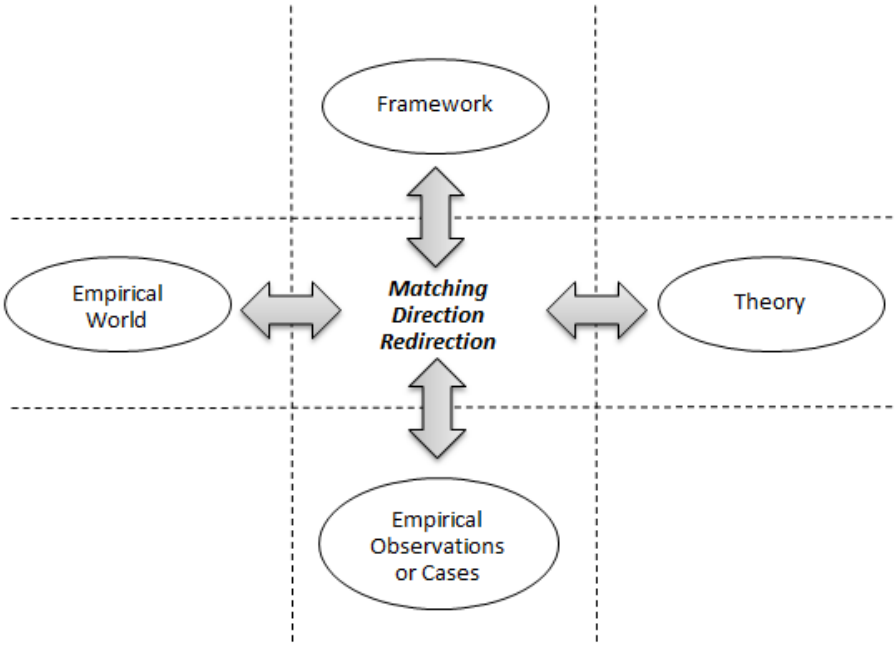
[7] According to Bryman and Bell (2007:16), positivism is an epistemological standpoint that supports the use of the science-based method to the study of social reality. In this case, knowledge is arrived at through the gathering of fact that provides the basis for a set of general rule.

questions) (Yin, 2003:20). Consequently, this thesis considers systematic combining (Dubois and Gadde, 2002) as an operational framework.

According to Dubois and Gadde, systematic combining is "a process where theoretical framework, empirical fieldwork, and case analysis evolve simultaneously". As shown in Figure 5, this approach allows "matching-direction-and redirection" of empirical observations and theoretical framework along the research process which offers researchers greater flexibility to proportionally adjust their assumptions, research methods, and even their research questions, during the process.

For a PhD study, such flexibility is very important as the study often faces data constraints or lack theoretical assumptions which, without "adjustment", will distort the research progress. This approach is also relevant since most PhD students are junior researchers or even beginners, who due to lack of experience and knowledge tend to apply a "trial and error" approach to gain understanding in their research. Furthermore, as shown in Figure 5 systematic combining allows researcher to start with any available prior knowledge and further develop and refine this knowledge through interaction with the empirical world which is framed with empirical observations or cases.

Figure 5.Systematic combining



Source: Dubois and Gadde (2002)

Based on the systematic combining framework, this research is implemented following the process flow as depicted in Figure 6. According to the figure, this research starts with the theoretical perspective obtained in the initial stage as in Annafari (2010b). At this stage the author recognizes the typology of mobile service adopters which also includes *quasi-subscribers*, (mobile telephony users with multiple subscriptions) and related problems in diffusion modelling, such as the problematic use of penetration rate as the proxy for explaining mobile telephony diffusion.

From this stage, the author proposes some preliminary assumptions in wider context that the dynamic of mobile telephony use characterize mobile telephony diffusion. Based on some

literatures, the dynamic pattern of mobile telephony use, like the dynamic pattern of other innovations, has certain connections with evolutionary properties. In addition, the author also assumes that possession of a mobile telephony subscription is actually the necessary condition to access mobile service, and therefore favours the expansion of the term of mobile telephony adopter to mobile service adopter.

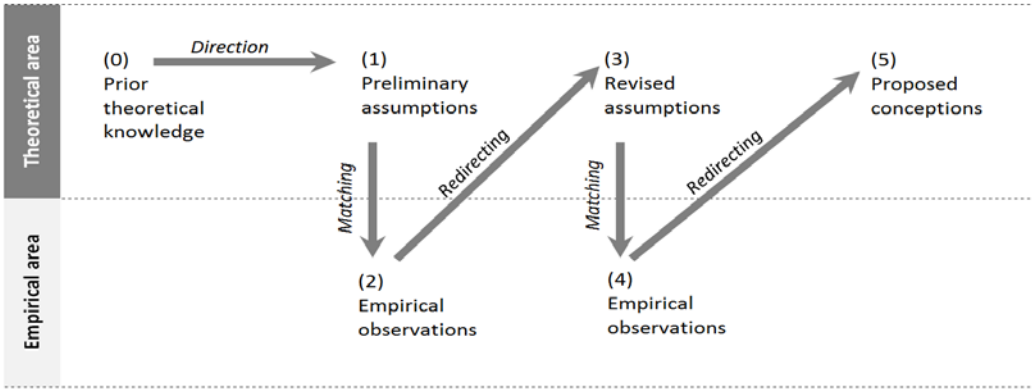
Based on these assumptions, the research continues with empirical explorations. At this stage, the main focus is to provide empirical evidence that could highlight the presence of evolutionary features, (variation and selective retention), in mobile service diffusion. For this purpose three studies are carried out with mobile use as the unit of analysis. In this case, each study addresses a different form of mobile use at population level. Paper I deals with mobile service only. Paper II relates to mobile service non-users and Paper III deals with multiple subscriptions mobile service.

As the outcome, this study proposes some general criteria or rules that should be clarified to justify whether the diffusion of innovation can be considered as an evolutionary process. These criteria are mainly based on the work of Dosi and Nelson (1994), which basically suggests three main prerequisites to frame a social phenomenon as evolutionary process: a relevant unit of selection, a mechanism of variation and selective retention. Based on this revised assumptions, three research questions are re-formulated as depicted in Table 1.

In the next process, two studies are carried out to addresses different issues related to the evolutionary feature of mobile service diffusion. The first study (Paper V) discusses the variation of mobile service use that can be seen, for instance, in the number of mobile phone subscriptions possessed. The last paper (Paper VI) studies the intergenerational effect of mobile technology on the diffusion pattern. In this study, the dynamic diffusion pattern of the mobile technology is described to show how the technology evolves over time and the “fittest” technology survives and preserves the characteristics of earlier technology that is relevant for survival.

The last stage of the research process studies the implication of having an evolutionary stance to the diffusion modelling. In this case, this thesis does not aim to construct a theoretical formulation to simulate the mobile service diffusion as an evolutionary process. Rather this thesis highlights the impact of essential evolutionary features, i.e. variation and selective retention, to the existing mobile service diffusion modelling. For this purpose, a literature study is carried out to construct relevant connections between diffusion of innovation theory and evolutionary models of technological changes (Paper VI).

Figure 6. Research flow



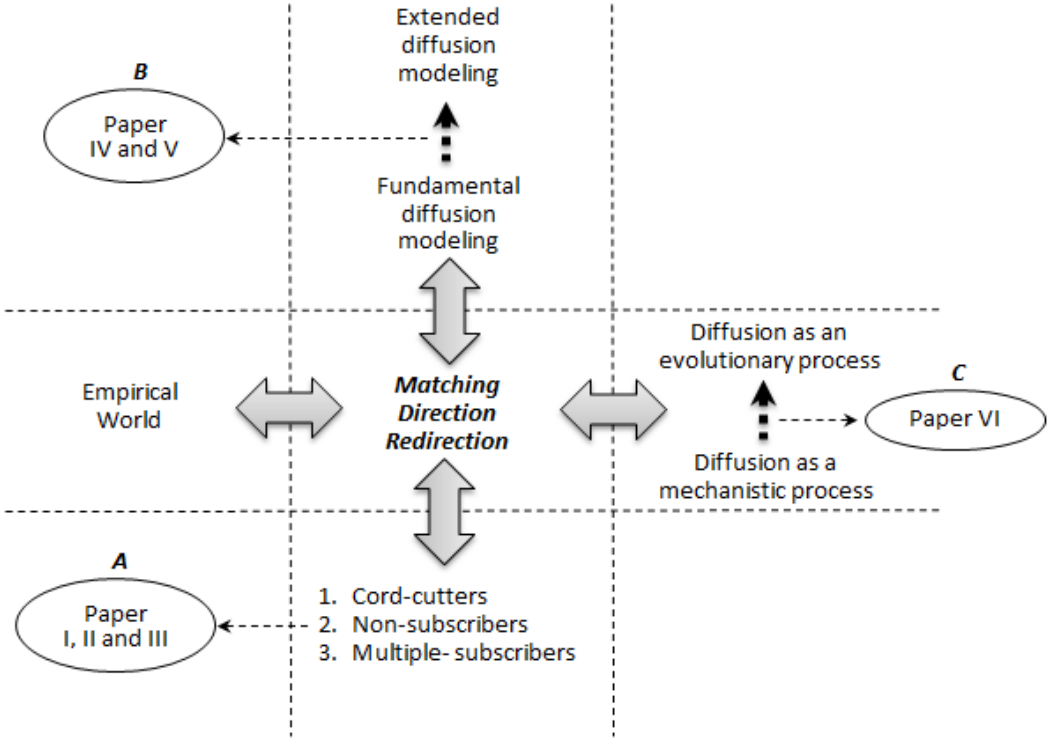
Furthermore, it is important to underscore that, for some reasons, such as publication deadlines and schedules, some papers were written simultaneously during the same period. Thus, the results of some papers (i.e. Paper IV and Paper V) cannot sequentially become the basis of discussion of other papers (i.e. Paper VI). However, some parts of the discussion in the various papers remain still relevant. In addition, when addressing the research questions, the results of several papers are therefore interrelated with this cover paper. This problem may be dealt with by re-arranging the links between of the papers to address the relevant research questions as shown in Table 4.

Table 4. Contribution of each paper in addressing research questions

Research question	Paper					
	I	II	III	IV	V	VI
1	XX	XX	XX	X	X	XX
2		X	X	XX	XX	
3				X	X	XX

XX= fully relevant, X= partially relevant

Figure 7. Application of systematic combining to the research process



The overall flow of the research process using the systematic combining is summarized in Figure 7. As shown in the figure, there are three stage of research namely, the empirical observations (stage A) where the observations of the empirical world were carried out to adjust the preliminary assumptions and result in Papers I, II and III. Based on the insight obtained in stage A, some alternative diffusion modelling for mobile service were proposed and resulted in Paper IV and V. In this stage (stage B), the alternative diffusion modelling will be discussed to adjusting the existing framework. In the last stage (stage C), several

theoretical reflections and proposal will be analysed to generate critical appreciation for the existing theoretical paradigm in diffusion of innovation theory.

3.3 Data collection

Since empirical observations are part of this study, the role of data is critical. As shown in Table 5, five out of six papers in this study involve data analysis and modelling as the basis of discussions. In this case, both primary and secondary data are used. The primary data is obtained from the individual survey of *Swedish Post och Telecom* (PTS)[8] - the Swedish post and telecom agency - whereas the secondary data are obtained from ITU statistics database, the PTS market report statistics[9]. In addition, some information related to the population characteristics are collected from the official website Statistics Sweden (SCB)[10]. In paper V, additional secondary data are based on study by Lindmark (1995) where the raw data is obtained upon personal request.

Table 5. Data sources and statistical method for each study

Paper	Data sources		
	PTS Statistics	**PTS annual survey**	**Others**
I	2002-2010	2002-2011	-
II	-	2002-2011	-
III	-	2009-2010	ITU statistics database
IV	-	2002-2010	statistika central byran (SCB)
V	1994-2010	-	Lindmark (1995)
VI	-	2002-2010	-

The PTS annual individual survey, the main source for primary data, is conducted as a nationwide survey and covers all regions in Sweden. On average, about 2,000 out of 4,000 questionnaire responses are collected annually from this survey of the Swedish population between 16 to 75 years old. The annual response rate is quite high and has a relatively balanced proportion across the region as can be seen in Table 6. As survey results are publicly accessible upon official request, therefore data credibility and reliability is not at issue.

In this study, data related to mobile service usage are mainly used for the analysis in addition to the basic socio-demographic information of the respondents. However, some information related to fixed communication as well as internet use is also incorporated in the study. Furthermore, since the survey is designed for a generic purpose, it is not always relevant to the underlying assumptions in this study.

In addition, some questions in the survey are modified in the later survey, which creates discrepancy in some of the responses. This situation also contributes to potential bias when interpreting the result of the analysis. It is important to address this bias since some papers need longitudinal-type studies which require consistent observations over time. Therefore, a thorough review and confirmation are often needed before using the data set. Additional notes

[8] PTS is the Swedish Posta and Telecom Agency (http://www.pts.se/en-gb/).
[9]The PTS market report is available per semester an can be found at: http://www.pts.se/en-gb/Industry/Telephony/Marknadsstatistik/
[10]The SCB is the Swedish government agency responsible for producing official statistics of Sweden. The official website can be access at: http://www.scb.se

are also provided to keep the reader aware of the data limitation so that a proportionate interpretation can be provided.

Table 6. Annual response rate (%) from each county (2002-20010)

County	2010	2009	2008	2007	2006	2005	2004	2003	2002
Stockholm	48	52	48	49	52	54	50	60	53
Uppsala	53	59	50	58	49	64	54	66	66
Södermanland	61	55	57	53	47	54	56	54	58
Östergötland	55	58	54	52	53	62	60	59	60
Jönköping	63	54	59	47	57	67	66	71	61
Kronoberg	55	55	49	61	46	42	64	60	80
Kalmar	61	56	57	40	60	55	59	66	60
Gotland	65	48	67	57	68	78	68	67	59
Blekinge	56	62	51	50	70	64	61	50	43
Skåne	51	55	54	45	52	54	52	57	55
Halland	65	54	61	56	55	67	64	71	63
VästraGötaland	54	57	59	51	51	55	57	60	58
Värmland	52	55	50	54	51	56	56	63	57
Örebro	55	58	58	50	59	63	54	59	64
Västmanland	59	56	50	52	59	54	57	65	53
Dalarna	55	67	50	40	59	52	60	64	60
Gävleborg	62	53	57	45	52	56	47	47	65
Västernorrland	53	58	57	45	58	62	56	64	47
Jämtland	58	59	65	61	54	63	49	67	73
Västerbotten	56	69	62	47	57	60	57	68	65
Norrbotten	59	65	58	52	48	54	63	73	66
Total	**53**	**56**	**54**	**50**	**53**	**57**	**56**	**61**	**58**

Source: PTS report (2010)

Each year, the sample is also weighted to counter the biases that may result from disproportionately sized sampling strata. In addition, a poolability test is conducted to examine the heterocedasticity of each variable for each year survey data to ensure the coefficients estimated over one group of data in a year are equal to the coefficients estimated over other years. This is because in each year of the survey there must be changes across variables under observations. The variables education and age for instance, typically will change every year and controlling the effect will be helpful to bring a sensible analysis

Nevertheless, despite such limitation and problems, having long time-series cross section data is extremely valuable for a study seeking to identify patterns and behavioural trends. As long series observations, longitudinal surveys enable us to identify variations among individuals, allowing researchers to perform a trend analysis. Therefore, even though possible bias and inaccuracy may be part of the analysis, it generally is worth a trade-off if the main purpose is only to describe and explain a process of change over time with less emphasis on exactness or precise predictions.

3.4 Data analysis

For the data analysis, each paper in this thesis applies statistical methods according to the nature of the study and specified model including descriptive statistics as shown in Table 7.

According to the table, two studies, i.e. Paper I and II are in a form of longitudinal studies. In Paper I, heteroskedastic probit regression is used to model dichotomous states of the mobile service users to identify their being mobile only users or not, while in Paper II a similar model using logistic regression is used for identifying the state of being mobile non-users or not.

Paper III uses the generalized Poisson regression (GPR) to handle the under-dispersed count data which represents the number of mobile service subscriptions per individual and to estimates the contribution of socio-economic factors to the incidence of multiple subscriptions. Unlike Papers I and II, in this paper no longitudinal analysis across socio-demographic factors is given, due to data restriction. Two studies, (Paper IV and Paper V), use curve fit estimation with non-linear regression to plot the diffusion pattern based on the specified model, (multiple ownerships diffusion model for Paper IV and Norton-Bass intergenerational model for Paper V). In both studies, the model employs simultaneous nonlinear equations to fit the data series. The last paper (Paper VI) uses descriptive statistics to support the theoretical arguments distilled from various literatures.

Table 7.Type of studies and the statistical method applied

Paper	Type of study	Statistical Method
I	Longitudinal/time series cross-sections study	Logistic regression
II	Longitudinal/time series cross-sections study	Logistic regression
III	Single cross-section study	Generalized Poisson regression
IV	Diffusion modelling	Non-linear regression
V	Diffusion modelling	Non-linear regression
VI	Literature review	Descriptive

For the analysis, the author uses both STATA and SAS software as each of these offers a specific function with particular advantages. For instance, STATA software has prefix -SVY to analyse survey data and the SVYPXCAT function (Garret, 2006), which is helpful to predict binary probabilities of a survey-based variable over time. While SAS software has the procedure GENMOD (Pedan, 2001) which is a powerful tool to overcome the problem of under-dispersion, and implement generalized Poisson regression.

Chapter 4

Framing mobile service diffusion as an evolutionary process

This chapter provides the results of some empirical observations and discusses their theoretical connections to address the first research question of this thesis.

4.1 Theoretical considerations

The first question of this thesis is "Why should mobile service diffusion be framed as an evolutionary process?" This question demands explanations based on a certain framework that could characterize mobile service diffusion as an evolutionary process. Framework selection should, therefore be discussed in advance before addressing the question. Before that, however, it is also important to discuss why the evolutionary conception is chosen as the source of inspiration.

In this study, the evolutionary conception is considered as the source of inspiration is simply because the conceptions have been studied at such depth as to provide a convenient vocabulary of concepts and processes, which is often useful for making analogies (Mokyr in Ziman, 2000:53). Moreover, many articles indicate that there is a close connection between the evolutionary perspective and the process of innovation diffusion[11]. The use of evolutionary perspective has even been the source of inspiration the first work on diffusion of innovation theory (Tarde, 1903:382). Studies by Metcalfe (2005) and David (2010) show that the process of innovation diffusion as represented either by Griliches logistic model or Mansfield logistic model indicates evolutionary characteristics. A study by Grubler (1996) also concludes that diffusion process has inherent features of the evolutionary process that governs social behaviour. All these arguments support the rationale that evolution is an intrinsic part of the diffusion process and therefore viewing the diffusion of innovation process, including the diffusion of mobile service, from an evolutionary perspective is relevant.

Furthermore, the use of evolutionary conception allows a dynamic view toward the process. As discussed in Chapter 2, the "static" diffusion modelling paradigm has been dominating mobile service diffusion studies (see Table 1, for instance). These studies are mostly rooted on the fundamental diffusion modelling, which considered by many, such as Mahajan and Peterson (1985) and Mahajan and Wind (1986), to have restricted assumptions which hinder the model to optimally represent the actual diffusion pattern. One way to relax this assumption is to consider an alternative theoretical framework that can explain mobile service diffusion as a dynamic process

[11] See also discussion in section 2.2 and section 2.3

that could naturally represent the essential features of actual diffusion pattern. In such a case, the evolutionary conceptions provide a dynamic view by allowing variation and selective retention to govern the evolutionary process. Therefore if a diffusion process can be framed using such conceptions, then the dynamic pattern of the diffusion can also be revealed.

In the context of diffusion of innovation, there are at least two basic criteria that can be used to justify whether the diffusion of innovation can be considered as an evolutionary process:

- Both diffusion of innovation and evolutionary process are historical process that can be represented as a function of time upon a specified unit of analysis which diffuses or evolves over time (Grubler, 1996). In this case, the prerequisite is finding a unit of analysis that is applicable to both diffusion and evolutionary process.
- During the process of diffusion or evolution, there is a dynamic change on the unit of analysis toward a certain point of disequilibrium. In the diffusion of innovation process, this point can be seen when a certain innovation reaches the saturation level. After this point the innovation typically will be replaced by a new innovation, either with similar or completely different characteristics. This marks the disequilibrium point or the end of product/innovation lifecycle. A similar situation also occurs during the evolutionary process, where any species through "natural selection", at a certain point will become distinct or mutate for any given reason, such as replication or recombination.

These similar basic properties of the diffusion and evolution processes can be used as initial criteria to justify that diffusion of innovation, including mobile phone diffusion, and can be framed as an evolutionary process, provided the prerequisite assumptions can be satisfied, (i.e. a unit of selection that can operate in both processes can be determined). However, this proposition still needs to be elaborated with empirical supports, as well as an operational framework so that it can be used as an alternative perspective to explain diffusion of innovation, particularly in the mobile communication field.

For this purpose, there are two views on the process of technological evolution that can be considered (Geels, 2002). In the first view, evolution is seen as a process of variation, selection and retention (Dosi and Winter, 1994). The second view considers as a process of unfolding that generates 'new combinations' which in turn results in paths and trajectories (Schumpeter, 1934: 66). Both views are relevant for studying the diffusion process. However, this thesis considers the first view with the framework proposed by Dosi and Nelson (1994) as it offers more comprehensive explanation for understanding a social phenomenon as an evolutionary process. In this framework, the term "evolutionary" is seen as a theory, argument, or model that has the following characteristics:

- The purpose is to explain, using a dynamic view, the movement of something over time or to explain that thing at a given in time in terms of how it got there.
- The explanation involves both random elements that generate or renew some variation in the variables in question and a mechanism that systematically examines existing variation.

This implies that viewing diffusion of mobile service using an evolutionary perspective will result in a dynamic process of diffusion that consists of a heterogeneous pattern that progress over time as a result of variation and a certain selection mechanism.

Moreover, Dosi and Nelson explain that to frame a social phenomenon, such as diffusion of mobile service, as an evolutionary process, there are at least three criteria - unit of selection, selective retention and variation - that should be satisfied. In the following section (section 4.2), some empirical observations from the Swedish mobile market will be presented to identify these evolutionary features. Discussion on these empirical findings will be included in section 4.3

4.2 Empirical observations

In general, a decision to adopt has only two choices: to adopt or reject (Rogers, 2005:170). In the context of mobile service adoption, this can be observed in the practice of using mobile-only services for communication purpose (cord-cutters), and the practice of not-using or rejecting mobile service. However, the practice of multiple adoptions is also a possibility as the use of multiple mobile service subscriptions is a phenomenon in the market (Annafari, 2010). To gain insight into these practices, some studies such as Katz and Aspden (1998), suggest the use of longitudinal research[12] to identify the socio-economic pattern of the users. Based on this study, if one may assume that adoption of mobile service is equivalent to ownership of the service (subscription), then mobile service adoption is likely to be guided by what is known as the *social-location* variable. This variable is defined by Katz and Aspden as *a combination of socio-economic, demographic, and life-style conditions which influence decisions perhaps more powerfully than do individual personality characteristics*. In this thesis, , all empirical observations will therefore be given as a longitudinal study that addresses the socio-economic patterns of mobile service. The summary results of these empirical observations are presented in the following sections:

4.2.1 Cord-cutters

The empirical observation of cord-cutter - the use of mobile-only services for communication purpose is described in Paper I. This paper is motivated by Rappoport, Alleman and Taylor (2009) who consider cord cutters as an emerging market segment with unique demographic and user profiles that are necessary for understanding this market trend. Cord-cutting is also likely become the future communication practice of our society, as was predicted more than a half century ago by Osborn (Ling, 2004:169)[13].

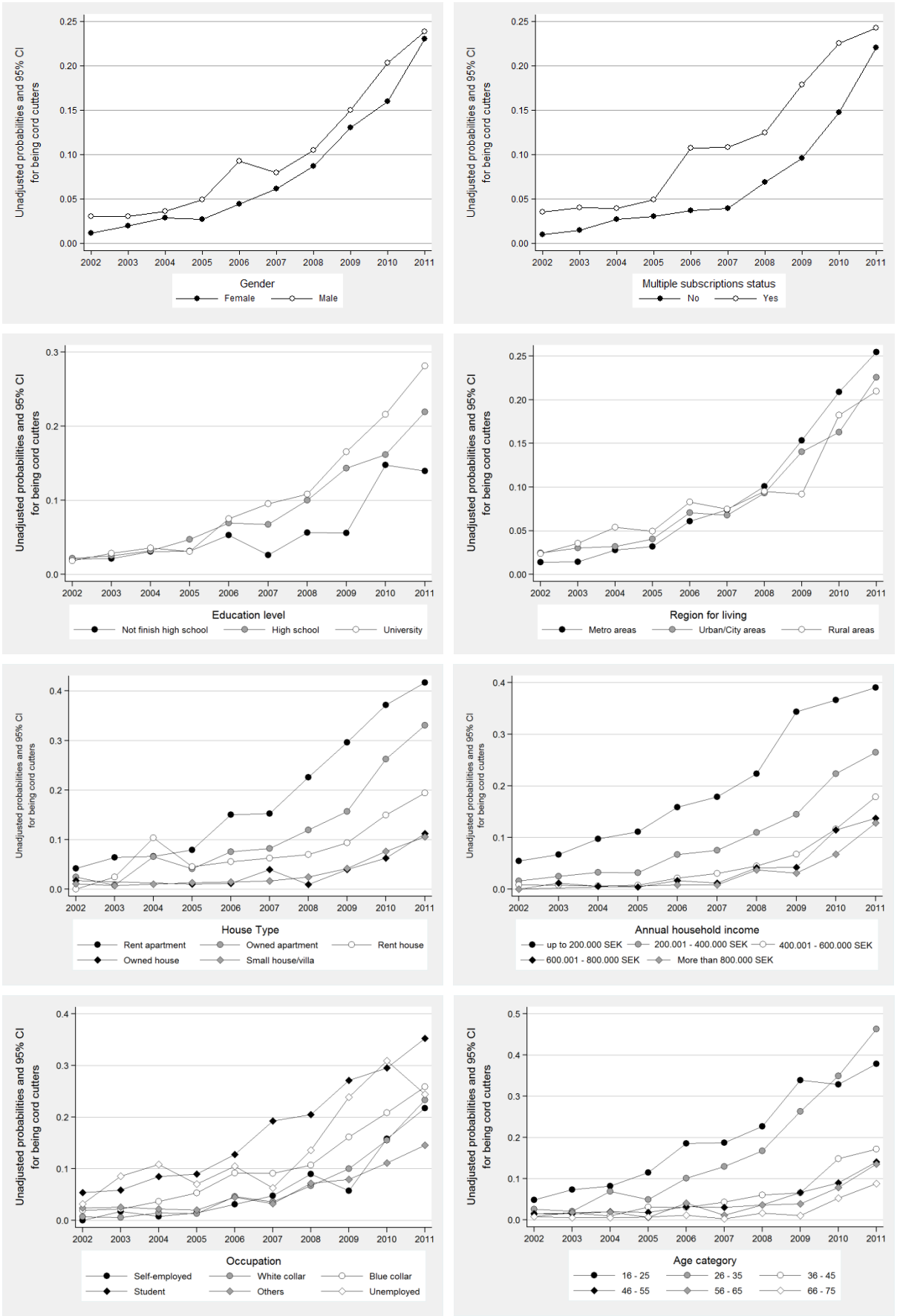
To identify the socio economic pattern of this segment of population the study uses a heteroskedastic probit model to fit independent multiyear cross-section data obtained from the PTS annual survey 2002-2011.For each year, the sample is weighted to counter the biases that may result from disproportionately sized sampling strata. In addition, a poolability test is conducted to examine the heterocedasticity of each variable for each year of survey data to ensure that the coefficients estimated for one group of data in a given year are equal to the coefficients estimated over other years[14]. This is because in each year of the survey there will be changes across the observed variables under observations. Variable household income, occupation and age category in particular, have greater tendency to change over time. Therefore these variables are suspected to contribute to heterocedasticity and need to be ”normalized”. To overcome this problem, this paper applies heterogeneous choice model (William, 2009), which could control the heterogeneity.

[12] A longitudinal research refers to studying a phenomenon over time, thus the research can be seen as a number of cross-sectional snapshots of phenomenon, taken over time (Åhlstrom and Karlsson, 2009:197)

[13] Howard Osborn is a former chief engineer of AT&T who in 1954 proposed a prediction in National Geographic Magazine that in the future every new born baby will likely to have their own mobile portable device with a unique number that represent their identity and that the device will be his or her life presence.

[14] The poolability test is carried out using Bartlett's tests for equal variances (Bartlett, 1937)

Figure 8. Patterns of cord-cutters across socio-economic attributes in Sweden (2002-2011)



The summary of the estimation results is shown in Figure 8. The figure gives the pattern of predicted probability of being cord-cutters across observed socio-demographic variables. All estimated probabilities of being a cord-cutter for each variable are found to be significant with p-value < 0.05. In this case, the probabilities of being a cord-cutters for each variable is estimated by assuming that the influence of other variables remain zero at the same time.

According to the figure, the probability trend of being a cord-cutter is increasing over time even though there are some variations across variables. In the empirical observations across gender, for instance, a slight difference is apparent. The figure shows that male have higher probability of being cord-cutters than females over time. However, the trend indicates that the difference is decreasing and both men and women can be expected to have similar probabilities to use mobile-only as their means of communication in the near future.

For education factors, those who have university level of education have a higher probability of being cord-cutters compared to others. At the same time, individuals who have not finished high school tend to have the lowest probabilities to be cord-cutters compare to others. Furthermore, individuals live in metro areas, (i.e. Stockholm, Göteborg and Malmö) show a greater probability of using mobile-only for communications, as compared to individuals living in other areas, even though this trend did not apply early on.

Similar shifting is also found in age categories. Here the latest trend indicates that individuals aged 26-35 have the highest probability of being cord-cutters compared to other categories. However, in the previous years, this is not the case as individuals aged 16-25 had a higher probability of being cord-cutters. This shift suggests that similar individuals may retain their behavioural routines since those who aged 16 (belonging to group I) in 2002 turned 26 ten years later (belonging to group II). Interestingly, other age groups (ages 36-45, 46-55, 56-65 and 65 or older) show a weaker tendency to adopt cord-cutting as a behavioural routine. This also indicates a selective retention process which, in this case, related to natural process in the population, the aging of an individual.

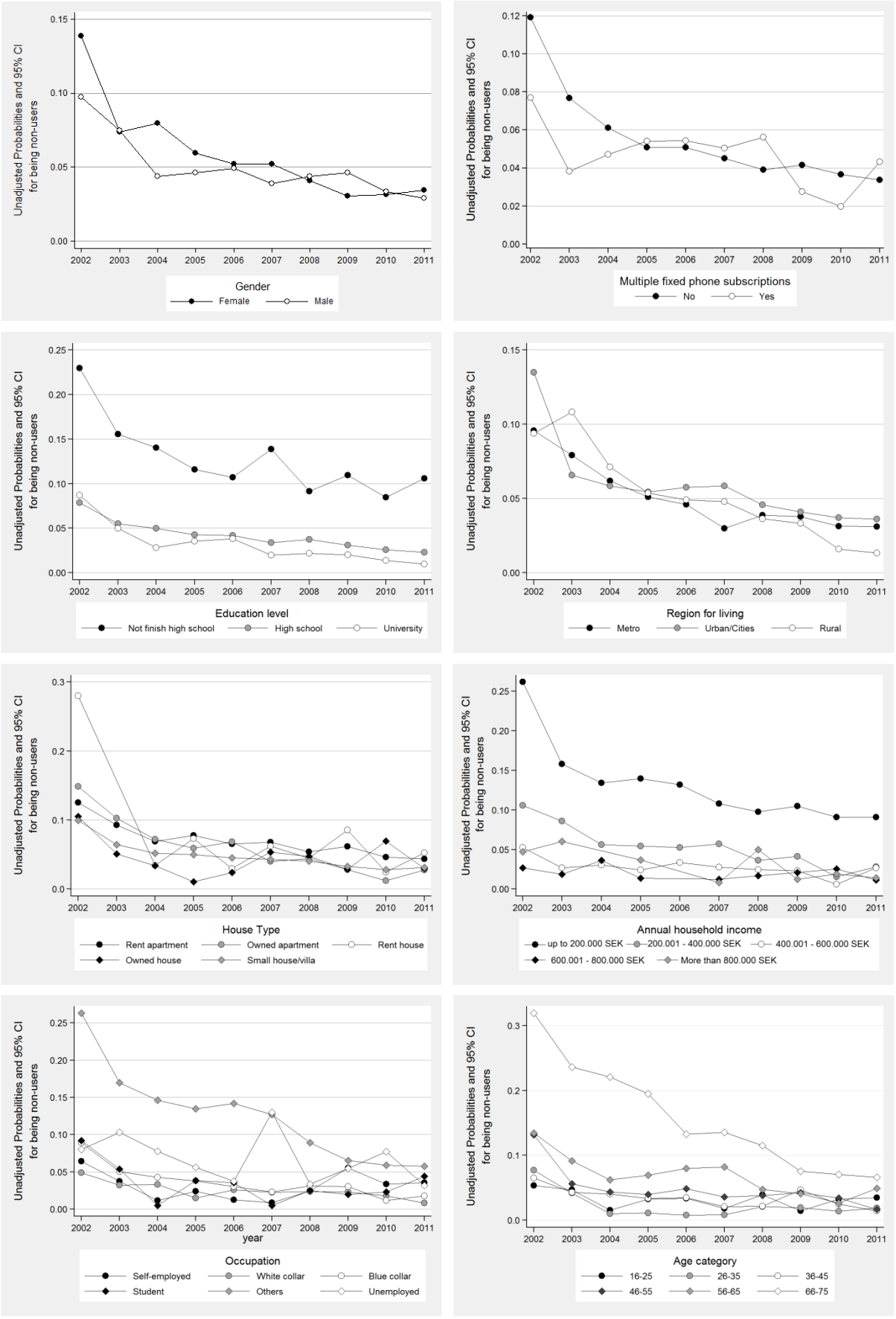
A stable trend is shown in the household income factor where households with less annual income have stronger tendency to use mobile-only as their means for communications compared to households with higher annual income. This suggests that different economic capacity may create different forces that influence the behavioural routine in using mobile communication service. A similar indication, with some variation, is indicated on the observation for occupation factor. As depicted in Figure 8, the probability of being cord-cutters is higher for individuals with least economic power, such as student, unemployed people. However, the latest trend indicates that individuals with stronger economic power, such as the white collar workers and self-employed workers who owned their own business, show a higher probability of being cord-cutters.

All these revealed trends indicate that cord-cutting as a behavioural routine shows a dynamic trend along the diffusion process. Based on the empirical observation, the trend is a result of heterogeneous socio-economic factors or the social-location factor as discussed in Katz and Aspden (1998). This also supports the argument of the paper that underline the importance of longitudinal studies to understand the mobile service users' behaviour.

4.2.2 Mobile service non-users

Paper II discusses the dynamics of mobile service non-users across several socio-demographic criteria along the diffusion process is discussed. In this case, understanding the dynamic trend of

Figure 9. Patterns of non-users across socio-economic attributes in Sweden (2002-2011)



non-users is critical as non-adoption is always a character of diffusion process. In addition, as argued in the paper, study of non-users is important to balance the view when understanding the diffusion of innovation. In this case, understanding non-users will be helpful to prevent *pro-innovation bias*[15] which pays more attention to powerful actors in the society rather than weaker groups (Wyatt, 2005:78).

For the analysis, paper II uses a similar data set as Paper I with a different dependent variable, i.e. the status of being mobile service non-users as indicated by the possession of no mobile telephony subscriptions. Since the study uses data set similar to that used in Paper I, a similar statistical approach is applied, i.e. (sample weighting to counter the biases that may result from disproportionately sized sampling strata and a poolability test to examine heterocedasticity of each variable for each year survey data). The estimation results are summarized in Figure 9.

According to the figure all estimated probabilities of being mobile non-users for each variable are found to be significant with p-value < 0.05. In this case, the probabilities of being non-users for each variable are estimated by assuming that the influence of other variables remain zero at the same time. In general, the figure shows that the trend of being mobile-service non-users is decreasing over time across all socio-demographic criteria. Thus the possession of mobile service subscription(s) by everyone is likely in the future. Nevertheless, the figure also shows that the probability pattern of being non-users across gender was slightly different with female having higher tendency to be non-users than males. However, recent trends show that both males and female have a similar propensity to be non-users, albeit with a lesser magnitude of probability.

Other variables, such as education, annual household income, age category and occupation show that population of individuals with less socio-economic power have a greater propensity to be non-users than others. For instance, in the education categories, as expected those who do not finish high school have higher probability of being mobile service non-users than those with higher levels of education. Similarly, those with an annual household income of less than 200.001 SEK have greater probabilities of being non-users than those with higher annual household income. The elderly, (i.e. individuals aged older than 65), also show similar indications. Nevertheless, the recent trend shows that the probability gap is becoming smaller. Thus, in the near future, one may expect a lower probability of being non-users regardless of one's socio-economic background.

Furthermore, all these findings support the argument that socio-economic factors are transient during different stages of the innovation adoption process (Dutton, Rogers and Jun, 1987). Thus what was significant some years ago may no longer be significant today. This indicates that society both shapes and is shaped by mobile technologies. Such a change has been happening rapidly as the result of a quick technological advancement in the field of mobile phones. Therefore, a longitudinal study is preferable in order to provide a comprehensive view of user dynamics and the evolving process, particularly when it comes to studies on have-nots and non-adopters.

4.2.3 Users with multiple mobile service subscriptions

The third empirical observation addresses the pattern of mobile service users based on the number of their subscriptions and factors that determine multiple subscriptions. This empirical observation is given in Paper III. Unlike Papers I and II, the binary logistic model cannot be

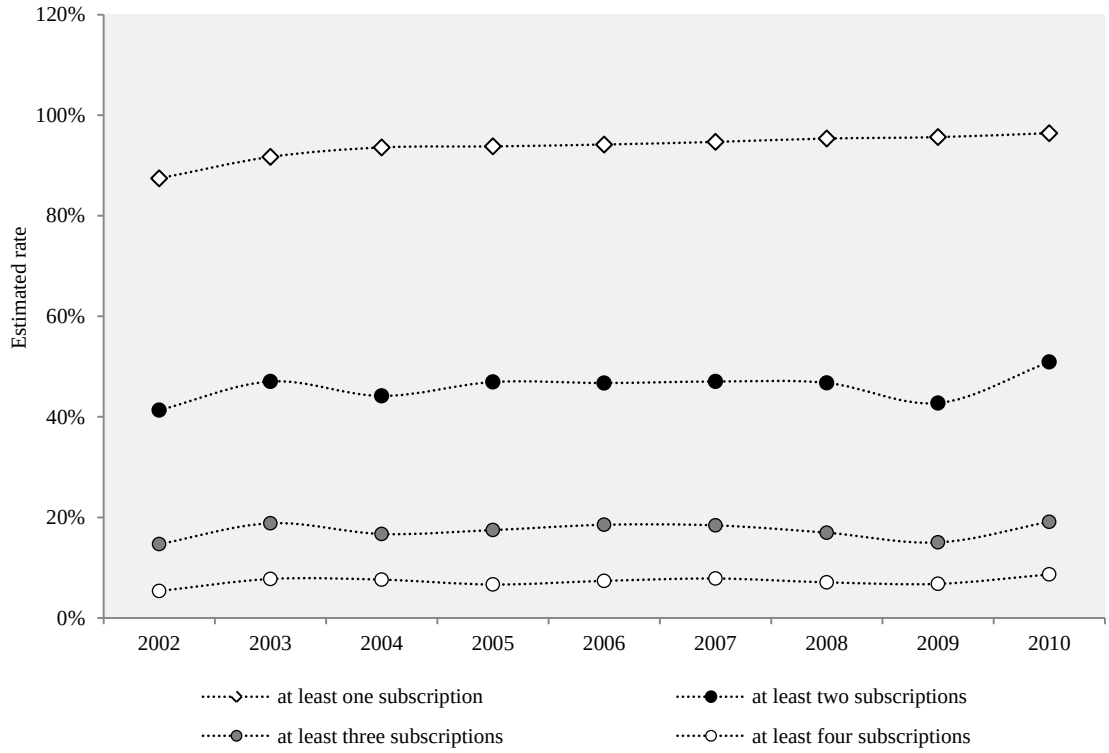
[15]*Pro-innovation bias* is defined as "*the implication in diffusion research that an innovation should be diffused and adopted by all members of a social system, that it should be diffused more rapidly and that innovation should be neither re-invented nor rejected*" (Rogers, 2005: 106).

applied in this study because the independent variable, (the number of subscriptions), is in the form of count data with a Poisson distribution. As discussed in paper III, the survey data that is used for the analysis also suffers from under-dispersed conditions, (i.e. the conditional variance smaller than the conditional mean), which is a common problem in analysis using sampling data. Therefore, this study considers two independent cross section studies with a generalized Poisson regression model (King, 1989).

The estimation results of two subsequence surveys (2009 and 2010) suggest that business subscriptions and subscriptions for mobile internet are the main determinant factors of multiple mobile phone subscriptions in Sweden. In addition some demographics characteristics such as age, income level and gender are also significant predictors of the incidence of multiple subscriptions.

Business subscriptions indicate that mobile phone operator should further consider the presence of organizations, such as businesses and households, as important units of consumers in the mobile market, critical for expanding their consumer base. As a unit of consumers, the organization also may bring a significant network effect to the individuals within the group. It may also yield higher revenue given the fact that the mobile service for this segment of consumers is typically used for value creation and creates a significant network effect as was the case in the fixed phone service era. The operator can take advantage of this by tightening the network effect to the existing subscribers. This can be done by encouraging them to have additional subscriptions from the same operator or intra-operator multiple subscriptions.

Figure 10. Pattern of mobile service use based on the number of subscriptions



As shown in Figure 10, despite some fluctuations, users with one subscription predominate in the market. However, the number of users with multiple subscriptions is also significant even though the higher the number of subscriptions the lower the percentage. The figure also shows that each category of users has different growth which indicates dynamic patterns. In this case it

important to note that, the possession of a mobile subscription is a point of departure to access mobile service. As happens with other type of consumption (Olshavsky and Granbois, 1979), differing intensity of mobile service use can occur out of necessity, due to many factors such as culturally mandated life style (i.e. business subscriptions), fashion, interlocked purchase (i.e. service bundling), network effect, backup and replacement purpose, as well as other random and superficial reasons.

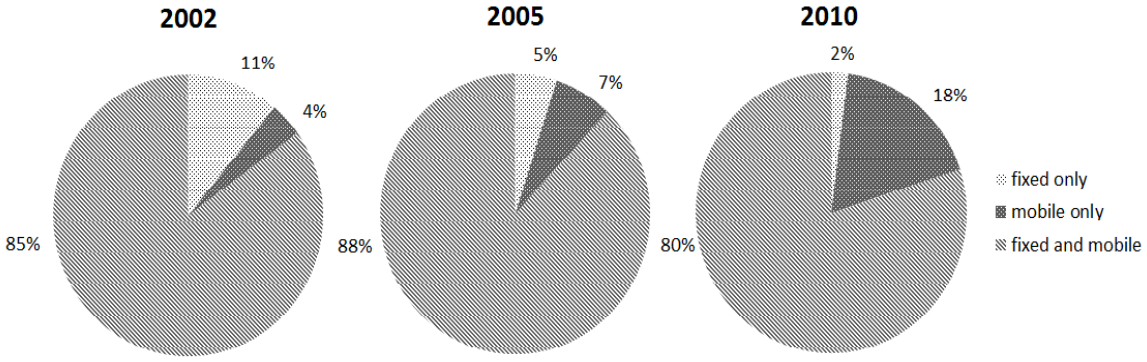
These factors underlay the mobile service users selection mechanism that determines what features of mobile service will be chosen or how the service should be used, (i.e. how many subscriptions they should have, to satisfy their needs). As discussed in Paper III, some people decided to have multiple subscriptions to separate between business and private communications. Others do it to separate between data and communication purposes. This indicates that mobile service use is mainly due to a response to social problem. Such variations of mobile service use in the long run will produce a dynamic behaviour pattern such as that shown in the Figure 10.

4.2.4 Inter and intra-technology competitions

Conceptually, any diffusion curve is the outcome of two processes: the one related to the growth of the market for the technology and another one related to the capacity to supply the technology to the market(Metcalfe, 1988:562). Accordingly, Tscherning and Damsgaard (2008) argue that the dynamic pattern of diffusion of innovation is likely influenced by both the supply side, (i.e. the dynamic of supply of mobile technology) and the demand side, (i.e. the dynamic of user or consumer behaviour). This section describes the observation of the Swedish market. These observations are derived partially from Paper V which addresses the intergenerational effects of technology.

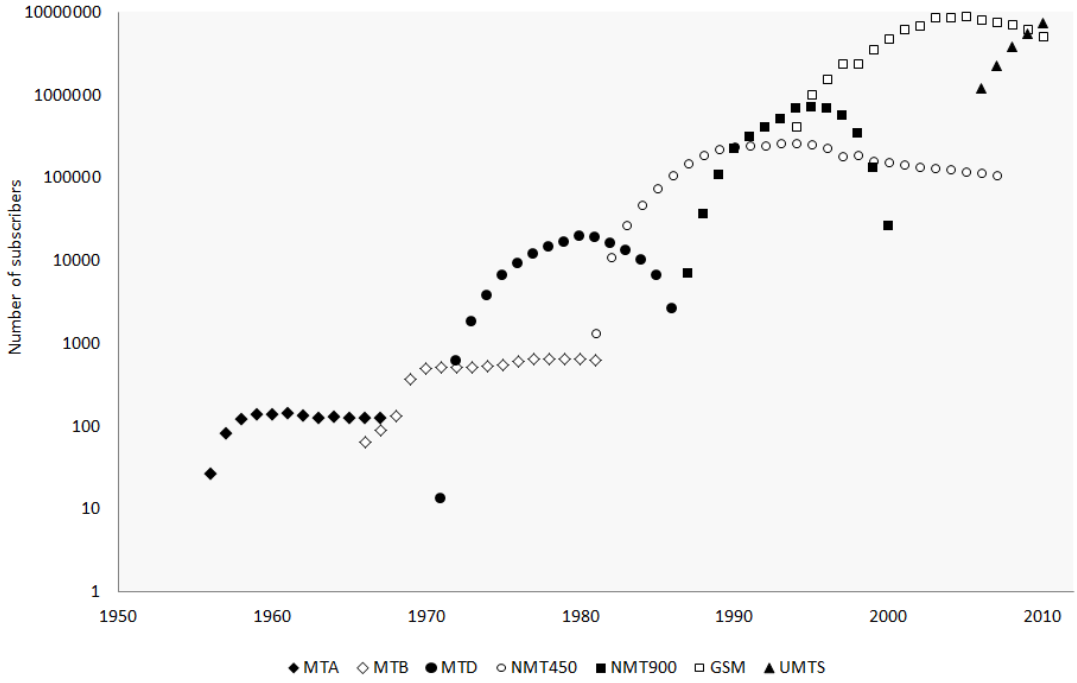
However, the discussion in this section is only to show that the supply side also plays a role in characterizing the dynamic pattern of mobile service diffusion. In this case, the dynamics of supply side of mobile service technology are presumably due to the competing technology, either come from the same class of technology, (between 2G technology and 3G), or from different classes of technology, such as between fixed and mobile communication.

Figure 11. The evolutionary transition from fixed to mobile phone in Sweden (2002-2010)



Source: PTS individual survey (author tabulation)

Figure 12. Dynamic intra-technology competitions of mobile service in Sweden (1956-2010)



Source: Adapted based on Lindmark (1995:160)

As shown in Figure 12, the dynamic diffusion pattern of mobile service can be observed in the Swedish market. According to the figure there are continuous intergenerational technology pattern where an earlier generation of mobile service technology at some point will be replaced by a later technology. In this case, each generation technology has its own lifecycle pattern which likely in the form of inverted U-shaped curve. In the long run these inverted U-shaped curves are connected and form an S-shape curve. This pattern indicates that variation as well as selection exists along the diffusion time lime. This also suggests that mobile service as a technology artefact is relevant as the unit of analysis to describe the diffusion process.

In the context of inter-technology competition, a similar indication can also be observed. A shown in Figure 11, the mobile communication platform that is represented by mobile-only users is growing over time and replacing the fixed telecommunication platform, which is represented by fixed only users. However, at the same time, both platform of technology shows complementarity as the number of users who use both platform of technology still predominate. This process is another indication that variation and selection characterize the diffusion of communication technology. In this case, however, a wider context of discussion will be needed as such substitution and complementarities can also be found in other technologies, such as the Internet. This will demand additional investigations as well as expanded discussions which are difficult to satisfy in a limited time frame such as in a PhD thesis. Therefore, in this thesis, the discussion will only be limited to address intra-technology competition which, in this thesis will be discussed in Chapter V and Paper V.

4.3 Discussion

In the previous section some empirical observations have been briefly discussed to provide real world insight on the dynamics of demand and supply of mobile use. These include observations

on the dynamic of demand side (mobile service users' behaviour as well as from supply side, i.e. mobile service technology). Together with discussion on theoretical considerations in section 4.1, this insight from the empirical world will be the point of departure to address the first question of this thesis: "Why should diffusion of innovation be framed as an evolutionary process?"

As discussed earlier, this question will be addressed by considering the framework of Dosi and Nelson (1994). According to Dosi and Nelson, to frame a social phenomenon, such as diffusion of mobile service, as an evolutionary process, there are at least three criteria: unit of selection, mechanism and criteria of selection as well as adaptation and variation that should be explained. The following sub section will discuss each of these criteria further with regard to the insight that has been revealed from empirical observations and the relevant literature.

4.3.1 Unit of selection in mobile service diffusion

In the context of application in social science, an evolutionary model can be defined as *a system that describes the history of a population composed of evolutionary entities* (Mokyr, 2000:52). This suggests that an evolutionary model should be a function of time, as it explains a historical process that concerns a larger group of identical or very similar units called evolutionary entities. Therefore, applying an evolutionary perspective to a social domain requires a clear definition of the evolutionary entity that serves as the basic unit of analysis as well as unit of selection. In this case, there are several aspects of technology that can be considered to be the basic unit of analysis. These are the technology artefacts (e.g., Basalla, 1988), the technical knowledge required to make them (Mokyr, 2000; Constant, 2000), or some combination of these. It can also be the interface of artefacts and ideas in technological practices (e.g., Fleck, 2000) or the organizations, (firms) necessary to produce artefacts (e.g., Nelson and Winter, 1982). It can also be a set of behavioural entities using technology, i.e. technological memes (Ziman, 1996, Dawkin 2006).

In the context of mobile communication studies, the diffusion process is typically also explained as a function of time (see for instance Jaakola, et.al (1998) or discussion in Chapter 2 of this thesis). Therefore, mobile service diffusion models actually share role that are similar to evolutionary models in the sense that both explain a historical process that addresses a unit of analysis, innovation. Based on empirical observations, there are mainly two units of analysis in use for diffusion models. These are the mobile service as a technology artefact and the use of mobile service as behavioural entity.

The diffusion of mobile service as a technological artefact can perhaps best be observed by explaining how mobile service handset has evolved from a set device with a weight of almost a kilogram and a single function, voice communication, into a tiny device with a weight of less than a hundred grams with multiple functions. The evolution of mobile technology, from a radio telephone to 4G technology is an example using the technical knowledge as a unit of analysis. However, in most mobile service diffusion studies, mobile service subscriptions or the possession of active SIM cards as the representation of a set behavioural routine is typically used as the proxy to plot the diffusion curve.

As shown in the empirical observations, both mobile service use as a technology artefact and mobile service use as a behavioural entity are able to play a role as unit of selection. The pattern of inter-technology and intra-technology substitution of mobile service technology for instance, shows that mobile service as a technology artefact generates variation and selective retention. Different intensity of mobile service use, (i.e. one subscription and multiple subscriptions), shows that mobile service as behavioural routine is a relevant unit of selection that is applicable in both

the evolutionary model and diffusion model. This suggests that both diffusion process and evolutionary process shares a similarity in relation to the unit of analysis that evolves or diffuses over time.

4.3.2 Variation and adaptation in mobile service diffusion

If mobile service both as a technology artefact and as a behavioural routine can be considered as the unit of analysis, then the empirical observations in the earlier sections shows some evidence of variation. This actually reflects the argument of Cowson, Haddon and Miles (1995:14) which posit that "*during the course of diffusion, the innovation itself is likely to be changing as innovators take account of market feedback and learn more about the product itself"*.

As shown in Figure 12 and Figure 14, mobile service diffusion process shows "horizontal" variation as a result of the inter-generationality of mobile service technology, (i.e. from MTA to 3G/UMTS). In this case the variation shows a path dependency and incremental pattern where the earlier technology typically becomes the basis of the development of the later technology (Ansari and Garud, 2009). However, a "vertical" variation is shown when mobile service use as behavioural routine is considered as the unit of analysis. This "vertical" variation is a result of different intensities of mobile service, which is represented by different numbers of mobile telephony subscriptions and also indicates a multiple-adoption.

Nevertheless, variation in both cases shows that there is a *dominant design*[16] indicating that the process of adaptation results in "the survival of the fittest". In the case of mobile service as a technology artefact for instance, the latest technology typically become the most adopted one and remains as the "dominant" one (see Figure 14). While as behavioural routine, the use of mobile service with one subscription become persistent over time compared to the use of one with multiple subscriptions indicating that this behavioural routine is still widely used as the "behavioural standard" of mobile service use in Sweden (see Figure 10), even though this may be not the case in other market. Still, a change may happen in the future whereby this behavioural routine will be replaced by others, such as mobile service use with multiple subscriptions.

A similar comparison can also be seen in Figure 10, where mobile-only communication is growing as a dominant behavioural routine and fixed only communication is decreasing. However, the combination of both communication styles, fixed and mobile, remains as the predominant design, even though in the near future one may expect that mobile-only communication will take over this position. This fact is also relevant with the conception of the technological paradigm and technological trajectory as discussed in Dosi (1982) [17]. In this case, in each context of its implementation, the technology tends to develop in predictable ways as the outcome of search behaviour and technological efforts of adopters acting within technological paradigms (Cowson, Haddon and Miles, 1995:15).

---

[16] Anderson and Tushman (1990) defined dominant design of technology as a *single architecture that becomes widely accepted as the industry standard.* In this study, however, the definition could be expanded to cover also the 'standard' behavioral routine of using a technology, i.e. single subscriptions or multiple subscriptions.

[17] "We shall define a 'technological paradigm' broadly in accordance with the epistemological definition as an 'outlook', a set of procedures, a definition of the 'relevant' problems and of the specific knowledge related to their solution. We shall argue also that each 'technological paradigm' defines its own concept of 'progress' based on its specific technological and economic trade-offs. Then, we will call a 'technological trajectory' the direction of advance within a technological paradigm." (Dosi, 1982)

Furthermore, Koski and Krestchmer (2007) argue that the dominant design, as can be observed in the case of mobile handset, can be in a form of *de jure*, or mandated, standardization as *de facto*, or market-driven, standardization. The former is typically established through a formal or coordinated standardization procedure, including the government intervention, direct negotiation among the leading firms (e.g. NMT technology in the Nordic countries) or via firm collaboration through private alliances (Berggren and Laestadius, 2003). In relation to the behaviour routine of using mobile service, this can be seen in the case of mandatory registration for mobile phone subscriptions, as in Japan, the United States and some African countries, which reduce the quasi-subscribers, (users with multiple mobile phone subscriptions). In contrast, *de facto* standardization is relatively unregulated in the process of finding a dominant design. In this case, market demand as well as various other factors typically determines the technological trajectory.

In other words, the sequence of the path dependence process in both cases consists of self-reinforcing and reactive sequences. Self-reinforcing sequences are dominated by structural mechanisms while reactive sequences are characterized by consequential, path shaping actions that often rearticulate existing structures and generate new trajectories. However, as we pointed out earlier, single events are embedded in multiple and overlapping sequences whose looser or tighter coupling tends to create complex and truncated trajectories (Araujo and Harrison, 2002).

4.3.3 Mechanisms and criteria of selection in mobile service diffusion

As discussed in Nelson (1987), one major challenge of developing socio-economic evolutionary explanations is to adequately define selection criteria and mechanisms. Therefore, an evolutionary explanation should not be satisfied with simple statements such as 'survival of the fittest', because that can lead to tautologies. In addition, it is important to explain how selection processes take place, and under what conditions, as well as how actors relate their actions to their interpretations of selection criteria, etc., (McKelvey, 1997).

Nelson (2000:69) identifies four different views on selection criteria and mechanisms which come from different points of departure, (evolutionary epistemology, sociology, economics and social construction or socio-technical view). However, rather than stick with any of these views, Nelson (2000:72) suggests that selection criteria should be seen as an outcome of technology effectiveness and user needs. This based on the practice aspect of technology where users through “market demand” select on new technologies. The “better” technology will be chosen and expand in use, (becoming the dominant design), while the “worse” technology will eventually diminish from the market. The similar rule applies in the context of behavioural routine in using the technology where users will select the most “comfortable” behavioural routine of using the technology and retain it as part of their lifestyle. They may also induce others to adopt a similar behavioural routine which expands the behaviour into a trend.

As has also been observed in empirical observations, the dynamic of mobile service use, in the context of mobile service diffusion, is mainly due to a response to social needs as the case of many other innovations (Freeman, 1979). This also supports argument by Katz and Aspden (1998) that posits that dynamic adoption is determined by heterogeneous *social-location* factor. The results of empirical observations also show that this factor has transient effects in each stage of the diffusion process (Dutton, Rogers, Jun 1987). In this case, users will retain behavioural routine that are “relevant” to existing social challenges. For instance, some individuals, i.e. students and unemployed people, retain mobile-only communications as behavioural routine as a response to

financial constraints. Certain others choose to use multiple mobile service subscriptions rather than use only one subscription and retain this as a behavioural routine in response their social needs.

Nevertheless, it is important to underline that the decision to retain a certain behavioural routine is time dependent as well due to technology supply or availability. In the early stage of mobile service commercialization, for instance, the practice of using multiple subscriptions may not be a suitable decision for most individual as at it would have been costly and less efficient. Therefore, both "demand pull" and "technology push" paradigms are relevant to address this issue.

In short, the empirical observations have shown that the process of selection in mobile service diffusion reflects both technological effectiveness and user needs (Nelson, 2000:72). This process typically involves the evaluation of few alternatives, little external search, few evaluation criteria and simple evaluation models (Olshavsky and Granbois, 1979). In this case, both the supply and demand of the innovation will shape each other and generate new behavioural routines, in a manner similar to the process of co-evolution in the evolutionary biology[18].

4.4 Summary

In general, the mobile service diffusion model, as other innovation diffusion models, is framed as a function of time (Jaakola, et.al, 1997). In this case, mobile service diffusion involves dynamic, developmental and historical economic processes which similar to evolutionary process (Mokyr, 2000:52). To frame the mobile service diffusion as an evolutionary process, some criteria grounded on Dosi and Nelson (1994) have been discussed based on empirical observations in the Swedish market.

Based on reflection of the empirical observations, both mobile service as a technology artefact and as behavioural entity are relevant units of selection. Mobile service as a technology artefact for instance, shows that it is applicable as unit of selection when representing the dynamic pattern of intra-technology substitution of mobile service. Different intensities of mobile service use, (single subscription and multiple subscriptions) show that mobile service as behavioural routine is a relevant unit of selection applicable to both evolutionary model and diffusion model. This suggests that mobile service use is a relevant unit of selection that works both in evolutionary conceptions and diffusion processes.

The mechanisms and criteria selection in mobile service diffusion can be observed by considering mobile service use as a form of micro-consumption of innovation with selection criteria that reflect both technological effectiveness and user needs (Nelson, 2000:72). For instance, the cord-cutter population implicitly indicates the presence of a selection mechanism by individuals who choose to retain mobile-only communications rather than other types of communication. Similarly the existence of mobile service non-users also implicitly indicates that certain individuals still attempt to retain the existing communication means. In this case, the behavioural routine of using mobile service will co-evolve over time as a reciprocal response to

[18] According to Thompson (1994: 8), coevolution is defined as *reciprocal evolutionary change in interacting species*. In this case, refers to Lundvall (1988), innovation is seen as an outcome of a collision between technological opportunities and user needs. Thus the term coevolution denotes to the reciprocal evolutionary change in the interaction between producers and users of innovation. However, in this case the reciprocal evolutionary change also may be seen as a result of internal interaction between technologies, i.e. intergenerational technology effects, internal interaction between users, i.e. network effect.

technological effectiveness and user needs. This process typically involves the evaluation of few alternatives, little external search, few evaluation criteria and simple evaluation models (Olshavsky and Granbois, 1979).

The discussion also finds that variation characterizes both demand and supply side of the diffusion of technology. In this case “vertical” variation is observed when one considering the mobile service use as behavioural entity with different intensities of use, single subscription and multiple subscriptions, which evolve over time. A “horizontal” variation is observed when mobile service use as a technology artefact is considered as the unit of selection. In this case the variation is a result of intra-technology generation of mobile service, i.e. from 1G to 3G, which occurs along the diffusion time line. In both cases, a “dominant design” is observed, which suggests that the diffusion is “path dependent” and incremental process rather than random and radical one.

Chapter 5

Incorporating evolutionary features into mobile service diffusion modelling

This chapter provides a discussion to address the second question of the thesis which related to the application of the framework obtained in the earlier chapters.

5.1 Theoretical considerations

The previous chapter discussed mobile service use as a relevant unit of selection that applicable to frame diffusion as an evolutionary process. In this case, mobile service use can be seen as representation of both a technology artefact and a behavioural routine that diffuse and evolves over time. During the process, mobile service use, both as a technology artefact and behavioural routine, undergoes a variation and selection by actors in society and this results in a dynamic diffusion pattern. To reveal the dynamic pattern of mobile service diffusion, therefore, requires a model that can best represent the variation and selection.

In classic diffusion modelling, particularly those using fundamental diffusion models, the variation and selection process can only be explained partially. This is because the fundamental diffusion model has static assumptions, such as assuming that all adoptions are first adoptions, and not recognizing multiple adoptions, assuming only a single generation of technology within the diffusion time line, and not recognizing any intra-technology competition. This results in a "crude" generalization, a single diffusion line, which falls short of representing the variation and selection in the real world. Such a generalization is also less intuitive in the performance of trend analysis because the actual dynamic pattern cannot be revealed.

To overcome this problem, Mahajan and Peterson (1985:35) suggest the extension of the fundamental diffusion model by relaxing one or several of its assumptions. Several attempts have been proposed by scholars, particularly from the field of management and marketing. For instance, Norton and Bass (1992) as well as Islam and Meade (1997) propose a modification of Bass model to allow a description of intra-technology competition during the diffusion process. Lilien et.al. (1983) proposes a multi adoption model to relax strong assumption of all adoption is first adoption. This work is extended by some other scholars such as, Bayus Hong and Labe (1989), as well as Steffen (2003). Sharif and Ramanathan (1976) also propose a model to address the population dynamics in the course of the diffusion timeline in contrast to traditional modelling which assumes population to be constant.

Nevertheless, all these model adjustments were proposed in the context of mathematical

improvement of the model. None of them, except Norton and Bass (1992), contextualize the discussion in relation to evolutionary feature of variation and selection. Norton and Bass, even though mentioning “evolution” in the title of their paper, but provide no comprehensive discussion on how the model can be framed to incorporate evolutionary features. This thesis, will make an attempt to do so the following section.

5.2 Empirical applications

In the following section, two aspects of mobile use, as a technology artefact and as behavioural routine, will be applied in empirical studies, and a discussion on how the modelling can be connected to evolutionary conceptions will be included. In this case, two basic assumptions of fundamental diffusion will be relaxed: the assumption that all adoption is first adoptions, and the assumption that no intra-technology competition exist. Both attempts are necessary to allow variation and selection to take place during the diffusion process. However, since this research is carried out in the context of innovation studies, the research ambition is more on describing and explaining the dynamic pattern of innovation diffusion (here mobile service diffusion), rather than focusing on complex mathematical modelling formulation as well as forecasting accuracy which is a tradition of other research field such as statistics and marketing. Therefore, all modelling formulation is based on models in the existing literature with minor extension to incorporate the available data set.

5.2.1 Modelling multiple mobile phone subscriptions

In this study, the use of mobile service, with the behavioural routines of single or multiple subscriptions, is considered as the unit of analysis to address the multiple subscriptions phenomenon which is a characteristic of the mobile service market (Annafari, 2010). This is an alternative approach to relax the assumption that all mobile service adoptions are the first adoptions, as applied in classic diffusion modelling. For this purpose, two ideas are proposed: the use of sampling based data as an alternative proxy for mobile service diffusion modelling and the use of multiple-unit diffusion modelling. The former idea is intended to ease the risk of bias when using subscription-based penetration rate and to control the dynamic potential adopters which grow following the dynamics of actual population. The latter idea is intended to apply the concept of artefact-activity which is introduced in earlier chapter. This is in contrast to the classical method where all adoptions or subscriptions are assumed to be the first adoptions or first subscriptions and implicitly assumes a mobile service merely as a single artefact, not paying attention to the set behavioural routine of using it. In other words, every subscription is assumed to be a single subscription.

This formulation provides a basis to represent the dynamic of mobile service diffusion with more detail and realistic explanation. In this case, multiple-subscriptions are not considered as a discrete decision because an individual can be considered to have multiple-subscriptions if and only if he already has at least one subscription as the critical threshold of adoption. With this logic, the estimated population with at least one subscription will represent all actual adopters of mobile service in the society, while the estimated population with at least two or more subscriptions represents the dynamic of multiple adoption of mobile service in the society.

To represent this, a sampling based data which consist of information on the number of mobile service subscriptions per individual is used as a proxy. The data is obtained from the PTS annual surveys from the year 2002-2010. In this case to have enough number of observations as

suggested by Srinivasan and Mason (1986), the data is interpolated as quarterly data with a total of 25 observations. In addition, some conception of the multiple-unit ownership Diffusion (MOD) model (Steffens, 20003) is applied to several fundamental diffusion models, such as the logistic, Gompertz and Bass model, to capture the demand variation level of the mobile service users as well as for comparison purposes. Each model consists of several non-linear equations with similar formulation and plot against the survey data in a simultaneous estimation process. For this purpose, this study considers procedure MODEL of SAS software. The detail discussion about the model and estimation procedure can be found in the appended paper (Paper IV).

Figure 13.Diffusion pattern of mobile service in Sweden based on several models

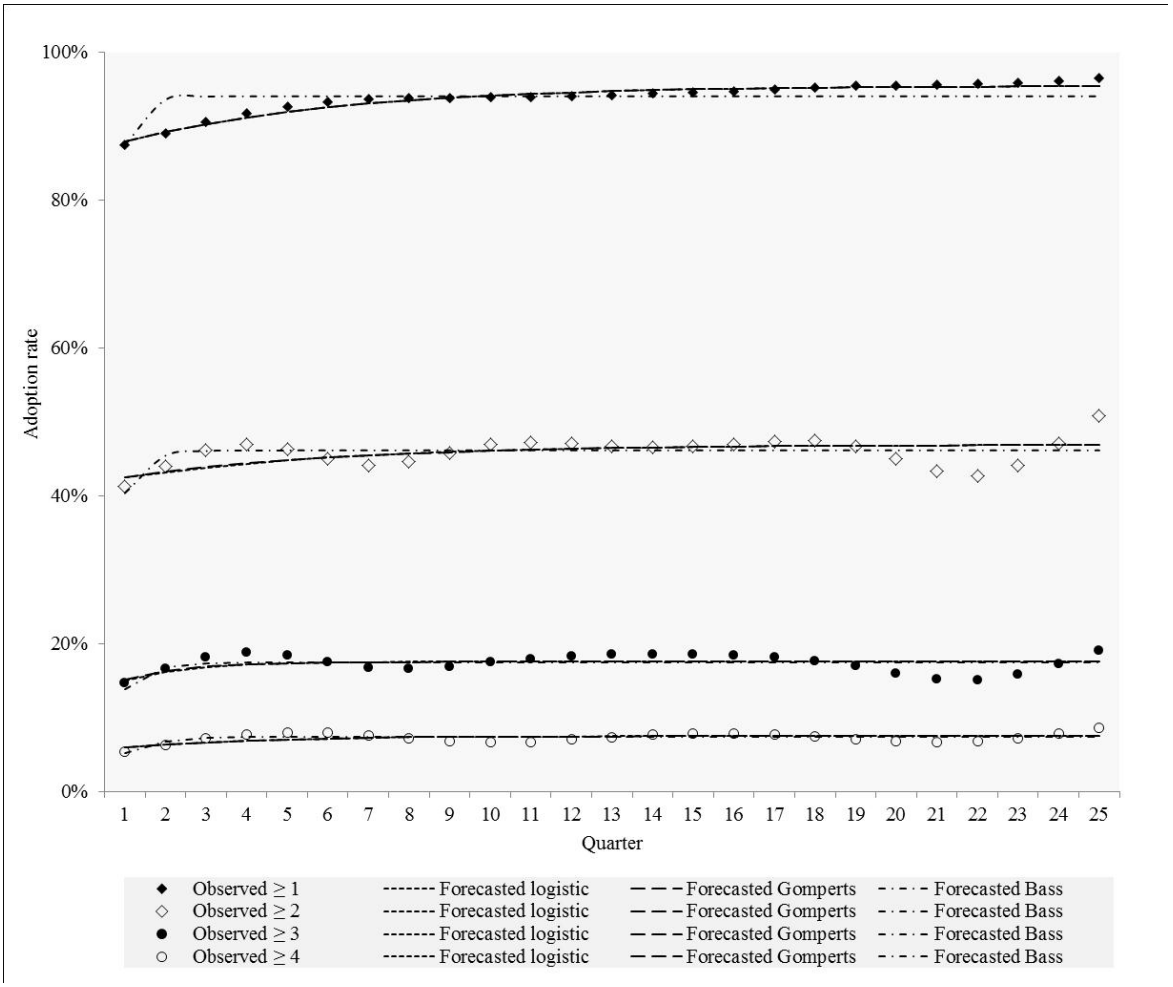


Figure 13 shows the outcome of this study, which provides a different description compared with classic diffusion modelling. As shown in the figure, the diffusion of mobile service process appears as several curves with different projections of saturation level as well as growth coefficient, (i.e. coefficient of innovation and imitation for Bass model, or delay factors for logistic and Gompertz model). This shows that demand variation exists in the market constituting a different shape of diffusion process and growth. In this case, as discussed earlier, a "vertical variation" exist showing different intensities level of using mobile service as a response to overcome social needs. Such an abstraction cannot be obtained when the data is aggregated into a single proxy with single diffusion model.

Furthermore, this finding also indicates that mobile service subscribers with single subscriptions have different innovation and imitation coefficients compared to mobile service subscribers with multiple subscriptions. This shows that the model is able to distinguish the different growth trend for each type of adopters. Conceptually different magnitudes of diffusion growth also show that a selection process occurs in society. Thus the stronger and steadiest pattern, (i.e. individuals with at least one subscription), is the 'dominant' behaviour routine of mobile service users in the society followed by the other type of behaviour routine. In the long run or in a different market setting, i.e. a market with extremely high penetration rate such as in the UAE, which has over a 200 percent mobile service penetration rate, a different abstraction may be obtained.

In practice, this disparity will help the business analyst and policy maker to identify the potential market segment. In addition, this also offers an ability to make a more comprehensive projection when estimating the market saturation level, since the level can be estimated for each segment of users. This also provides a description of actual demand forces and their distribution which drives the growth of mobile service diffusion in the market.

5.2.2 Intergenerational effects of technology in mobile diffusion

In this study the author aims to demonstrate the evolutionary features of the mobile service diffusion process by showing that the intra-technology variation exists in the supply side of mobile service and that the retention selection process takes place as intra-technology competition. In this case, mobile service is considered as a set of technology artefacts and the number of individuals using them is used as the proxy.

For this purpose two diffusion models are considered, i.e. Norton and Bass model (1992) and Islam and Meade (1997). In both models, the diffusion pattern is assumed as a result of simultaneous interaction of different generation of technology. In this case, the model assumes that different generations of technology substitutes for each other with a tendency for new technology generations to increase the innovative power of a product. In this process, a new generation product does not immediately replace the previous one after the introduction. Instead they compete against each other and create a sequence of simultaneous diffusions of the same product on the market. This offers an opportunity to show how the intra-technology competition occurs in mobile service technology along the diffusion process. This formulation provides a ground to describe the dynamic diffusion pattern across technology which cannot be provided in classic diffusion modelling where each adopter is assumed to use the same generation or class of technology over time. In this case, based on insight obtained in the earlier empirical observations (see discussion in Chapter 4), mobile service technology is assumed to be heterogeneous along the diffusion timeline as a result of variation and selection, and that mobile service as technology artefact is the unit of selection.

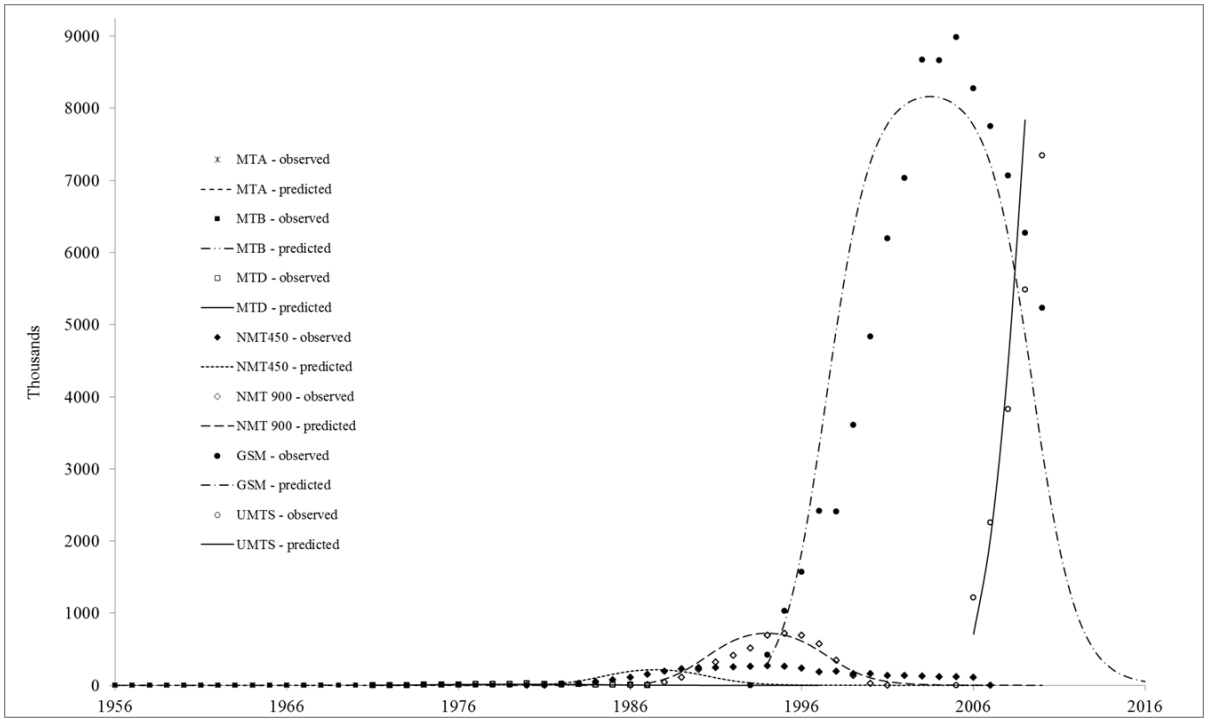
To generate the diffusion curves, the models construct a single equation for each generation of technology. These equations are composed into single formulations which then are estimated simultaneously. In this case the model is plotted using secondary data of mobile service user from each category of mobile service technology, (e.g. MTA, NMT GSM). The data has been available since 1956, the starting year of mobile service commercialization in Sweden. The time series data are compiled based on data obtained from PTS statistics[19] and study by Lindmark (1995). This results in total 98 point of observations from seven different mobile service technologies. In this

[19] See htttp://www. statistics. pts.se

case, since the data are not coming from the same source, which may cause a biased interpretation, a general assumption is made to the effect that the data are collected in the same time frame and treated as equal annual data.

The outcome of this study is shown in Figure 14. In this case, only estimation using the Norton-Bass model is shown as the estimation using Islam and Meade model could not achieve a convergence status. The results indicate that intergenerational effects exist in the mobile service diffusion in the Swedish market. The effects are positive toward the newer technology, but the converse is not true. This can be seen on the different size of each "wave" of each generation of technology where the newer technology tends to have a higher and wider wave. This suggests that new generations of technology tend to require a lower threshold to penetrate the market and its presence gradually diminishes the diffusion growth of earlier technology. This also explains why potential users tend to increase from generation to generation. In this case, the intergenerational diffusion process is comparable to an evolutionary process in the sense that the process consists of two main evolutionary features, i.e. variation and selection.

Figure 14. Intergenerational effects of technology in mobile services diffusion in Sweden



The variation can be seen from the fact that several generations of technology exist along the diffusion time line. In this case, each generation of technology has different features and performance. However, newer technology typically still inherits most features of previous technology, which suggests that retention and technological path-dependence characterize the process. The selection can be observed from the different curves that are generated during the diffusion time line. In this case, each curve shows that each generation of technology has its own lifecycle, which is a result of competition with other generations of technology, particularly the new one. In this case, the emergence of a newer generation of technology is the result of a selection of several generations of technology by market demand. Typically, the latest technology becomes the dominant design as it is developed based on "improved features" of earlier generation of technology and therefore offers better features and value to the users.

All these findings suggest that the main evolutionary features can be incorporated into the Norton-Bass model. Nevertheless, there are some limitations that should be taken into account. First, while the dynamic of diffusion pattern can be described for each generation of technology, Norton-Bass model assumes a constant value of the coefficient of imitation and coefficient of imitation. Therefore, the variation actually results from a constant paradigm of growth. This limitation is also addressed by Islam and Meade (1997) who suggest the use of a dynamic coefficient of innovation and coefficient of imitation for each generation of technology.

Nevertheless, as discussed in Norton and Bass (1997), the Norton-Bass model is a simplification of reality as are many other models. This implies that the justification of the model should be made based on the empirical application. Thus, if the model fits the empirical data well under this assumption, then it implies that the assumption is justified. In this context, the model actually plays a role as the law-like relationship which offers limited generality rather than universality. The model also offers approximate rather than exact estimation which often not necessarily derived from theory and the model is broadly descriptive than directly causal[20].

5.3 Discussion

Two empirical studies have been discussed to show how the main evolutionary features can be accommodated in diffusion modelling. In both cases, mobile service use is considered as the unit of selection. In the first study the mobile service use is seen as a behavioural routine with different intensities level which results in a "vertical" variation of diffusion pattern. In this study, multiple-adoption assumption is allowed and the dynamic population changes are inherently represented by the use of annual sampling data.

In the second study, the mobile service use is considered as a representation of a technology artefact in which intra-technology or inter-generational technology compete, resulting in a "horizontal" variation of diffusion pattern. In this case, multi-innovation supply is allowed as is the flexibility for users to use different generations of technology. However, due to data constraints, the modelling process still assumes a constant growth factor for different generations of technology.

In both cases, the process of incorporating evolutionary insights into diffusion modelling considers two critical issues that determine the success of it. The first issue related to the availability of comprehensive and representative data set and the second issue related to the selection and use of a relevant diffusion model. Each of these issues will be discussed in the following section.

5.3.1 Data granularity

Data always play important role in any analysis. This role is even more critical when the focus of analysis is to capture and describe the phenomenon of the real world. This is typical in empirical studies. In diffusion analysis, the role of data is indispensable since no diffusion pattern can be described from a sophisticated model without suitable data. In the context of diffusion modelling with an evolutionary perspective, several conditions have to be satisfied, including the variation and selection features of the unit of analysis. Therefore, data in use should also be able to represent these features.

[20] Further discussion on this issue can be found in Ehrenberg (1975)

As discussed earlier, variation is an important feature of the evolutionary process and therefore an important character of the evolutionary diffusion process. As shown in both Papers IV and V, variation generates dynamic diffusion patterns, each of which each represents “species” of the unit of selection. In Figure 13, for instance, each curve represents a level of mobile service use, (i.e. one subscription, two subscriptions etc.), while in Figure 14, each inverted U-shaped curve represents a generation of mobile service technology, i.e. GSM, UMTS etc.

Such a description is very helpful for a comprehensive trend analysis. Having a trend projection of individual with at least one subscription for instance, is helpful to estimate how many people are actually still disconnected from the mobile service as this can be observed by spotting the difference between the estimated curves with the 100% limit as shown in Figure 13. This can be a reference to identify the level of possible digital divide in the society.

However, this is only possible when the data granularity is available to the intended level of observation with a reliable accuracy. For instance, if one wants to model multiple-subscriptions then the data should be able to represent the level of number of subscriptions observed in reality. In this case, a maximum threshold can be assumed with sensible reasons, but the most important issue is that the level has to represent the large part of practice in the real world. For instance, it may be safe to assume a maximum four mobile service subscriptions per individual, because those with subscriptions exceeding four, while they may well exist, are not very common. In the case of inter-generational technology, the granularity should be able to represent the number of technologies available in the market so that it can be plotted in simultaneously in several non-linear equations.

Furthermore, as other diffusion modelling, having a sufficient number of observations is also a necessity. The minimum number of observations usually should be more than the number parameters to be estimated. Srinivasan and Mason (1986) even suggest at least ten observations should be available to make a sensible analysis in a single diffusion modelling estimation. In fact, diffusion modelling with evolutionary features usually has more parameters to be estimated, as the model consists of several equations that will be estimated simultaneously. In practice, however, obtaining a comprehensive and representative set of data is not an easy task. This often militates against a “realistic” working model. Therefore, some techniques can be applied such as interpolation or model adjustment. In study the by Islam and Meade (1997), for instance, the researchers adjust the model by assuming a constant coefficient of imitation to obtain a convergence status. This problem sometimes can also be solved by setting a sensible initial value for parameter to be estimated.

Even though the results of this study suggest that the use of longitudinal cross-section data obtained through survey sampling can be an alternative proxy in mobile service diffusion modelling, its application in this study has some limitations. It is only based on a short series of observation an there are problems with the accuracy of sampling based data. However, constraints are as also found in other studies which address similar issues but using secondary data or census data, i.e. Steffen (2003), Kamakura and Balasubramanian (1987), Bayus, Hong and Labe (1989). In these studies, a detailed data requirement, i.e. time to buy the replacement product or repeated purchase, is necessary. In fact such data is not widely available. Therefore, data availability can be a strength, as well as a weakness, of this approach, as most researchers apply classical diffusion modelling due to its nature of demanding less data. However, such a trade-off between the need to have a comprehensive analysis and data limitation can take place in any study, including diffusion studies.

Nevertheless, in the context of mobile communication studies, in a market with a well administered subscriber system such as Japan, this kind of data may can be obtained, and thus this type of modelling may be relevant to use. Conducting a continuous nationwide data sampling as is done in Sweden is valid suggestion for regulators who wish to understand the diffusion of mobile service. Alternatively, a mandatory procedure for mobile service subscriptions should be applied, even though this might be difficult in markets where prep-paid subscribers predominate.

5.3.2 Model selection and refinement

The application of evolutionary perspective in diffusion modelling violates some assumptions in classic diffusion modelling. For instance, the variation features allows multiple-adoption to occur in the diffusion process. . In addition, the data granularity which has several levels of observations also requires a particular model to deal with. Consequently, the existing model, such as fundamental diffusion models, cannot be used for this purpose. As suggested by Mahajan and Peterson (1985:35), in such a situation a researcher needs to consider the use of refinement or extended diffusion models which could relax one or several static assumptions in fundamental diffusion modelling.

There are several models in the literature that can be selected for application or as the source of inspiration to develop alternative model. In this study several of them have been applied in empirical applications. These are MOD model (Steffen, 2003), Norton-Bass model (Norton and Bass, 1987) and Islam-Meade model (Islam and Meade, 1997).

The MOD model is considered in this study as it allows multiple-adoption to take place along the diffusion time line. This feature is relevant to address the variation and selection process in mobile service use as a behavioural routine which allow multiple subscriptions. This model is a variant of Bass model, which relaxes the assumptions of population dynamics by considering the work of Sharif and Ramanathan (1976) and a modification of the repeated purchase model by Bayus, Hong and Labe (1989). However, since this study uses a different type of data set, which is obtained through sampling, the assumption of population dynamics is no longer needed as it has been inherently represented in the sample. Therefore only the logic of the model (i.e. that the saturation level of a subsequence adoption is a constant proportion of previous adoption) is considered. This results in several non-linear equations, which are computed simultaneously in a model. This process is applied in three fundamental diffusion models - Logistic, Gompertz and Bass models - to enable performance comparison, and to select the most reliable model.

The estimation results indicate that the model can explain the large part of variation on the first level of abstraction, which involves a population with at least one subscription, but not on the subsequent level. This can be a result of a bias or inconsistency of the data as the number of users with multiple subscriptions is far lower compared to those who have only one. However, for description purposes, the model works well by giving a sensible estimation level of saturation rate as well as growth factor. These estimation results show that the specified model can explain the magnitude of variation as well as the selection process. This result cannot be achieved using fundamental diffusion models which assume aggregate abstraction for all levels of mobile service use.

In the second study, the Norton-Bass model and Islam-Meade model are considered. Both models offer similar propositions that intergenerational technology existing along the diffusion time line, and that a new generation of technology compete with preceding generation of technology and resulting in an inter-generational effect which forms “horizontal” variation of

diffusion pattern. In this study, despite its more realistic propositions, such as assuming a dynamic coefficient of innovation and imitation for each generation of technology, the Islam-Meade model cannot achieve convergence status due to data limitation.

In contrast, Bass model with simpler yet less realistic assumptions, such as constant coefficient innovation and coefficient of imitation across generation of technology, yield a convergence point. This suggests that a more realistic model is not always "better" and is often less applicable. Meade and Islam (2002:593) also emphasize that simpler diffusion models tend to forecast better than more complex ones. This principle should be taken into account when deciding a suitable model to represent the case at hand. In this case, however, even though evolutionary based diffusion modelling demands complex formulation and comprehensive data, it does not always mean this approach is less applicable. In addition, the complex formulation is a trade-off for a more detail and rigorous analysis. Therefore a proportional model specification based on a sensible focus is suggested, rather than merely considering the simplest model which in this case is the fundamental diffusion model.

5.3.3 Limitations

The real world has unlimited variation, but model specification and data granularity have a limit. Therefore accuracy should not always be the top priority in diffusion modelling. Instead, the model should focus more on capturing and explaining regularities and variation of the real world as they often give more insight than would merely describing an aggregate pattern. This is also a main purpose of evolutionary based diffusion modelling. In the process of incorporating evolutionary features into a diffusion model, however, limitations are often found. These can be related to data availability as well as complex model specification.

Both empirical examples given in this chapter also suffer from such constraints. In the first example (Paper IV), no specification to control possible sampling error for each year's survey is given. In addition, the models also do not incorporate market mix variables such as service price and disposable income to bring in information related to the contribution of such variables which likely also determine the dynamic pattern. The interrelated consumption of other complementary or substitute technology, such as the use of fixed communication and Internet use, should also be taken into account. However, this kind of more realistic explanation will result in a very complex model, as well as demanding data which often hinder its applicability in addressing the problem. This is also the rational why this research considers the modelling approach as in current form.

In Paper V, the main limitation that has not been addressed by the model is the assumption of constancy of diffusion growth factor for each generation of mobile service technology. In fact, each generation of mobile service technology offers different features and specification which likely attract the potential adopters in different way. Such an assumption is thus not realistic. However, the application of Islam and Meade's model which was supposed to be able to overcome the problem is also constrained by the data characteristics.

Furthermore, unlike other evolutionary-based diffusion studies, such as by Kwasnicka, Galar and Kwasnicki (1983) and Kwasnicki and Kwasnicka (1997), the approach used in the empirical work of this thesis does not apply a system dynamic perspective, which requires a more robust model. In addition, the diffusion model in Paper V also does not provide a specification to address inter-technology competition. This is pressure that comes from different classes of technology such as fixed telecom technology, the Internet, and computer technology, which typically has direct implications to the dynamic diffusion pattern.

For instance, when examining the diffusion of mobile service, the diffusion of related technologies such as fixed phone, broadband, PC etc. should also be investigated. This is because in the evolutionary system dynamic, these technologies co-exist in the same ecosystem and have interrelated influence. The rapid diffusion of mobile service in a market for example, will sooner or later have an implication to the diffusion of fixed telephony as well as fixed broadband. Nevertheless, the application of evolutionary system dynamic modelling often demands comprehensive assumptions and data that often restrict its applicability on a simulation level. This approach also needs a broad range of relevant entities to be simultaneously incorporated in the analysis which often complicates the interpretation.

Nevertheless, one should, again, consider the fact that a more realistic model is not always "better" and is often less applicable. In this case, applying a principle of forecasting as suggested by Meade and Islam (2002:593) that simpler diffusion models tend to forecast better than more complex ones, is relevant.

5.4 Summary

This chapter has shown the empirical application of evolutionary features such as the unit of selection, selection mechanism and variation, into mobile service diffusion modelling. The results show that evolutionary insights obtained in the earlier empirical observations (see chapter 4) can be incorporated into diffusion modelling with some conditions and restrictions. The results show a "vertical" variation trend when explaining the level of mobile service use and a "horizontal" variation when explaining the inter-generationality of mobile service technology. In this case, two critical issues determine the success of incorporating evolutionary features into diffusion modelling of mobile service. These are availability of comprehensive and representative data set and the use of relevant diffusion model.

Data granularity plays important roles in representing the inherent dynamic variation of the unit of analysis in which its interaction effect through selection mechanism can be estimated through relevant diffusion model. In both cases, however, restrictions often take place. Data availability is the most common limitation, as evolutionary based diffusion modelling usually demands long time series data with a certain granularity level. The model to fit such comprehensive data also requires a complex specification, which also often hinders its applicability. Therefore, a careful consideration should be made to determine the most optimum trade-off between rigorous and realistic assumptions and empirical applicability.

After all, despite all the above-mentioned restrictions and limitations, the empirical results in this thesis show that evolutionary framework offered in this thesis is feasible as an alternative to understand mobile service diffusion as an evolutionary process. This can be achieved by taking the mobile service framed as artefact-activity coupled as the unit of analysis that evolves over time with certain dynamic characteristics. As an early attempt in this field of research, this alternative theoretical point of view needs further exploration in a different context of application which should become the future research agenda.

Chapter 6

Implications on future studies of mobile service diffusion

This chapter provides discussions on the conceptual and practical implication of understanding mobile service diffusion as an evolutionary process. Some practical implications and challenges are described.

6.1 Conceptual implications

The previous chapters have provided a discourse to frame the diffusion of innovation as an evolutionary process. Some empirical applications of this framework have also been described. Most of the discussion emphasizes the need to relax one or several static assumptions of fundamental diffusion modelling to explain the diffusion of mobile service. One way to do this is by considering a theoretical structure that can frame the mobile service diffusion as a dynamic process so it can represent the essential features of actual diffusion pattern. This can be achieved, for instance by considering the extended or refined diffusion modelling as discussed in Mahajan and Peterson (1985:35). However, such an approach will only solve the technical and mathematical formulation which is in practice often restricted by the lack of data support. Moreover, it does not provide a theoretical ground for explaining the philosophical mechanisms that underlie the process. In fact, such concept formulation is often useful as the point of departure to comprehend the diffusion of innovation process.

Traditionally, the conceptual formulation of diffusion of innovation theory is dominated by scholars in the field of sociology (see Chapter 2). However, evolutionary discourses, particularly one related to diffusion of innovation, are often given by economists. Schumpeter (1939:86)[21], for instance, explains diffusion as the interplay between innovation and the economic system over time. This inspires Cairnaca, Colombo and Mariotti (1988) to develop evolutionary perspective principles on diffusion of innovation which consist the following conceptions:

- Technological progress consists in the *simultaneous* interaction of technical change and innovation diffusion
- *Variety* is a driving force of the process. In this case, at every instant, a spectrum of

[21] "The changes in the economic process brought about by innovation, together with all their effects, and the response to them by the economic system, we shall designate by the term Economic Evolution" (Schumpeter1939: 86).

technological alternatives is present, and rivalry exists between the new technology and the old one**,** within the set of technological solutions generated by the new technology and between this set and that generated through adapting and improving the old technology

- Two different mechanisms are constantly at work, shaping the dynamics of the process and determining the "winning solutions". These are the selection of firms which depends on the characteristics of the institutional and market environments, and imitation and learning (both within firms and among firms).
- The interaction between the demand for and the supply of innovations cause technology and market structure change endogenously along the innovation-diffusion process.

These principles are also in line with a framework of Dosi and Nelson (1994), which set up criteria to characterize an evolutionary process in the social science domain:

- A fundamental unit of selection (genes)
- A mechanism linking the genotype level with the entities (phenotypes) that actually undergo environmental selection
- Some process of interaction yielding the selection dynamics
- Some mechanisms generating variation in the population of genotypes and through that among phenotypes.

Nevertheless, the empirical applications of both frameworks mostly are done in the context of inter-firm diffusion where the unit of analysis consists of firms or organizations as the actors of the "supply side". Mansfield (1968), for instance, studies the diffusion of various innovations including the coke oven, diesel locomotive, thin container, etc. across industries in the United States. A study by Cairnaca, Colombo and Mariotti (1988) also conducted studies on the application of flexible automation systems, (i.e. Flexible Manufacturing Cells (FMC)), across industries, while Kwasnicka, Galar and Kwasnicki (1983) apply this framework in the context of energy industry.

In fact, Nelson and Consoli (2010) underscore that innovation studies pay most attention to the supply side of innovation and pay less attention to the demand side. Therefore Nelson and Consoli suggest applying the evolutionary conceptions to understand how individual consumers respond to new goods and services in a realistic way. This is even more relevant because in these days a significant portion of the innovation going on in capitalist countries has been in the form of new consumer goods and services.

This implies that evolutionary conceptions should be applied to understanding the spread of innovation among individuals, with a focus on consumer goods and services. This thesis therefore, provides a different application of the evolutionary conception such as the spread of mobile service among individual users. The aim is to map the framework of Dosi and Nelson (1994) into applicable conceptions. In this case, the conceptual formulation covers three main evolutionary features, the unit of selection, selective retention mechanisms, as well as variation and adaptation. The empirical observations of these evolutionary features into diffusion of innovation theory have been discussed in earlier chapters and the conceptual reflections of these features will be addressed in the following sections with reference to the artefact-activity conceptions by Fleck (2000: 248-266).

6.1.1 Conceptual formulation of unit of selection

Discussions in Chapter 5 have shown that mobile service use, both as behaviour routine and as representation of technology artefact use, is applicable as the unit of selection when explaining the evolutionary based diffusion process. In both cases, the use of mobile service as a unit of selection plays a similar role as the unit of adoption in traditional diffusion innovation theory. The difference is that in traditional diffusion modelling, the spread of innovation is assumed as a homogeneous process. This means that the spread is through communication channel and eventually all members of the population will be adopters of the innovation. However, as an evolutionary process, the spread of innovation goes through a process of variation and selective retention, and therefore there are different patterns of diffusion for the same unit of selection. In this case, the spread is through cultural transmission which is governed by learning processes among population members.

With this analogy, the diffusion process can be viewed as a cultural or social evolution process that is driven by a learning process. In this case, a successful innovation can be directly taught and spread to others through social transmission (i.e. a mimicking process). Thus, the unit of adoption plays an equivalent role as a unit of cultural transmission or a unit of imitation to a form of *meme* (Dawkin, 2006:192). Each unit of adoption evolves over time and shapes a certain diffusion pattern. The roles of a meme, in this process, are explained following the argument of Fleck (2000:250), as both a replicator and interactor. As a replicator, a meme passes on most of its structure in sequential replications, whereas as an interactor a meme engages in a cohesive interaction with its environment in such a way as to generate a differentiated replication.

Since in practice the use of mobile services entails both physical aspects, being a technology artefact, and non-physical aspect, relating to the behavioural routine of using it, the next challenge is how to encapsulate both aspects into a single entity. In this case, the framework of artefact-*activity couple* (Fleck, 2000: 257) is relevant to consider. Thus, mobile service use which represents a dynamic combination of the technology artefact, (i.e. the handset and mobile service technology), with the immediate set of individual routines that sustain the use and development of mobile service, should be considered as the unit of selection.

Nevertheless, translating this conceptual framework into practical application in diffusion modelling will require a multi-featured dataset, which is a unit of data that includes the type of technology and level of use, that may be only available in certain circumstances, such as in a market with mandatory mobile service registration, or in a well administered mobile operator data warehouse, which may limit its practical application. Still, as a theoretical explanation, it offers a wider perspective that is more realistic in understanding the diffusion process of mobile service.

6.1.2 Conceptual formulation of variation

In the previous section, it was argued that formulating a relevant unit of selection is the key to understanding mobile service diffusion as an evolutionary process. In this thesis, the mobile service use is framed as artefact-activity couple that transmittable as a meme, and is considered as the unit of selection or the unit of analysis. In this case, as the unit of social transmission, the meme plays roles as a replicator and interactor.

In practice, the meme representation of mobile service as a replicator can be seen from internal and external aspects. Internally, this role will create a self-replication, such as multiple-adoption, among individuals. Externally, this role will generates pressure or influence to adopt the innovation on other individuals which is similar to a contagion process in diffusion of innovation

theory. The internal aspect will result in different intensity of mobile service use, such as the number of subscriptions, the number of handset or handset features etc. The external aspect will generate new adopters and diffusion growth. On the other hand, the meme representation of mobile service as an interactor can be seen, for instance, in the diversification of mobile service use into different platforms or lifestyle, such as mobile internet, mobile media, mobile banking etc. With such conceptualization, future mobile service diffusion studies can address a broad range of mobile service use with different levels of abstraction. For example, a study on the diffusion of handset features or technology, a study on the diffusion of mobile applications, etc.

The roles of a meme as a replicator and interactor are also applicable to explain the mechanism of contagion in evolutionary diffusion of mobile service which inherently involves the dynamic process of variation and selective retention. The interactor-based mechanism of variation, which allows random process and yield in heterogeneous variations, could satisfy the argument of Ziman (2000:7) who argues that "*there is usually enough diversity and relatively blind variation in a population of technological entities to sustain an evolutionary process."* In this case, the term "relatively blind" should be understood as that the variation may go into unpredictable direction as it is governed by random individual needs and a heterogeneous capacity of learning.

Furthermore, as argued by Dosi (2000:186): the heterogeneity of potential adopters is also a possible source of random variation in a diffusion of innovation process. He further argues that "*the universe of potential adopters cannot be realistically assumed to be composed of identical units."* This is because each potential adopter, whether a firm or an individual, has specific characteristics, such as needs, learning capacity, physical, resources constraints, rate capacity of utilization, etc., which in aggregate may form a different shape of the diffusion process (Silverberg, Dosi, and Orsenigo, 1988). This conception of variation should be taken into account when developing mobile service diffusion, for instance by allowing multiple-adoption to occur along the diffusion time line. As shown in Paper IV, with this approach, the potential adoption can be loosely projected based on the rate of consumption capacity for each type of adopter.

Another source of variation in the diffusion of innovation is the characteristics of the innovation itself and its diffusion environment (Metcalfe, 1982). In the case of mobile services, this can be seen in the intergenerational effects of mobile service technologies (i.e. Paper V). As discussed in Paper V, inter-generationality of technology characterizes mobile service diffusion as the result of competition between new generations of mobile service technology and earlier generation technologies. Garud and Ansari (2009) also show that the presence of forces for both change and continuity across heterogeneous social and technical elements characterizes the transition between the 2G and 3G mobile communications technology platforms. This creates various incentives for adopters and potential adopters of mobile services that, in aggregate, influence the overall diffusion process by creating a series of diffusion curves (see Figure 14).

Accordingly Metcalfe's (2005) also argues that "*what is being diffused is not usually a single innovation but rather a design opportunity in which the evolution of design is not invariant to the process of diffusion but reflects diffusion induced learning. Moreover, it is misleading to focus solely on the innovation that is being diffused and thereby lose sight of any improvements that may follow from the rival technologies that it seeks to displace"*. Based on this argument, the diffusion process can be explained in two ways. It traces the progress of key performance indicators, which usually follow an *S*-shaped curve (Foster, 1986), and it traces the emergence of dominant designs (Dosi, 1982; Abernathy and Utterback, 1978).

In both cases, the variation is driven by the process of adaptation, which comprises both endogenous forces (individual preferences) as well as exogenous forces, (the competing

technology and related institutions). In this case, the variations are also both continuous and discrete. A mobile service user, for instance, will keep using a mobile service and be considered a mobile service adopter even if he or she changes technological platform. This indicates continuous variation. At the same time, the discontinuation of old technology use indicates that the process is discrete. As shown in Figure 14, the number of mobile service subscribers in aggregate is continuing to grow over time. However, if the subscriber is projected for each technology platform, there is a discrete curve for each technology type.

In diffusion modelling, this is similar to the idea that views the diffusion process as a series of self-organized disequilibrium processes (Silverberg, Dosi and Orsenigo, 1988). In this case, the S-shaped curve, which may be useful in depicting the outcomes of competing technology, becomes less useful in understanding issues that arise during transitions (Latour, 1991). The traditional S-shaped curve that typically projected to a single platform technology also falls short of capturing this phenomenon. Accordingly, the result of Paper V, in addition to Norton and Bass (1992) and Islam and Maede (1997), shows that successive product or technology generations have a significant impact on the aggregate demand. Therefore, diffusion modelling should incorporate such effects to provide a more detailed demand projection.

6.1.3 Conceptual formulation of selective retention

Framing the unit of selection of mobile service diffusion as artefact-activity couple suggest that, as a meme, mobile service can spread or propagate through two mechanisms, as replicator and as interactor. As a replicator, a mobile service passes its most of its structure in sequential replications. This process, in many senses, is similar to contagion in classic diffusion of innovation theory where a potential adopter will become an adopter when they have a contact with an adopter. However, the variation in evolutionary framework is determined by the role of a meme as an interactor. In this case a different contagion process occurs when a meme as an interactor makes a cohesive interaction with its environment in such a way as to generate a differentiated replication. The difference is that in the contagion process of classic diffusion modelling, this always results in a decision to adopt the innovation, thus characterizing the diffusion as a homogenous process. In contrast, the cohesive interaction of a meme as an interactor with its environment may result in various decision outcomes such as adopting exactly in the same way, adopting with modification, multiple adoptions, not adopting etc. In aggregate, this will result in heterogeneous diffusion pattern.

Furthermore, once a meme plays a role as an interactor and creates a cohesive interaction with its environment, there is a possibility that variation will occur. This mechanism will lead to selection, which in turn can give a rise to the emergence of an entity that persists indefinitely through time either in the same state or altered as a result of replication. A concrete example of this proposition can be observed in the emerging phenomenon of cord-cutters - a segment of population that relies on mobile communication only. In Paper I, this group of mobile users is studied. The results indicate that the population of cord-cutters grew significantly from only about 4 percent in 2002 to 18 percent in 2010. At the same time, the population of fixed-only users decreases from 11 percent to only 2 percent, whereas population that used both fixed and mobile phone decreased slightly from 85 percent to 80 percent (see Figure. 11).

This indicates that, cord-cutters are emerging as a new entity, which will further grow in the future as most of them, based on Paper I, are youngsters who will potentially carry this behavioural routine for a longer period of time. By contrast, the fixed-only users represent an entity that soon diminished as it less adaptive to environmental forces. A large proportion of

population with both mobile and fixed line show that the fixed-line life style is still a dominant routine as it has persisted for a long time. However, the facts indicate that this group is decreasing and their routine is acceptable only if it is complemented with a mobile phone. This shows that as a behavioural routine, the practice has fragile persistence and may significantly decrease in the near future.

A similar conclusion is also revealed in Paper II which investigates the characteristics of mobile service have-nots or non-users. Based on the analysis results of three consecutive years of surveys, the study finds that the population of mobile non-users is no longer significant on the Swedish mobile market. This suggests that living without mobile service may no longer persist as a meme. Moreover, the study also finds that the influence of socio-economic factors is transient over time. This suggests that internal-influence alone, such as personal characteristics or attitudes toward technology, are not sufficient to determine the persistency of the meme of mobile service non-use. This, again, underscores that internal-influence diffusion modelling is not appropriate as the basis for modelling evolutionary diffusion of mobile service.

Another empirical observation in Chapter 4 also supports this theoretical proposition. For instance, the observation in Paper III shows that the decision to use mobile service is not a uniform across individuals. Some individuals, for any given reason, may decide to have more than one mobile service which is indicated through the possession of more than one active SIM cards or mobile subscriptions. There are a number of reasons for this decision, such as differentiate private and business subscriptions, subscriptions for other family members such as children and the household, and mobile data communications purposes, etc. This indicates that the process of cohesive interaction of a meme with its environment does not always end up as a one-to-one relationship, but can also be a one-to-several, or even a one-to-many relationship. Therefore, this evolutionary feature should be incorporated when formulating the diffusion of mobile service.

Furthermore, paper III also indicates that the cohesive interaction of a meme as an interactor also generates heterogeneous adopters. This can be observed, for instance, from the presence of mobile service subscriptions for business purpose. The results in paper III indicate that this type of subscription is a key determinant of the multiple subscriptions phenomenon in the Swedish market. This suggests that even though the mobile service is essentially a service for individual use, environment intervention, i.e. the mobile service subscriptions policy of the company or organizations, may also influence the adoption of mobile service. The network effect from a social group, such as a family or colleagues, may also exert a similar influence. This implies that modelling the mobile service diffusion pattern should incorporate both internal and external influence.

6.2 Practical implications and challenges

A changing theoretical paradigm brings practical implications. This is also the case when framing mobile service diffusion as an evolutionary process. As a direct implication, the essential features of evolutionary conceptions, (unit of selection, selection and retention and variation) should be incorporated when modelling the diffusion of mobile service to bring about a more realistic and detailed explanation of the diffusion process.

Nevertheless, modelling all evolutionary features will be constrained by data availability and complex mathematical formulation, which lead to impractical applications. This study, therefore, suggest focusing on the relevant characteristics of each adopter and potential adopter as well as the dynamic supply of the innovation which is likely to influence the diffusion pattern. For

instance, the intensities level of mobile service uses, (single use, multiple use etc.), (see Paper IV) and the dynamic of technological supply, from MTA to 3G/UMTS technology (see Paper V). The latter study is particularly relevant since the straightforward diffusion of a basic artefact into widespread use essentially as originally invented is actually quite unusual.

In addition, Papers IV and V also show that a series of inverted U-shaped abstraction, in addition to a series of S-Shaped curves can be an alternative to describing the diffusion pattern. As suggested by Lindqvist (1994:278) an inverted U-shaped abstraction offers a better mental image of technological development, and is therefore more recommended than an S-shape curve when used to describe technological development process. This is because the use of the S-shaped curve brings two fundamental fallacies, i.e. the S-shape only depicts half the life cycle of a technology and it exaggerates the importance of the initial stage of growth in the life cycle of a technology (ibid: 274-276).

Nevertheless, both Papers IV and V emphasize that single curves will fall short when attempting to represent the actual dynamic pattern of the diffusion as an evolutionary process. In both paper, therefore, a series of curves is suggested for each level of investigated innovation to show how the variation and selection process take place in the diffusion time line. Such description is very helpful when performing a more detailed trend analysis, including product and demand life cycle.

While an evolutionary perspective is quite promising and intuitive on the theoretical level, it has many barriers in application. This is due to the fact that the evolutionary conceptions always demand a “natural” way to model a social phenomenon, which unfortunately, often not easy. The biggest challenge is to obtain a suitable data set that could perfectly fit the specified model. In this case an alternative data source as discussed in Chapter V, such as through survey sampling or combined sales data can be considered. In many cases this can also be solved through simulation, but this is mainly left as a research agenda.

Furthermore, the conceptual formulation in this thesis of the evolutionary diffusion process has been primarily focusing on the application in context of mobile services as an independent innovation. This overlooks the fact that a possible interrelation with other type of innovation may exist. For instance, the influence of fixed communication and Internet use, which have an obvious relation to mobile service use. Furthermore, there is the dynamic interrelation with market mix variables, such as price, service bundling etc. However, this limitation is expected as in this thesis diffusion study is aimed at describing behavioural events, such as the spread of mobile service innovation. In addition, as a trend analysis, the discussion typically focuses on examining the relation of the trend to function of time rather than with other factors.

After all, it is important to take into account the argument of Shannon (1975: 27): "*The tendency (in modelling) is nearly always to simulate too much detail rather than too little. Thus, one should always design the model around the questions to be answered rather than imitate the real system exactly ...*" So it is impossible to fully model reality as each model typically requires constraints and restricted assumptions. Therefore, the best model is the one that can best represent the diffusion process with all available resources and constraints.

6.3 Summary

This chapter proposes the following principles that should be taken into account when one wishing to apply an evolutionary perspective to diffusion studies (Cairnaca, Colombo and Mariotti, 1988):

- Technological progress consists in the simultaneous interaction of technical change and innovation diffusion
- Variety is a driving force for the process.
- Two different mechanisms are constantly at work, shaping the dynamics of the process and determining the "winning solutions". These are: the selection and the imitation and learning.
- The interaction between the demand for and the supply of innovations cause technology and market structure change endogenously along the innovation-diffusion process.

With regard to these general principles, several conceptual formulations are proposed as theoretical implications of framing mobile service diffusion as an evolutionary process. In this case, as in the discussion in chapter IV, the formulation is based on a framework by Dosi and Nelson (1994), which suggest three main evolutionary features as the threshold to characterize a social evolutionary process, the unit of selection, selective retention and variation.

Conceptually, future mobile service diffusion studies should consider mobile service use as the unit of selection and frame it as artefact-activity couple. With this conception, mobile service use is assumed to act as a meme and have two mechanisms, as replicator and as interactor. Typically, the variation is determined by the role of the meme as an interactor, in which the meme makes a cohesive interaction with its environment in such a way as to generate various possibilities, (i.e. mobile service adoption exactly in the same way, adoption with modification, multiple adoptions, not adopt etc.). In aggregate, this will result in a dynamic mobile service diffusion pattern.

As an interactor, a meme of mobile service use creates a cohesive interaction with its environment, and there is a possibility of variation occurring. This mechanism will lead to selection, which in turn can give a rise to the emergence of an entity that persists indefinitely through time either in the same state or altered as a result of replication. This can be seen for instance in the diversification of mobile service use into different platform or lifestyles, such as mobile internet, mobile media, mobile banking etc. With such conceptualization, future mobile service diffusion studies can address broad range of mobile service use with different levels of abstraction, such as a study on the diffusion of handset features or technology or a study on the diffusion of mobile applications.

While the conceptual formulations of mobile service diffusion as an evolutionary process are rich with intuitive descriptions for future studies, the application into empirical works may be limited. Data constraints and complex model specification are the common barriers. Therefore, it is suggested to design the model around the questions to be answered. Furthermore, the use of simple formulation should be the priority, as the simpler the model the better the forecasting power (Meade and Islam, 2002:592). Still, as a conceptual explanation, understanding mobile service diffusion as an evolutionary process is worth considering as it offers more realistic descriptions on how the actual diffusion process may occurs. These evolutionary insights, therefore, should be carefully taken into account when modelling diffusion patterns, and should be applied whenever possible to bring about more accurate trend analysis and projection.

Chapter 7

Concluding remarks

This chapter provides the summary of the thesis, discussions of its contributions, as well as the managerial implications. The last part describes limitations and possible directions for future studies.

7.1 Conclusions

This thesis highlights the connection between two conceptions in the field of economics of innovation. These are diffusion of innovation theories and the evolutionary model of technological changes, within the context of mobile communication research. Three research questions are proposed: Why should mobile service diffusion be understood as an evolutionary process? How should mobile service diffusion be explained and modelled using evolutionary conceptions? And in what way could the evolutionary framework influence future mobile service diffusion studies?

Based on a literatures review and some empirical observations of the Swedish market, this thesis concludes that the diffusion of mobile service should be framed as an evolutionary process. This is based on the fact that the mobile service diffusion process could satisfy three main features of the social evolutionary process, the presence of a unit of selection, variation and selective retention. In this case, mobile service use as representation of both a technology artefact and behavioural routine satisfy a condition as the unit of selection. The variation can be observed in the intensity level of mobile use, (i.e. the number of subscriptions) which creates “vertical” variation along the diffusion time-line. The variation can also be recognized in the inter-generationality of mobile service technology which generates “horizontal” variation along diffusion time line.

Selective retention can be observed by considering mobile service use as a form of micro-consumption of innovation with its selection criteria reflecting both technological effectiveness and user needs (Nelson, 2000:72). The presence of cord-cutters population, for instance, implicitly indicates the selection mechanism of individuals who choose to retain mobile-only communications rather than other type of communication. Similarly the existence of mobile service non-users also implicitly shows that some individuals still attempt to retain the existing communication means. In this case, the behavioural routine of using mobile service will co-evolve over time as a reciprocal response to technological effectiveness and user needs.

Furthermore, this thesis also concludes that mobile service diffusion can be explained and modelled using evolutionary conceptions by selecting a relevant design of the diffusion model as well as providing data granularity to the level of necessary abstraction. For this purpose, the thesis shows both primary and secondary data are useful and applicable, but data granularity is the critical point in both cases. Since modelling all evolutionary features will be constrained by data availability and complex mathematical formulations which lead to impractical application. This thesis, instead, suggests focusing on the relevant characteristics of each adopter and potential adopter, as well as the dynamic supply of the innovation, which likely influences the diffusion pattern. For instance, the level of mobile service uses, (single use, multiple uses etc.) (see Paper IV) and the dynamic of technological supply, (from MTA to UMTS technology) (see Paper V).

As a direct implication, the essential features of evolutionary conceptions should be incorporated when modelling the diffusion of mobile phone to bring about a more realistic and detailed explanation of the diffusion process. In this case, a sensible conceptual formulation across the three main evolutionary features is critical. In this thesis, such a formulation is developed with reference to the artefact-activity coupled conception and views the diffusion as a cultural evolution where the meme plays a role as medium for generating variation and selective retention.

7.2 Contribution

This thesis is among few scientific attempts that addresses the connections between the diffusion of innovation theory and the evolutionary models of technological change, particularly within the mobile communication field. Along the research process, the following insights have been generated to enhance the understanding on the related issue.

- It is highly relevant to provide a reference that addressing the issue of cord-cutters, as the prototype of future mobile society. This thesis contribute by providing two studies, i.e. a single cross section study addressing basic socio-economic characteristics and behaviour of cord-cutters population in the Swedish market (Annafari and Bohlin, 2010b), as well as a longitudinal study addressing the dynamic socio-demographic pattern of cord-cutters over time (paper I).
- It is also critical for business and policy maker to balance their view regarding the diffusion of innovation which typically suffer from pro-innovation bias[22]. This is addressed in paper II which studies the population of mobile-phone non-users in the Swedish market. This paper also provides an empirical explanation to show that high mobile penetration rate is often loosely interpreted, since in a country with high penetration rate such as Sweden, the mobile-phone non-users exist and persist over time.
- This thesis also contributes to understanding the fact that multiple adoptions exist and influence the diffusion process of mobile service. This is done by providing a study that addresses factors that determine multiple-mobile phone subscription (paper III) and a diffusion modelling study incorporating the multiple adoption incidence, in the case of mobile service (paper IV). The latter paper also provides an empirical example of how survey sampling based data can be applied in the diffusion modelling.
- The last paper in this thesis is also among the few studies that address and provide empirical evidence of intergenerational effect of mobile service. The empirical evidence uses a

[22] Pro-innovation bias is defined "*the implication in diffusion research that an innovation should be diffused and adopted by all members of a social system, that it should be diffused more rapidly and that innovation should be neither re-invented nor rejected*" Rogers (2003: 106).

comprehensive data set which could cover almost all generation of mobile service technology in Sweden since it was first commercialized in 1950s.

In the context of application of evolutionary framework within technology studies, this thesis is one of the first attempts to apply the notion of artefact-activity couple to a real example, particularly in the case of diffusion of mobile services. In this case, the application of the artefact-activity couple concept is combined with the conception of meme (Dawkin 2006:196) to explain the contagion process of mobile service diffusion as an evolutionary process. By the use this concept, the mobile service use can be encapsulated as a cultural entity that is socially transferrable through replication and interaction and at the same time able to integrate mobile service use as an amalgam of handset, mobile service and a set of behavioural routine of using the service.

This abstraction is a promising as a theoretical contribution and opens a new perspective for further studies as an alternative to existing theoretical paradigms, which are still based on mechanistic assumptions. The empirical applications of this framework in this study, through MOD and Norton-Bass model, show that the concept is applicable and relevant to use. The results also offer a different projection as well as a richer perspective regarding the diffusion process of mobile service.

The empirical work also addresses recent issues in the mobile communication field, offering a certain sense of newness related to methods application and research topic. A study about multiple-subscription in mobile service (Annafari, 2010) for instance, is among the first empirical studies addressing this issue in the field of mobile communication, and introduces the application of generalized Poisson regression a way of dealing with underdispersed cross-section count data. Other empirical studies, such as ones addressing cord cutters (Annafari and Bohlin, 2010b) and mobile service have-nots (Paper III), are among the few studies of their kind, particularly with the Swedish market as their research setting.

The last paper which addresses the intergenerational technologies in mobile service diffusion contributes to the literature by explaining the impact of technological substitution on the diffusion pattern of mobile services. This study is among the few studies addressing this issue and among the first studies in mobile communication field which uses Norton-Bass modelling (Norton and Bass, 1992) to explain the impact of technological substitution. Even though this paper uses a very extensive secondary data, overall work in this thesis advocates and encourages the use of primary data as a proxy to plot the diffusion curve as an alternative to the problematic operator-based secondary data as previously discussed in the licentiate thesis (Annafari, 2010b).

Since the main argument of this thesis is that diffusion of mobile services should be explained as an evolutionary process, the direct implication is that the evolutionary features have to be incorporated when explaining the mobile service diffusion. However, incorporating all essential evolutionary features into a single model seems too complicated and difficult for empirical testing. Therefore, this thesis suggests considering only the relevant features or sub-evolutionary features in diffusion modelling that are most applicable using the recent diffusion model available in the literature.

Some examples have been given in this study, such as a multiple-ownership diffusion model (Annafari, 2011) and an intergenerational technology model (Annafari, Lindmark and Bohlin, 2011). These studies have shown that considering the dynamic aspects of both the demand and the supply sides of the innovation under investigation will bring about a deeper understanding and better foresight toward the diffusion pattern. The studies also suggest that the evolutionary

framework that encapsulates the mobile service use as the artefact-activity entity, despite data related constraints, is empirically applicable and gives rise to an insightful diffusion description. Consequently, future empirical studies employing this approach should be encouraged to improve the applicability of the evolutionary framework which will purposefully support decision making.

7.3 Direction for future research

The conceptual framework developed in this chapter indicates some stimulating directions for future research in the mobile service domain. For instance, framing mobile service use as artefact-activity coupled allows for broad range theme for diffusion studies, such as the diffusion of various mobile service application, handset features, as well as bundled service. In this case, the critical point is that the use of mobile service as a form of consumers' innovation should be seen as both a unit of set behavioural routine and technology artefact.

Although, the evolutionary perspective in this study is only explained in the context of mobile service diffusion, its applicability may be generalized to other types of innovations. This is based on the rationale that each innovation, regardless of its having been constructed for a different purpose and technology, will be adopted or rejected in a similar way, by mimicking others. The impact of technological evolution on the diffusion process across innovations is also similar, with regard to path dependence, intergenerational effect, etc. This indicates that viewing the diffusion of innovation as an evolutionary process has the potential of being generalized into a more global phenomenon so that it is applicable to all type of innovations. However, a more thorough discussion is necessary to illuminate this issue and this should be part of the future research agenda.

Furthermore, advancing the conceptions of diffusion of mobile service as an evolutionary process also remains as an important agenda. A more thorough conceptual formulation enables the theory to be empirically studied and gain more practical implications, especially for trend forecasting. In this case, however, it is important to have a consistent unit of analysis, as this will determine the scale at which the evolutionary framework becomes most illuminating for explaining the diffusion process. This scale ranges from the individual artefact set of ideas, (routines), to even wider industry segments on the firm level. Again, however, it is important to emphasize that modelling a system or phenomenon should focus on that which is essential, rather than to precisely imitate the reality.

References

Abernathy, W.J., and Utterback, J.M. (1978). Patterns of industrial innovation, *Technology Review* 80(7), 40-47.

Annafari, M.T. and Bohlin E. (2009a). Counting active SIM cards or subscribers: Implication for policy and research, in *Proceedings of the 8th Conference on Telecommunication and Techno-Economics (CTTE),* Stockholm, Sweden, June 15-17.

Annafari, M.T. and Bohlin E. (2009b). Estimating non-subscribers and quasi-subscribers by sampling, in *Proceedings of the2nd IEEE Global Information and Infrastructure Symposium (GIIS),* Hammamet, Tunisia, 23-25 June.

Annafari, M.T., Bohlin, E. (2010a). Quasi-subscribers and demand saturation: An analysis in the Swedish mobile phone market, in *Proceedings of the Conference on Telecommunication and Techno-economics*, Ghent, Belgium, June 7-15.

Annafari, M.T., and Bohlin, E. (2010b). Recognizing cord-cutters in the Swedish telecom market, in *Proceedings of the International Conference on Management Science and Information engineering,* Zhengzou, China, December 16-19.

Annafari, M.T., (2010a). An empirical analysis of the factors determining multiple subscriptions in the Swedish mobile service market, *Proceedings of the 9th International Conference on Mobile Business, ,* Athens, Greece, June 13-15.

Annafari, M.T., (2010b). *Quasi-subscribers in the Swedish mobile phone market: The phenomenon and determinant factors,* Licentiate Thesis, Department of Technology Management and Economics, Chalmers University of Technology, Chalmers Reproservice, Gothenburg.

Annafari, M.T. (2011). A multiple ownerships diffusion model of mobile service: A study of the Swedish market. Presented at the *2nd ITS PhD symposium*, Budapest, Hungary, September 22-23.

Annafari, M.T., Lindmark, S. and Bohlin, E (2011). Intergenerational diffusion model of mobile service. Presented at the 5th ITS Africa-Asia-Australasia Regional Conference, Perth, Western Australia, November13-16.

Ansari, S., and Garud, R. (2009). Inter-generational transitions in socio-technical systems: The case of cellular communications, *Research Policy*, 38(2), 382-392.

Araujo, L. and Harrison, D. (2010). Path dependence, agency and technological evolution, *Technology analysis & strategic management*, 14(1), 5-19.

Ayres, R.U. **(**1969). *Technological forecasting and long-range planning*. New York: McGraw-Hill.

Bass, F.M. (1969). A new product growth model for consumer durables. *Management Science*15, 215–227.

Baptista, R. (1999). The diffusion of process innovations: a selective review, *International Journal of the Economics of Business,* 6 (1), 107-29.

Bartlett, M. S. (1937). Properties of sufficiency and statistical tests, *Proceedings of the Royal Society of London Series A*, 160, 268–282.

Basalla, G. (1988). *The evolution of Technology*. New York: Cambridge University Press.

Bayus, B.L., Hong, S. and Labe Jr., R.P. (1989). Developing and using forecasting models of consumer durables. *Journal of Production Innovation Management*, 6, 5–19.

Bayus, B.L. and Gupta, S. (1992). An empirical analysis of consumer durable replacement intentions. *International Journal of Research in Marketing*, 9, 257–267.

Ben-Zion, U., and Ruttan, V.W. (1978). Aggregate demand and the rate of technical change. In: Binswanger, Hans, P., and Ruttan, Vernon W. eds. *Induced innovation: Technology institutions and development*. Baltimore: Johns Hopkins University Press, 261-275.

Berggren, C. and Laestadius, S. (2003). Co-development and composite clusters-the secular strength of Nordic telecommunications. *Industrial and Corporate Change*, 12 (1), 91-114.

Bohlin, A., Gruber, H., and Koutroumpis, P. (2010). Diffusion of new technology generations in mobile communications. *Information Economics and Policy, 22*(1), 51-60.

Brown, L. A, (1981) *Innovation Diffusion: A New Perspective*, 1st edition, New York: Methuen.

Bruland, K., (1995). Patterns of resistance to new technologies in Scandinavia: A historical perspective. In: Bauer, M. (Ed.), *Resistance to New Technology*. Cambridge: Cambridge University Press, 124–144.

Bryman, A. and Bell, E. (2007), *Business research methods*, 2nd edition, Oxford: Oxford University Press.

Cainarca, G.C., Colombo, M.G., and Mariotti, S. (1989). An Evolutionary Pattern of Innovation Diffusion: The Case of Flexible Automation, *Research Policy* 18 (2), 59-86.

Campbell, D.T (1965). Variation and Selective retention in socio-cultural evolution. In: Herbert R. Barringer, George I. Blanksten and Raymond W. Mack (Eds.), *Social change in developing areas: A reinterpretation of evolutionary theory*, Cambridge: Schenkman, 19–49.

Chapin, F.S. (1928). *Cultural change*. New York: Century Company.

Chen, C., Watanabe, C., and Grify-Brown, C. (2007). The coevolution process of technological innovation – an empirical study of cellular service vendors and telecommunication service operators in Japan, *Technology in Society*, 29(1) 1-22.

Chow, G.C (1967). Technological change and the demand for computers, *American Economic Review*, 57(5), 1117-30.

Constant, E. (2000). Recursive practice and the evolution of technological knowledge. In: Ziman, J. ed. (2000) *Technological innovation as evolutionary process*, Cambridge: Cambridge University Press, 219-233.

Cowson, I., Haddon, L., Miles, I. (1995). The shape of things to consume: Delivering Information Technology into the home, Avebury, Alderhot, United Kingdom.

Dawkins, R (2006). *The selfish Gene*, 30th anniversary edition, New York: Oxford University Press.

David, P.A. (1985). Clio and the economics of QWERTY, *American Economic Review*, 76, 332-337.

David, P.A (2010). Zvi Griliches and the Economics of Technology Diffusion: Adoption of innovations, Investment Lags, and Productivity Growth – "Connecting the Dots" ,*Stanford Institute for Economic Policy Research*, Discussion paper 09-016, (March 31, 2010 version).

De Marez, Lieven, S. B., and Gino, B. M. V. (2004). ICT-innovations today: Making traditional diffusion patterns obsolete and preliminary insight of increased importance. *Telematics and Informatics*, 21(3), 235-260.

Dosi, G. (1982). Technological paradigms and technological trajectories: A suggested integration of the determinants and directions of technical change, *Research Policy*, 11, 147-172.

Dosi, G., and Nelson, R.R. (1994). An introduction to evolutionary theories in economics, *Journal of Evolutionary Economics*, 3, 153-172.

Dosi, G. (2000). The research on innovation: An assessment. In: Dosi, G. ed. (2000) *Innovation, organizations and economic dynamics: Selected essays*, Massachusetts: Edward Elgar Publishing Inc., 115-144.

Dubois, A. and Gadde, L-E (2002). Systematic combining: An abductive approach to case research, *Journal of Business Research*, 55, 553–560

Ehrenberg, A.S.C. (1975). *A Primer on Data Reduction: An Introductory Statistics Textbook*, London: John Willey and Son.

Fleck, J. (2000). Artefact ↔ activity: The coevolution of artefacts, knowledge and organization in technological innovation. In: Ziman, J. eds (2000) *Technological innovation as evolutionary process*, Cambridge: Cambridge University Press, 248-266.

Foster, R. (1986). *Innovation, the Attacker's Advantage*. New York: Summit Books.

Franses, P.H. (1994). A method to select between Gompertz and logistic trend curves, *Technological Forecasting and Social Change*, 46, 45-49.

Funk, J.L. (2009). The co-evolution of technology and methods of standard setting: the case of cellular service industry, *Journal of Evolutionary Economics*, 19, 73-93.

Gamboa, L.F., and Otero, J. (2009). An estimation of the pattern of diffusion of cellular services: The case of Colombia, *Telecommunications Policy*, 33(11), 611-620.

Garrett, J. M., (2006). SVYPXCAT: Stata module to calculate predicted means or proportions for nominal X's for survey data. Retrievable from: http://EconPapers.repec.org/RePEc:boc:bocode:s449902.html.

Grajek, M., and Kretschmer, T. (2009). Usage and diffusion of cellular telephony, 1998-2004, *International Journal of Industrial Organization*, 27, 238-249.

Geels, F.W. (2002) Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study, *Research Policy*, 31(8-9), 1257-1274.

Geels, F.W. (2004). From sectoral systems of innovation to socio-technical systems Insights about dynamics and change from sociology and institutional theory, *Research Policy*, 33, 897-920.

Graham, Gordon (2002). *Genes: a philosophical inquiry*, New York: Routledge.

Granovetter, M. (1978). Threshold models of collective behaviour, *American Journal of Sociology*, 83, 1420-1443.

Griliches, Z. (1957). Hybrid Corn: An Exploration in the economics of technological change, *Econometrica*, 25 (4), 501-522.

Griliches, Z. (1960). Hybrid corn and the economics of innovations. *Science*, July, 275-280.

Grubler, A. (1996). Time for a change: On the patterns of diffusion of innovation, *Daedalus* 125(3), 19-42.

Gruber, H., and Verboven, F. (2001). The diffusion of cellular telecommunications services in the European Union, *European Economic Review*, 45(3), 577-588.

Grubler, A. (1996). Time for a change: On the pattern of diffusion of innovation, *Daedalus*, 125(3), 19-37.

Hwang, J., Cho, Y., and Long, N. V. (2009). Investigation of factors affecting the diffusion of mobile telephone services: An empirical analysis for Vietnam. *Telecommunications Policy, 33*(9), 534-543.

Islam, T., and Meade, N. (1997). The diffusion of successive generations of a technology: A more general model, *Technological Forecasting and Social Change*, 56 (1), 49-60.

Jaakkola, H., Gabbouj, M., Neuvo, Y. (1998). Fundamentals of technology diffusion and mobile phone case study, *Circuits Systems and Signal Processing*, 17(3), 421-448.

Jang, S., Dai, S. and Sung, S. (2005). The pattern and externality effect of diffusion of mobile telecommunications: The case of the OECD and Taiwan. *Information Economics and Policy, 17*(2), 133-148.

Kamakura , W and Balasubramanian, S. (1987). Long term forecasting with innovation diffusion models: the impact of replacement purchases. *Journal of Forecasting* 6 , 1–19.

Kline, R and Pinch, T. (1996). Users as agents of technological change: The social construction of automobile in the rural United States. *Technology and Culture*, 37(3), 763-795.

Kwasnicka, H., Galar, R., Kwasnicki, W.(1983). Technological substitution forecasting with a model based on biological analogy, *Technology Forecasting and Social Change*, 23, 41-58.

Kwasnicki, W., Kwasnicka, H. (1992). Market, innovation, competition. An evolutionary model of industrial dynamics, *Journal of Economic Behaviour and Organization*, 19, 343-68.

Kwaśnicki, W., and Kwaśnicka, H. (1996). Long-term diffusion factors of technological development – an evolutionary model and case study, *Technological Forecasting and Social Change*, 52(1), 31-57.

Koski, H., and Kretschmer, T. (2005). Entry, standards and competition: Firm strategies and the diffusion of cellular telephony, *Review of Industrial Organization*, 26(1), 89-113.

Koski, H., and Kretschmer, T. (2007). Innovation and dominant design in mobile telephony, *Industrial & Innovation*, 26(1), 89-113.

Latour, B. (1991). Technology is society made durable. In: J. Law, Editor, *A Sociology of Monsters: Essays on Power, Technology and Domination*, London: Routledge, 103-131.

Lee, M., and Cho, Y. (2007). The diffusion of cellular telecommunications services in Korea, *Applied Economics Letters*, 14(7), 477-481.

Liikanen, J., Stoneman, P., and Toivanen, O. (2004). Intergenerational effects in the diffusion of new technology: the case of cellular services, *International Journal of Industrial Organization*, 22, 1137-54.

Lindmark, S. (1995). *The history of the future: An investigation of the evolution of cellular telephony*, Licentiate Thesis, Department of Industrial Management and Economics, Chalmers University of Technology, Gothenburg, Sweden.

Lieven, D.M., Gino V. (2004). Innovation diffusion: The need for more accurate consumer insight. Illustration of the PSAP scale as a segmentation instrument. *Journal of Targeting, Measurement & Analysis for Marketing*, 13(1), 32-49.

Lindqvist, S. (1994) Changes in the technological landscape: The temporal dimension in the growth and decline of large technological systems, in Granstrand, O. (ed). *Economics of Technology*, Amsterdam: North-Holland, 271-288.

Lundvall, B.A., (1988). Innovation as an interactive process: fromuser–producer interaction to the national system of innovation. In: Dosi, G., Freeman, C., Nelson, R., Silverberg, G., Soete, L. (Eds.). *Technical Change and Economic Theory*. London: Pinter publisher, 349–369.

Mahajan**,** V**.,** and Peterson**,** R.A. **(**1985**).** *Models for Innovation Diffusion*, Beverly Hills, CA: SAGE Publications.

Mahajan, V., Muller, E., and Bass, F.M. (1990). New product diffusion models in marketing: A review and directions for research, *Journal of Marketing*, 54, 1-26.

Mahajan, V., Muller, E., and Srivastava, R.K. (1990). Determination of adopter categories by using innovation diffusion models, *Journal of Marketing Research*, 27 (1), 37-50.

Maier, F.H. (1996). Substitution among successive product generations: An almost neglected problem in innovation diffusion models. In. Richardson, G. P. and Sterman, J. D. (eds.) *System Dynamics '96*, Boston, MA. , 345-348.

Maier, F.H. (1996). New product diffusion models in innovation management - a system dynamics perspective. *System Dynamics Review,* 14(4), (Winter), 285-308.

Mansfield, E. (1961). Technical Change and the Rate of Imitation, *Econometrica*, 29(4), 741-766.

McKelvey M (1997). Coevolution in Commercial Genetic Engineering, *Industrial and Corporate Change,* 6(3): 503-532.

Meade, N. and Islam, T. (2001). Forecasting the diffusion of innovations: implications for time series extrapolation, in Armstrong, J.S. (Ed.), *Principles of forecasting: a handbook for researchers and practitioners*, Norwell, MA : Kluwer Academic Publishers, 577–595.

Metcalfe, J.S. (1982). On the Diffusion of Innovation and the Evolution of Technology. In: Williams, B.R. ed., *Knowns and Unknowns in the Analyses of New Technology*, Technical Change Centre.

Metcalfe, J.S. (1988). The diffusion of innovation: an interpretative survey. In: Dosi, G. Freeman, C. Nelson, R. Silverberg, G., and Soete, L. (eds.), *Technical Change and Economic Theory*, London: Pinter Publisher, 560-586.

Metcalfe, J.S. (2005). Ed Mansfield and the Diffusion of Innovation: An Evolutionary Connection, *The Journal of Technology Transfer*, 30(22), 171-181.

Michalakelis, C., Varoutas, D., and Sphicopoulos, T. (2008). Diffusion models of mobile telephony in Greece. *Telecommunications Policy, 32*(3-4), 234-245.

Mokyr, J. (2000). Evolutionary phenomena in technological change. In: Ziman, J. ed. *Technological innovation as evolutionary process*, 52-65. Cambridge: Cambridge University Press.

National Telecommunications and Information Administration –NTIA (1995) Land Mobile Spectrum Planning Options, Chapter I, Retrieved April 30, 2011, from: http://www.ntia.doc.gov/page/land-mobile-spectrum-planning-options-chapter-1-introduction.

Nellevad, P., and Bergsveen, A. (2010) Svenskarnas användning av telefoni and internet 2010,*PTS reportnumber: PTS-ER-2010: 25* (in Swedish). As retrieved on July 11, 2010 from: http://statistics.pts.se/pts1h2010E/download/Individundersökning%202010.pdf.

Nelson, R. R. and Winter, S. G. (1982), *An Evolutionary Theory of Economic Change*, Belknap Press, Cambridge,Mass. and London.

Nelson, R.R. and Consoli, D. (2010) An evolutionary theory of household consumption behaviour, Journal of Evolutionary Economics, 20(5), 665-687 .

Nelson, R.R. (2000). Selection criteria and selection process in cultural evolution theory. In: Ziman, J. ed. *Technological innovation as evolutionary process*, Cambridge: Cambridge University Press, 66-74.

Norton, J.A., and Bass, F.M. (1992). The evolution of technological generations: The law of capture, *Sloan Management Review*, 33(2), 66-77.

Olshavsky, R. W. and Granbois, D.H. (1979).Consumer decision-making - Fact or fiction. *Journal of Consumer Research,* 6, 93-100.

Olson, J. and Choi, S. (1985). A product diffusion model incorporating repeat purchases. *Technological Forecasting and Social Change*, 27, 385–397.

Oudshoorn, N., Pinch, T. (Eds.), (2003). *How users matter: The co-construction of users and technology*, Cambridge, MA: The MIT Press.

Padmore, T.,Schuetze, H., and Gibson, H. (1998). Modelling systems of innovation: an enterprise-centered view. *Research Policy*, 26, 605–24.

Parker, P.M. (1994). Aggregate diffusion forecasting models in marketing: A critical review, *International Journal of Forecasting*, 10 (2), 353-380.

Pedan, A. (2001). Analysis of count data using the SAS® system, in *Proceedings Statistics, Data Analysis and Data Mining, SAS Institute Inc. Paper*, 247-26. Retrievable at: http://www2.sas.com/proceedings/sugi26/p247-26.pdf.

Pemberton, H. E. (1936) The curve of culture diffusion rate, *American Sociological Review*, 1 (4): 547-556.

Peres, R., Muller, E., and Mahajan, V. (2010). Innovation diffusion and new product growth models: A critical review and research directions, *International Journal of Research in Marketing*, 27, 91-106.

Silverberg, G., Dosi, G., and Orsenigo, L. (1988). Innovation, diversity and diffusion: A self-organization model, *The Economic Journal*, 98(393), 1032-1054.

Rogers, E. M. (1962). *Diffusion of innovations.* (1st edition), New York: Free Press.

Rogers, E.M. (2005). *Diffusion of Innovations.* (5th edition), New York: Free Press.

Rouvinen, P. (2006). Diffusion of digital mobile telephony: Are developing countries different? *Telecommunications Policy*, *30*(1), 46-63.

Ryan, B., Gross, N.C. (1943). The diffusion of hybrid seed corn in two Iowa communities, *Rural Sociology* 8 (1), 15-23.

Saviotti, P. and Mani, G (1995) Competition, variety and technological evolution: A replicator dynamics model, *Journal of Evolutionary Economics*, 5(4), 369-392.

Schejter, A. M., Serenko, A., Turel, O., Zahaf, M. (2010). Policy implications of market segmentation as a determinant of fixed-mobile service substitution: What it means for carriers and policy makers, *Telematics and Informatics*, 27(1), 90-102.

Schumpeter, J.A. (1934). *The theory of economic development: an inquiry into profits, capital, credit, interest, and the business cycle*, Cambridge, MA: Harvard University Press.

Schumpeter JA (1939) *Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process*, New York: McGraw-Hill.

Schumpeter JA (1947) The creative response in economic history. *The Journal of Economic History*, 7(2), 149-159.

Shannon, R. **(**1975). *System simulation : The art and science*, Prentice. Hall, New York: Englewood Cliffs.

Singh, S. K. (2008). The diffusion of mobile phones in India. *Telecommunications Policy*, *32*(9-10), 642-651.

Statistiskacentralbyrån (SCB) (2009).Population statistics. Retrieved January 20, 2010 from: http://www.scb.se/Pages/ProductTables____25809.aspx.

Steffens, P.R. (2003). A model of multiple-unit ownership as a diffusion process, *Technological Forecasting and Social Change*, 70(9), 901-917.

Stoneman, P., (2002). *The economics of technological diffusion*, Blackwell Publishers, Oxford UK.

Stoneman, P., (1983). *The economic analysis of technological change*, Oxford: Oxford University Press.

Sutherland, E. (2009). Counting customers, subscribers and mobile phone numbers, *Info*, 11(2), 6-23.

Swedish Post and Telecom Agency (PTS) (2009).*Swedish market information 2008*, online version, Retrieved January 20, 2010 from: http://www.statistik.pts.se/pts2008e/index.html.

Swedish Post and Telecom Agency (PTS), (2010).*First half year market report*, online version. Retrieved January 20, 2010 from: http://statistics.pts.se/PTS1H2009E/index.html.

Tarde, G. (1903). *The Laws of Imitation*, translated by E.C. Parsons with introduction by F. Giddings, reprint, Gloucester, MA: Peter Smith.

Tscherning, H., and Damsgaard, J., (2008). Understanding the Diffusion and Adoption of Telecommunication Innovations: What We Know and What We Don't Know.*in IFIP International Federation for Information Processing, Volume 287, Open IT-Based Innovation: Moving Towards Cooperative IT Transfer and Knowledge Diffusion*, eds. León, G., Bernardos, A., Casar, J., Kautz, K., and De Gross, J. Boston: Springer, 39-60.

Van Dijk, J., A. G. M. (2005). *The deepening divide: Inequlity in the information society*, California: SAGE publications.

Valente, T. W., & Rogers, E. M. (1995). The origins and development of the diffusion of innovations paradigm as an example of scientific growth. *Science Communication: An Interdisciplinary Social Science Journal*, 16 (3), 238-269.

Von Hippel, E. (1976). The dominant role of users in the scientific instrument innovation process. *Research Policy*, 5 (3), 212–39.

White, L.A. (1945). Diffusion versus evolution? An anti-evolutionist fallacy, *American Anthropologist,* 47 (3), 339-356.

William, R. (2009). Using heterogeneous choice models to compare logit and probit coefficients across groups, *Sociological Methods and Research,* 37 (4), 531-559.

Winter, G.,S. (1964). Economic 'natural selection' and the theory of the firm. *Yale Economic Essays 4(1),* 225-272.

Wu, F.S. and Chu, W.L. (2010). Diffusion models of mobile telephony, *Journal of Business Research,* 63, 497-501.

Yin, R. K. (2003) *Case Study Research, 3rd edition.* London, England: SAGE Publications.

Young, H.P. (2006). Innovation Diffusion in Heterogeneous Populations: Contagion, Social Influence, and Social Learning. *American Economic Review*, 99(5), 1899–1924.

Ziman, J. (2000). Evolutionary models for technological change. In: Ziman, J. ed. *Technological innovation as evolutionary process,* Cambridge: Cambridge University Press, 3-12.